PATENT APPLICATION

MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS

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MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS

BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to the field of orthodontics, and more particularly to the design of multilayer dental positioning appliances.

[0002] An objective of orthodontics is to move a patient's teeth to positions where function and/or aesthetics are optimized. Traditionally, appliances such as braces are applied to a patient's teeth by a treating practitioner and the set of braces exerts continual force on the teeth and gradually urges them toward their intended positions. Over time and with a series of clinical visits and reactive adjustments to the braces by the practitioner, the appliances to move the teeth toward their final destination.

[0003] More recently, alternatives to conventional orthodontic treatment with traditional affixed appliances (*e.g.*, braces) have become available. For example, systems including a series of preformed appliances/aligners have become commercially available from Align Technology, Inc., San Jose, CA, under the trade name Invisalign® System. The Invisalign® System is described in numerous patents and patent applications assigned to Align Technology, Inc. including, for example in U.S. Pat. Nos. 6,450,807, and 5,975,893, as well as on the company's website, which is accessible on the World Wide Web (see, *e.g.*, the url invisalign.com"). The Invisalign® System includes designing and/or fabricating multiple, and sometimes all, of the aligners to be worn by the patient before the aligners are administered to the patient and used to reposition the teeth (*e.g.*, at the outset of treatment). Often, designing and planning a customized treatment for a patient makes use of computer-based 3-dimensional planning/design tools, such as Treat™ software from Align Technology, Inc. The design of the aligners relies on computer modeling of the patient's teeth in a series of planned successive tooth arrangements, and the individual aligners are designed to be worn over the teeth, such that each aligner exerts force on the teeth and elastically repositions the teeth to each of the planned tooth arrangements.

[0004] While recently developed orthodontic treatment technologies, such as those described above, represent a considerable advancement in the field of orthodontics, additional advancements remain of interest. For example, in some instances it may be advantageous to

develop materials that improve properties of the appliances/aligners used for orthodontic treatment. As such, there is a need for shell aligners that can, for example, produce more continuous force and better bring a patient's teeth into a desired occlusion.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention provides multilayer orthodontic positioning appliances, as well as related methods and systems. The disclosed multilayer appliances include a removable orthodontic tooth positioning appliance having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth. The multilayer appliances can include a hard polymer layer disposed between two soft polymer layers. The multilayer dental appliances of the present invention, among many aspects, provide, for example, improved material performance, stress relaxation properties and longer working range. In addition, the mechanical properties of the materials and appliances described herein can improve orthodontic treatments by, for example, reducing the need for midcourse corrections during treatment and the number of aligners used for a given treatment.

[0006] The disclosed methods include methods for making multilayer dental appliances. The disclosed systems including a plurality of appliances having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth. The appliances can be successively worn by a patient to move teeth from one arrangement to a successive arrangement. At least one of the appliances in the system can include a hard polymer layer disposed between two soft polymer layers.

[0007] For a fuller understanding of the nature and advantages of the present invention, reference should be made to the ensuing detailed description and accompanying drawings. Other aspects, objects and advantages of the invention will be apparent from the drawings and detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 illustrates a jaw and an incremental positioning appliance for the jaw, in accordance with an embodiment of the present invention.

[0009] Figure 2 shows an arrangement of polymer layers in a sheet having a hard polymer layer disposed between two soft polymer layers, in accordance with an embodiment of the present invention.

[0010] Figure 3 depicts a method of making a multilayer dental appliance, in accordance with an embodiment of the present invention.

[0011] Figure 4 is a simplified block diagram illustrating a method for fabricating a dental appliance, in accordance with an embodiment of the present invention.

[0012] Figure 5 provides a stress relaxation comparison for dental appliances, in accordance with an embodiment of the present invention.

[0013] Figure 6 provides another stress relaxation comparison for dental appliances, in accordance with an embodiment of the present invention.

[0014] Figure 7 shows a long-term unloading comparison for dental appliances, in accordance with an embodiment of the present invention.

[0015] Figure 8 provides a long-term movement comparison for dental appliances, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] In the following description, various embodiments of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

[0017] Multilayer orthodontic positioning appliances are provided, as well as related methods and systems. During orthodontic treatment, it may be necessary to apply forces to a tooth to generate movement of the tooth to, for example, bring the patient's teeth into a better occlusion in a mesial or distal direction. The presently disclosed appliances, methods, and systems provide means by which such forces can be applied during orthodontic treatment where appliances having teeth receiving cavities are used, such as preformed appliances/aligners available from

Align Technology, Inc., San Jose, CA, under the trade name Invisalign® System. As provided by the present invention, the aligners that include multilayer sheets can, for example, provide increased durability of the aligners so that they can better withstand wear due to aligner reinsertion and removal and other mechanical stresses put on the aligner during treatment. In addition, the aligners have improved elastic properties that allow for less degradation in the shape of the teeth receiving cavities during a stage of treatment. For example, during a multistage orthodontic treatment, the force exerted by an aligner to perform defined tooth movement can degrade and may cause the treatment to include more aligners to reach a final ideal arrangement and/or result in a mid-course correction that could be prevented by using aligners with improved physical properties, such as those provided herein.

[0018] In one embodiment, the present invention provides a dental appliance for positioning a patient's teeth. The dental appliance can include a removable orthodontic tooth positioning appliance having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth, the appliance comprising a hard polymer layer disposed between a first soft polymer layer and a second soft polymer layer.

[0019] In another embodiment, the present invention provides an orthodontic system for positioning a patient's teeth. The orthodontic system can include a plurality of incremental position adjustment appliances having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth, wherein the appliances are successively worn by a patient to move teeth from one arrangement to a successive arrangement, and wherein at least one of the appliances comprises a hard polymer layer disposed between a first soft polymer layer and a second soft polymer layer.

[0020] In yet another embodiment, the present invention provides a method of making a dental appliance for positioning a patient's teeth. The method can include providing a sheet comprising a hard polymer layer of polymeric material disposed between a first soft polymer layer and a second soft polymer layer, providing a positive model of the patient's teeth in a target position; and fabricating an appliance as a negative of the positive model comprising thermoforming the sheet over the positive model.

[0021] Referring now to the drawings, in which like reference numerals represent like parts throughout the several views, Figure 1 provides an appropriate starting point in a detailed

discussion of various embodiments of the present invention with respect to tooth repositioning appliances designed to apply repositioning forces to teeth. A tooth repositioning appliance 10 can be worn by a patient in order to achieve an incremental repositioning of individual teeth in the jaw 12. The appliance can include a shell (*e.g.*, a polymeric shell) having teeth-receiving cavities that receive and resiliently reposition the teeth. In many embodiments, a polymeric appliance can be formed from a sheet of suitable layers of polymeric material. An appliance can fit over all teeth present in an upper or lower jaw, or less than all of the teeth. In some cases, only certain teeth received by an appliance will be repositioned by the appliance while other teeth can provide a base or anchor region for holding the appliance in place as it applies force against the tooth or teeth targeted for repositioning. In some cases, many or most, and even all, of the teeth will be repositioned at some point during treatment. Teeth that are moved can also serve as a base or anchor for holding the appliance as it is worn by the patient. Typically, no wires or other means will be provided for holding an appliance in place over the teeth. In some cases, however, it may be desirable or necessary to provide individual anchors on teeth with corresponding receptacles or apertures in the appliance so that the appliance can apply a selected force on the tooth. Exemplary appliances, including those utilized in the Invisalign® System, are described in numerous patents and patent applications assigned to Align Technology, Inc. including, for example, in U.S. Pat. Nos. 6,450,807, and 5,975,893, as well as on the company's website, which is accessible on the World Wide Web (see, *e.g.*, the url invisalign.com").

[0022] An appliance can be designed and/or provided as part of a set of a plurality of appliances. In such an embodiment, each appliance may be configured so a tooth-receiving cavity has a geometry corresponding to an intermediate or final tooth arrangement intended for the appliance. The patient's teeth can be progressively repositioned from an initial tooth arrangement to a target tooth arrangement by placing a series of incremental position adjustment appliances over the patient's teeth. A target tooth arrangement can be a planned final tooth arrangement selected for the patient's teeth at the end of all planned orthodontic treatment. Alternatively, a target arrangement can be one of many intermediate arrangements for the patient's teeth during the course of orthodontic treatment, which may include where surgery is recommended, where inter-proximal reduction (IPR) is appropriate, where a progress check is scheduled, where anchor placement is best, where palatal expansion is desirable, etc. As such, it is understood that a target tooth arrangement can be any planned resulting arrangement for the

patient's teeth that follows one or more incremental repositioning stages. Likewise, an initial tooth arrangement can be any initial arrangement for the patient's teeth that is followed by one or more incremental repositioning stages. The adjustment appliances can be generated all at the same stage or in sets or batches, *e.g.*, at the beginning of a stage of the treatment, and the patient wears each appliance until the pressure of each appliance on the teeth can no longer be felt or has resulted in the maximum amount of expressed tooth movement for that given stage. A plurality of different appliances (*e.g.*, set) can be designed and even fabricated prior to the patient wearing any appliance of the plurality. After wearing an appliance for an appropriate period of time, the patient replaces the current appliance with the next appliance in the series until no more appliances remain. The appliances are generally not affixed to the teeth and the patient may place and replace the appliances at any time during the procedure (*e.g.*, patient-removable appliances). The final appliance or several appliances in the series may have a geometry or geometries selected to overcorrect the tooth arrangement, *i.e.*, have a geometry which would (if fully achieved) move individual teeth beyond the tooth arrangement which has been selected as the "final." Such over-correction may be desirable in order to offset potential relapse after the repositioning method has been terminated, *i.e.*, to permit movement of individual teeth back toward their pre-corrected positions. Over-correction may also be beneficial to speed the rate of correction, *i.e.*, by having an appliance with a geometry that is positioned beyond a desired intermediate or final position, the individual teeth will be shifted toward the position at a greater rate. In such cases, the use of an appliance can be terminated before the teeth reach the positions defined by the appliance.

[0023] In general, structures, methods and systems of the present invention utilize a multilayer sheet for use in orthodontic appliances. The multilayer sheet can include three layers, in which a hard polymer layer is disposed between two soft polymer layers. The multilayer sheets used in the present invention can be used in making dental aligners having improved durability for use, e.g., to the elastic properties of the multilayer sheet when formed into an aligner. In addition, the bonding strength between the layers further improves the durability of the aligners, for example, by withstanding teeth grinding by a patient.

[0024] Figure 2 shows a multilayer structure according to the present invention. As shown, a multilayer sheet 20 can include a three layer structure: a hard polymer layer 24 and two soft

polymer layers 22, 26. The hard polymer layer can be disposed between a first soft polymer layer and a second soft polymer layer. In some embodiments, the hard polymer layer can be thicker than either of the soft polymer layers. The soft polymer layers can have the same or different thicknesses. For example, the hard polymer layer can have a thickness in a range from about 400 μm to about 1100 μm, about 450 μm to about 1000 μm, about 500 μm to about 900 μm, or about 550 μm to about 750 μm. The soft polymer layers can have a thickness in a range from about 25 μm to about 100 μm, about 30 μm to about 90 μm, or about 35 μm to about 80 μm. Multilayer sheets used for making appliances having a hard polymer layer disposed between two soft polymer layers can range from a thickness of about 500 μm to about 1200 μm, about 550 μm to about 1100 μm, or about 600 μm to about 1000 μm. In some embodiments, the thicknesses of the various layers can be tailored for a particular stage of treatment for the patient.

[0025] Suitable polymeric materials for the hard polymer layer can include a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, a polytrimethylene terephthalate or a combination thereof (e.g., a blend of at least two of the listed hard polymeric materials). In some embodiments, the hard polymer layer of the appliances can include polymeric materials, such as a polycarbonate, a co-polyester, a polyester, and a thermoplastic polyurethane. In some embodiments, the hard layer can be composed of multiple hard layers, e.g., two or three hard polymer layers co-extruded to form one hard layer.

[0026] The hard polymer layer of the appliances of the present invention can have a variety of physical properties that can, e.g., improve treatment options for a practitioner. For example, physical properties such as tensile strength, elongation at yield, elongation at break, tensile modulus, flexural modulus, stress relaxation over time, and light transmission can each be specifically tailored for a particular application. In some embodiments, the hard polymer layer of the appliances can have a physical property of at least one of a tensile strength at yield of between about 4000 pounds per square inch (psi) and 6500 psi, an elongation at yield of greater than about 4%, an elongation at break of greater than about 70%, a tensile modulus of greater than about 150,000 psi, a flexural modulus greater than about 150,000 psi, a stress relaxation at

24 hours testing in a high humidity environment (e.g., between about 90%-100% relative humidity) is greater than 10%, and a light transmission between 400 nm and 800 nm of greater than about 75%.

[0027] Suitable polymeric materials for the soft polymer layers of the appliance can include a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a polyolefin blend elastomer, a thermoplastic co-polyester elastomer, a thermoplastic polyamide elastomer, or a combination thereof (e.g., a blend of at least two of the listed soft polymeric materials). The soft polymer layers can be the same material or a different material. In certain embodiments, the first soft polymer layer and the second soft polymer layer are the same polymeric material.

[0028] The soft polymer layers of the appliances can have a variety of physical properties. For example, physical properties such as hardness, ultimate tensile strength, elongation at break, tensile modulus, compression set, flexural modulus, and light transmission can each be specifically tailored for a particular application. In some embodiments, the soft polymer layers of the appliances can independently have a physical property of at least one of a hardness of about 60A to about 85D, an ultimate tensile strength of greater than about 5000 psi, an elongation at break of greater than about 200 %, a compression set at about 70 °C of greater than 40% after 24 hours, a flexural modulus of greater than about 35,000 psi, and a light transmission between 400 nm and 800 nm of greater than about 75%.

[0029] As described herein, the layers of the appliances can include a hard polymer layer disposed between two soft polymer layers. In one embodiment, the multilayer appliances can include a hard polymer layer of one type of material (e.g., a co-polyester), and two soft polymer layers of other types of material that can be the same or different (e.g., two soft polymer layers of thermoplastic polyurethane elastomer). In some embodiments, the multilayer appliances can also include a hard polymer layer of at least two layers of polymer material. For example, the hard polymer layer can include several polymer layers laminated together to form the hard polymer layer. The laminated hard polymer layer can include at least two layers of any combination of the following polymer materials: a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene

copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, and a polytrimethylene terephthalate. Similarly, in some embodiments, the multilayer appliances can include a soft polymer layer of at least two layers of polymer material. For example, the soft polymer layers can include a layer of several polymer layers laminated together. The laminated soft polymer layers can include at least two layers of any combination of the following polymer materials: a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a polyolefin blend elastomer, a thermoplastic co-polyester elastomer, and a thermoplastic polyamide elastomer.

[0030] The tooth positioning appliances can be fabricated using a variety of methods. For example, methods for making the appliances can include thermoforming a multilayer sheet into an aligner by heating the sheet and then molding the sheet to a particular configuration. Exemplary methods for fabricating the appliances, including those utilized in the Invisalign® System, are described in numerous patents and patent applications assigned to Align Technology, Inc. including, for example, in U.S. Appl. No. 13/186,374 as well as on the company's website, which is accessible on the World Wide Web (see, *e.g.*, the url invisalign.com").

[0031] Figure 3 depicts an example embodiment of a process 30 for forming a multilayer tooth positioning appliance, in accordance with an embodiment of the present invention. As shown, a multilayer sheet 32 can be formed into a tooth positioning appliance 36. The multilayer sheet 32, as depicted, can include three layers: a hard polymer layer disposed between two soft polymer layers. In this example process, the tooth positioning appliance 36 can be produced with the use of a physical tooth model, or mold, 34. The tooth positioning appliance 36 can be produced by heating the thermoformable multilayer sheet 32 and then vacuum or pressure forming the sheet over the teeth in the physical tooth model 34. The tooth positioning appliance 36 is a direct representation of the physical tooth model. Excess material from the sheet can be trimmed to form a final tooth positioning appliance that can be used for orthodontic treatment of a patient.

[0032] One or a series of physical tooth models, such as the model described above, may be used in the generation of elastic repositioning appliances for orthodontic treatment. Similar to

the process above, each of the appliances can be generated by thermoforming a multilayer polymeric material over a mold of a desired tooth arrangement to form a dental appliance. The tooth positioning appliance of the desired tooth arrangement generally conforms to a patient's teeth but is slightly out of alignment with the initial tooth configuration. Placement of the elastic positioner over the teeth applies controlled forces in specific locations to gradually move the teeth into the desired configuration. Repetition of this process with successive appliances comprising new configurations eventually moves the teeth through a series of intermediate configurations to a final desired configuration.

[0033] The present invention includes a variety of methods for fabricating dental appliances. Figure 4 shows a simple schematic for a method 40 of fabricating a removable orthodontic tooth positioning appliance having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth, in accordance with an embodiment of the present invention. The method can include providing a multilayer sheet having a hard polymer layer disposed between two soft polymer layers (Step 42). The method can further include providing a positive physical model of a patient's teeth (Step 44). The tooth positioning appliance can be fabricated by thermoforming the multilayer sheet over the positive physical model (Step 46), in which the tooth positioning appliance is a negative of the positive model. As described above, the methods of fabrication can further include trimming or cutting portions of the sheet to render a final, usable appliance for orthodontic treatment.

[0034] Multilayer sheets of the present invention were analyzed and determined to provide a variety of improved properties for aligners used in orthodontic treatment. As further described herein, the multilayer sheets formed into aligners can, for example, provide increased durability of the aligners so that they can better withstand wear due to teeth grinding and other mechanical stresses put on the aligner during treatment. In addition, the aligners have improved elastic properties that allow for less degradation in the shape of the teeth receiving cavities during a stage of treatment. For example, during a multistage orthodontic treatment, the capability of an aligner to force tooth movement can degrade and may cause the treatment to include more aligners to reach a final ideal arrangement and/or result in a mid-course correction that could be prevented by using aligners with improved physical properties, such as those provided herein.

[0035] Figures 5-8 provide example test results that compare various physical properties of the multilayer sheet appliances of the present invention with other already existing aligner materials (Material 1). Samples of varied thicknesses were tested. For example, multilayer sheets were tested having a hard polymer layer with thicknesses ranging from about 580 μm to about 715 μm thick. In some examples, the hard layer was a co-polyester hard polymer layer. The soft layers tested ranged between about 50 μm to about 100 μm. In some examples, the hard polymer layer was disposed between thermoplastic polyurethane elastomer soft polymer layers. As shown in Figures 5 and 6, one example of the multilayer sheet material (Material 2) showed improved stress relaxation properties as compared to another already existing material (Material 1) at room temperature and at a 37 °C/90-100% relative humidity condition. In addition, Figure 7 shows improved long-term unloading characteristics of the multilayer sheet Material 2 versus the already existing Material 1 in a 37 °C/90-100% relative humidity condition. The multilayer sheet showed less deflection under force loads. Figure 8 also shows improved long-term movement data for the multilayer sheet Material 2 versus Material 1 in a 37 °C/90-100% relative humidity condition.

[0036] The use of the terms "a" and "an" and "the" and similar referents in the context of describing embodiments (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. The term "connected" is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (*e.g.*, "such as") provided herein, is intended merely to better illuminate embodiments and does not pose a limitation on the scope unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of at least one embodiment.

[0037] Variations of the embodiments described herein may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for embodiments to be constructed otherwise than as specifically described herein. Accordingly, suitable embodiments include all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is contemplated as being incorporated into some suitable embodiment unless otherwise indicated herein or otherwise clearly contradicted by context. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the pending claims along with their full scope or equivalents.

ABSTRACT OF THE DISCLOSURE

Multilayer sheet tooth positioning appliances are provided, as well as related methods and systems.

63961806v.1

Electronic Acknowledgement Receipt

EFS ID:	12769840
Application Number:	13470681
International Application Number:	
Confirmation Number:	5655
Title of Invention:	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
First Named Inventor/Applicant Name:	Chunhua Li
Customer Number:	46718
Filer:	Christopher L. Kuyper/Ashley Fife
Filer Authorized By:	Christopher L. Kuyper
Attorney Docket Number:	83289-831160 (022900US)
Receipt Date:	14-MAY-2012
Filing Date:	
Time Stamp:	14:59:06
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	$1790
RAM confirmation Number	1609
Deposit Account	201430
Authorized User	KUYPER,CHRISTOPHER

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Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		2012_05_14_NON_PROV_APP_83289_831160.pdf	574075 7c6cc63f44d733152b362192f0367406b7e02e78	yes	34

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal of New Application	1	1
Fee Worksheet (SB06)	2	2
Specification	3	15
Claims	16	21
Abstract	22	22
Drawings-only black and white line drawings	23	30
Application Data Sheet	31	34

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Attorney Docket No.	83289-831160 (022900US)
First Inventor	Chunhua Li
Title	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. ☒ **Fee Transmittal Form (e.g., PTO/SB/17)**
   (Submit an original and a duplicate for fee processing)
2. ☐ **Applicant claims small entity status.**
   See 37 CFR 1.27.
3. ☒ **Specification** [*Total Pages* 20]
   Both the claims and abstract must start on a new page
   (For information on the preferred arrangement, see MPEP 608.01(a))
4. ☒ **Drawing(s)** (*35 U.S.C.113*) [*Total Sheets* 8]
5. **Oath or Declaration** [*Total Sheets* ___]
   a. ☐ Newly executed (original or copy)
   b. ☐ A copy from a prior application (37 CFR 1.63 (d))
   (for a continuation/divisional with Box 18 completed)
   i. ☐ DELETION OF INVENTOR(S)
   Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. ☒ **Application Data Sheet.** See 37 CFR 1.76
7. ☐ **CD-ROM or CD-R** in duplicate, large table or Computer Program *(Appendix)*
   ☐ Landscape Table on CD
8. **Nucleotide and/or Amino Acid Sequence Submission**
   (if applicable, items a.-c. are required)
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10. ☐ **37 C.F.R. 3.73(b) Statement** ☐ **Power of Attorney**
    (when there is an assignee)
11. ☐ **English Translation Document** *(if applicable)*
12. ☐ **Information Disclosure Statement** (PTO/SB/08 or PTO-1449)
    ☐ Copies of citations attached
13. ☐ **Preliminary Amendment**
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18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in the first sentence of the specification following the title, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No:

Prior application information: *Examiner* _____ *Art Unit:* _____

19. CORRESPONDENCE ADDRESS

☒ The address associated with Customer Number 46718 OR ☐ Correspondence address below

Name					
Address					
City		State		Zip Code	
Country		Telephone		Email	

Signature	/Christopher L. Kuyper/	Date	May 14, 2012
Name (Print/Type)	Christopher L. Kuyper	Registration No. (Attorney/Agent)	59,611

This collection of information is required by 37 CFR 1.53(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

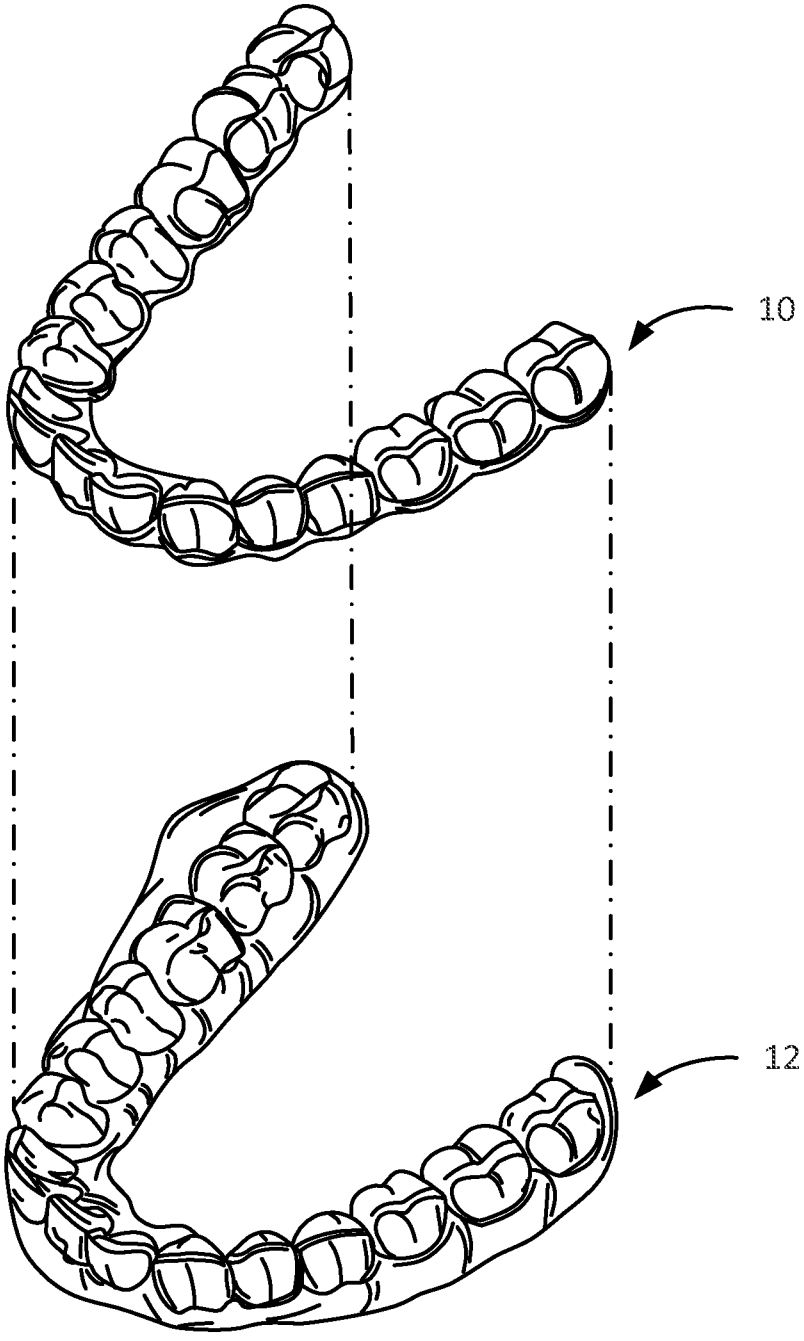


FIG. 1

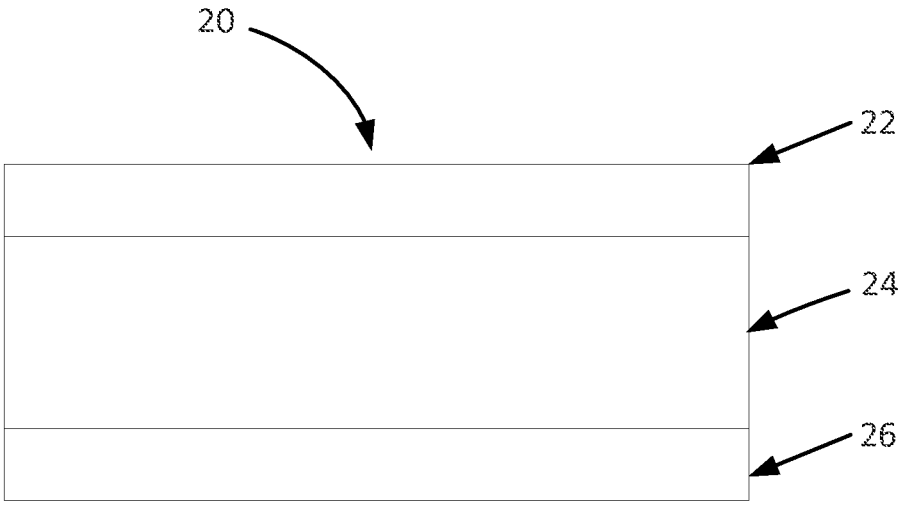


FIG. 2

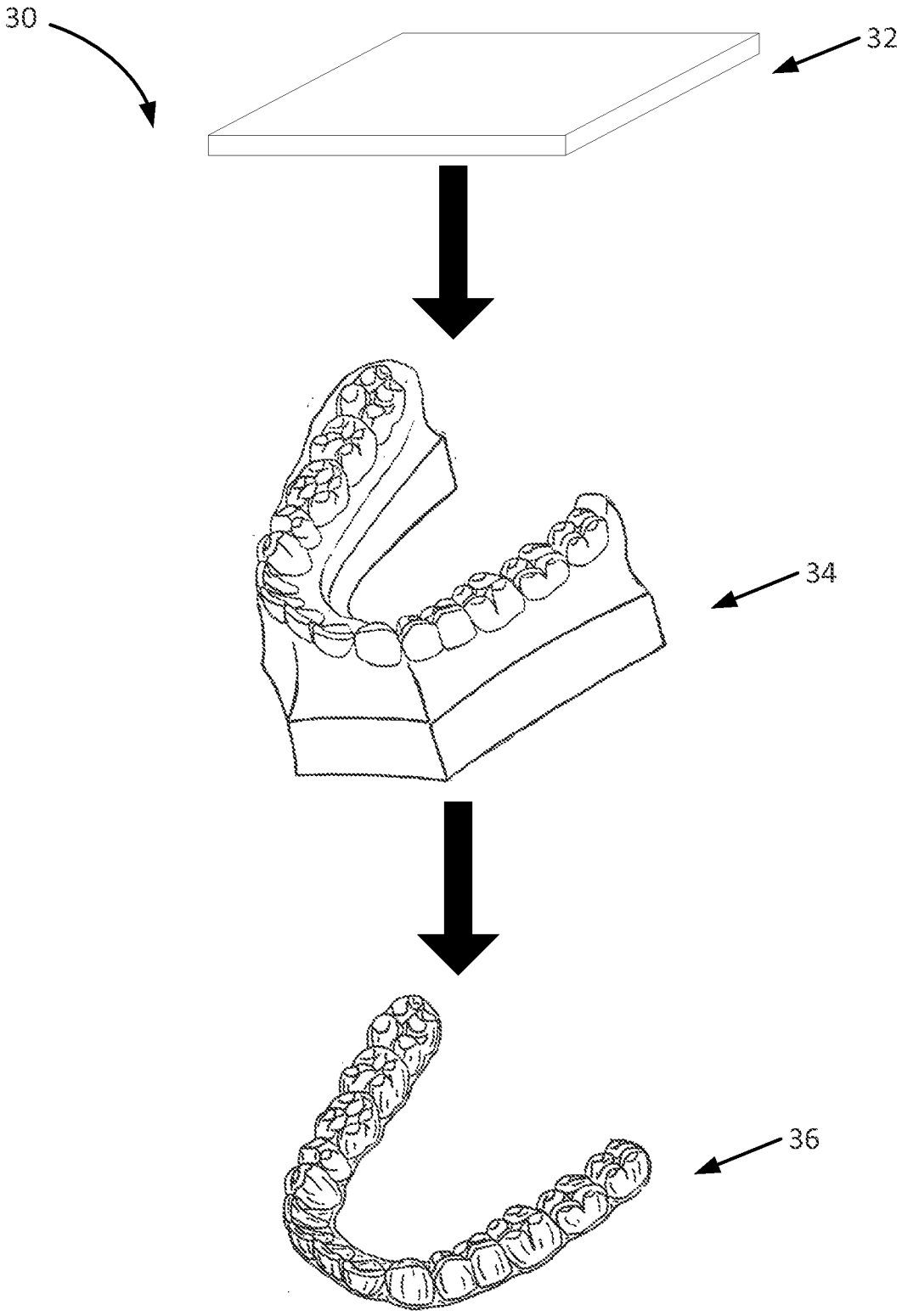


FIG. 3

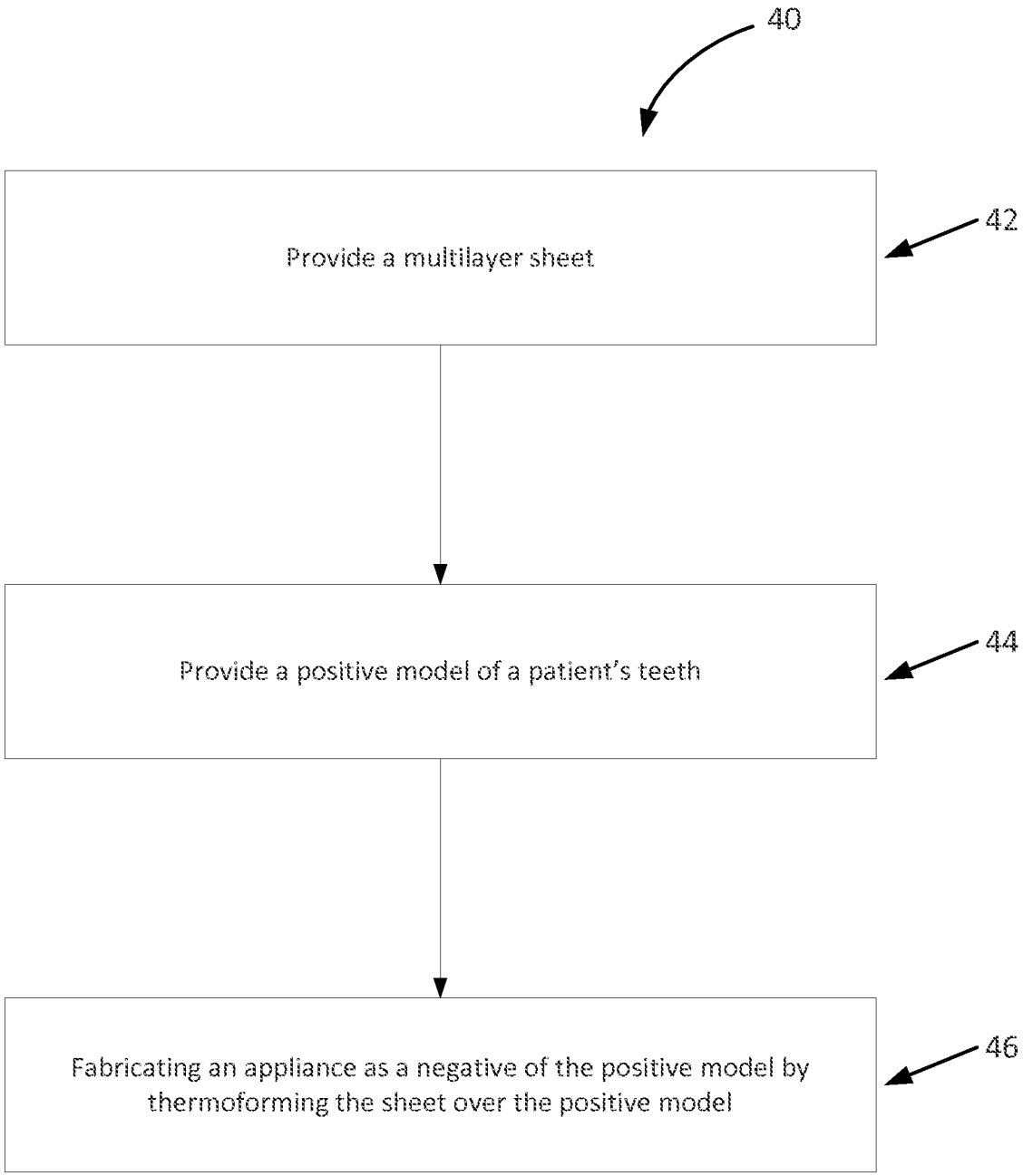

40
Provide a multilayer sheet
42
Provide a positive model of a patient's teeth
44
Fabricating an appliance as a negative of the positive model by thermoforming the sheet over the positive model
46

FIG. 4

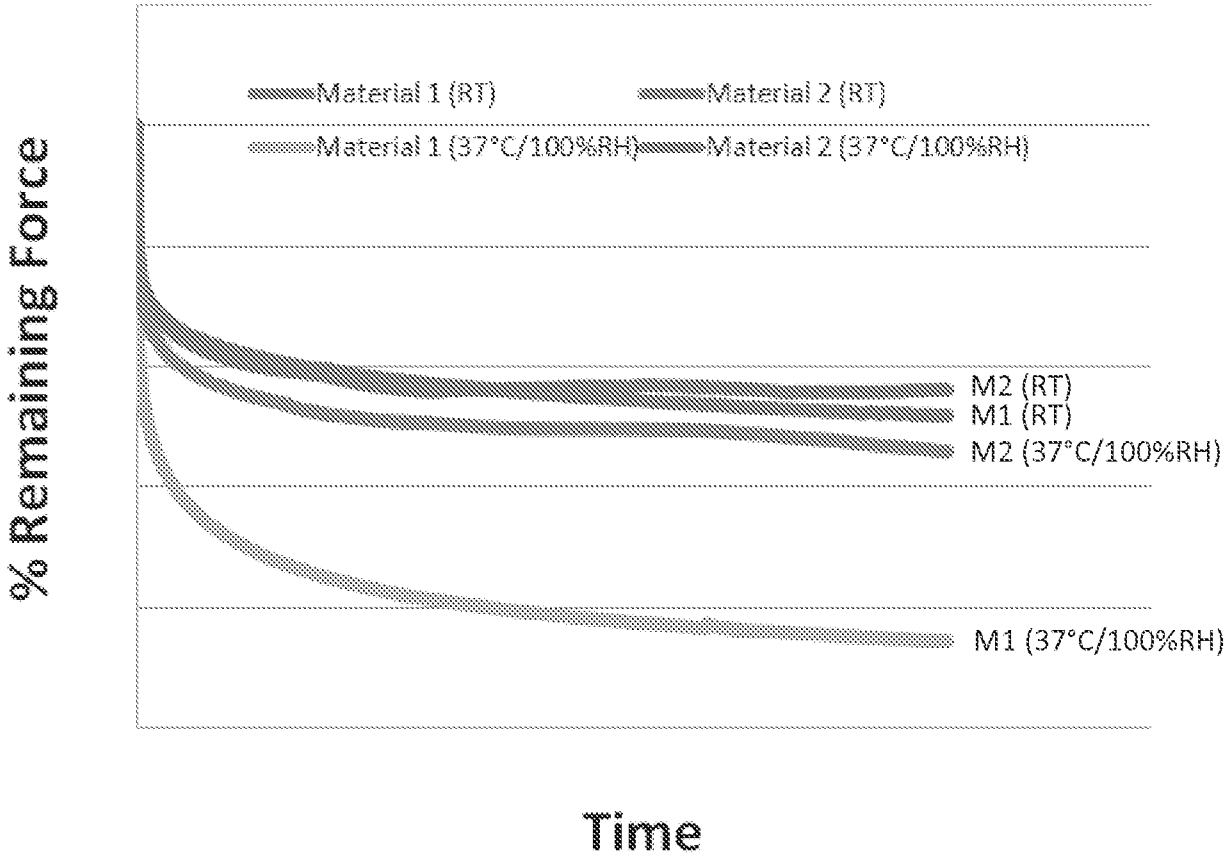

Material 1 (RT)
Material 2 (RT)
Material 1 (37°C/100%RH)
Material 2 (37°C/100%RH)
M2 (RT)
M1 (RT)
M2 (37°C/100%RH)
M1 (37°C/100%RH)
% Remaining Force
Time

FIG. 5

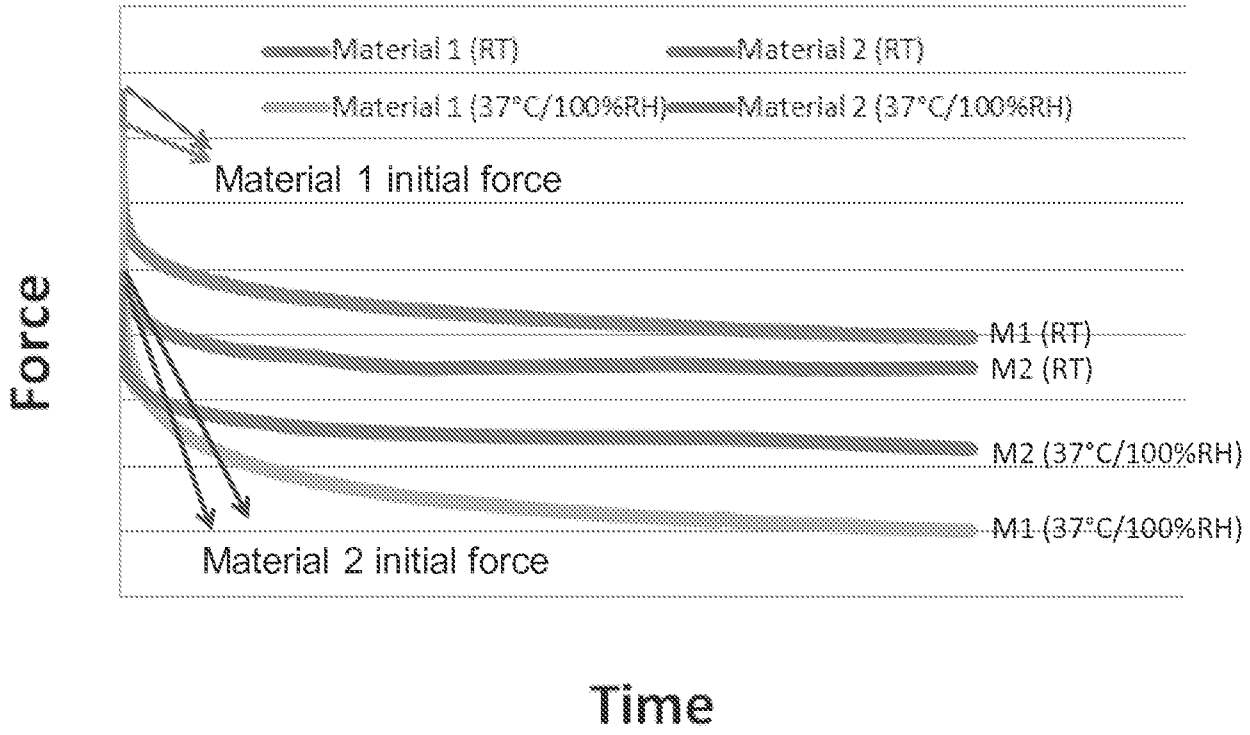

Material 1 (RT)
Material 2 (RT)
Material 1 (37°C/100%RH)
Material 2 (37°C/100%RH)
Material 1 initial force
M1 (RT)
M2 (RT)
M2 (37°C/100%RH)
M1 (37°C/100%RH)
Material 2 initial force
Force
Time

FIG. 6

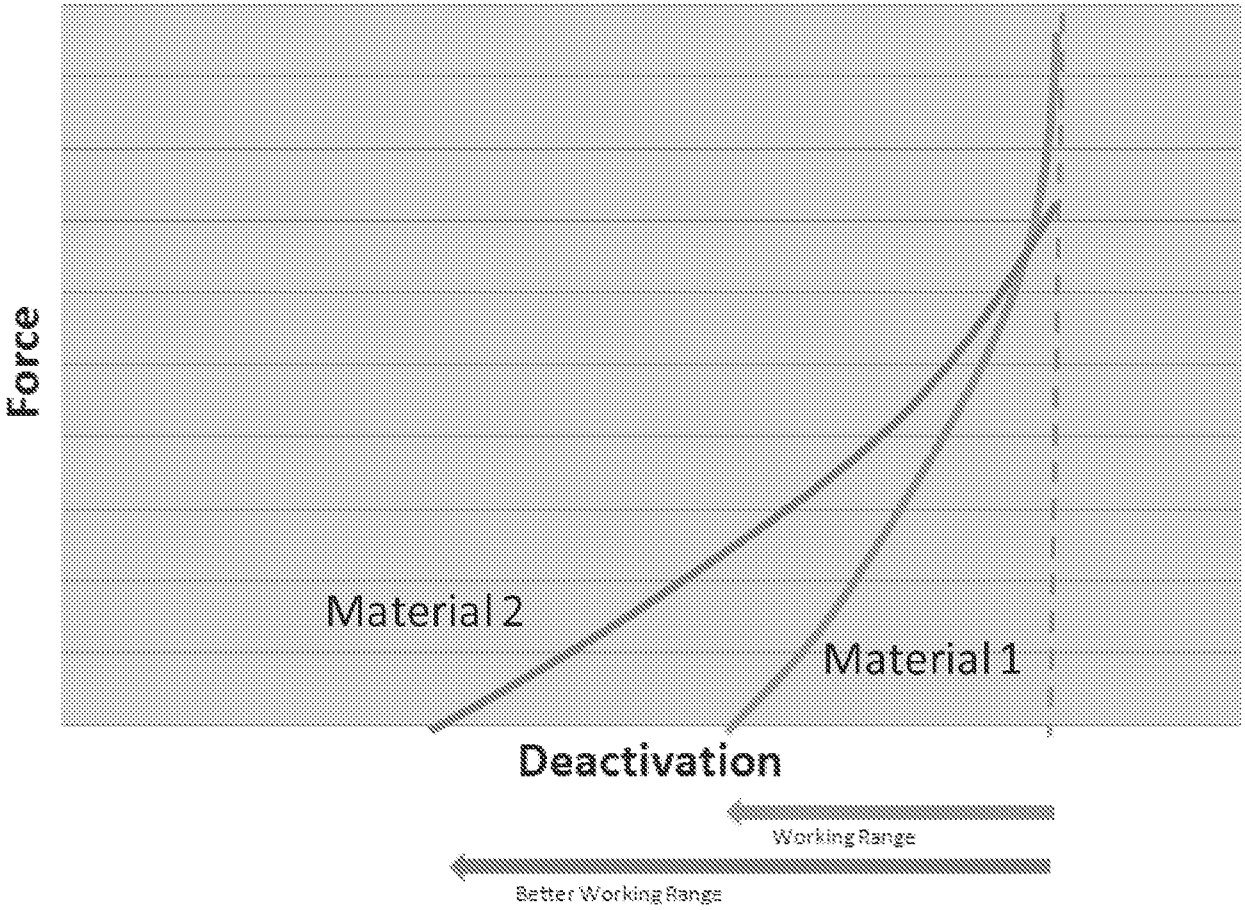

Force
Material 2
Material 1
Deactivation
Working Range
Better Working Range

FIG. 7

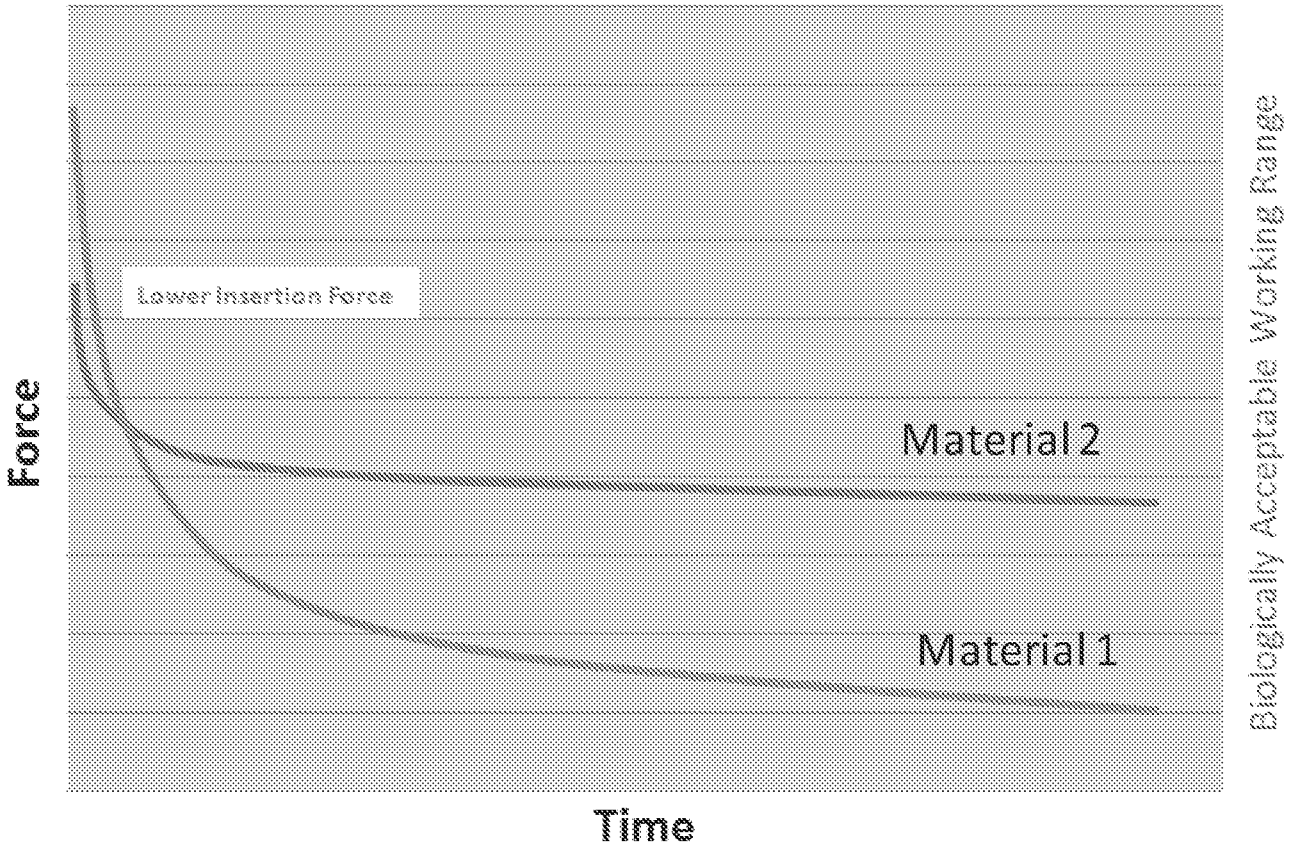

Force
Lower Insertion Force
Material 2
Material 1
Time
Biologically Acceptable Working Range

FIG. 8

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
First Named Inventor/Applicant Name:	Chunhua Li
Filer:	Christopher L. Kuyper/Ashley Fife
Attorney Docket Number:	83289-831160 (022900US)

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility application filing	1011	1	380	380
Utility Search Fee	1111	1	620	620
Utility Examination Fee	1311	1	250	250
Pages:				
Claims:				
Claims in excess of 20	1202	9	60	540
Miscellaneous-Filing:				
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**1790**

WHAT IS CLAIMED IS:

1. A dental appliance for positioning a patient's teeth, comprising:

a removable orthodontic tooth positioning appliance having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth, the appliance comprising a hard polymer layer disposed between a first soft polymer layer and a second soft polymer layer.

2. The dental appliance of claim 1, wherein the hard polymer layer comprises a layer of a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, a polytrimethylene terephthalate, or a combination thereof.

3. The dental appliance of claim 1, wherein the hard polymer layer comprises a layer of a polycarbonate, a co-polyester, a polyester, or a thermoplastic polyurethane.

4. The dental appliance of claim 1, wherein the hard polymer layer comprises at least two layers and the at least two layers are independently selected from a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, and a polytrimethylene terephthalate.

5. The dental appliance of claim 1, wherein the hard polymer layer comprises a thickness in a range from about 400 μm to about 1100 μm, about 450 μm to about 1000 μm, about 500 μm to about 900 μm, or about 550 μm to about 750 μm.

6. The dental appliance of claim 1, wherein each of the first soft polymer layer and the second soft polymer layer independently comprises a layer of a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a

polyolefin blend elastomer, a thermoplastic co-polyester elastomer, a thermoplastic polyamide elastomer, or a combination thereof.

7. The dental appliance of claim 1, wherein each of the first soft polymer layer and the second soft polymer layer independently comprises a layer of an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a thermoplastic co-polyester elastomer, a polyurethane elastomer, or a polyester elastomer.

8. The dental appliance of claim 1, wherein at least one of the first soft polymer layer and the second soft polymer layer comprises at least two layers, and wherein the at least two layers are independently selected from the group consisting of a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a polyolefin blend elastomer, a thermoplastic co-polyester elastomer, and a thermoplastic polyamide elastomer.

9. The dental appliance of claim 1, wherein the soft polymer layer comprises a thickness in a range from about 25 μm to about 100 μm, about 30 μm to about 90 μm, or about 35 μm to about 80 μm.

10. The dental appliance of claim 1, wherein the hard polymer layer, the first soft polymer layer and the second soft polymer layer combined comprises a thickness of about 500 μm to about 1200 μm, about 550 μm to about 1100 μm, or about 600 μm to about 1000 μm.

11. The dental appliance of claim 1, wherein the hard polymer layer comprises at least one of a tensile strength at yield of between about 4000 pounds per square inch (psi) and 6500 psi, an elongation at yield of greater than about 4%, an elongation at break of greater than about 70%, a tensile modulus of greater than about 150,000 psi, a flexural modulus greater than about 150,000 psi, a stress relaxation at 24 hours testing in a high humidity environment of greater than about 10%, and a light transmission between 400 nm and 800 nm of greater than about 75%.

12. The dental appliance of claim 1, wherein the first soft polymer layer and the second soft polymer layer each independently comprise at least one of a hardness of about 60A to about 85D, an ultimate tensile strength of greater than about 5000 psi, an elongation at break of greater than about 200%, a compression set at about 70 °C of greater than 40% after 24 hours, a flexural modulus of greater than about 35,000 psi, and a light transmission between 400 nm and 800 nm of greater than about 75%.

13. An orthodontic system for positioning a patient's teeth, comprising:

a plurality of incremental position adjustment appliances having teeth receiving cavities shaped to directly receive at least some of the patient's teeth and apply a resilient positioning force to the patient's teeth, wherein the appliances are successively worn by a patient to move teeth from one arrangement to a successive arrangement, and wherein at least one of the appliances comprises a hard polymer layer disposed between a first soft polymer layer and a second soft polymer layer.

14. The orthodontic system of claim 13, wherein the hard polymer layer comprises a layer of a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, or a polytrimethylene terephthalate.

15. The orthodontic system of claim 13, wherein the hard polymer layer comprises at least two layers and the at least two layers are independently selected from a group consisting of a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, and a polytrimethylene terephthalate.

16. The orthodontic system of claim 13, wherein each of the first soft polymer layer and the second soft polymer layer independently comprises a layer of a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a

polyolefin blend elastomer, a thermoplastic co-polyester elastomer, a thermoplastic polyamide elastomer, or a combination thereof.

17. The orthodontic system of claim 13, wherein at least one of the first soft polymer layer and the second soft polymer layer comprises at least two layers, and wherein the at least two layers are independently selected from the group consisting of a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a polyolefin blend elastomer, a thermoplastic co-polyester elastomer, or a thermoplastic polyamide elastomer.

18. The orthodontic system of claim 13, wherein the hard polymer layer comprises at least one of a tensile strength at yield of between about 4000 pounds psi and 6500 psi, an elongation at yield of greater than about 4%, an elongation at break of greater than about 70%, a tensile modulus of greater than about 150,000 psi, a flexural modulus greater than about 150,000 psi, a stress relaxation at 24 hours testing in a high humidity environment greater than about 10%, and a light transmission between 400 nm and 800 nm of greater than about 75%.

19. The orthodontic system of claim 13, wherein the first soft polymer layer and the second soft polymer layer each independently comprise at least one of a hardness of about 60A to about 85D, an ultimate tensile strength of greater than about 5000 psi, an elongation at break of greater than about 200 %, a compression set at about 70 °C of greater than 40% after 24 hours, a flexural modulus of greater than about 35,000 psi, and a light transmission between 400 nm and 800 nm of greater than about 75%.

20. A method of making a dental appliance for positioning a patient's teeth, the method comprising:

providing a sheet comprising a hard polymer layer of polymeric material disposed between a first soft polymer layer and a second soft polymer layer;

providing a positive model of the patient's teeth in a target position; and

fabricating an appliance as a negative of the positive model comprising thermoforming the sheet over the positive model.

21. The method of claim 20, wherein the hard polymer layer comprises a layer of a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, a polytrimethylene terephthalate, or a combination thereof.

22. The method of claim 20, wherein the hard polymer layer comprises at least two layers and the at least two layers are independently selected from a group consisting of a polyester, a co-polyester, a polycarbonate, a thermoplastic polyurethane, a polypropylene, a polyethylene, a polypropylene and polyethylene copolymer, an acrylic, a cyclic block copolymer, a polyetheretherketone, a polyamide, a polyethylene terephthalate, a polybutylene terephthalate, a polyetherimide, a polyethersulfone, and a polytrimethylene terephthalate.

23. The method of claim 20, wherein each of the first soft polymer layer and the second soft polymer layer independently comprises a layer of a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a polyolefin blend elastomer, a thermoplastic co-polyester elastomer, a thermoplastic polyamide elastomer, or a combination thereof.

24. The method of claim 20, wherein at least one of the first soft polymer layer and the second soft polymer layer comprises at least two layers, and wherein the at least two layers are independently selected from the group consisting of a styrenic block copolymer (SBC), a silicone rubber, an elastomeric alloy, a thermoplastic elastomer (TPE), a thermoplastic vulcanizate (TPV) elastomer, a polyurethane elastomer, a block copolymer elastomer, a polyolefin blend elastomer, a thermoplastic co-polyester elastomer, or a thermoplastic polyamide elastomer.

25. The method of claim 20, wherein the hard polymer layer comprises at least one of a tensile strength at yield of between about 4000 pounds psi and 6500 psi, an elongation at yield of greater than about 4%, an elongation at break of greater than about 70%, a tensile modulus of greater than about 150,000 psi, a flexural modulus greater than about 150,000 psi, a stress

relaxation at 24 hours testing in a high humidity environment greater than about 10%, and a light transmission between 400 nm and 800 nm of greater than about 75%.

26. The method of claim 20, wherein the first soft polymer layer and the second soft polymer layer each independently comprise at least one of a hardness of about 60A to about 85D, an ultimate tensile strength of greater than about 5000 psi, an elongation at break of greater than about 200 %, a compression set at about 70 °C of greater than 40% after 24 hours, a flexural modulus of greater than about 35,000 psi, and a light transmission between 400 nm and 800 nm of greater than about 75%.

27. The method of claim 20, further comprising fabricating a plurality of appliances corresponding to different arrangements of the patient's teeth.

28. The method of claim 27, wherein fabricating the plurality of appliances comprises digitally staging a plurality of digital models of the patient's teeth and generating a plurality of physical models from the digital models.

29. The method of claim 27, wherein two or more of the plurality of appliances comprise a sheet comprising a hard polymer layer of polymeric material disposed between a first soft polymer layer and a second soft polymer layer.

Initial Application Data Sheet

Application Information

Application number::	Not Yet Assigned
Filing Date::	Concurrently Herewith
Application Type::	Regular
Subject Matter::	Utility
Suggested classification::	
Suggested Group Art Unit::	
CD-ROM or CD-R??::	
Number of CD disks::	
Number of copies of CDs::	
Sequence Submission::	
Computer Readable Form (CRF)?::	
Number of copies of CRF::	
Title::	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
Attorney Docket Number::	83289-831160
Request for Early Publication::	No
Request for Non-Publication::	No
Suggested Drawing Figure::	2
Total Drawing Sheets::	8
Small Entity?::	No
Latin name::	
Variety denomination name::	
Petition included?::	No
Petition Type::	
Licensed US Govt. Agency::	
Contract or Grant Numbers One::	
Secrecy Order in Parent Appl.::	No

Applicant Information

Applicant Authority Type::	Inventor
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Family Name	Li
Suffix	
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State or Province of Residence:	CA
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State or Province of Mailing Address:	CA
Country of Mailing Address:	US
Zip of Mailing Address:	95014

Applicant Information (Continued)

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Family Name	Chen
Suffix	
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Country of Residence:	US
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City of Mailing Address:	Cupertino
State or Province of Mailing Address:	CA
Country of Mailing Address:	US
Zip of Mailing Address:	95014

Correspondence Information

Correspondence Customer Number:: 46718

Representative Information

Representative Customer Number:: 46718

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::

Foreign Priority Information

Country	Application	Date Filed

Assignee Information

Assignee Name::	Align Technology, Inc.
Street of mailing address::	2560 Orchard Parkway
City of mailing address::	San Jose
State or Province of mailing address::	CA
Country of mailing address::	US
Postal or Zip Code of mailing address::	95131

PTO/SB/17 (09-11)
Approved for use through 01/31/2014. OMB 0651-0032
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FEE TRANSMITTAL for FY 2009

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT	($) 1,790

Complete if Known	
Application Number	Not Yet Assigned
Filing Date	Concurrently Herewith
First Named Inventor	Chunhua Li
Examiner Name	Not Yet Assigned
Art Unit	Not Yet Assigned
Attorney Docket No.	83289-831160 (022900US)

METHOD OF PAYMENT (check all that apply)

☐ Check ☒ Credit Card ☐ Money Order ☐ None ☐ Other (please identify) : _____

☒ Deposit Account Deposit Account Number: 20-1430 Deposit Account Name: Kilpatrick Townsend & Stockton, LLP

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

☐ Charge fee(s) indicated below ☐ Charge fee(s) indicated below, **except for the filing fee**

☒ Charge any additional fee(s) or underpayments of fee(s) Under 37 CFR 1.16 and 1.17 ☒ Credit any overpayments

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

	FILING FEES		SEARCH FEES		EXAMINATION FEES		
		Small Entity		Small Entity		Small Entity	
Application Type	Fee ($)	Fee($)	Fee($)	Fee($)	Fee($)	Fee($)	Fees Paid ($)
Utility	380	190	620	310	250	125	1,250
Design	250	125	120	60	160	80	
Plant	250	125	380	190	200	100	
Reissue	380	190	620	310	750	375	
Provisional	250	125	0	0	0	0	

2. EXCESS CLAIM FEES

Fee Description	Fee ($)	Small Entity Fee ($)
Each claim over 20 (including Reissues)	60	30
Each independent claim over 3 (including Reissues)	250	125
Multiple dependent claims	450	225

Total Claims		Extra Claims		Fee($)		Fee Paid ($)
29	-20 or HP=	9	x	60	=	540

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims		Extra Claims		Fee($)		Fee Paid ($)
3	- 3 or HP=	0	x	250	=	0

HP = highest number of independent claims paid for, if greater than 3.

Multiple Dependent Claims	
Fee ($)	Fee Paid ($)
450	0

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets		Extra Sheets		Number of each additional 50 or fraction thereof		Fee ($)	Fee Paid ($)
28	- 100 =	0	/ 50 =	0 (round **up** to a whole number)	x	310 =	0

4. OTHER FEE(S)

	Fees Paid ($)
Non-English Specification, $130 fee (no small entity discount)	0
Other (e.g., late filing surcharge) : _____	0

SUBMITTED BY

Signature	/Christopher L. Kuyper/	Registration No. (Attorney/Agent) 59,611	Telephone 206-467-9600
Name (Print/Type)	Christopher L. Kuyper		Date May 14, 2012

This collection of information is required by 37 CFR 1.136. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this

SCORE Placeholder Sheet for IFW Content

Application Number: 13470681 Document Date: 5/14/2012

The presence of this form in the IFW record indicates that the following document type was received in electronic format on the date identified above. This content is stored in the SCORE database.

- Drawings – Other than Black and White Line Drawings

Since this was an electronic submission, there is no physical artifact folder, no artifact folder is recorded in PALM, and no paper documents or physical media exist. The TIFF images in the IFW record were created from the original documents that are stored in SCORE.

To access the documents in the SCORE database, refer to instructions developed by SIRA.

At the time of document entry (noted above):

- Examiners may access SCORE content via the eDAN interface.
- Other USPTO employees can bookmark the current SCORE URL (http://es/ScoreAccessWeb/).
- External customers may access SCORE content via the Public and Private PAIR interfaces.

Form Revision Date: February 8, 2006

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/470,681	05/14/2012	Chunhua Li	83289-831160

CONFIRMATION NO. 5655

46718
TOWNSEND AND TOWNSEND AND CREW, LLP (018563)
TWO EMBARCADERO CENTER, EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

FORMALITIES LETTER

OC000000054484268

Date Mailed: 05/25/2012

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
  Note: If a petition under 37 CFR 1.47 is being filed, an oath or declaration in compliance with 37 CFR 1.63 signed by all available joint inventors, or if no inventor is available by a party with sufficient proprietary interest, is required.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- A surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of $**130** for a non-small entity, must be submitted.

SUMMARY OF FEES DUE:

Total fee(s) required within **TWO MONTHS** from the date of this Notice is $**130** for a non-small entity
- $**130** Surcharge.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/tnnguyen/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/470,681

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	380
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	620
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	250
TOTAL CLAIMS (37 CFR 1.16(i))	29 minus 20 =	* 9			OR	x 60 =	540
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*				x 250 =	0.00
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						0.00
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							0.00
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	1790

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/470,681	05/14/2012	3732	1790	83289-831160	29	3

CONFIRMATION NO. 5655

46718
TOWNSEND AND TOWNSEND AND CREW, LLP (018563)
TWO EMBARCADERO CENTER, EIGHTH FLOOR
SAN FRANCISCO, CA 94111-3834

FILING RECEIPT

OC000000054484267

Date Mailed: 05/25/2012

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Chunhua Li, Cupertino, CA;
Yan Chen, Cupertino, CA;

Assignment For Published Patent Application

Align Technology, Inc., San Jose, CA

Power of Attorney: None

Domestic Priority data as claimed by applicant

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)

If Required, Foreign Filing License Granted: 05/24/2012

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/470,681**

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

ClearCorrect Exhibit 1010, Page 44 of 1447

Title

MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS

Preliminary Class

433

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as

set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage, facilitate, and accelerate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

Attorney Docket No.: 83289-831160 (022900US)
Client Ref. No.: 1228.US.P

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS

As the below named inventor(s), I/we declare that:

This declaration is directed to:

☐ The attached application, or

☒ Application No. 13/470,681, filed on May 14, 2012,

☐ as amended on _____ (if applicable);

I/we believe that I/we am/are the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought;

I/we have reviewed and understand the contents of the above-identified application, including the claims, as amended by any amendment specifically referred to above;

I/we acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me/us to be material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT International filing date of the continuation-in-part application.

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

All statements made herein of my/our own knowledge are true, all statements made herein on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and may jeopardize the validity of the application or any patent issuing thereon.

FULL NAME OF INVENTOR(S)

Inventor: Chunhua Li — Date: 5/16/12

Signature: _____ Citizen of: US

Inventor: Yan Chen — Date: 5/16/2012

Signature: _____ Citizen of: US

☐ Additional inventors or a legal representative are being named on _____ additional form(s) attached hereto.

I hereby certify that this correspondence is being filed via EFS-Web with the United States Patent and Trademark Office on July 17, 2012.

WILSON SONSINI GOODRICH & ROSATI

By: /Ashley Fife/

PATENT
Attorney Docket No.: 22773-826.201 (022900US)
Client Reference No.: 1228.US.P

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:	
Chunhua Li	Confirmation. No.: 5655
Application No.: 13/470,681	Examiner: Not Yet Assigned
Filed: May 14, 2012	Art Unit: Not Yet Assigned
For: MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS	RESPONSE TO NOTICE OF MISSING PARTS
Customer No.: 104076	

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Pursuant to the Notice to File Missing Parts of Nonprovisional Application, dated May 25, 2012, enclosed are the following to be made of record in the above-identified application:

1) Executed Declaration
2) Power of Attorney
3) Certificate of Assignee Under 37 C.F.R. § 3.73(b)

Please charge Deposit Account No. 23-2415 for the following fees:

Large Entity:	(a)	Missing Parts Surcharge	$130
		TOTAL FEES TO BE CHARGED	$130

The Commissioner is hereby authorized to charge any additional fees associated with this paper or during the pendency of this application, or credit any overpayment, to Deposit Account No. 23-2415.

Respectfully submitted,

Dated: July 17, 2012

/Christopher L. Kuyper/

Christopher L. Kuyper
Reg. No. 59,611

WILSON SONSINI GOODRICH & ROSATI
650 Page Mill Road
Palo Alto, CA 94304-1050
Phone 650-493-9300
Fax 650-493-6811
CKUY:af6

Electronic Acknowledgement Receipt

EFS ID:	13275651
Application Number:	13470681
International Application Number:	
Confirmation Number:	5655
Title of Invention:	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
First Named Inventor/Applicant Name:	Chunhua Li
Customer Number:	46718
Filer:	Christopher L. Kuyper/Ashley Fife
Filer Authorized By:	Christopher L. Kuyper
Attorney Docket Number:	22773-826.201 (022900US)
Receipt Date:	17-JUL-2012
Filing Date:	14-MAY-2012
Time Stamp:	18:28:06
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$130
RAM confirmation Number	5602
Deposit Account	232415
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		2012_07_17_RESP_NTFMP_POA_373B_22773_826_201.pdf	355004 d2b65e32873712a9c6c0c4e40c707b0fc6a4bd3d	yes	5

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Applicant Response to Pre-Exam Formalities Notice	1	2
	Oath or Declaration filed	3	3
	Power of Attorney	4	4
	Assignee showing of ownership per 37 CFR 3.73(b).	5	5

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	30139 0e59b3c453a62a65ba535d4a9146343b4a4c642c	no	2

Warnings:

Information:

Total Files Size (in bytes):	385143

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/SB/80 (11-08)
Approved for use through 11/30/2011. OMB 0651-0035
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(b).

I hereby appoint:

☑ Practitioners associated with the Customer Number: 107046

OR

☐ Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name	Registration Number	Name	Registration Number

as attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with any and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignment documents attached to this form in accordance with 37 CFR 3.73(b).

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73(b) to:

☑ The address associated with Customer Number: 107046

OR

☐ Firm or Individual Name			
Address			
City		State	Zip
Country			
Telephone		Email	

Assignee Name and Address:

ALIGN TECHNOLOGY, INC.
2560 Orchard Parkway
San Jose, California 95131

A copy of this form, together with a statement under 37 CFR 3.73(b) (Form PTO/SB/96 or equivalent) is required to be filed in each application in which this form is used. The statement under 37 CFR 3.73(b) may be completed by one of the practitioners appointed in this form if the appointed practitioner is authorized to act on behalf of the assignee, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record

The individual whose signature and title is supplied below is authorized to act on behalf of the assignee

Signature		Date	6-7-2012
Name	Roger E. George	Telephone	408-470-1000
Title	Vice President, Legal Affairs and General Counsel		

This collection of information is required by 37 CFR 1.31, 1.32 and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PTO/SB/96 (07-09)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

STATEMENT UNDER 37 CFR 3.73(b)

Applicant/Patent Owner: Chunhua Li et al.

Application No./Patent No.: 13/470,681 Filed/Issue Date: May 14, 2012

Titled: MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS

Align Technology, Inc. , a corporation

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.

states that it is:

1. [x] the assignee of the entire right, title, and interest in;

2. [ ] an assignee of less than the entire right, title, and interest in (The extent (by percentage) of its ownership interest is _____ %); or

3. [ ] the assignee of an undivided interest in the entirety of (a complete assignment from one of the joint inventors was made)

the patent application/patent identified above, by virtue of either:

A. [x] An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 028539, Frame 0426, or for which a copy therefore is attached.

OR

B. [ ] A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

2. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

3. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

[ ] Additional documents in the chain of title are listed on a supplemental sheet(s).

[x] As required by 37 CFR 3.73(b)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (*i.e.*, a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Christopher L. Kuyper/ July 17, 2012

Signature Date

Christopher L. Kuyper Attorney of Record

Printed or Typed Name Title

This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Electronic Patent Application Fee Transmittal

Application Number:	13470681
Filing Date:	14-May-2012
Title of Invention:	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
First Named Inventor/Applicant Name:	Chunhua Li
Filer:	Christopher L. Kuyper/Ashley Fife
Attorney Docket Number:	22773-826.201 (022900US)

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Late filing fee for oath or declaration	1051	1	130	130
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
			Total in USD ($)	**130**

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
13/470,681	05/14/2012	3732	1920	22773-826.201 (022900US)	29	3

CONFIRMATION NO. 5655

107046
WSGR / Align Technology , Inc.
650 Page Mill Road
Palo Alto, CA 94304

UPDATED FILING RECEIPT

OC000000055532754

Date Mailed: 07/23/2012

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Chunhua Li, Cupertino, CA;
Yan Chen, Cupertino, CA;

Assignment For Published Patent Application

Align Technology, Inc., San Jose, CA

Power of Attorney: The patent practitioners associated with Customer Number 107046

Domestic Priority data as claimed by applicant

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.)

If Required, Foreign Filing License Granted: 05/24/2012

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/470,681**

Projected Publication Date: 11/14/2013

Non-Publication Request: No

Early Publication Request: No

ClearCorrect Exhibit 1010, Page 56 of 1447

Title

MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS

Preliminary Class

433

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

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Title 37, Code of Federal Regulations, 5.11 & 5.15

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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 13/470,681

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	380
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	620
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	250
TOTAL CLAIMS (37 CFR 1.16(i))	29 minus 20 =	* 9			OR	x 60 =	540
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*				x 250 =	0.00
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						0.00
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							0.00
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	1790

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
13/470,681	05/14/2012	Chunhua Li	22773-826.201 (022900US)

CONFIRMATION NO. 5655

107046
WSGR / Align Technology , Inc.
650 Page Mill Road
Palo Alto, CA 94304

POA ACCEPTANCE LETTER

OC000000055532827

Date Mailed: 07/23/2012

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 07/17/2012.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

/dgela/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

Orthodontic treating device and method of manufacturing same

Patent Number: US4504225
Publication date: 1985-03-12
Inventor(s): YOSHII OSAMU [JP]
Applicant(s): YOSHII OSAMU [JP]
Requested Patent: AU517102
Application Number: US19830531558 19830913
Priority Number(s): JP19760132323 19761105
IPC Classification: A61C7/00
EC Classification: A61C7/08, A61K6/093
Equivalents: AU3031677, CA1121955, DE2749802, ES463897, FR2369828, GB1550777, JP53058191, US4505673

Abstract

Original models of plaster are obtained from impressions of the dentition of the upper and lower jaws of a patient with malocclusion. The teeth are then separated from the base of the models and reset in wax to a normal occlusion. The realigned teeth are fixed in place with wax, and impressions of the upper and lower models are taken to duplicate the rearranged models, forming working models made of plaster. The working models are mounted on an anatomic dental articulator and a wax occluding model is constructed of the new occlusion to cover both upper and lower arches. The working upper and lower models, together with the wax occluding model are buried in plaster in a split cast. The wax occluding model in the split cast is heated and the wax is melted and discharged out of the cast. Silicone resin is then placed into the impression of the occluding model and cured.

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CUSTOM ORTHODONTIC APPLIANCE FORMING METHOD AND APPARATUS

Patent Number:	WO9410935
Publication date:	1994-05-26
Inventor(s):	ANDREIKO CRAIG A; PAYNE MARK A
Applicant(s):	ORMCO CORP [US]
Requested Patent:	JP8508174T
Application Number:	WO1993US10858 19931109
Priority Number (s):	US19920973844 19921109; US19920973947 19921109; US19920973965 19921109; US19920973973 19921109
IPC Classification:	A61C7/00; A61C13/00
EC Classification:	A61C7/00, A61C7/14P, A61C7/20
Equivalents:	AU5598894, DE69327661D, DE69327661T, EP0667753 (WO9410935), B1, JP3380553B2
Cited Documents:	EP0502227; WO9008512

Abstract

A system (10) and method by which an orthodontic appliance (25) is automatically designed and manufactured from digital lower jaw and tooth shape data (26) of a patient (14) provides for scanning, preferably from a model (20) of the patient's mouth, to produce two or three dimensional images, and digitizing contours and selected point on the patient's teeth and jaw. From the scanned individual patient data, a computer (30) constructs archforms and calculates finish tooth positions, then designs an appliance (25), preferably including archwires and brackets, to move the teeth to the calculated positions. Lower teeth are positioned at the gums on an arch defined by the lower jaw bone and modified to best fit the tooth tips on a smooth curve. Then upper archforms are derived from the lower archform. Crown long axes of the teeth are derived and optimally inclined in the treatment which places all lower teeth but the cuspids in a plane and fits the occluding teeth to them. Overlaps for the upper incisors and cuspid rise are calculated. Brackets each have a base and an archwire support in which an archwire slot is to be cut to a custom inclination, depth, location and curvature, in a blank clamped to an inclinable holder, using a blade of a cutting machine (39). The holder and blade are moved by commands from a computer (30c). An archwire is automatically formed by a wire bender (40) into an optimize smooth arcuate shape and optimal low profile bracket design. Arch equations preferably start with a cubic spline equation and are converted to the form of a series of circle segments for machine control instructions for a numerically forming equipment. Placement jigs, simultaneously designed and automatically made with numerically controlled machinery (41) for positioning and orienting the appliance at connection points on the teeth, each have a surface custom shaped to the contour of a tooth. The machines (38-41) for making the brackets, wires and jigs are driven by commands derived from digitized tooth and jaw shape data and from digital representations of the tooth finish positions and appliance design.

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(19)日本国特許庁（ＪＰ）　(12) **公表特許公報（Ａ）**　(11)特許出願公表番号

特表平8－508174

(43)公表日　平成８年(1996)９月３日

(51)Int.Cl.[6]		識別記号	庁内整理番号	ＦＩ		
Ａ６１Ｃ	7/20		7108－4C	Ａ６１Ｃ	7/00	Ａ
	7/14		7108－4C			Ｂ
	7/28					

審査請求　未請求　予備審査請求　有　（全121頁）

(21)出願番号　特願平6－512324
(86)(22)出願日　平成５年(1993)11月９日
(85)翻訳文提出日　平成７年(1995)５月９日
(86)国際出願番号　ＰＣＴ／ＵＳ９３／１０８５８
(87)国際公開番号　ＷＯ９４／１０９３５
(87)国際公開日　平成６年(1994)５月26日
(31)優先権主張番号　０７／９７３，８４４
(32)優先日　1992年11月９日
(33)優先権主張国　米国（ＵＳ）
(31)優先権主張番号　０７／９７３，９４７
(32)優先日　1992年11月９日
(33)優先権主張国　米国（ＵＳ）

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最終頁に続く

(54)【発明の名称】　注文歯科矯正器具形成方法及び装置

(57)【要約】
患者（１４）のデジタル下顎及び歯形状データ（２６）から歯科矯正器具（２５）が自動的に設計及び製作されるシステム（１０）及び方法は、好ましくは患者の口のモデル（２０）から、走査を行って２次元もしくは３次元画像を生成し、患者の歯及び顎の輪郭及びその上の選定点をデジタル化する。走査された個別の患者データからコンピュータ（３０）が弧線を描き仕上げ歯位置を計算し次に、好ましくは、弧線及びブラケットを含む器具（２５）を設計して歯を計算された位置へ動かす。下歯は下顎により画定される弓上のガムに配置され歯の先端を滑らかな曲線上に最良適合させるように修正される。歯の歯冠長軸が引き出され犬歯を除く全ての下歯を面内に配置して咬合する歯をそれらに適合させる治療において最適に傾斜される。上部切歯及び犬歯隆起に対する重畳が計算される。各ブラケットがベース及び弧線サポートを有し、切断機（３９）の刃を使用して、傾斜可能なホルダーに締着されたブランクに弧線溝が注文傾斜、深さ、位置及び曲率で切り込まれる。ホルダー及び刃はコンピュータ（３０ｃ）からのコマンドにより動かされ

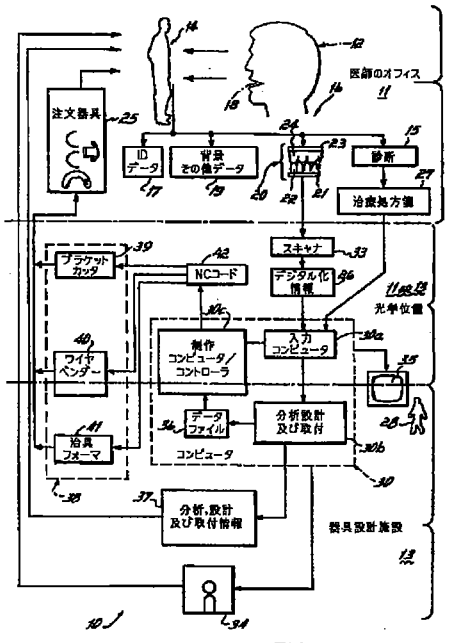


FIG. 1

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【特許請求の範囲】

1．患者の口腔の解剖学的形状を測定する段階と、前記患者の個々の歯の前記形状を表す歯の3次元的形状データを備えたディジタル化された解剖学的形状データを前記測定段階から得る段階と、前記ディジタル化された解剖学的形状データに少なくとも部分的に依存するディジタル化された数学的アーチ形状モデルを作成するためにプログラムされたディジタル・コンピュータで前記ディジタル化された解剖学的形状データを処理することにより理想的な歯のアーチ形状を得る段階と、得られた前記の理想的な歯のアーチ形状に沿って歯に中間の遠心方位に間隔をあけるために、およびそれぞれの個々の歯に対する前記3次元的歯形状に少なくとも部分的に基づく位置および方位に対し得られた前記の理想的な歯のアーチ形状に対して歯の位置および方位を定めるために、前記ディジタル化された解剖学的形状データからおよび前記ディジタル化された数学的アーチ形状モデルから歯の完成位置を前記コンピュータで得る段階と、複数個の歯のおのおのに装具連結点を設定する段階と、ディジタル化された前記3次元的歯形状データと、設定された前記装具連結点と、得られた前記歯の完成位置とから、装具のそれぞれの連結点における歯と得られた前記歯の完成位置における歯とを相互連結する寸法の装具構成体をカスタム歯科矯正装具が有するように、ディジタル化された前記3次元的歯形状データからコンピュータでもって前記カスタム歯科矯正装具を設計する段階と、前記装具設計段階の結果に関連する幾何学的情報を含みかつ機械が読み出し得る制御信号を生成する段階と、前記設計された装具構成体を有するカスタム歯科矯正装具を作成するように前記制御信号に含まれる前記形状寸法情報に従って前記装具を成形するために機械が読み出し得る前記制御信号に応答する機械でカスタム歯科矯正装具を製造する段階と、を有する、患者の口腔の中の好ましい完成位置に患者の歯を配置するためのカスタム歯科矯正装具を製造する方法。

2．第1項記載の方法において、前記歯が下顎歯および上顎歯を有し、かつ前記解剖学的形状測定段階が、患者の下顎を測定する段階と、それにより下顎の形状のディジタル化されたデータを生成する段階と、患者の下顎歯および上顎歯を

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測定する段階と、それにより個々の下顎歯形状および個々の上顎歯形状のディジタル化されたデータを生成する段階とを有し、かつ前記アーチ形状を得る段階が前記ディジタル化された下顎形状データから下顎骨格アーチ形状をコンピュータで得る段階を有し、かつ前記歯の完成位置を得る段階が前記下顎骨格アーチ形状に対して歯を配列するために前記歯形状データと前記得られた下顎骨格アーチ形状とから歯の完成位置を得る段階を有する、前記方法。

3．第1項または第2項に記載の方法において、前記アーチ形状を得る段階が、前記ディジタル化された解剖学的形状データに基づいて曲線を定める段階と、滑らかで連続したアーチ形状方程式を生成するために最適化の統計的方法により前記曲線を滑らかにする段階とを有し、かつ前記完成位置を得る段階および前記装具構成体設計段階が前記アーチ形状方程式に少なくとも部分的に基づいて行われる、前記方法。

4．第1項または第2項に記載の方法において、コンピュータの中のアーチ形状方程式により前記得られたアーチ形状をディジタルに表示する段階と、一連の逐次の接触円セグメントにより前記アーチ形状方程式をディジタルに表示する段階とをさらに有し、かつ前記装具設計段階が前記アーチ形状方程式の円セグメントから得られる円セグメント長および円セグメント半径を表す一連のディジタル値に少なくとも部分的に従ってアーチ形の装具を設計する段階を有し、かつ前記装具製造段階が、前記セグメント長およびセグメント半径を変換して前記制御信号を生ずるための一連の命令にする段階と、前記信号にに応答して前記設計された装具構成体に整合する信号に応答してそのおのおののセグメント長に対応する半径に前記装具を順次に作成する段階とを有する、前記方法。

5．第1項または第2項に記載の方法において、前記測定段階が患者の複数個の歯のおのおのの唇側表面および舌側表面の上の種々の点のデータをディジタル化する段階を有し、かつ前記点に関してそれぞれの歯の歯冠長軸の方位のディジタル表示を前記ディジタル化した唇側表面データおよび舌側表面データから得る段階と、前記ディジタル化されたデータと歯の前記歯冠長軸の前記ディジタル表示とから歯の完成位置を計算する段階とをさらに有し、かつ前記計算された完成位置が好ましい歯冠長軸方位を有する、前記方法。

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6．第5項記載の方法において、複数の患者に対して前記好ましい歯冠長軸方位を計算する段階と、前記計算された好ましい歯冠長軸方位の記録を作成する段階と、患者のおのおのの個人データを記録する段階と、前記計算された好ましい歯冠長軸方位を前記個人データと関連させる段階と、前記関連に基づいて患者を集団群に分類する段階と、前記集団群の患者に対し好ましい歯冠長軸方位の統計的記録を作成する段階と、をさらに有する前記方法。

7．第1項または第2項に記載の方法において、前記装具設計段階が歯の形状のデータから装具配置ジグ構成体を設計する段階を有し、かつ装具配置ジグ構成体のおのおのがその上の連結点の位置およびそれへの装具の連結を容易にするためにそれぞれの歯の表面に適合するジグ表面を有し、かつ前記制御信号生成段階が設計された前記装具配置ジグ構成体に少なくとも部分的に従って制御信号を生成する段階を有し、かつ前記装具製造段階が設計された前記配置ジグ構成体に整合した制御信号に応答して装具配置ジグを機械で自動的に製造する段階を有する、前記方法。

8．第1項または第2項に記載の方法において、患者のそれぞれの上側後部歯と下側後部歯との咬合対を識別する段階と、顎が閉じた位置にある時前記対の下側歯の最高限度から前記対の上側歯の最低限度までの垂直距離をおのおのの対に対しディジタル化された前記歯形状データから決定する段階と、その上の最高点がほぼ平坦な咬合表面の上の垂直位置にある患者の下顎歯の完成位置をディジタル化された前記データから計算して調整された最大垂直距離を選定する段階と、前記咬合表面のそれぞれの上および下の範囲内の患者の上犬歯および下犬歯の完成位置を計算する段階と、をさらに有する前記方法。

9．第1項または第2項に記載の方法において、患者の歯茎からの最適の間隔を得るためにおよび患者の反対側の顎の歯との最適の隙間を得るために、連結位置設定段階が、装具の対の形状寸法をディジタル化する段階と、ディジタル化された前記歯形状データから患者の反対側の顎の歯の表面の上の種々の点における関係を計算する段階と、患者の歯茎からの最適の間隔を得るためにおよび患者の反対側の顎の歯との最適の隙間を得るために装具が連結されるべき患者の1つの顎の歯の表面の上の位置をディジタル化された前記データから計算する段階と、

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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 376 873 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **89630211.4**

(51) Int. Cl.5: **G05B 19/42**

(22) Date of filing: **06.12.89**

(30) Priority: **30.12.88 IL 88842**

(43) Date of publication of application:
04.07.90 Bulletin 90/27

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IT LI NL SE

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(54) Apparatus for digitizing the contour of a three-dimensional surface, particularly useful for preparing a dental crown.

(57) Apparatus for digitizing the contour of a three-dimensional surface of an object includes a handle (20), a probe (26) carried by the handle (20) and movable along three independent axes to contact sample points on the three- dimensional surface, and a positional sensor for sensing the position of the handle (20) along the three axes and for outputting positional values. The probe(26) includes an arm (28) deflectable during the movement of the probe (26), which deflections are sensed by a sensor. A digital processor processes the positional values only when one of the deflection sensors senses a deflection in its respective arm above a predetermined threshold value, and modifies the positional values by the deflection values.

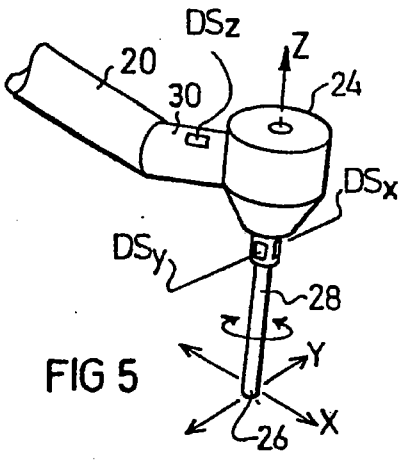


FIG 5

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APPARATUS FOR DIGITIZING THE CONTOUR OF A THREE-DIMENSIONAL SURFACE, PARTICULARLY USEFUL FOR PREPARING A DENTAL CROWN

The present invention relates to apparatus for digitizing the contour of a three-dimensional surface. The invention is particularly applicable for digitizing a dental surface, e.g., a ground tooth for preparing a dental crown, and is therefore described below with respect to this application.

When a tooth is in an advanced state of decay, it may become necessary to apply a crown. This involves grinding the tooth and then fixing the crown to it. If one or more teeth are missing or are to be removed, it may be necessary to insert a bridge, which includes a crown applied to each of the two teeth to be bridged and integrally formed with one or more artificial teeth to fill the space of the missing tooth or teeth.

The metal infrastructure for preparing a crown or bridge is conventionally produced by making a cast model of the respective part of the oral cavity, and then using the cast model for building the crown or bridge. Such a procedure is very time-consuming and requires a large number of visits by the patient to the dentist. Moreover, this procedure is greatly dependent on the skill and experience of both the dentist and the laboratory technician in making the cast model and the crown or bridge based on it, as well as on the precision of the equipment used.

Many systems have been proposed for automatically producing crowns and bridges by digitizing the contour of the tooth to be crowned. Some of the proposed systems are based on optical measurements, as illustrated for example in US Patents 4,742,464, 4,663,720, 4,611,288 and 4,575,805. Other proposed systems are based on the use of contact-type probes which are passed over the surface of the tooth to be crowned. Examples of the latter type system are illustrated in US Patents 4,182,312, 4,478,580, 4,411,626 and 4,324,546.

US Patent 4,182,312 discloses a contact-type dental probe in which an aluminum tray is fixed in the patient's mouth such that when the dentist applies the probe to the patient's tooth or gum tissues, an electrical circuit is completed, via the saliva in the patient's mouth, to the tray to enable the transducer to output the positional signals of the probe. However, since the contact of the probe with the surface being digitized is based on completing an electrical circuit to the tray via the subject's saliva, the results would be distorted by the thickness of the saliva film, which is significant when compared to the precision required for dental probes of this type. US Patent 4,478,580 discloses apparatus for treating teeth in which a rotary cutter head is provided with stress sensors so that both the shape of the tooth being ground, as well as the resistance to grinding, are sensed during the grinding operation.

Insofar as we are aware, apparatus for digitizing the contour of a tooth in order to automatically prepare a crown or a bridge has not yet gained widespread use despite the long felt need and search for such an apparatus.

An object of the present invention is to provide improved apparatus for digitizing the contour of a three-dimensional surface, particularly a dental surface to enable dental crowns and bridges to be produced in a more efficient manner than by the present conventional techniques, and in a more precise manner than in the previously-proposed automated techniques.

According to the invention, there is provided apparatus for digitizing the contour of a three-dimensional surface of an object, comprising: a handle graspable by the user; mounting means for mounting the handle with respect to the object; a probe connected to and carried by the handle and movable thereby along three independent axes to contact sample points on said three-dimensional surface; positional sensor means for sensing the position of the handle along the three axes and for outputting positional values corresponding thereto; the probe including an arm deflectable along first and second ones of the three axes during the movement of the probe along the three-dimensional surface by the handle; first and second deflection sensor means for sensing the deflection of the arm along the first and second axes, respectively, and for outputting deflection values corresponding thereto; and a digital processor including means for processing the positional values only when one of the deflection sensors senses a deflection in its respective arm above a predetermined threshold value, and means for modifying the positional values by the deflection values to output digital surface-location values representing the location of the points on the three-dimensional surface during the movement of the probe thereabout by the handle.

It will thus be seen that the deflection sensors serve the double function of: (1) determining when contact is made by the probe with the three-dimensional surface being contoured, and (2) correcting the measurements by the deflections of the probe. The apparatus thus permits three-dimensional surfaces to be digitized in an automatic and highly-precise manner. A deflection sensor for the third axis may be provided but is not essential for the

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above purposes.

The above-described apparatus is particularly useful for digitizing a dental surface of a subject, in which case the described mounting means includes a biting member to be clamped between the upper and lower teeth of the subject.

Further featues and advantages of the invention will be apparent from the description below.

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Fig. 1 illustrates one form of probe assembly constructed in accordance with the present invention for digitizing the contour of a patient's tooth;

Fig. 2 is a perspective view more particularly illustrating the construction of the probe assembly;

Fig. 3 is a perspective view more particularly illustrating the mounting for the handle and probe in the probe assembly;

Fig. 4 illustrates the construction of one of the slides provided for each orthogonal axis in the probe assembly;

Fig. 5 illustrates the deflection sensors in the probe assembly of Figs. 1 and 2 for sensing deflections in the three orthogonal axes;

Fig. 6 illustrates the manner of using the probe assembly for digitizing the contour of a ground tooth;

Fig. 7 illustrates a bridge circuit provided for each of the three pairs of deflection sensors in the probe assembly;

Fig. 8 is a block diagram illustrating one form of data processor system for use with the probe assembly;

Fig. 9 illustrates the setup for precalibrating the probe assembly by producing and storing a look-up table for the respective probe assembly;

Fig. 10 is a flow diagram illustrating the operation of the system of Figs. 1-9 where both the digitizing and processing operations are performed "on-line";

Fig. 11 is a flow diagram more particularly illustrating the compensation, transform and sort operations indicated by Routine-A in the diagram of Fig. 10;

Fig. 12a illustrates a semi-sphere geometrically divided by a plurality of longitudinal meridian lines and a plurality of horizontal latitude lines into a plurality of segments for use in defining the contour of the surface of the tooth to receive the crown;

Fig. 12b defines the X-Y plane of the semi-sphere of Fig. 12a, and particularly the manner of measuring the medidian angle "α" in the plane of the tooth base;

Fig. 12c illustrates the X-Z plane of the semi-sphere of Fig. 12a, and particularly the manner of measuring the latitude "β" in the plane perpendicular to the tooth base; and

Figs. 13a and 13b are flow diagrams illustrating another operation of the system of Figs. 1-9, particularly when using a low-power (e.g., personal) computer, in which the digitizing operation (illustrated in Fig. 13a) is performed "on-line", and the processing operations (illustrated in Fig. 13b) are performed "off-line".

Figs. 1 and 2 illustrate a probe assembly constructed in accordance with the present invention for use in digitizing the contour of the surface of a tooth to receive a dental crown. After the dentist has ground the tooth as required, this probe assembly would be used with the data processor system illustrated in Fig. 8 to digitize the contour of the ground surface of the tooth in order to produce digital data for use in automatically preparing the crown according to that contour.

The probe assembly illustrated in Figs. 1 and 2 comprises a wedge-shaped mounting member 2 to be clamped between the upper and lower teeth of the subject. Mounting member 2 is secured to one end of an arm 4 connected at its opposite end by an articulated joint 6 to one end of a second arm 8. The opposite end of arm 8 carries an articulated joint 10 to which is mounted one section 12a of a slide 12, having a second, relatively-movable section 12b to which is mounted a base member 14. Base member 14 mounts one section 16a of a further slide 16 having a second, relatively-movable section 16b which is movable perpendicularly to the direction of movement of section 12b of slide 12. Slide section 12b in turn mounts one section 18a of a third slide 18 having a second, relatively-movable section 18b movable perpendicularly to the directions of movements of both slide sections 12b and 16b. Slide section 18b in turn mounts a handle 20 knurled at one end 22 to facilitate grasping by the dentist. The opposite end of handle 20 mounts a probe head 24.

The illustrated probe assembly further includes a digitizer switch SW conveniently accessible to the dentish when probing the outer surface of the ground tooth.

As shown more particularly in Fig 5, probe head 24 carries a probe 26 at the tip of an arm 28 depending from the probe head. Arm 28 is deflectable along both the X-axis and the Y-axis. A pair of deflection sensors DSx are fixed on the two opposite sides of arm 28 aligned with each other along the X-axis, and a second pair of deflections sensors DSy are fixed on the remaining two opposite sides of arm 28 aligned with each other along the Y-axis. Probe head 24 is in turn mounted to the end of handle 20 by a further arm 30 which may be deflectable along the Z-axis, and which may include a third pair of deflection sensors DSz fixed on its opposite sides aligned with each other

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along the Z-axis. Deflection sensors DSx, DSy, DSz may be resistance-type strain gages producing analog outputs.

It will thus be seen, as shown more particularly in Fig. 3, that the three slide assemblies 12, 16 and 18 permit handle 20 and probe 26 to move along the three orthogonal axes with respect to the mounting member 2. Thus, slide assembly 12 permits movement along the X-axis, slide assembly 16 permits movement along the Y-axis, and slide assembly 18 permits movement along the Z-axis.

Fig. 4 more particularly illustrates the construction of slide assembly 12, it being appreciated that slide assemblies 16 and 18 are similarly constructed. Thus, slide assembly 12 includes slide member 12a fixed to joint 10 and formed with a dove-tail rib 12a′ received within a dove-tail groove 12b′ formed in slide member 12b fixed to the common base member 14 (Fig. 2). A plurality of roller bearings 12c, e.g., of the cylindrical type, are interposed between rib 12a′ and groove 12b′. Such slide assemblies are well-known and permit precise movement of one of its slide members (12b, 16b, 18b) with respect to its other slide member (12a, 16a, 18a) along its respective orthogonal axis.

The probe assembly illustrated in Fig. 2 further includes a linear encoder Ex coupled to slide member 12b of slide assembly 12 outputting an electrical signal corresponding to the magnitude of movement of slide member 12b along the X-axis. The movable slide members 16b and 18b of slide assemblies 16 and 18, respectively, are similarly coupled to linear encoders Ey, Ez (Fig. 8), outputting electrical signals corresponding to the magnitude of movement of these two slide members along the Y-axis and Z-axis, respectively. The linear encoders may be potentiometers outputting analog electrical signals.

Fig. 6 illustrates the manner of using the probe assembly for probing the surface of a ground tooth GT to receive a crown. During the probing operation, handle 20 is grasped by the dentist and is manipulated to cause the probe 26 to engage and move along the outer surface of the ground tooth. As soon as the probe 26 contacts the ground tooth, a deflection will be produced in its arm 28 along the X-axis and/or Y-axis, and/or in arm 30 (if included) along the Z-axis, as sensed by the deflection sensors DSx, DSy on arm 28, and DSz on arm 30. These deflections are used both for determining when the probe 26 is in contact with the ground tooth GT, and also for modifying the positional data outputted by the encoders Ex, Ey, Ez, representing the instantaneous position of handle 20 in order to compensate this positional data by the deflections produced in arms 28 and 30.

Fig. 7 illustrates a bridge circuit which may be used for each pair of the deflection sensors. While the bridge circuit of Fig. 7 illustrates the pair of deflection sensors DSx_1, DSx_2 for detecting the deflection of arm 28 along the X-axis, it will be appreciated that a similar bridge circuit may be provided for each of the other two pairs of sensors for detecting the deflection of arm 28 along the Y-axis, and Z-axis, respectively.

Thus, the circuit illustrated in Fig. 7 includes a Wheatstone bridge having four arms: two arms are occupied by resistors R_1, R_2, whereas the remaining two arms are occupied by the two deflection sensors DSx_1, DSx_2. The arrangement is such that, upon deflection of arm 28 in either direction along the X-axis, the outputs of the two deflection sensors DSx_1, DSx_2 are cumulative, thereby multiplying the sensitivity of the sensors, but the influence of temperature on the outputs of the two sensors is equal and opposite such that the bridge circuit tends to cancel temperature effects.

Fig. 8 illustrates the main components of the data processor system for use with the probe assembly of Figs. 1 and 2. Thus, the data processor system receives the positional data from the three linear encoders Ex, Ey, Ez, representing the instantaneous position of the handle 20, and also receives the deflection data from the three pairs of deflection sensor DSx, DSy, DSz. The deflection data is used for determining when contact of the probe 26 is made against the ground tooth GT, and also for compensating the positional data by the deflections of the two arms 28, 30 in order to produce the correct instantaneous positions of the probe 26 which define the contour of the surface of the tooth GT being probed.

Thus, as shown in Fig. 8, the positional data outputs from the three encoders, Ex, Ey, Ez are fed to an analog-to-digital converter 42 which converts the analog data to digital data before such data is transmitted to the central bus 44. Similarly, the deflection data outputs from the three pairs of deflection sensors DSx, DSy, DSz, after being processed by the Wheatstone bridge 40x, 40y, 40z for the respective sensor pair (Fig. 7), are converted to digital form in an analog-to-digital converter 46 before being transmitted to the central bus 44.

The data processor system illustrated in Fig. 8 further includes an operator panel 48 connected to the central bus 44 via an input/output unit 50. Also connected to the central bus 44 are a keyboard and display unit 52, a RAM (random-access memory) unit 54, a hard disk 56 for storing interim data, and a CPU (central processor unit) 58 controlling the overall operation of the system. The digital data outputted by the system, representing the measured sample points on the contour of the surface of the tooth to receive the crown, is outputted to one or more diskettes (floppy disks) 59, in a form to be usable in a milling machine for cutting the

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crown according to the contour as digitized by the illustrated system.

The positional data detected by the three encoders Ex, Ey, Ez are modified by the deflections in the two arms 28, 30 as sensed by the three pairs of deflection sensor DSx, DSy, DSz. These modifications are effected by means of a look-up table stored in memory unit 54 of the digital processor system which is precalibrated for the respective probe assembly to indicate the deflections corresponding to various readings of the deflection sensors. Fig. 9 illustrates a set-up which may be used for preparing this precalibrated look-up table.

As shown in Fig. 9, a precalibrating device 60 having a precisely measurable deflector element 62 is used to deflect arm 28 of the probe assembly separately along each of the three orthogonal axes. The digital positions of the delector element 62 are recorded in a computer 64 simultaneously with the outputs of the deflector sensors, to prepare a table relating the deflections, as produced and measured by deflector element 62, to the outputs of the deflection sensors DSx, DSx, DSz.

For relating the deflections to the outputs of the X-axis deflector sensors DSx, precalibrating device 60 is oriented so as to project its deflecting element 62 at precisely measured distances along the X-axis, while the readings of the deflection sensors DSx are recorded simultaneously with the instantaneous position of the deflector element 62. This procedure may be done in a continuous manner while periodically sampling, e.g., every two milliseconds, the instantaneous position of the deflector element 62 and the reading of its respective deflector sensors DSx. The same procedure would be followed also with respect to the Y-axis and the Z-axis, such that the look-up table prepared in this manner would provide precalibration data relating the outputs of all the deflector sensors DSx, DSy, DSz to the actual deflections along the three orthogonal axes.

When the apparatus is first installed and before used for digitizing the contour of a ground tooth, it is precalibrated as described above with reference to Fig. 9, in order to produced the precalibrated look-up table. This look-up table is stored in memory unit 54 of the digital processor illustrated in Fig. 8.

When the apparatus is to be used for digitizing the contour of a ground tooth GT (Fig. 6) for a particular patient, the probe assembly is attached to the patient's mouth by having the patient firmly clamp the mounting device 2 (Fig. 2) between the upper and lower teeth of the patient, with the probe handle 20 projecting outwardly of the patient's mouth, and the probe head 24 located within the patient's mouth in the general area of the ground tooth to be probed. The articulated joints 6 and 10 of the probe assembly illustrated in Fig. 2 permit manipulation of the probe handle 20 and the probe head 24 for this purpose.

The dentist, while grasping end 22 of handle 20, turns "on" the digitizer switch SW and moves the probe 26 into contact with and along the surface of the ground tooth GT (Fig. 6) so as to cover substantially its complete outer surface. During this probing operation, the three encoders Ex, Ey, Ez carried by the three slides 12, 16, 18 (Fig. 2), output positional data representing the instantaneous position of the probe handle 20; whereas the three pairs of deflector sensors DSx, DSy, DSz, output deflection data representing the deflections of probe arm 28 about the X-axis and Y-axis, and the deflections of probe arm 30 about the Z-axis. The foregoing positional data and deflection data are converted to digital form by A/D converters 42, 46 (Fig. 8) before being fed to the distribution bus 44 of the data processing system.

Preferably, the dentist first coats the tooth to be probed with a colored substance which is automatically removed where contacted by the probe. In this manner, the dentist can see whether the complete surface of the ground tooth has been probed. In any event the computer, as described below, also provides an indication whether sufficient sample points have been probed in order to reconstruct the tooth contour.

Figs. 10-12c illustrate one mode of operation when a high-power computer is available, permitting all the operations to be performed "on-line". If, however, only a low-power computer is available, e.g., a personal computer, then the digitizing operation as illustrated in Fig. 13a may be performed "on-line", while the processing operations illustrated in Fig. 13b may be performed "off-line".

When a high-power computer is available enabling all the operations to be performed "on-line", the system operates as illustrated in Figs. 10-12c.

At the start, a "flag" bit (15) is "off", i.e., IS = 0 (block 70), indicating that the digitizing switch DS has not yet been actuated. During this time, the dentist may adjust the probe assembly within the patient's mouth. When the probe assembly is properly adjusted, the dentist actuates the digitizing switch SW (block 72), whereupon the "IS" flag is turned "on"; i.e., IS = 1 (block 74).

As the dentist moves the probe over the ground tooth, the positional data from the three encoders Ex, Ey, Ez, and the deflection data from the three pairs of deflection sensor DSx, DSy, DSz, are collected every two milliseconds (block 76) in the distribution bus 54 (block 78), and a decision is made (block 80) whether the deflection data shows a deflection above a predetermined threshold (N) to indicate that proper contact has been made by the probe 26 with the ground tooth GT being

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probed. If the deflection data in all three axes is less than the predetermined threshold (N), this indicates that no proper contact has been made by the probe with the ground tooth, and therefore the collected positional data and deflection data are not stored. However, if the deflection data along any of the three axes is greater than the threshold value (N), thereby indicating that the probe tip has properly contacted the ground tooth, the collected positional data and deflection data are stored in the memory unit 54.

The storing of the positional and deflection data in the memory unit 54 is effected in Routine-A (block 82) of the flow diagram of Fig. 10, and more particularly illustrated in Fig. 11. Thus, as shown in Fig. 11, the collected positional data, representing the instantaneous positions of the handle 20, is modified by the collected deflection data, representing the deflections of arms 28 and 30 when producing the positional data, in order to compensate the positional data for such deflections. This compensation (indicated by block 82a, Fig. 11) is effected by the use of the look-up table stored in the digital processor for the respective probe assembly which had been precalibrated, as described above and as illustrated in Fig. 9, to indicate the actual deflections corresponding to various outputs of the deflection sensors. The so-compensated data thus represents the instantaneous positions of the probe 28 when in contact with the tooth surface, and thereby the digital surface-location values representing surface sample points on the tooth surface.

Since the above-described probing process is done manually, the data so produced will not be in a logical array. The produced data may also be insufficient for the resolution required, which resolution may be initially inputted into the system via the keyboard 52. Accordingly, the data processor system arranges the inputted digitized data into a logical array for use in producing the data defining the digitized contour. In addition, the system checks the inputted data to see that sufficient sample points were taken to meet the required resolution for the crown to be produced.

The foregoing operations performed in Routine-A are more particularly indicated by blocks 82b-82f in Fig. 11, and by the diagrams in Figs. 12a-12c.

As shown particularly in the diagrams of Figs. 12a-12c, the digitization space is represented by a semi-sphere which has been geometrically divided into a plurality of segments by vertically-extending meridian lines ML, and horizontally-extending latitude lines LL. The digitization space is characterized by a polar display in which each segment is defined by: (1) the angle "α" (Fig. 12b) from the center "O" of the semi-sphere to the respective segment in the plane of the base of the tooth; and (2) the angle "β" (Fig. 12c) from the center "O" of the semi-sphere to the respective segment in the plane perpendicular to the tooth base. These segments are identified by the numbers "E" and "J". For example, "E" is the number of divisions of angle α, and "J" is the number of divisions of angle β. Thus, segment "5-6" is the fifth segment with respect to angle α, and the sixth segment with respect to angle β.

For each of the sample points stored in the memory as a result of the Digitization Operation, the data processor system executes a transformation to polaric as illustrated by block 82b in Fig. 11, in order to transform these stored sample points in relation to the above-described segments of the semi-spherical digitization space. Thus, the transformation process transforms the stored data, in cartesian coordinates (X, Y, Z) around the center point "O" of the tooth, to polaric coordinates, wherein each point is defined by the length "R" and the angles α and β around point "O". Each point is thus identified by the distance "R" for the respective segment number (R_{EJ}). Such transformations are well-known, and therefore further details of the manner of producing them are not set forth herein.

Routine-A illustrated in Fig. 11 also sorts the sample points to their respective segments E, J (block 82c). As each sample is sorted to its respective segment, a check is made (block 82d) to determine whether the respective segment has yet received a sample point: if not, that sample point is recorded therein as "R" (block 82e); but if the respective segment had previously received a sample point, then the respective "R" is averaged with the previously-recorded "R's" for the respective segment (block 82f). This completes Routine-A of Fig. 11.

Returning to the flow diagram of Fig. 10, after all the sample points have been sorted to their respective segments, a check is made of all the segments to see whether there are too many unfilled segments (block 84), which could indicate that the data is sufficient according to the required resolution. For example, the required resolution, as initially inputted into the data processor system via keyboard 52, may have specified that there must be no more than two adjacent vacant segments. If the system determines that insufficient data was inputted, the system signals the dentist to sample more points (block 86), whereupon the dentist continues to scan the tooth with the probe in order to introduce additional sample point data until the "Sample More" display is extinguished.

When the "Sample More" display is extinguished, indicating to the dentist that sufficient points have been sampled, the dentish will turn-off the digitizer switch SW. This turns-off the flag "IS";

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i.e., IS = 0 (block 88). The system will then interpolate the values of adjacent segments which are absent a sample point in order to fill in the vacant segment or segments (block 90).

The process is completed by outputting a CNC file, e.g., to a diskette 59 (Fig. 8), representing the digitized contour of the surface of the tooth to receive the crown (block 92). This digital file may then be used for controlling a milling machine to cut the crown according to the digitized contour. The so-produced CNC file may be in a form defining the tool-path points of the milling machine to cut the digitized contour, or in a form convertible in the milling machine itself to the tool-path points of the milling machine.

The milling machine may be included in the above-described system so that the cutting of the crown can be effected immediately after the tooth surface has been digitized, thereby enabling the patient to be fitted immediately with the crown. Alternatively, the milling machine may be at another location, e.g., at a centralized dental laboratory for cutting dental crowns in accordance with CNC files supplied to it, in which case the patient would be fitted with the crown in a subseqent visit to the dentist.

Figs. 13a, 13b illustrate a flow diagram which may be used in order to enable the computations to be performed by a low-power computer, e.g., a personal computer, whereupon the digitizing operation (illustrated in Fig. 13a) is performed on-line, but the processing operations (illustrated in Fig. 13b) are performed off-line.

With reference to Fig. 13a illustrating the digitizing operation, the probing and data- collecting steps are the same as in the flow diagram illustrated in Fig. 10, and therefore the steps are identified by the same reference numerals 70-80. However, whereas in the Fig. 10 operation Routine-A (block 82, more particularly illustrated in Fig. 11) was entered after a decision was made that the probe had sufficient contact with the tooth, in the flow diagram illustrated in Fig. 13a following this decision the data is stored in the memory (block 100). When the memory is full, the operations illustrated by block 104 are performed, namely: the "off" light is energized; a beep is sounded, the data is stored in the hard disk; another beep is sounded; and the "on" light is energized, following which the computer returns to the beginning of the digitizing process.

This continues until the digitizing switch SW is manually turned off, wherepon flag IS is "0" (block 106), at which time all the data remaining in the memory is transferred to the hard disk (block 108). This completes the digitizing operations performed on-line.

At any time thereafter, the processing of the collected data may be done off-line, as illustrated by the flow diagram in Fig. 13b. First, the positional and deflection data are read from the hard disk (block 110), and then the computer performs the compensation, transformation and sort operations of Routine-A (block 82) as described above and as more particularly illustrated in Fig. 11. After Routine-A has been completed, the computer interpolates the values of the segments about a sample point (block 112) in the same manner as described above with respect to Fig. 10 (block 90), and the data is outputted in the form of a CNC file on the hard disk (block 114).

When the collection of the data has thus been completed on the hard disk (block 116), a decision is made, in the same manner as described above with respect to block 84 in Fig. 10, whether there is sufficient data (block 118), in which case the appropriate display (block 120 or 122) is energized. This ends the off-line processing. Should it be determined that there is insufficient data, it will be necessary for the dentist to re-examine the patient in order to complete the data obtained.

Many variations may be made in the above-described apparatus. Thus, the Z-axis sensor DS_Z may be omitted since the other two sensors DS_X, DS_Y are sufficient to sense deflection. Also, a single sensor may be provided for each axis, rather than a pair, in which case DS_{X2} (Fig. 7) could be a variable resistor. Instead of using two analog-to-analog digital converters, as shown in Fig. 8 at 42 and 46, one may be used and switched-over between the two circuits. Further, instead of inputting a resolution value to determine whether sufficient points have been sampled, the sampled points can be displayed on a reproduction of the tooth involved, and it can be left to the dentist to decide whether sufficient points have been sampled to provide the required coverage. Still further, the biting teeth (2, Figs. 1, 2) may be fixed in place by cement. The described apparatus may also be used for digitizing other surfaces or contours, in which case there may be two or more guides for each axis. Many other variations, modifications and applications of the invention will be apparent.

Claims

1. Apparatus for digitizing the contour of a three-dimensional surface of an object, comprising:
a handle graspable by the user;
mounting means for mounting the handle with respect to the object;
a probe connected to and carried by the handle and movable thereby along three independent axes to contact sample points on said three-dimensional surface;

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positional sensor means for sensing the position of the handle along the three axes and for outputting positional values corresponding thereto;
said probe including an arm deflectable along first and second ones of said three axes during the movement of the probe along the three-dimensional surface by the handle;
first and second deflection sensor means for sensing the deflection of said arm along said first and second axes, respectively, and for outputting deflection values corresponding thereto;
and a digital processor including means for processing said positional values only when one of said deflection sensors senses a deflection in its respective arm above a predetermined threshold value, and means for modifying said positional values by said deflection values to output digital surface-location values representing the location of the sample points on said three-dimensional surface during the movement of the probe therealong by said handle.

2. The apparatus according to Claim 1, wherein each of said deflection sensor means comprises a strain sensor fixed on a side of said deflector arm in alignment with its respective axis.

3. The apparatus according to either of Claims 1 or 2, wherein said means for modifying said positional values by said deflection values comprises a look-up table stored in said digital processor and precalibrated for the respective probe to indicate the deflections corresponding to various outputs of said deflection sensor means.

4. The apparatus according to any one of Claims 1-3, wherein said mounting means for mounting the handle with respect to said object comprises three slides, one for each of the three axes, each slide including roller bearings to permit displacement of the handle along the respective axis of the slide.

5. The apparatus according to Claim 4, wherein said positional sensor means comprises three linear encoders, one for each of said three axes and coupled to the slide of its respective axis.

6. The apparatus according to Claim 5, wherein said mounting means further comprises a common base member mounting said three slides, three encoders, handle and probe.

7. The apparatus according to Claim 6, wherein said mounting means further comprises a pair of articulated arms adjustably supporting said common base member, including the three slides, three encoders, handle and probe mounted thereto.

8. The apparatus according to any one of Claims 1-7, wherein the apparatus is to be used for digitizing a dental surface of a subject, said mounting means comprising a mounting member to be clamped between the upper and lower teeth of the subject.

9. The apparatus according to any one of Claims 1-8, wherein the probe is mounted on an arm which is deflectable along the third independent axis.

10. The apparatus according to any one of Claims 1-9, wherein said probe arm includes a first pair of deflection sensors on opposite sides of the arm, and a second pair of deflection sensors on the remaining opposite sides of the arm.

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FIG.1

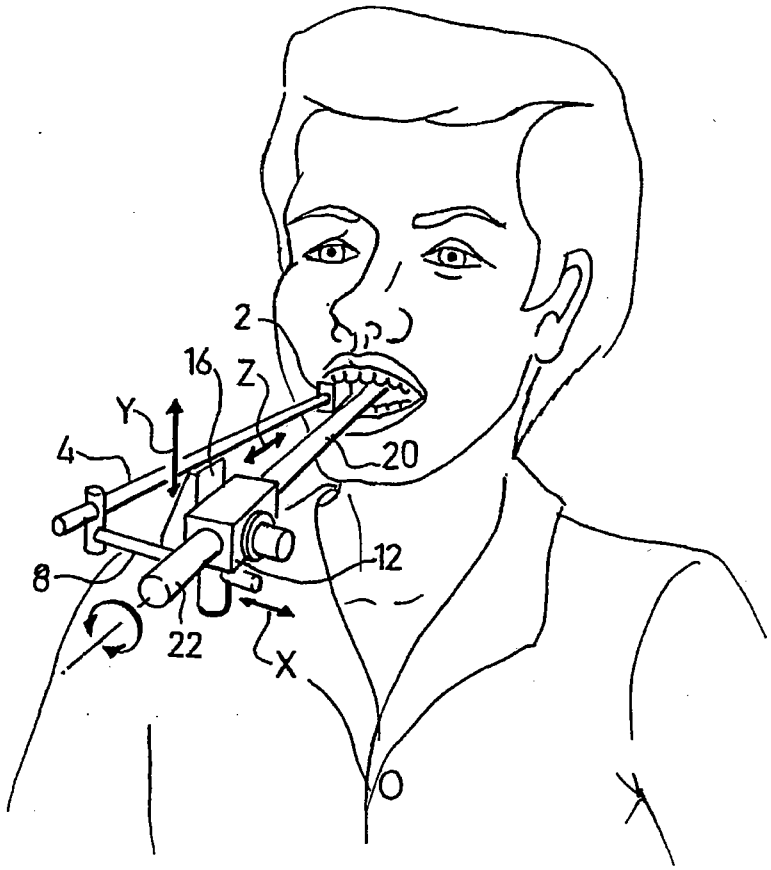
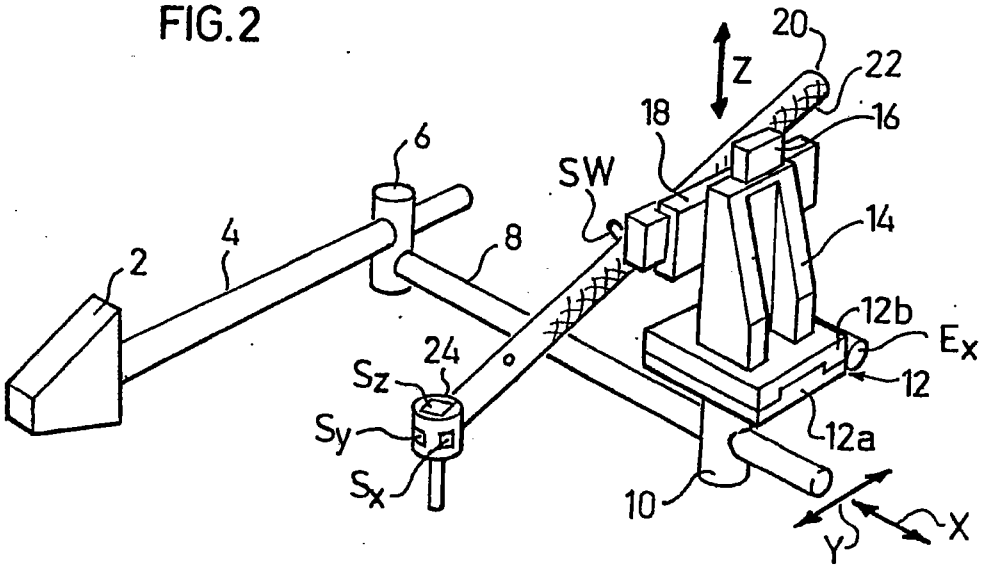

2
16
Z
Y
4
20
12
8
22
X
O

FIG.2


20
Z
22
18
16
6
SW
14
4
8
2
12b
Ex
24
Sz
12
Sy
12a
Sx
10
Y
X

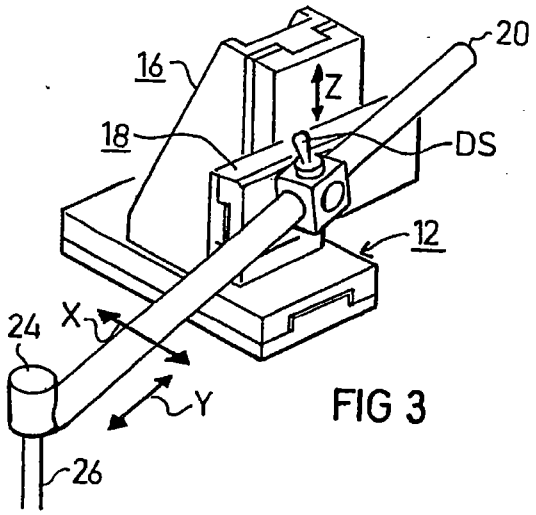


FIG 3

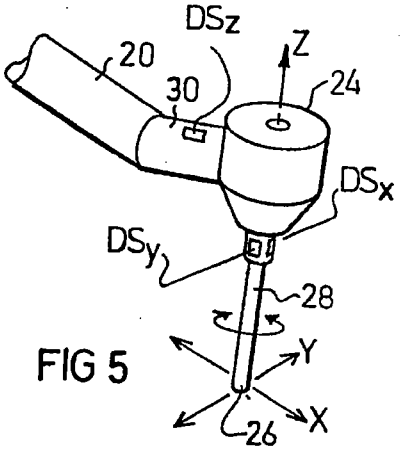
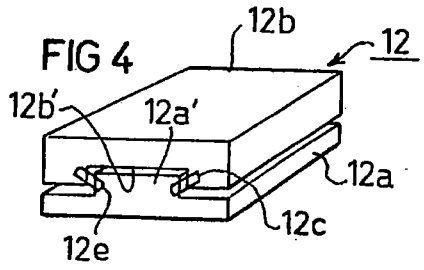


FIG 5

FIG 4



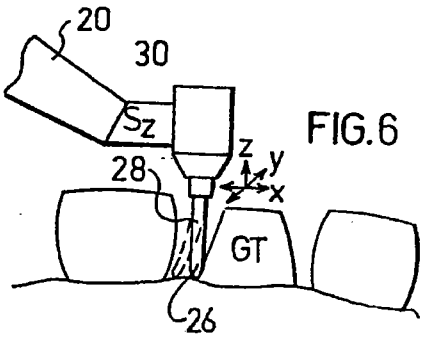


FIG.6

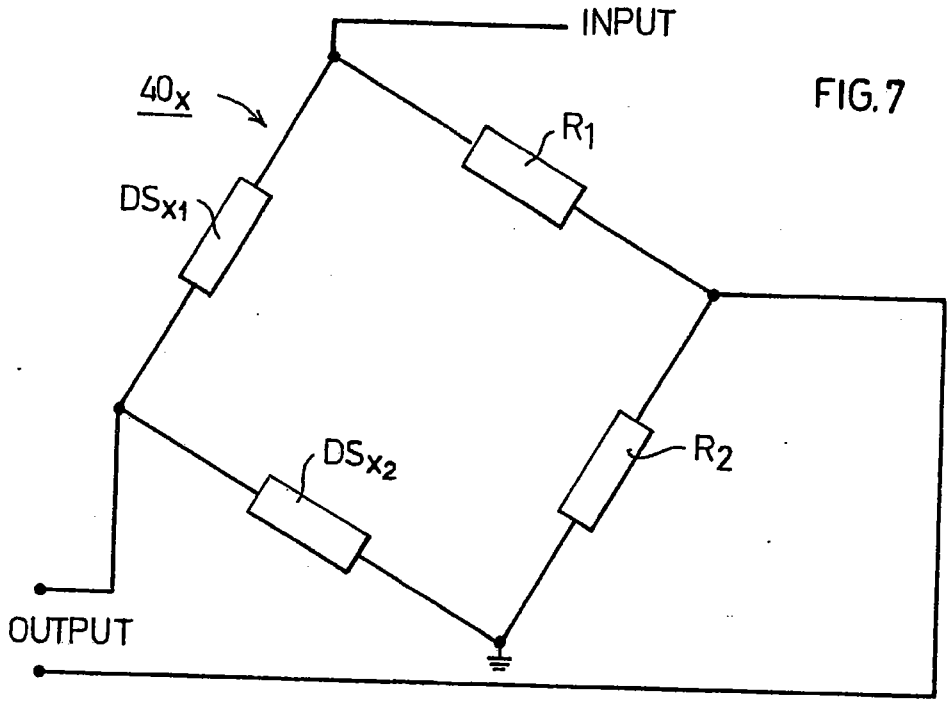


FIG.7

FIG. 8

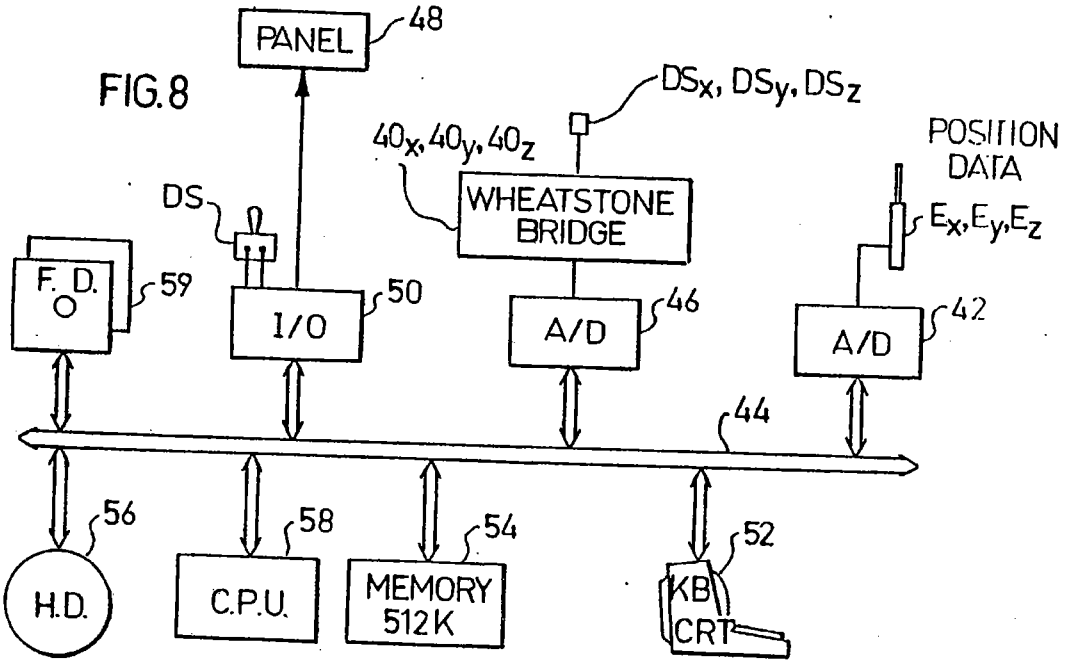

PANEL
48
DSx, DSy, DSz
40x, 40y, 40z
POSITION DATA
DS
WHEATSTONE BRIDGE
Ex, Ey, Ez
F. D.
59
I/O
50
A/D
46
A/D
42
44
56
58
54
52
H.D.
C.P.U.
MEMORY 512K
KB
CRT

FIG. 9

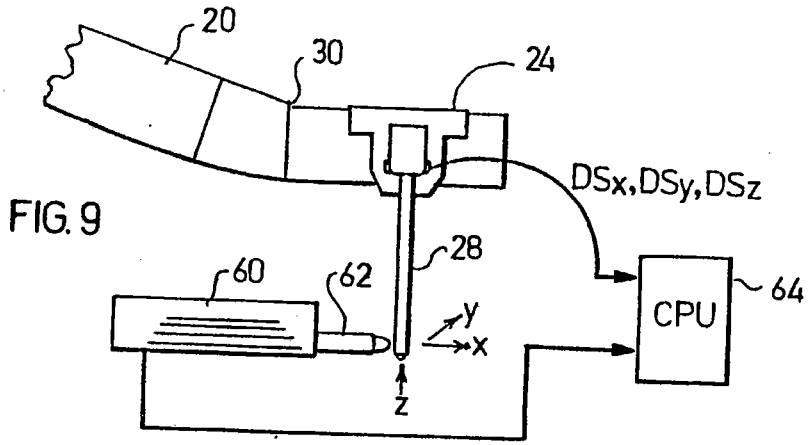

20
30
24
DSx, DSy, DSz
28
60
62
64
CPU
y
x
z

FIG. 10

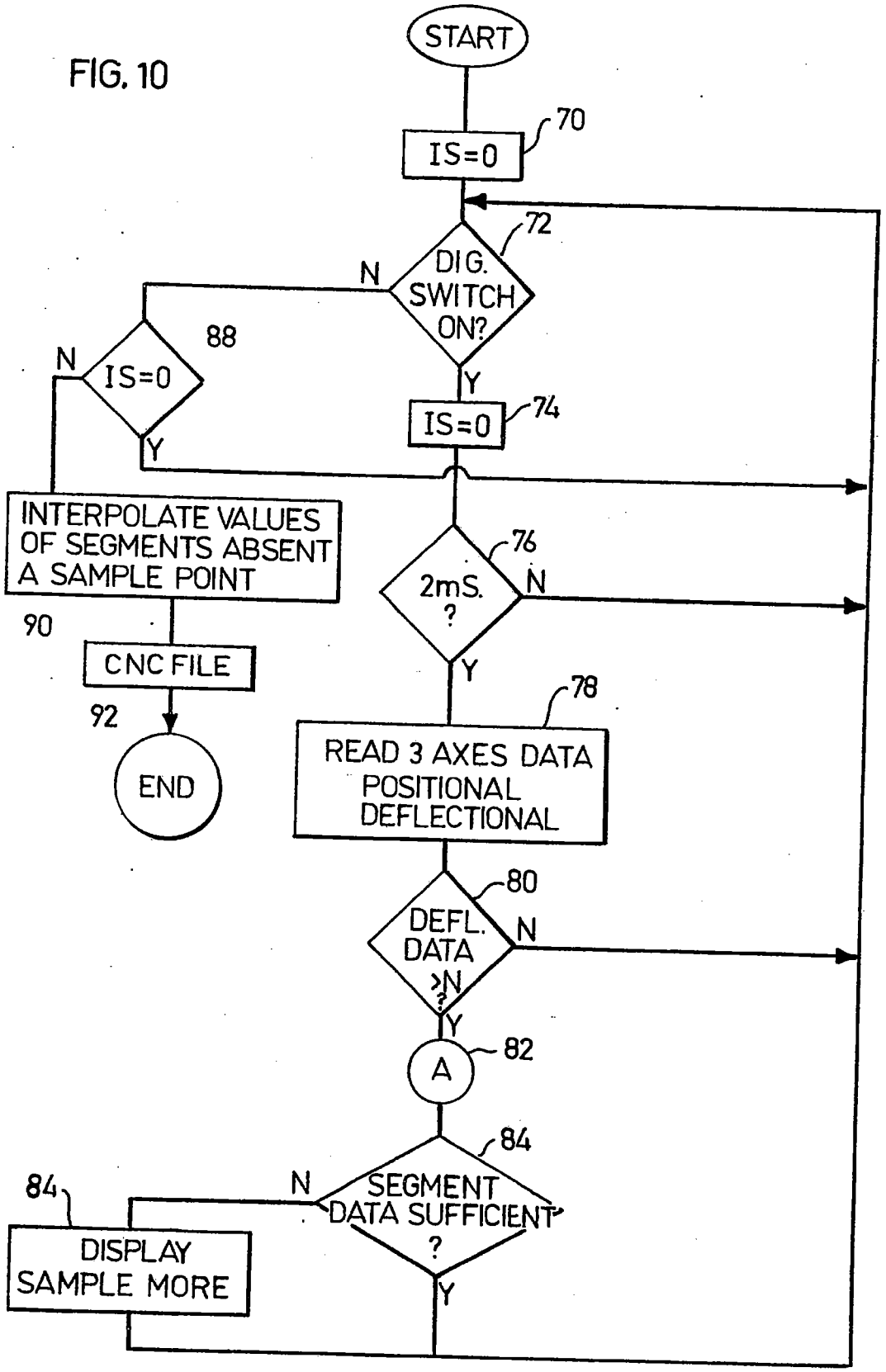
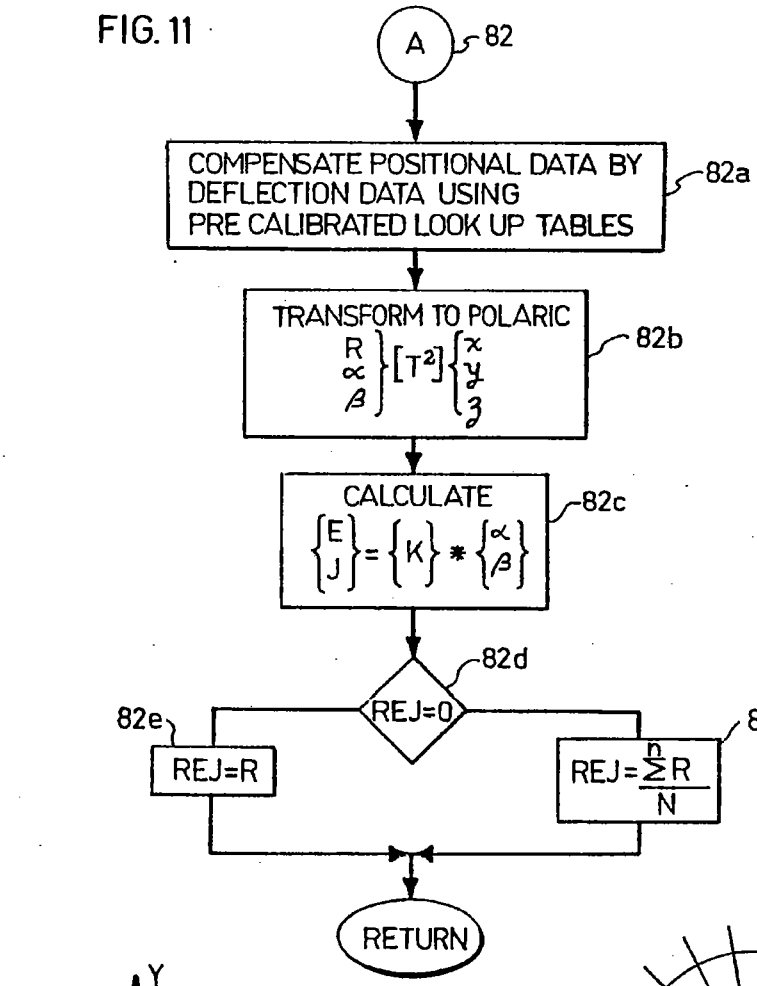

START
70
IS=0
72
DIG. SWITCH ON?
N
Y
88
IS=0
N
Y
74
IS=0
INTERPOLATE VALUES OF SEGMENTS ABSENT A SAMPLE POINT
76
2mS. ?
N
Y
90
CNC FILE
92
END
78
READ 3 AXES DATA POSITIONAL DEFLECTIONAL
80
DEFL. DATA >N ?
N
Y
82
A
84
SEGMENT DATA SUFFICIENT ?
N
Y
84
DISPLAY SAMPLE MORE

FIG. 11



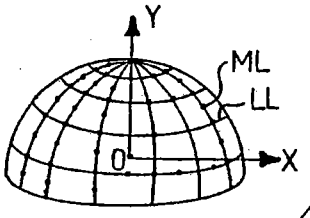


FIG 12a

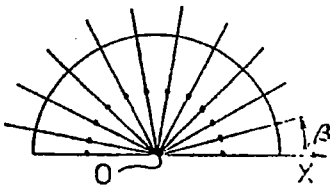


FIG 12c

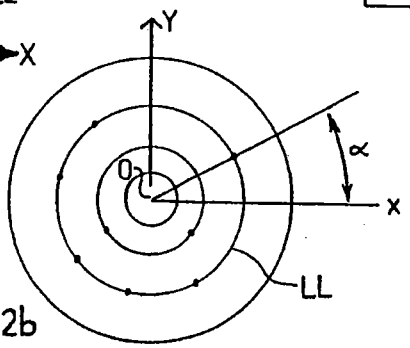


FIG 12b

FIG 13a
(ON-LINE DEFINITION)

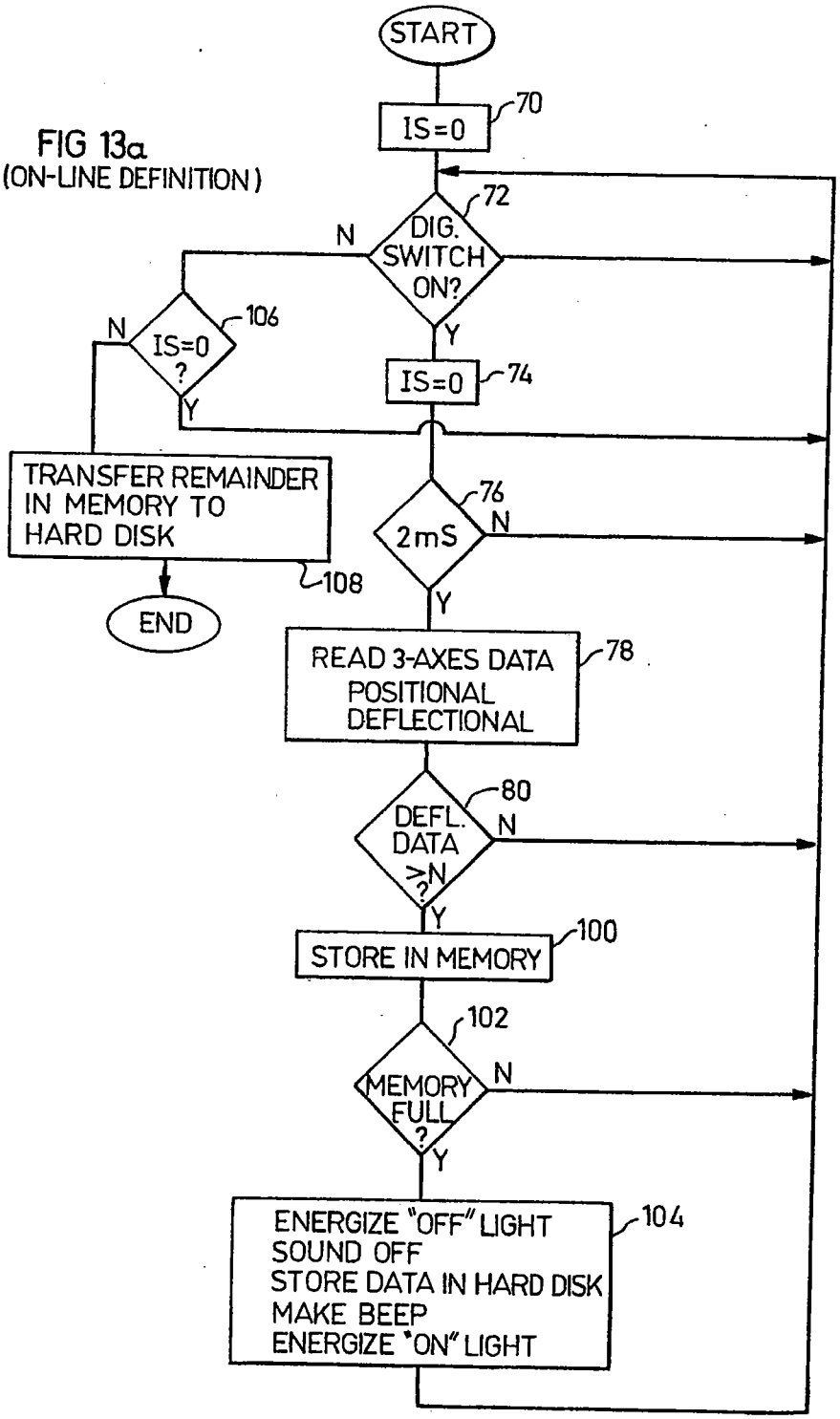
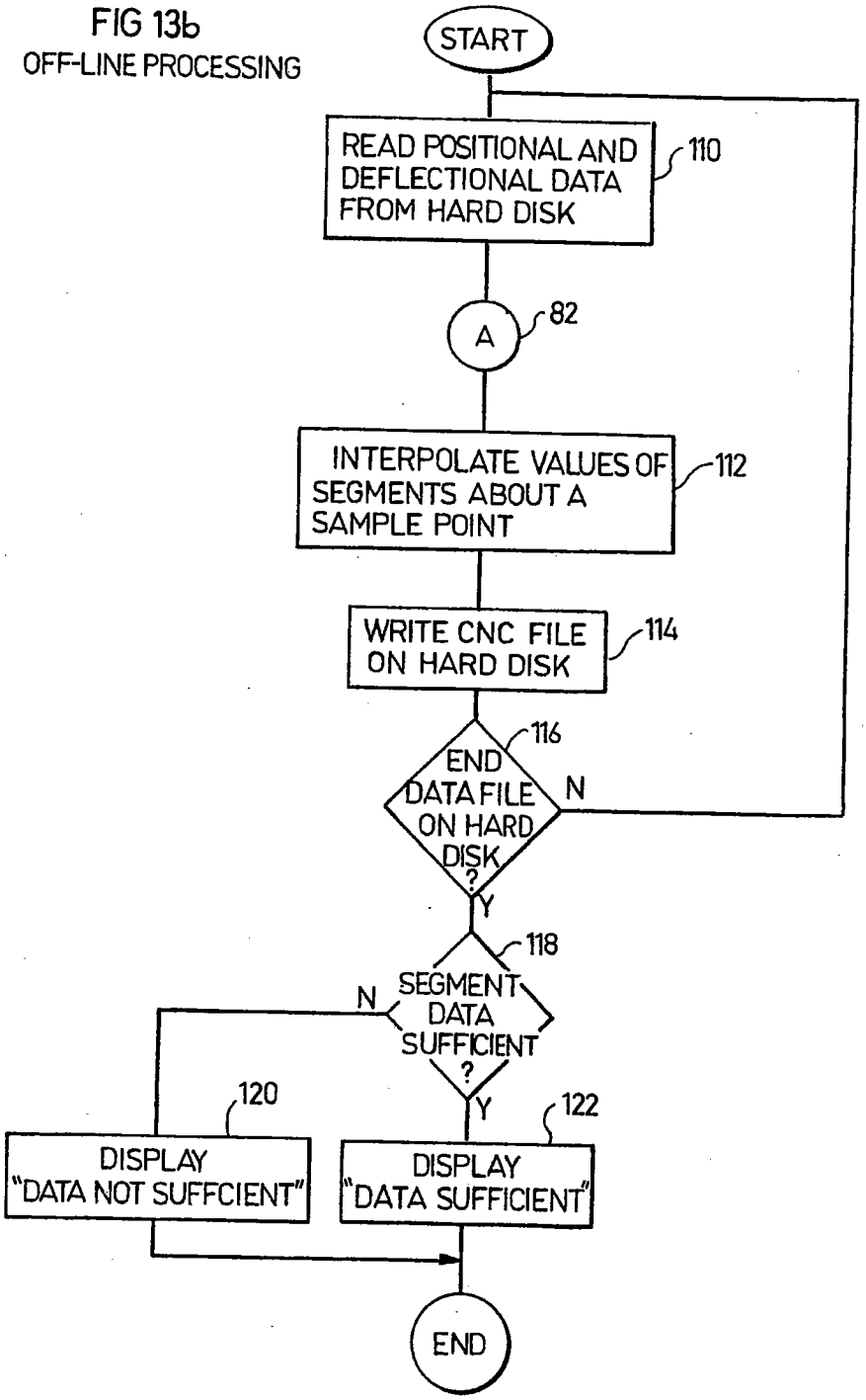


FIG 13b
OFF-LINE PROCESSING



Method for producing dental prosthesis

Patent number: EP0299490
Publication date: 1989-01-18
Inventor: STEINBICHLER HANS DR; WILLER JURGEN DR
Applicant: STEINBICHLER HANS (DE)
Classification:
- international: A61C9/00
- european: A61C13/00C; A61C13/00C1; G01B11/25M
Application number: EP19880111349 19880714
Priority number(s): DE19873723555 19870716

Also published as:
US4964770 (A1)
JP1034353 (A)
EP0299490 (A3)
DE3723555 (A1)
EP0299490 (B2)
more >>

Cited documents:
EP0040165
DE2719696
US4070683
US4663720
EP0054785
more >>

Abstract of **EP0299490**

The method is used for producing a dental prosthesis. In order to provide a method of this type which is actually practicable, simple and quick, contour lines (6) are produced on the ground tooth (5) and its surroundings. The lines (6) are recorded by an optoelectronic device (7). The spatial structure of the tooth and of the dental prosthesis is calculated from the recorded values. The dental prosthesis is then prepared by methods known per se (Figure 1).

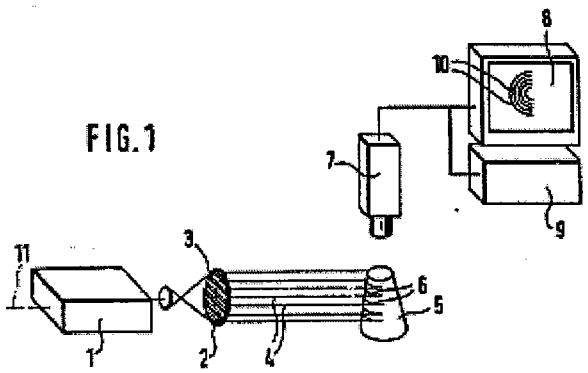


FIG.1

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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Veröffentlichungsnummer: **0 299 490**
A2

(12) EUROPÄISCHE PATENTANMELDUNG

(21) Anmeldenummer: **88111349.2**

(51) Int. Cl.4: **A61C 9/00**

(22) Anmeldetag: **14.07.88**

(30) Priorität: **16.07.87 DE 3723555**

(43) Veröffentlichungstag der Anmeldung:
18.01.89 Patentblatt 89/03

(84) Benannte Vertragsstaaten:
AT BE CH DE ES FR GB GR IT LI LU NL SE

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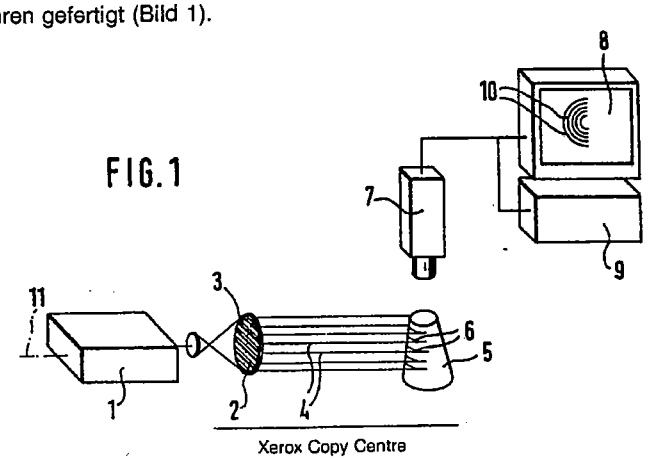
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(54) Verfahren zur Herstellung von Zahnersatz.

(57) Ein Verfahren dient zur Herstellung von Zahnersatz. Um ein derartiges Verfahren zu schaffen, das tatsächlich ausführbar, einfach und schnell ist, werden Höhenschicht- oder Konturlinien (6) auf dem beschliffenen Zahn (5) und seiner Umgebung erzeugt. Die Linien (6) werden mit einer optoelektronischen Einrichtung (7) erfaßt. Aus den erfaßten Werten wird die räumliche Struktur des Zahnes und des Zahnersatzes berechnet. Der Zahnersatz wird dann nach ansich bekannten Verfahren gefertigt (Bild 1).

EP 0 299 490 A2

FIG.1



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Verfahren zur Herstellung von Zahnersatz

Die Erfindung betrifft ein Verfahren zur Herstellung von Zahnersatz.

Die bisher gebräuchliche Methode, Zahnersatz herzustellen, beruhte darauf, die individuell unterschiedlichen klinischen Mundverhältnisse mit Abdrücken und danach gewonnenen Modellen wiederzugeben. Ein Verfahren zur Herstellung von Zahnersatz muß es ermöglichen, eine hohe Paßgenauigkeit des Zahnersatzes zu erreichen, da diese Paßgenauigkeit Voraussetzung ist für die sichere Verankerung und den dauerhaften Sitz des Zahnersatzes. Alle am Kauvorgang beteiligten Gewebe sind dann in der Lage, die einwirkenden physiologischen Belastungen ohne Schädigung zu kompensieren.

Alle zahnärztlichen und alle sich anschließenden zahntechnischen Arbeitsgänge erfolgen nach seit Jahrzehnten gebräuchlichen Methoden, welche am Beispiel einer Einzelkrone kurz beschrieben werden sollen:

1.) Abdruck des präparierten Zahnstumpfes mit einem gummielastischen oder hydrocolloidalen Abdruckmaterial;

2.) Provisoriche Versorgung;

3.) Ausgießen des Abdruckes mit Superhartgips und Herstellen eines Arbeitsmodells sowie eines Gegenbißmodells;

4.) Einbringen der Modelle in einen Artikulator;

5.) Herstellen einer künstlichen Zahnkrone nach Wachsmodellation und Metallguß;

6.) Einpassen des Gußstückes im Mund auf den Zahnstumpf und definitives Eingliedern der künstlichen Krone.

Diese konventionelle Herstellung aus Metall oder anderen Materialien erfordert eine Vielzahl zahnärztlicher und zahntechnischer Abläufe, welche eine große Zahl von Ungenauigkeiten und Fehlermöglichkeiten beinhalten. Paßungenauigkeiten können die Folge sein, die Wiederholungen der Arbeitsabläufe erforderlich machen.

Materialeigenschaften wie Gipsexpansion, Metallschrumpfung und ähnliches sowie unsachgemäße Verarbeitung und schwierige Mundverhältnisse sind dafür verantwortlich zu machen.

Sei einiger Zeit sind Bemühungen im Gange, nach denen unter Verwendung anderer Techniken die konventionelle Abdruckmethode sowie zahlreiche anschließende Arbeitsvorgänge ersetzt werden sollen. Diesen Techniken liegen mechanische oder optische drei. dimensionale Meß- und Abtastvorrichtungen zugrunde. Die so gewonnenen Informationen werden gespeichert und an Steuerungsvorrichtungen von bereits in der Werkzeugmaschinenindustrie gebräuchlichen NC-Bearbeitungsmaschinen (numerisch gesteuerten Bearbeitungsmaschinen) weitergegeben.

Die US-PS 4 182 312 zeigt eine mechanische Abtastung dreidimensionaler Oberflächeninformationen von Zähnen und umliegenden Geweben direkt am Patienten. Dabei wird eine Sonde vom Behandler im Munde des Patienten geführt. Eine mechanische Abtastung bringt jedoch gewisse Ungenauigkeiten mit sich.

Die US-PS 3 861 044 beschreibt ein Verfahren, welches die Kavität des Zahnes fotografisch erfaßt. Ein Wachsfüllkörper wird vom Zahnarzt in die gewünschte Endform gebracht.

Auch die im europäischen Patent 0 054 785 beschriebene Methode erfordert konstruktive Korrekturen, bevor die notwendige Paßgenauigkeit erreicht wird. Vorher werden Oberflächen von Körperorganen in ihrer räumlichen und topografischen Gestalt auf optischem Wege berührungsfrei erfaßt.

Das im europäischen Patent EP-0 040 165 aufgezeigte Verfahren versucht, mit Hilfe der holografischen Interferometrie Daten eines präparierten Zahnstumpfes zu erfassen und weiterzuleiten. Mit Laser erzeugtes Licht wird optoelektronisch verarbeitet und einem Rechner zugeführt. Dieses Verfahren wird in der EP-0 040 165 zwar beschrieben; ein derartiges Verfahren konnte jedoch in der Praxis bis heute noch nicht ausgeführt werden.

Aufgabe der Erfindung ist es, ein tatsächlich ausführbares, einfaches und schnelles Verfahren zur Herstellung von Zahnersatz anzugeben.

Diese Aufgabe wird erfindungsgemäß dadurch gelöst, daß Höhenschicht- oder Konturlinien auf dem beschliffenen Zahn und seiner Umgebung erzeugt werden, daß die Linien mit einer optoelektronischen Einrichtung erfaßt werden, daß aus den erfaßten Werten die räumliche Struktur des Zahnes und des Zahnersatzes berechnet wird und daß der Zahnersatz dann nach ansich bekannten Verfahren gefertigt wird.

Wesentlich für die Erfindung ist es, daß Höhenschichtlinien oder Konturlinien auf den Zahnstumpf aufgebracht werden. Die vorliegende Erfindung unterscheidet sich von der in der europäischen Patentschrift EP-0 040 165 beschriebenen Methode grundsätzlich dadurch, daß ihm eine optische Methode zur Erzeugung von Höhenschichtlinien oder Konturlinien zugrundeliegt.

Die Form des beschliffenen Zahnstumpfes, die der Nachbarzähne und der Antagonisten wird durch Konturlinien oder Höhenschichtlinien erfaßt. Die Erzeugung dieser Konturlinien oder Höhenschichtlinien geschieht durch bereits bekannte Verfahren wie beispielsweise Projektionsverfahren oder

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durch Moire.

Biem Projektionsverfahren werden auf direktem Wege Koturlinien, also Linien, die die äußere Form des Zahnstumpfs beschreiben, aufprojiziert (Bild 1). Die Konturlinien können interferometrisch mit einem Laser oder durch Schattenwurf erzeugt werden. Beim Moire-Verfahren wird der Zahnstumpf durch ein Gitter beleuchtet und durch das gleiche Gitter über eine Fernsehkamera im Abstand von der Lichtquelle beobachtet. Durch Überlagerung des aufprojizierten Schattenmusterns auf dem Zahnstumpf mit dem Gitter entsteht ein Moire, das die kontur des Zahnstumpfes beschreibt (Bild 2).

Die Konturlinien können mit einer Videokamera erfaßt werden, wobei dies direkt oder über Glasfasern erfolgen kann.

Die Auswertung der Konturlinien erfolgt in einem Bildverarbeitungssystem. Im Gegensatz zu Linienverfolgungs-Programmen wird die Auswertung auf eine Intensitätsmessung zurückgeführt, die über eine Fernsehkamera leicht durchgeführt werden kann. Die Intensität ist im Videosignal für jeden Bildpunkt enthalten.

Die berechnete Kontur läßt sich dann direkt auf eine numerisch gesteuerte Fräsmaschine übertragen, so daß der Zahnersatz paßgenau angeferigt werden kann. Der Zahnersatz kann festsitzend und/oder herausnehmbar sein.

Das erfindungsgemäße Verfahren bringt den Vorteil mit sich, daß ein Zahnstumpf, die Nachbarzähne und die Antagonisten optisch erfaßt, sofort ausgewertet und die Form des Zahnersatzes berechnet werden kann. Das Verfahren ist tatsächlich ausführbar, einfach und schnell. Die Fertigung des Zahnersatzes erfolgt direkt ohne zeitlichen Zwischenraum und ohne Kontaktabdrücke. Der Zahnersatz kann also während einer Behandlung eingesetzt werden.

Eine vorteilhafte Weiterbildung der Erfindung ist dadurch gekennzeichnet, daß mindestens drei verschiedene Höhenschicht- oder Konturlinien-Muster erzeugt werden. Diese Verfahrensweise ermöglicht eine vollautomatische Herstellung des Zahnersatzes.

Der Berechnung der räumlichen Struktur des Zahnes und des Zahnersatzes liegt folgende Formel zugrunde: (1) $I = a \times (1 + m \times \cos \theta)$
In dieser Formel bedeuten:

I - Intensität
a - Untergrundhelligkeit
m - Kontrast
θ - Winkel

Die Intensität I kann gemessen werden. Sie liegt bei der Aufnah me mit einer Videokamera für jeden Bildpunkt fest. Wenn das Videobild aus 512 x 512 Bildpunkten besteht, kann also diese Intensität für jeden einzelnen der Bildpunkte aus dem Videosignal eindeutig bestimmt bzw. gemessen werden. In der Gleichung verbleiben also drei Unbekannte: die Untergrundhelligkeit a, der Kontrast m und der Winkel θ. Die gesuchte Größe ist der Winkel θ. Wenn der Winkel θ für jeden einzelnen Bildpunkt feststeht, kann daraus auch für jeden einzelnen Bildpunkt die Höhen-Koordinate (z-Koordinate) berechnet werden. Diese Höhen-Koordiante z ist eine Funktion von θ. Mit der Bestimmung der Höhen-Koordinate z für jeden einzelnen Bildpunkt x, y liegt die räumliche Form des Zahnes und des Zahnersatzes eindeutig fest. Ziel ist es also, für jeden einzelnen Punkt x, y die Höhen-Koordinate zu berechnen. Hierzu ist es erforderlich und ausreichend, für jeden einzelnen Bildpunkt x, y den Winkel θ zu berechnen. Dies gelingt mit der Gleichung (1) noch nicht, weil diese Gleichung drei Unbekannte beinhaltet. Man benötigt also drei Gleichungen. Um diese drei Gleichungen zu erhalten, verschiebt man zunächst das Höhenschicht- oder Konturlinien-Muster um einen bestimmten Weg, um auf diese Weise ein sich vom ersten Muster unterscheidendes Muster von Höhenschicht- oder Konturlinien zu erhalten. Für dieses zweite Muster gilt dann folgende Gleichung: (2) $I(2) = a \times (1 + m \times \cos (\theta + \theta(2)))$

Der Verschiebewinkel $\theta(2)$ ist bekannt, da er dem Maß der Linienverschiebung entspricht. Es bleibt also bei den bisherigen drei Unbekannten a, m und θ. Anschließend wird das Höhenschicht- oder Konturlinien-Muster ein weiteres Mal verschoben. Vorzugsweise betragen die Höhen dieser Verschiebungen ein Viertel bis ein Drittel des Gitterabstandes; es sind aber auch andere (wohldefinierte) Verschiebungen möglich. Die Gleichung für das dritte Muster lautet: (3) $I(3) = a \times (1 + m \times \cos (\theta + \theta(3)))$

Auch der Winkel $\theta(3)$ ist bekannt, da vorgegeben. Das aus den Gleichungen (1), (2) und (3) entstehende Gleichungssystem ermöglicht jetzt also die Berechung der Unbekannten θ und damit die Berechnung der Höhen-Koordinate z. Wenn dieses Verfahren für jeden der Bildpunkte durchgeführt worden ist, ist die gesamte räumliche Struktur berechnet.

Das soeben beschriebene Verfahren der "Phasenverschiebung" bzw. "Linienverschiebung" ermöglicht es, den Zahnersatz vollautomatisch herzustellen. Wenn lediglich ein einziges Höhenschicht- oder Konturlinien-Muster erfaßt und ausgewertet wird, muß nämlich zusätzlich noch von Hand eingegeben werden, in welcher Richtung aufsteigende Höhenschichtlinien und in welcher Richtung absteigende Höhenschichtlinien verlaufen. Weiterhin muß noch eingegeben werden, in welchen Bereichen Schatten oder Fissuren liegen. Das erfin-

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dungsgemäße Verfahren funktioniert also auch dann, wenn lediglich ein einziges Höhenschicht- oder Konturlinien-Muster genommen wird; es ist dann aber erforderlich, die Informationen über die Steigrichtung der Höhenschichtlinien und über die Schatten und Fissuren von Hand zusätzlich einzugeben, was interaktiv über den Bildschirm geschehen kann.

Wenn mit drei verschiedenen Höhenschicht- oder Konturlinien-Mustern gearbeitet wird, brauchen diese zusätzlichen Informationen nicht mehr eigens eingegeben werden. Nach dem oben beschriebenen Verfahren können dann aus den drei Gleichungen (1), (2) und (3) die z-Koordinaten für jeden Bildpunkt x, y berechnet werden. Eine gesonderte Information über den Anstiegsverlauf der Höhenschichtlinien ist also nicht erforderlich. Die Schatten und die Fissuren können dadurch erkannt werden, daß sie in jedem der drei verschiedenen Musterbilder stets an derselben Stelle liegen.

Die Auswertung der Kontur erfolgt dadurch, daß mindestens drei Bilder in den Rechner eingegeben werden, wobei jeweils das Linienmuster um ein vorherbestimmtes Maß verschoben wird. Aus dem Abstand der Verschiebung und der Intensitätsänderung in jedem Bildpunkt läßt sich die Kontur dann eindeutig berechnen.

Ein Ausführungsbeispiel der Erfindung wird nachfolgend anhand der beigefügten Zeichnungen im einzelnen erläutert. In der Zeichnungen zeigt

Bild 1 die Erzeugung von Konturlinien durch Projektion und

Bild 2 die Erzeugung von Konturlinien durch Moire.

Wie in Bild 1 zu sehen, erzeugt ein Projektor 1 Lichtstrahlen, die auf ein Gitter 2 treffen. Dieses Gitter 2 besitzt lichtundurchlässige Bereiche und waagerechte, lichtdurchlässige Bereiche 3 in einem vorherbestimmten, vorzugsweise gleichen Abstand voneinander. Die Lichtstrahlen verlassen also das Gitter 2 in waagerechten, parallel zueinander verlaufenden Ebenen 4. Sie treffen auf den Zahnstumpf 5 und erzeugen dort Höhenschichtlinien 6. Diese Höhenschichtlinien 6 auf dem Zahnstumpf 5 werden von der Fernsehkamera 7 aufgenommen und an den Monitor 8 sowie an den Computer 9 weitergeleitet. Auf dem Monitor 8 können die Höhenschichtlinien 6 sichtbar gemacht werden, wie mit der Bezugsziffer 10 angedeutet. Der Computer 9 berechnet aus den Intensitätswerten für jeden der Bildpunkte des Monitors die räumliche Struktur des Zahnstumpfs 5. Der Monitor kann beispielsweise aus 512 x 512 Bildpunkten bestehen.

Wenn lediglich ein einziges Bild mit Höhenschichtlinien genommen wird, muß dem Computer noch die Information eingegeben werden, in welcher Richtung die höheren und in welcher Richtung die tieferen Bereiche des Zahnes liegen. Weiterhin muß dem Computer noch die Information eingegeben werden, welche Bereiche Schatten und/oder Fissuren beinhalten.

Um das System vollautomatisch zu machen, ist eine Phasenverschiebung oder Linienverschiebung erforderlich. Zunächst wird ein Bild mit bestimmten Höhenschichtlinien aufgenommen. Dann wird der Projektor 1 senkrecht zur Projektionsachse 11, also senkrecht zu den Ebenen 4, verschoben, und zwar um eine wohldefinierte Höhe, die vorzugsweise etwa ein Viertel bis ein Drittel des Gitterabstandes, also des Abstandes der lichtdurchlässigen Bereiche 3 des Gitters 2 entspricht. Hierdurch wird ein zweites, verschobenes Linienmuster auf dem Zahnstumpf 5 erzeugt und von der Fernsehkamera 7 abgenommen. Dieser Vorgang wird dann ein drittes Mal wiederholt. Auf diese Weise gelangen drei verschiedene Höhenlinienmuster in den Computer 9. Dieser Computer 9 kann daraus die räumliche Zahnstumpfform vollkommen automatisch selbständig berechnen. Die Schatten und/oder Fissuren werden dadurch erkannt, daß sie bei allen drei Aufnahmen an derselben Stelle liegen und sich nicht - wie die Höhenlinien - verschieben. Diese Schatten und/oder Fissuren können also später automatisch bei der Berechnung vom Computer 9 weggelassen werden.

Wenn lediglich ein einziges Höhenschichtlinienbild aufgenommen wird, muß dem Computer 9 auf andere Weise die Information gegeben werden, wo "oben" und "unten" ist und wo Schatten und/oder Fissuren liegen. Dies kann interaktiv über den Monitor 8 geschehen.

Bild 2 zeigt die Erzeugung von Konturlinien durch Moire. Von der Lichtquelle 21 werden Lichtstrahlen ausgesendet und auf ein Gitter 22 geworfen. Dieses Gitter besteht aus lichtundurchlässigen Bereichen und aus linienförmigen lichtdurchlässigen Berei chen 23. Die linienförmigen lichtdurchlässigen Bereiche sind parallel zueinander angeordnet und verlaufen in einem wohldefinierten, vorzugsweise gleichen Abstand. Die Gitterebene verläuft senkrecht zur Achse 24 des Zahnstumpfs 5. Durch das Gitter werden auf dem Zahnstumpf 5 Konturlinien erzeugt, von denen im Bild 2 lediglich eine einzige Konturlinie 25 gezeigt ist. Die Fernsehkamera 7 befindet sich im Abstand von der Lichtquelle 21. Der Zahnstumpf 5 wird also durch das Gitter 22 beleuchtet und durch das gleiche Gitter 22 über die Fernsehkamera 7 beobachtet. Durch Überlagerung des aufprojizierten Schattenmusters (Konturlinien 25) auf dem Zahnstumpf 5 mit dem Gitter 22 entsteht ein Moire, das die Kontur des Zahnstumpfes 5 beschreibt. Dieses Moire kann auf dem Monitor 8 sichtbar gemacht werden, wie durch die Linien 26 angedeutet. Die Fernsehkamera 7 ist mit dem Monitor 8 und mit dem Computer 9 ver-

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bunden.

Die in Bild 2 dargestellte Verfahrensweise unterscheidet sich von derjenigen des Bildes 1 nur dadurch, daß beim Bild 1 Konturlinien durch Projektion erzeugt werden, während beim Bild 2 Konturlinien durch Moire erzeugt werden. Im übrigen gelten also für das Verfahren nach Bild 2 die Ausführungen zum Verfahren nach Bild 1.

Ansprüche

1. Verfahren zur Herstellung von Zahnersatz, dadurch gekennzeichnet,
daß Höhenschicht- oder Konturlinien (6; 25) auf dem beschliffenen Zahn (5) und seiner Umgebung erzeugt werden,
daß die Linien (6; 25) mit einer optoelektronischen Einrichtung (7) erfaßt werden,
daß aus den erfaßten Werten die räumliche Struktur des Zahnes und des Zahnersatzes berechnet wird
und daß der Zahnersatz nach ansich bekannten Verfahren gefertigt wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Höhenschicht- oder Konturlinien durch ein Projektionsverfahren (Bild 1) erzeugt werden.

3. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Höhenschicht- oder Konturlinien durch ein Moire-Verfahren erzeugt werden (Bild 2).

4. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Höhenschicht- oder Konturlinien durch Schattenwurf erzeugt werden.

5. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Höhenschicht- oder Konturlinien interferometrisch durch Laser erzeugt werden.

6. Verfahren nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß die Linien (6; 25) mit einer Videokamera (7) erfaßt werden.

7. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß mindestens drei verschiedene Höhenschicht- oder Konturlinien-Muster erzeugt werden, deren Abstand vorherbestimmt ist und vorzugsweise ein Viertel bis ein Drittel des Höhenlinien-Abstandes beträgt.

8. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die räumliche Struktur des Zahnes durch die Formel

$$(1)\ I = a \times (1 + m \times \cos \theta)$$

berechnet wird.

9. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die räumliche Struktur des Zahnes durch die Formeln

$$(1)\ I = a \times (1 + m \times \cos \theta)$$

$$(2)\ I(2) = a \times (1 + m \times \cos (\theta + \theta(2))$$

$$(3)\ I(3) = a \times (1 + m \times \cos (\theta + \theta(3))$$

berechnet wird.

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FIG. 1

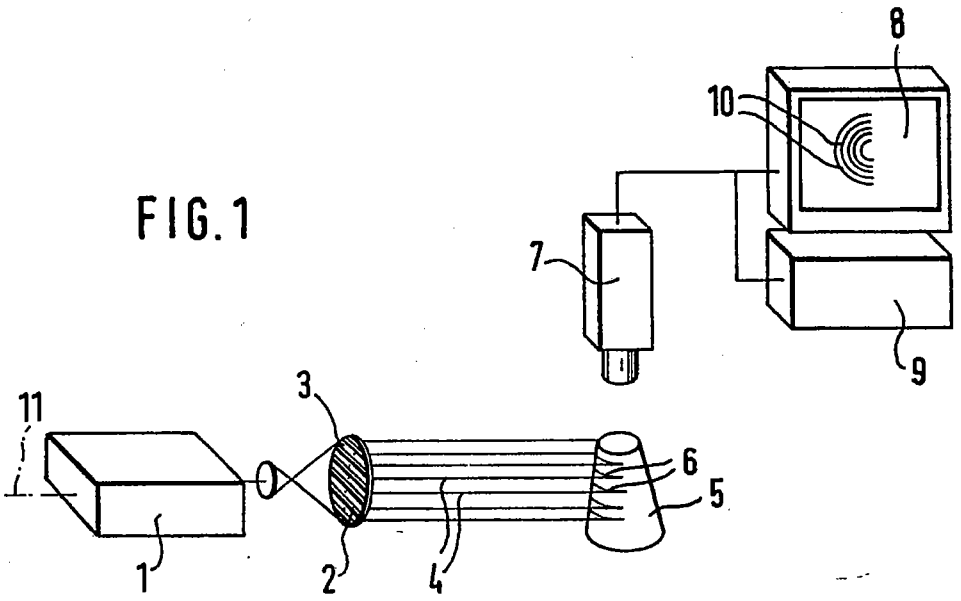
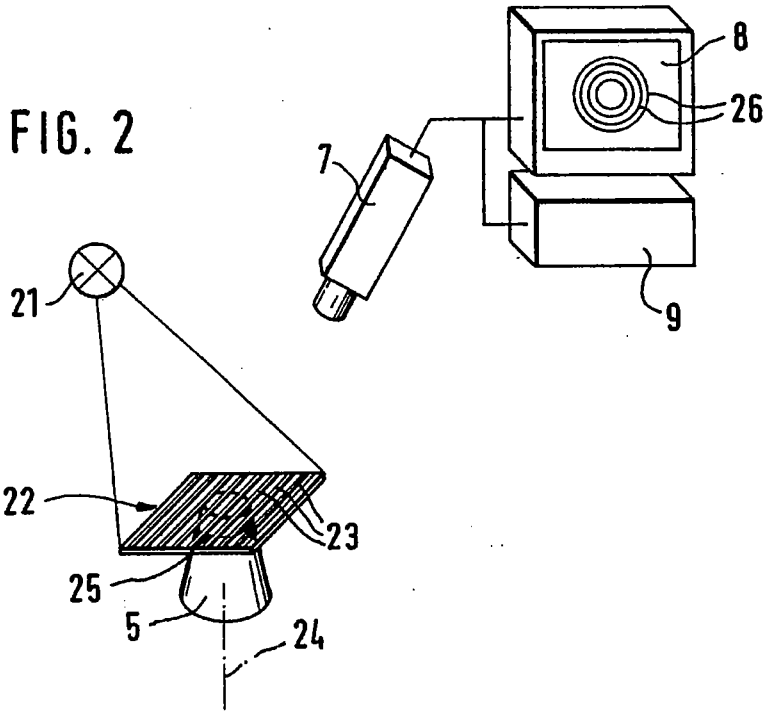


FIG. 2



(11) (A) No. 1,121,955

(45) ISSUED 820420

(52) CLASS 18-57
C.R. CL. 83-1

(51) INT. CL.[3] A61C 13/08,
B29D 31/00

(19) (CA) **CANADIAN PATENT** (12)

(54) ORTHODONTIC TREATING DEVICE AND METHOD OF MANUFACTURING SAME

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(21) APPLICATION No. 290,280

(22) FILED 771104

(30) PRIORITY DATE Japan (51-132323) 761105

No. OF CLAIMS 7

DISTRIBUTED BY THE PATENT OFFICE, OTTAWA.
CCA-274 (3-80)

270, 230

ABSTRACT OF THE DISCLOSURE

Conventional orthodontic treatment is accomplished with metal bands provided with an attachment made to adapt to the teeth and is fixed to the teeth with cement, and metal wire is made to run through it to move the teeth. However, using this technique, it has been recognized that tremendous amounts of energy and skill as well as long periods of education are needed. Also, such treatment not only causes discomfort to the patient, but also other problems such as decayed or decalcified teeth or peridontal disease result from food particles adhering to the teeth during the orthodontic treatment, and, moreover, costs rise enormously. The present invention provides a method and means for manufacturing an orthodontic treating device by which a malocclusion can be treated simply by utilizing the elastic force of silicone resins as a functional force instead of the metal wire presently being employed, and since it is easily detachable, it does not render any discomfort to the patient, making it possible to accomplish the orthodontic treatment when used at bedtime and waking hours as needed.

Conventional orthodontic treatment is accomplished with metal bands provided with an attachment made to adapt to the teeth and is fixed to the teeth with cement, and metal wire is made to run through it to move the teeth. In this case, the correcting force (stress to move the teeth) primarily utilizes the elastic forces of the metal wire itself, and it is generally widely used as the orthodontic treating device.

However, in the orthodontic treatment using this multi-banded technique with the bending of the metal wire in complicated shapes, it has been recognized that tremendous amounts of energy and skill as well as long periods of education are needed. Also, such treatment not only causes discomfort to the patient, but also other problems such as decayed or decalcified teeth or periodontal disease result from food particles adhering to the teeth during the orthodontic treatment, and, moreover, costs rise enormously.

The present invention has been conceived with a view to manufacturing an orthodontic treating device by which a malocclusion can be treated simply by utilizing the elastic force of silicone resins as a functional force instead of the metal wire presently being employed, and since it is easily detachable, it does not render any discomfort to the patient, making it possible to accomplish the orthodontic treatment when used at bedtime and waking hours as needed.

First, it is necessary to select an elastic high molecular material that satisfies sufficiently the special and severe conditions of intraoral treatment. The applicants have found that silicone resins are an elastic material suitable for orthodontic treatment bringing about the best results from the standpoint of science, engineering and clinical study. Namely, the material has been recognized to have scientific and engineering quality so that it does not deteriorate in its elasticity while in the mouth, has sufficient breaking stress, and does not deform for long periods of time due to force during treatment. Because of these important properties, the treating device of the present invention can be used to treat patients from the initial stages until completion of treatment.

Moreover, by changing the hardener portion of the silicone resins and catalysts and the blending thereof, hardness of the molded

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silicone resin can be changed freely. Forces can be provided from a light force to a strong force which is advantageous from the clinical standpoint. The device maintains a high degree of transparency without having any taste or odor, and is prepared from a composition which causes no harm to the human body. These properties cannot be found in other rubber materials.

In addition to the silicone resin, polyurethane resins have somehwat similar qualities mentioned above, but silicone resins provide additional advantages such as shorter hardening processing time as compared with the polyurethane resin, and the manufacturing process can be accomplished simply, and therefore a remarkable difference is recognized between the two resins. In addition, where polyurethane resins are used to prepare similar devices, such resins break down in the patient's mouth and are not transparent. Therefore, such devices are only used during the final stages of treatment and cannot be used from the initial stage.

Accordingly, the applicants have discovered that the treating device of the present invention made from silicone resins for the first time, provides a means of treating a patient from the beginning to completion. To date, this has only been possible through the known procedure of using metal bands.

The present invention is directed to providing an orthodontic treating device and method of making, which ultimately utilizes characteristics of the silicone resin mentioned above.

Fig. 1 is an occlusal view of an original model with malocclusion.

Fig. 2 is an elevation of several teeth separated from the model of Fig. 1.

Fig. 3 is an occlusal view of a model obtained by rearranging in wax the teeth from the original model to a normal occlusion.

Fig. 4 is an occlusal view of the complete orthodontic treating device.

Fig. 5 is a front elevation of the orthodontic treating device.

Fig. 6 is a cross sectional view taken along a line VI - VI in Fig. 5.

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Fig. 7 is an end cross sectional view of the cross section taken along a line VII - VII in Fig. 4.

Fig. 8 is a comparison view showing before and after the orthodontic treatment and 8A shows before and 8B shows after the treatment.

Fig. 9 shows the first embodiment of the present invention, and 9A shows an end view of the condition where a split-cast (9) is separated, and 9B shows an end cross sectional view of the condition where the silicone resin is filled in the split-cast, and 9C shows an end cross sectional view of the condition where the separated portions of the split-cast are joined.

Fig. 10 shows a second embodiment of the present invention, and 10A shows a top view of an anatomical articulator, and 10B shows a side view of the condition where the wax plate material necessary to fix the upper and lower plaster models is melted and discharged, and 10C shows a side view of the condition where the silicone resin is pressure contacted on the surface of the working model to produce the orthodontic treating device, and 10D shows a cross sectional view taken along a line X - X of 10A.

The present invention is directed to a first method of making a silicone resin orthodontic treating device by (a) preparing plaster models of a patient's upper and lower jaw including the teeth showing malocclusion, (b) determining the centric relationship between the patient's upper and lower teeth by taking a wax impression, (c) taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face, (d) placing the face-bow in an anatomical articulator, (e) positioning the upper and lower models of step (a) in the anatomical articulator using the face-bow and the wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator, (f) removing the teeth from the models and realigning the teeth in wax to normal occlusion, (g) duplicating the normal occlusion of the models with a duplicating material to form negative impressions, (h) forming positive plaster

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models from the negative impressions, (i) removing the wax models from the articulator and replacing them with the plaster models of step (h) while maintaining the same upper and lower jaw relationship, (j) opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge, (k) forming heat-curable silicone resin composition comprising a silicone resin base material and a catalyst including an oil, around the upper and lower teeth and curing the resin, and (l) removing the resulting treating device.

In one aspect the invention provides a method of manufacturing a silicone resin orthodontic treating device as mentioned above, which comprises, before step (k), the steps of: (m) placing wax in the space formed in step (j) to obtain an impression of the upper and lower teeth in normal occlusion, (n) placing the teeth of the upper and lower plaster models of step (h) into the wax impressions of step (m), (o) covering the resulting combination of step (n) with wax such that the wax will have substantially the same shape and thickness as the desired silicone resin treating device, (p) flasking the wax covered model combination of step (o) in a split-cast, (q) subjecting the split-cast containing the wax covered model to heat sufficient to melt the wax and produce a void, and (r) removing the wax; and wherein step (k) comprises filling the void with said hot-curable silicone resin composition comprising a silicone resin base material and a catalyst including an oil, and curing the resin.

Although either of the above-identified procedures may be used to make the orthodontic treating device of the present invention, the first method is preferred, since it provides the means of using adequate pressure to force the silicone resin into every crevice surrounding the teeth and

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the resulting treating device provides an accurate duplication of the patient's teeth in normal occlusion.

The present invention is accomplished in a process employing the following steps:

(a) Preparing plaster models of the patient's upper and lower jaw including the teeth showing malocclusion.

An impression is taken of the patient's upper and lower teeth and surrounding tissue by using a duplicating material to obtain a negative impression. The duplicating material is removed from the teeth and a void

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is formed in the material. Plaster is poured into the void of the negative impression to obtain a positive plaster mold of the patient's upper and lower teeth.

(b) Determining the centric relationship between the patient's upper and lower teeth by taking a wax impression.

Wax is placed between the patient's upper and lower teeth to obtain an imprint of the bite to determine the centric relationship of the upper and lower teeth. This wax impression is used later in the process to properly align the upper and lower plaster models prepared in step (a).

(c) Taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face.

A face-bow is used to take a wax impression of the patient's upper teeth to reproduce the upper jaw relationship to the head and face. This step is critical to the process of the invention, since it provides the only means of accurately reproducing the ultimate relationship of the patient's upper and lower jaw and this procedure serves the basis for properly aligning the plaster models from which the orthodontic treating device is to be prepared. The device must have the same upper and lower jaw relationship as that of the patient such that, when the device is used, the relationship of the teeth will properly fit into the device to cause the teeth to move towards normal occlusion.

(d) Placing the face-bow in an anatomic articulator.

The face-bow with the wax impression of the patient's upper teeth is attached to an anatomical articulator to properly align the upper and lower plaster models.

(e) Positioning the upper and lower models of step (a) in the anatomic articulator using the face-bow and the wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator.

This procedure is accomplished by placing the teeth of the upper plaster model as prepared in step (a) into the wax impression of the face-bow which has been attached to the anatomical articulator. Plaster is placed on top of the upper model and forced against the top of the articu-

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lator and permitted to dry, thereby, causing the upper model to be attached to the top of the articulator. Once the plaster has become dry, the face-bow is removed from the articulator. The upper model has now been placed into the articulator in the same relationship as the natural position of the patient's upper teeth and jaw.

The wax bite impression as prepared in step (b) is placed over the teeth of the upper model and luted or attached. The lower plaster model from step (a) is inserted into the lower portion of the wax impression which is attached to the upper model. Plaster is poured over the surface of the lower model and the articulator is closed and the plaster permitted to dry such that the lower model becomes attached to the articulator.

Up to this point in the process of the invention, the upper and lower plaster models have been attached to the articulator in the manner such that an exact reproduction of the patient's jaw and teeth relationship has been established.

(f) Removing the teeth from the models and realigning the teeth in wax to normal occlusion.

The plaster teeth are individually removed from the plaster model by means of a thin blade saw. Then, wax material is placed upon the base of the plaster models from which the individual teeth have been removed and the teeth are placed into the wax and arranged in normal occlusion. At this point, the upper and lower models have the teeth positioned in the manner such that the silicone resin orthodontic treating device to be made from the process of the invention will move the teeth to the position formed by the wax models.

(g) Duplicating the normal occlusion of the models with a duplicating material to form negative impressions.

A duplicating material is formed around the wax models to form negative impressions in normal occlusion. The material is removed from the models and the impressions show voids of the teeth in normal occlusion.

(h) Forming positive plaster models from the negative impression.

Plaster is poured into the voids of the negative impression to

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prepare positive plaster models which show the position of the patient's teeth after treatment with the orthodontic treating device made by the process of the invention.

(i) Opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge.

The articulator is opened such that a space is formed of from 3 to 5 mm, preferably 4 mm, between the upper and lower incisor edge. This space is necessary to properly form the orthodontic treating device in that the silicone resin will fill the space between the teeth and when the patient bites down on the resin during orthodontic treatment, the biting force and the resilience of the resin assist in moving the teeth.

(j) Placing wax in the space to obtain an impression of the upper and lower teeth in normal occlusion.

This step is necessary to obtain the proper relationship between the upper and lower teeth. This impression will be later used to replace the wax models with the plaster models of step (h) in the articulator.

(k) Placing the teeth of the upper and lower plaster models of step (h) into the wax impressions of step (j).

The plaster models in normal occlusion as prepared in step (h) are placed into the wax impression as obtained in step (j). The wax impression is employed to properly align the upper and lower plaster models. This combination or assembly is accomplished separately and outside of the articulator.

(l) Covering the resulting combination of step (k) with wax such that the wax will have substantially the same shape and thickness as the silicone resin treating device.

Wax is placed over the entire teeth surface areas and the portion representing the tissue of the upper and lower models which includes the wax material placed between the teeth in step (k). The wax material should have substantially the same shape and thickness as the silicone resin treating device which is to be prepared during the process as will hereinafter be explained.

(m) Flasking the wax covered model combination of step (l) in a split-

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cast.

The combination as prepared in step (l) is placed into the lower half of a split-cast and plaster is poured into the cast to cover the entire lower half of the combination model. The plaster is permitted to dry and harden and a separating medium is applied over the hardened plaster layer.

The split-cast is turned over and plaster is poured into the cast and the cast is closed such that the exposed upper portion of the combination is totally embedded into the soft plaster. Sufficient plaster should be used so that the plaster covers the entire surface of the combination model as evidenced by excess plaster flowing out of the cast. The cast is then clamped closed and the plaster permitted to dry.

(n) Subjecting the split-cast containing the wax covered model to heat sufficient to melt the wax and produce a void.

The entire split-cast containing the model as prepared in step (m) is heated such as by placing into boiling water for a time sufficient to melt the wax.

(o) Removing the wax.

The split-cast is opened and the melted wax is removed leaving a void around the teeth and tissue of the plaster model including the space between the upper and lower teeth.

(p) Filling the void with heat-curable silicone resin and curing the resin.

A soft silicone resin material is placed into the void in amounts sufficient to completely fill the void. The cast is closed tightly such that the resin material will fill every space and crevice completely and excess material will flow out of the void. The split-cast is then subjected to heat such as boiling water for a period of about 40 minutes to cure the silicone resin material.

(q) Removing the silicone resin treating device.

The split-cast is removed, cooled, opened and the resulting silicone resin orthodontic treating device is removed.

As a final step, the resulting treating device may be coated with a silicone resin solution containing two different silicone resins, including a catalyst, to provide a clear, invisible smooth surface. The two

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solutions are mixed in a ratio of about 10 to 1. The procedure discussed above is the preferred method, since the treating device is made as a result of using a split-cast to force the silicone resin into each space and crevice of the void in the plaster model.

In a second embodiment of the invention, a similar process is employed, except that only steps (a) through (h) of the former process are repeated. The second embodiment is accomplished by the following steps:

(a) Preparing plaster models of the patient's upper and lower jaw including the teeth showing malocclusion.

An impression is taken of the patient's upper and lower teeth and surrounding tissue by using a duplicating material to obtain a negative impression. The duplicating material is removed from the teeth and a void is formed in the material. Plaster is poured into the void of the negative impression to obtain a positive plaster mold of the patient's upper and lower teeth.

(b) Determining the centric relationship between the patient's upper and lower teeth by taking a wax impression.

Wax is placed between the patient's upper and lower teeth to obtain an imprint of the bite to determine the centric relationship of the upper and lower teeth. This wax impression is used later in the process to properly align the upper and lower plaster molds prepared in step (a).

(c) Taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face.

A face-bow is used to take a wax impression of the patient's upper teeth to reproduce the upper jaw relationship to the head and face. This step is critical to the process of the invention, since it provides the only means of accurately reproducing the ultimate relationship of the patient's upper and lower jaw and this procedure serves the basis for properly aligning the plaster models from which the orthodontic treating device is to be prepared. The device must have the same upper and lower jaw relationship as that of the patient such that, when the device is

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used, the relationship of the teeth will properly fit into the device to cause the teeth to move towards normal occlusion.

(d) Placing the face-bow in an anatomic articulator.

The face-bow with the wax impression of the patient's upper teeth is attached to an anatomical articulator to properly align the upper and lower plaster models.

(e) Positioning the upper and lower models of step (a) in the anatomic articulator using the face-bow and the wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator.

This procedure is accomplished by placing the teeth of the upper plaster model as prepared in step (a) into the wax impression of the face-bow which has been attached to the anatomical articulator. Plaster is placed on top of the upper model and forced against the top of the articulator and permitted to dry, thereby, causing the upper model to be attached to the top of the articulator. Once the plaster has become dry, the face-bow is removed from the articulator. The upper model has now been placed into the articulator in the same relationship as the natural position of the patient's upper teeth and jaw.

The wax bite impression as prepared in step (b) is placed over the teeth of the upper model and luted or attached. The lower plaster model from step (a) is inserted into the lower portion of the wax impression which is attached to the upper model. Plaster is poured over the surface of the lower model and the articulator is closed and the plaster permitted to dry such that the lower model becomes attached to the articulator.

Up to this point in the process of the invention, the upper and lower plaster models have been attached to the articulator in the manner such that an exact reproduction of the patient's jaw and teeth relationship has been established.

(f) Removing the teeth from the models and realigning the teeth in wax to normal occlusion.

The plaster teeth are individually removed from the plaster model

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by means of a thin blade saw. Then, wax material is placed upon the base of the plaster models from which the individual teeth have been removed and the teeth are placed into the wax and arranged in normal occlusion. At this point, the upper and lower models have the teeth positioned in the manner such that the silicone resin orthodontic treating device to be made from the process of the invention will move the teeth to the position formed by the wax models.

(g) Duplicating the normal occlusion of the models with a duplicating material to form negative impressions.

A duplicating material is formed around the wax models to form negative impressions in normal occlusion. The material is removed from the models and the impressions show voids of the teeth in normal occlusion.

(h) Forming positive plaster models from the negative impression.

Plaster is poured into the voids of the negative impression to prepare positive plaster models which show the position of the patient's teeth after treatment with the orthodontic treating device made by the process of the invention.

(i) Removing the wax models from the articulator and replacing them with the plaster models of step (h) while maintaining the same upper and lower jaw relationship.

The duplicated plaster models as prepared in step (h) are mounted on the articulator in accordance with the following steps:

(1) The upper wax model is removed from the articulator and the upper plaster model is positioned and placed onto the lower wax model such that the plaster model maintains exactly the same relationship to the lower wax model as the upper wax model which has been removed. At this point, the upper model is made of plaster and the lower model has the teeth positioned in wax.

(2) Plaster is poured on the top of the plaster upper model and the articulator closed such that, when the plaster dries, the upper plaster model is attached to the articulator.

(3) The lower wax model is removed from the articulator and replaced with the lower plaster model of step (h) by placing and positioning

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the lower plaster model in alignment with the upper model now attached to the articulator in the manner as described above. Plaster is then poured over the surface of the lower plaster model, the articulator closed and upon drying of the plaster, the lower model becomes attached to the articulator.

(j) Opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge.

Again, this space is necessary to properly form the silicone resin treating device as previously discussed in step (i) of the first procedure.

(k) Forming heat-curable silicone resin around the upper and lower teeth and curing the resin.

Soft silicone resin is pressed by hand over the entire surface areas of the teeth, front and back, and between the upper and lower teeth to fill the space created in the previous step. The resin is shaped to the final form of the treating device by trimming any excess material. The entire assembly is then subjected to heat such as placing in the boiling water for about 40 minutes to cure the resin. It is to be understood that in either procedure of the present invention, the resin may be cured by heating to a temperature of 100° to 130°C by means of, for example, boiling water or hot air.

(l) Removing the resulting treating device.

After curing of the resin, the entire assembly of the plaster model having applied thereto the silicone resin material is cooled, the articulator opened and the resulting treating device removed from the plaster cast.

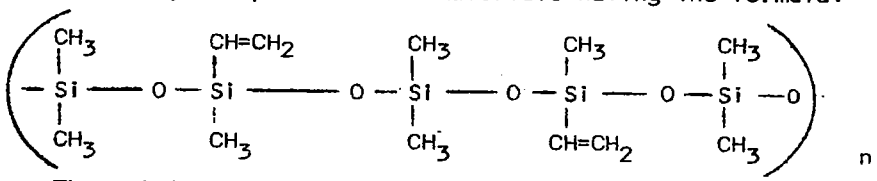
The device may then be coated with the two-component silicone resin solution as described above to provide a final product having a smooth finish.

Various types of silicone resin materials may be employed in the present invention, provided that they have the proper physical properties for moving a patient's teeth from malocclusion to normal occlusion. The properties provided by the silicone resin materials as employed in the

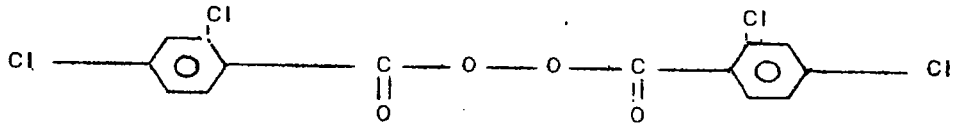
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present invention include resins which are easily curable by subjecting to heat in the temperature range of from 100° to 130°C, have no odor, taste or any chemical ingredients that would be harmful to the body. In addition, the resins of the present invention are transparent such that the patient's teeth and gums can be observed through the treating device during treatment.

The silicone resin materials employed in the present invention are prepared in a composition containing (a) a silicone resin base material and (b) a catalyst including an oil such as silicone oil. Although various types of silicone resin materials may be employed having the properties as discussed above, examples include materials having the formula:

(a) 

The catalyst employed in the silicone resin composition includes those represented by the following formula:

(b) 

The catalyst composition includes an oil such as silicone oil. The catalyst composition contains about from 40 to about 50% of the catalyst and from about 50 to 60% of the oil. The ratio of the silicone resin material to the catalyst composition may be about 100g of (a) to from about 1 to about 2g of (b), respectively.

The silicone resin composition may be prepared by mixing together (a) and (b) in a mixer for a time sufficient to obtain a complete physical blend of the materials. The resulting composition may then be stored in a cool area such as a refrigerator.

The properties of the silicon resin material to be employed in the present invention are as follows:

1)	Hardness (JIS)	about 40 to about 60
2)	Tensile strength	about 85 to about 130 kg/cm^2
3)	Strain	about 400 to about 560%

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4) Molecular weight about 6×10^5 (base silicone)

5) 200% modulus about 35 to about 45 kg/cm^2

Fig. 1 shows the original plaster model after taking an impression of the malocclusion of a patient to be treated including teeth 1 also made of plaster.

Fig. 2 shows the respective teeth removed from the original model of Fig. 1, and Fig. 3 shows the condition where the teeth are rearranged into the normal occlusion using wax 2 employed for mounting and fixing the teeth. Fig. 4 shows the complete orthodontic treating device using silicon resin 14 as blank material, and Fig. 5 shows the device having ventilation holes 3 for respiration and the teeth shown by dotted lines are negative impressions of the teeth which are rearranged to the normal occlusion. The malaligned teeth of the patient to be treated are inserted into the device having the negative impressions by the patient closing his jaws together. When the silicone resin device is deformed by the teeth, the restoring force of the resin is generated and the correcting force causes the teeth to shift to the normal occlusion of the device.

Fig. 6 is a cross sectional view taken along a line VI - VI of the preceding drawing, and Fig. 7 is an end sectional view taken along a line VII - VII of Fig. 4 showing a concave mold 4 of the device for insertion of a molar of the upper jaw, and a concave mold 5 for a molar of the lower jaw. Fig. 8 is a comparison drawing showing the conditions before and after the orthodontic treatment with the device of the invention, and 8A shows before the orthodontic treatment and 8B shows after the orthodontic treatment and also showing an anterior tooth 6 of the upper jaw, and an anterior tooth 7 of the lower jaw. Fig. 8A shows gaps on the lip side of the upper anterior tooth and on the tongue side of the lower anterior tooth. Fig. 8B does not show the gap due to the movement of the tooth with the orthodontic force generated from the restoring force of the resin during the treatment.

Fig. 9 shows the first embodiment of the present invention, and 9A shows the condition where the split-cast 9 is separated and contains the plaster models with the teeth in normal occlusion embedded in plaster 12, and 9B shows the condition where the silicone resin 8 is filled or poured into the

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lower half portion of the split-cast, and 9C shows the condition where the separated split-cast are joined and the silicone resin 8 completely surrounds the teeth, and 10 denotes a connecting member for the split-cast.

Fig. 10 shows the second embodiment of the present invention, and 10A is a top view of the anatomical articulator 11, and 10B is the side view thereof, showing the condition where the wax plate is melted and discharged, and in this conditional position, the silicone resin is pressure contacted and molded over the plaster models to form the orthodontic treating device. The drawing 10C is a side view of the orthodontic treating device formed with the silicone resin, and when this device is cured by hot water or hot air, a final product is formed. Fig. 10D is a cross sectional view taken along a line X - X of the 10A. The number 12 denotes a working model, and number 14 denotes the orthodontic treating device.

The silicone resin treating device as prepared above has negative impressions or voids which duplicate the patient's teeth and move the teeth to a desired position such as normal occlusion during treatment. Complete orthodontic treatment is accomplished by (a) opening the patient's mouth to expose the upper and lower jaws and teeth, (b) fitting the device by using finger pressure to force the device over the upper teeth, and (c) closing the lower jaw to force the device over the lower teeth. The actual movement of the teeth is accomplished by (d) forcing or clenching the upper and lower teeth together for short periods of time, preferably from about 10 to 20 seconds to cause the device to place pressure or force against the teeth, relaxing the jaws to relieve the pressure and repeating the clenching and relaxing during the patient's waking hours, (e) retaining the device over the patient's teeth during sleeping hours, and (f) repeating steps (d) and (e) for a period of time sufficient to move the teeth to the desired position.

It is to be understood that where the malocclusion is severe such that the teeth must move considerable distances, it may be necessary to use several treating devices of the invention such that the teeth may be moved short distances with each treatment in accordance with the above treatment procedures. Furthermore, where several devices are necessary for treatment, each device can be prepared in accordance with the above-described procedures.

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The orthodontic treating device obtained according to the present invention produces a normal occlusion on the basis of the rearranged teeth of the patient. As the teeth are gradually corrected after placing it in the mouth, it renders no undue stress to the teeth or the periodontal structure, causing the correcting force of the device to work and, as a result, the orthodontic treatment is accomplished.

Because of its properties, the orthodontic treating device molded from silicone resin cannot be permanently deformed and is free from changes due to stress. Its hardness can be changed freely and it can be made transparent without taste and odor, whereby it has advantageous points that it provides not only an excellent orthodontic treatment but also ease of use on the part of the patient.

Particularly, the present invention is advantageous in comparison with known polyurethane resins, since the time for polymerizing the polyurethane is about 20 minutes and therefore the present invention shortens the manufacturing time tremendously. Also, the polyurethane resin produces foam of carbonic acid gas in large quantities when reacted with the water in the plaster and, therefore, the working model has to be manufactured by using special resins, and it has the drawback of producing deformations due to the great shrinkage resulting from heat curing the resin. Therefore, in the case of using silicone resin of the present invention, plaster can be used to make the working model and absolutely no deformation occurs and, as a result, the orthodontic treating device can be produced with improved accuracy.

Furthermore, in using polyurethane resins, handling of the undiluted liquid is attended with danger, and also defoaming during the stirring process with a vacuum pump is needed to prevent the foaming of the polyurethane. Also, a high pressure compressor and an autoclave must be used, and, moreover, in the molding, a large size grinder is required, so there are complicated operation processes and inconveniences of using special machines. On the contrary, the present invention is extremely safe, since it employs the silicone resin, eliminating the defoaming during the stirring process and polishing and finishing procedures, and, accordingly, it has many excellent effects.

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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of manufacturing a silicone resin orthodontic treating device which comprises

(a) preparing plaster models of a patient's upper and lower jaw including the teeth showing malocclusion,

(b) determining the centric relationship between the patient's upper and lower teeth by taking a wax impression,

(c) taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of upper jaw to the head and face,

(d) placing the face-bow in an anatomical articulator,

(e) positioning the upper and lower models of step (a) in the anatomical articular using the face-bow and wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator,

(f) removing the teeth from the models and re-aligning the teeth in wax to normal occlusion,

(g) duplicating the normal occlusion of the models with a duplicating material to form negative impressions,

(h) forming positive plaster models from the negative impressions,

(i) removing the wax models from the articulator and replacing them with the plaster models of step (h) while maintaining the same upper and lower jaw relationship,

(j) opening the articulator to form a space of from 3 to 5mm between the upper and lower incisor edge,

(k) forming heat-curable silicone resin composition comprising a silicone resin base material and a catalyst

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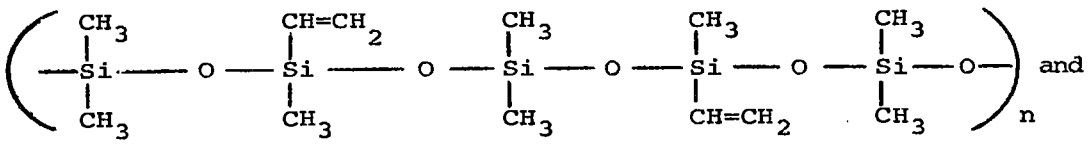
including an oil, around the upper and lower teeth and curing the resin, and

(l) removing the resulting treating device.

2. The method according to Claim 1 wherein the resin is cured at a temperature of from about 100°C to about 130°C.

3. The method of Claim 1 wherein the silicone resin composition contains

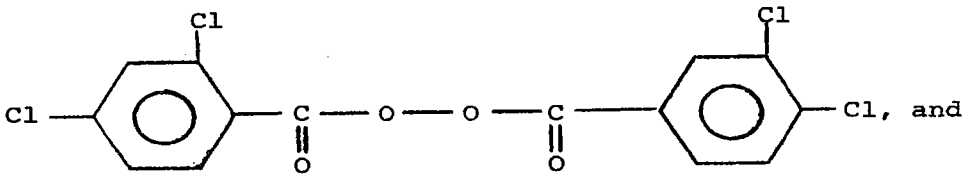
(a) a silicone resin having the following formula



and

(b) a catalyst containing

(1) a compound having the formula



Cl, and

(2) a silicone oil.

4. The method of manufacturing a silicone resin orthodontic treating device as claimed in Claim 1, which comprises, before step (k), the steps of:

(m) placing wax in the space formed in step (j) to obtain an impression of the upper and lower teeth in normal occlusion,

(n) placing the teeth of the upper and lower plaster models of step (h) into the wax impression of step (m),

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(o) covering the resulting combination of step (n) with wax such that the wax will have substantially the same shape and thickness as the desired silicone resin treating device,

(p) flasking the wax covered model combination of step (o) in a split-cast,

(q) subjecting the split-cast containing the wax covered model to heat sufficient to melt the wax and produce a void, and

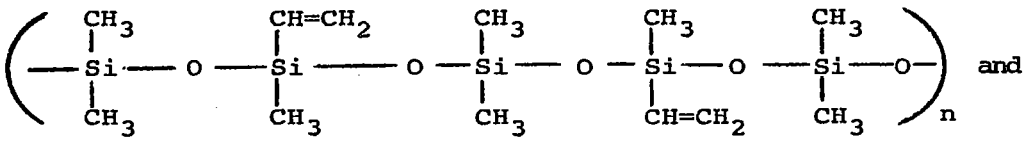
(r) removing the wax; and

wherein step (k) comprises filling the void with said hot-curable silicone resin composition comprising a silicone resin base material and a catalyst including an oil, and curing the resin.

5. The method according to Claim 4 wherein the resin is cured at a temperature of from about 100°C to about 130°C.

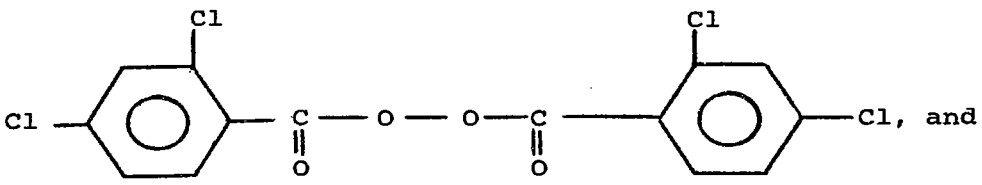
6. The method of Claim 4 wherein the silicone resin composition contains

(a) a silicone resin having the following formula



(b) a catalyst composition containing

(1) a compound having the formula

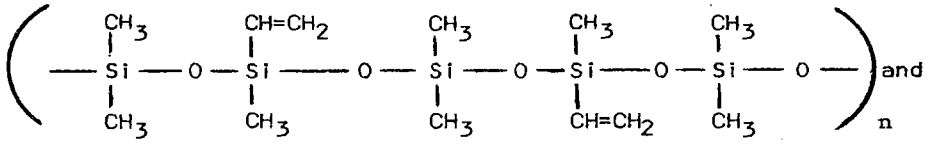


(2) a silicone oil.

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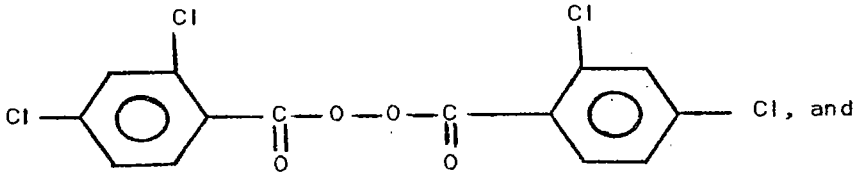
7. A silicone resin composition treating device for the complete treatment of malocclusion of a patient's teeth, said device having upper and lower negative impressions which duplicate the patient's upper and lower teeth and move the teeth to a desired position during treatment, wherein the silicone resin composition contains

(a) a silicone resin having the following formula



(b) a catalyst composition containing

(1) a compound having the formula



(2) a silicone oil.

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FIG. 1

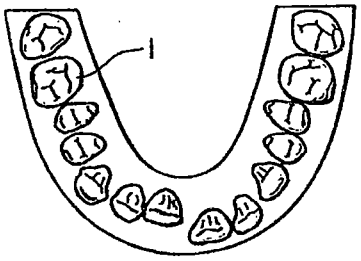


FIG. 2

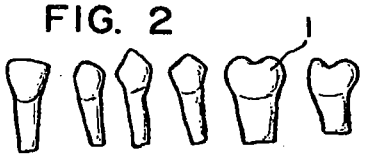


FIG. 3

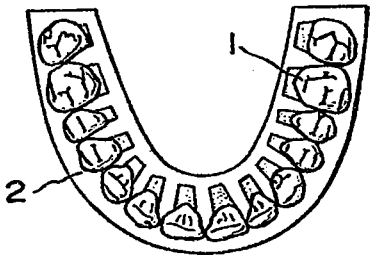


FIG. 4

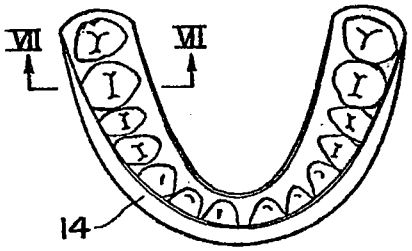


FIG. 5

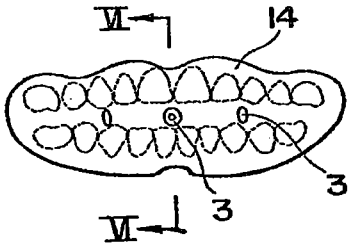


FIG. 6

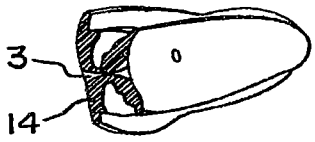


FIG. 7



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FIG. 8A

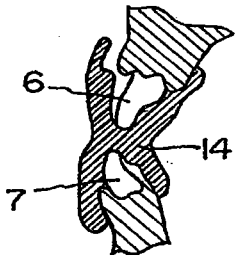


FIG. 8B

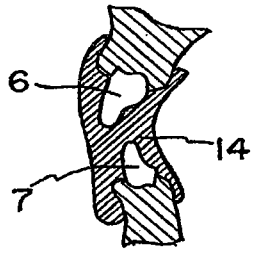


FIG. 9A

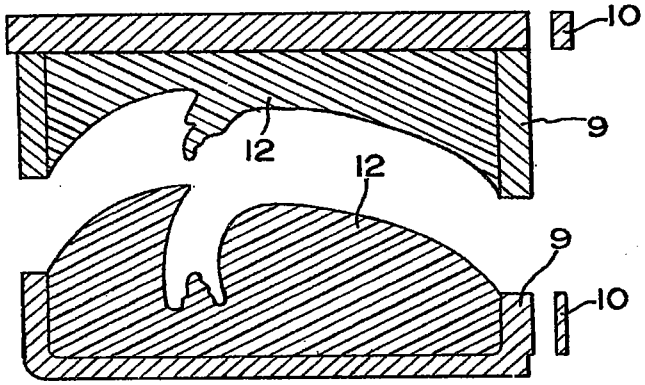
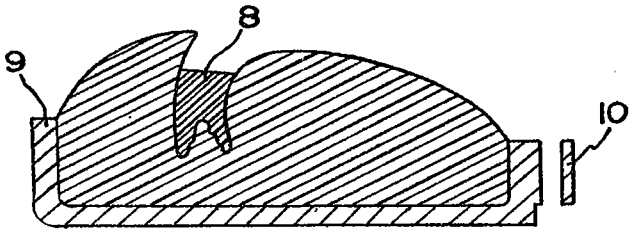


FIG. 9B



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FIG. 9c

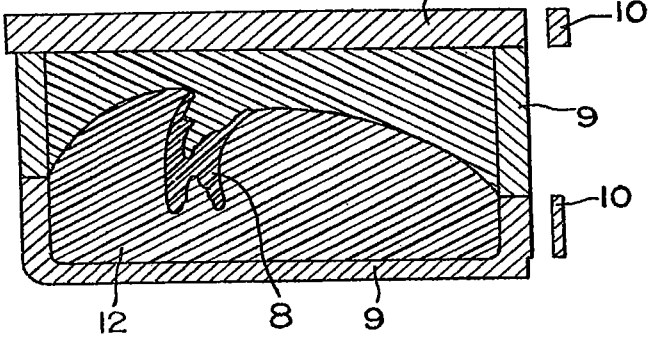


FIG. 10A

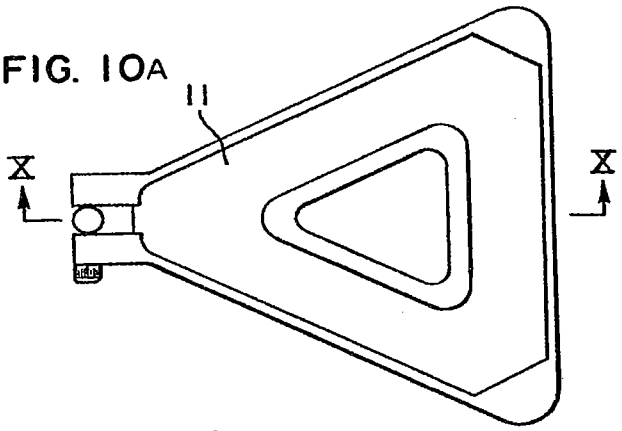
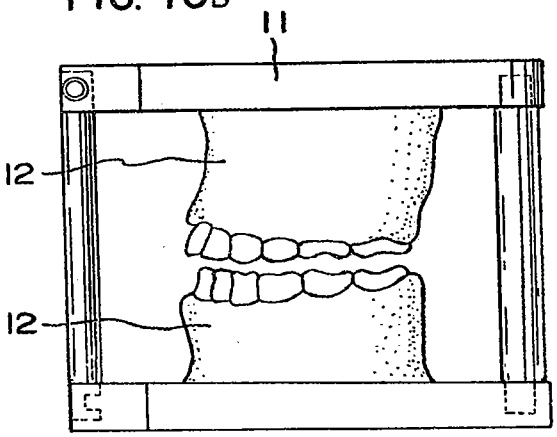


FIG. 10B



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FIG. 10C

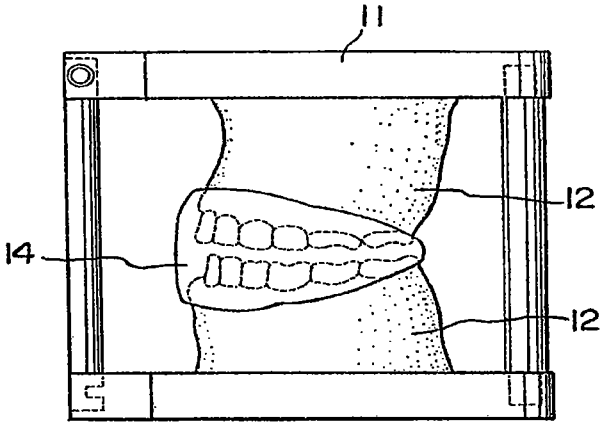
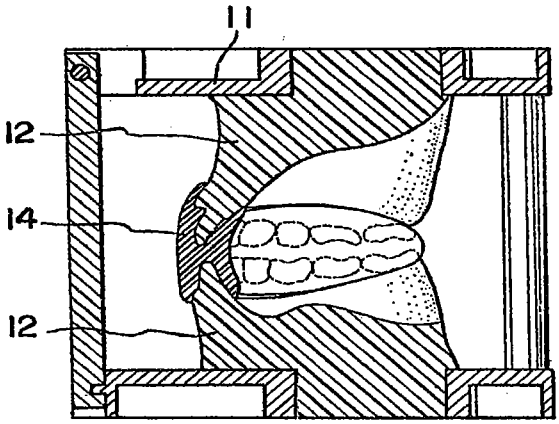


FIG. 10D



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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : A61C 7/00 — A1

(11) International Publication Number: WO 90/08512

(43) International Publication Date: 9 August 1990 (09.08.90)

(21) International Application Number: PCT/US90/00361

(22) International Filing Date: 24 January 1990 (24.01.90)

(30) Priority data:
301,606 24 January 1989 (24.01.89) US

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(81) Designated States: AT (European patent), AU, BE (European patent), BR, CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FI, FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), NO, SE (European patent).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: A METHOD OF PRODUCING AN ORTHODONTIC BRACKET

(57) Abstract

A method for providing an orthodontic bracket for placement on a malocclused tooth in a patient's jaw to correct the malocclusion, comprises the steps of generating digitized information representative of the shape of the tooth and its location with respect to the jaw; using data processing equipment to generate a mathematical model of the tooth as located in the jaw, from the digitized data, and to calculate the finish position in the jaw to which the tooth is to be moved; determining the form of the bracket and its placement position on the tooth in order to move the tooth to the finish position in a selected course of orthodontic treatment; and providing the bracket of such form. A jig may also be provided to ensure correct placement of the bracket on the tooth.

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A Method of Producing an Orthodontic Bracket

This invention relates to the provision of orthodontic brackets and like appliances.

Early in the history of orthondontics, dentists constructed their own applicances to treat patients. As the use of appliances grew, the orthodontic supply company became economically feasible. At first, all orthondontic brackets, or braces, whether produced by the doctor or supply company, were designed simply as handles to which the force-producing agents, most often archwires, were attached. Both the magnitudes and directions of orthodontic forces were controlled by placing appropriate bends in the archwires. See for example, Figures 1 and 3 of U.S. Patent No. 3,447,128.

The next major evolutionary step in appliance design was the "singular wire" concept. See, for example, Figures 2 and 4 to 19 of U.S. Patent No. 3,477,128. Force magnitudes were still determined by wire and not the brackets. However, force vector directions were transferred from the wire to the brackets. Bracket slots were cut so that the desired forces were applied to each tooth in the arch by simply atacching, fully ligating, a straight length of wire with rectangular cross-section into the bracket slots. Furthermore, different bracket base thicknesses were employed to control labial-lingual dental positioning. See, for example, U.S. Patent No. 3,660,900. These developments reduced considerably the amount of wire bending, and therefore, the length of time required by a dentist to treat a case. While such systems are generally considered to represent the state-of-the-art today, there remains a major disadvantage in the treatment mechanics of these products.

In the current "straight wire" systems, of which

there are several, all bracket force vectors for specific tooth types (e.g., upper cuspids, upper central incisors, lower first molars, etc.) are manufactured to polulation averages. Thus there is no individual adaptability in any given straight wire system. The patient's specific pretreatment malocclusion, the condition requiring treatment, dental surface morphology, and facial type tend to be completely disregarded, as are individualized treatment goals. It is well known, however, that these factors influence the selection of ideal mechanical parameters for every case.

Viewed from one aspect the invention provides a method for producing an orthodontic bracket for placement on a malocclused tooth in a patient's jaw to correct the malocclusion, comprising the steps of generating digitized information representative of the shape of the tooth and its location with respect to the jaw; using data processing equipment to generate a mathematical model of the tooth as located in the jaw, from the digitized data, and to calculate the finish position in the jaw to which the tooth is to be moved; determining the form of the bracket and its placement position on the tooth in order to move the tooth to the finish position in a selected course of orthodontic treatment; and providing the bracket of such form.

Viewed from another aspect the invention provides a method for determining orthodontic bracket placement on a malocclused tooth in a subject's jaw to correct the malocclusion, comprising the steps of generating digital information defining the shape and location of the malocclused tooth with respect to the patient's jaw; generating a mathematical model of the malocclused tooth as positioned in the jaw from the digitized information; calculating the finish position in the jaw to which the malocclused tooth is to be moved from the digitized information; and calculating the placement position of an orthodontic bracket on the malocclused

tooth required in order to move the malocclused tooth to its finish position by a preselected orthodontic treatment.

Viewed from a further aspect the invention provides a method for determining orthodontic bracket placement on a dental arch to correct a malocclusion, comprising the steps of generating digital information defining the shape and location of the teeth with respect to the arch; generating a mathematical model of the teeth as positioned in the arch from the digitized information; calculating the finish position in the arch of the teeth from the digitized information; and calculating the placement position of orthodontic brackets on selected teeth required in order to move malocclused teeth to their finish positions by a preselected orthodontic treatment.

Viewed from a still further aspect the invention provides a method for determining orthodontic appliance placement on at least one dental arch to correct malocclusion between teeth in the arches, comprising the steps of generating digital information defining the shape and location of the teeth in each dental arch with respect to the other dental arch; generating a mathematical model of the arches as positioned in the head from the digitized information; calculating the finish position of the dental arches which is required to correct the malocclusion from the digitized information; and calculating the placement position of an orthodontic appliance on at least one of the arches required in order to correct the malocclusion by a preselected orthodontic treatment.

Thus, in accordance with the invention it is possible to have orthodontic applicance placement with individualized parameters.

In carrying out the invention, and in accoradnce with the particular method of subsequent orthodontic treatment which has been selected to be used on the

patient by the practitioner, the correct position in which to place a bracket on the tooth to move the tooth to the finish position is calculated from the mathematical model and finish position which are determined. The correct bracket position is defined as that position which yields zero force in all directions, if, and only if, the subject tooth is in its ideal position with the archwire installed. Thus, when the brackets are subsequently placed and fixed in the patient's mouth, an archwire is placed on the bracket slots, and the archwire is fully ligated, the resultant individual force vectors will automatically move the teeth to the finish position.

The particular type of orthodontic bracket to be used in the method may be selected either before or after calculating its placement position on the tooth. In either event, in the preferred embodiments of the invention a standard bracket is thereafter modified, if desired, so as to provide for tooth movement to the finish position which has been determined individually for the patient, in view of the patient's physical deviations from the dental and skeletal statistical averages for an ideal finish position.

Precise fixation of the brackets at the prescribed location in the patient's mouth is necessary for the proper corrective forces to be achieved. A further step in the preferred embodiment of the invention is to calculate the shape of a positioning device, such as a bracket positioning jig, for the orthodontic appliance to provide for the positioning of the bracket on the tooth in precisely the calculated placement position, and then forming a positioning jig to conform to the shape of the jig so calculated. When the positioning jig with the bracket attached is placed over a patient's tooth, the bracket is automatically located at the precise position which will result in the required force vectors for treatment when attached to the tooth.

In the preferred embodiments the forces to effect treatment are produced by archwires. The archwires, when installed, act as springs which have been deflected by an amount proportional to the deviation of the tooth from its ideal location. An archwire, preformed in accordance with the requirements to move the affected tooth to its finish position when attached to the bracket, produces appropriate force magnitudes at various stages of treatment to move the tooth to its ideal position. An additional step in the preferred embodiments is thus the step of forming an archwire with respect to the mathematical model and the bracket into the configuration to cause to tooth to move to the calculated finish position when installed in the bracket on the tooth.

While normally the orthodontic treatment to be undertaken with brackets provided in accordance with the invention will contemplate realignment of the patient's teeth in one or both arches, or even one arch with respect to the other, the preferred method of bracket production, for purposes of clarity and brevity of description, will be described with respect to the repositioning of a single malocclused tooth.

The first step of the method is the generation of accurate digital information defining the shape and location of the malocclused tooth with respect to the patient's jaw. This information may be generated in a number of ways, such as electromechanically, by laser scanning, sonic ranging, digital video scanning or magnetically. Various devices which may be so utilized are described in Rekow, Computer Aided Design And Manufacture In Dentistry: A Review Of The State Of The Art, 58 The Journal of Prosthetic Dentistry 512 (1987). Sonic ranging devices of this type are described, for example, in U.S. Patent No. 3,821,469.

The second step of the preferred embodiment is the generation of a mathematical model, utilizing the

digitized information. The use of digitized information to generate mathmetical models is well known in the Computer-Aided Design ("CAD") art, and need not be described at the present time in view of the state of the art. It should be noted that each of the three systems described in the Rekow article previously referred to uses CAD.

The mathematical model may be as detailed as the particular circumstances require, dependent only upon the quantity of dititized information generated in the prior step. Thus, in many applications of the preferred embodiment, a complete "model-", as that term is used in the dental art to refer to a full replication of the upper and lower dental arches and associated jaw structure, will be mathematically generated. A physical embodiment of such a model is shown, for example, in Figure 1 of U.S. Patent No. 2,467,432.

The next step is the calculation of the "finish" position of the malocclused tooth or teeth, with respect to their positions in the mathematical model. Movement to the finish position typically may involve "tipping", that is, movement toward or away from adjacent teeth, "torquing", that is, angulating toward or away from the center of the mouth, and "rotation", that is, rotary movement of the tooth about its longitudinal axis, intrusional-extrusional or bodily movement.

There are a number of methods of treatment commonly used by the orthodontist. Each method takes different factors into account with varying degrees of emphasis. For the purposes of the preferred embodiment the orthodontist provides a description of the desired results, which is prescribed for reaching the finish position of each individual tooth relative to adjacent teeth, opposing teeth, supporting bony foundations and soft tissue, and the entire cranial-facial complex. Utilizing standard statistical tooth position data, the repoisitioning of the teeth is calculated to provide a

methematical model of the finish position. In the prior art, a similar step was accomplished manually in order to account for individual tooth morphology by physically removing duplicated teth from a model and repositioning them in a new model in the finish position. See for example, Figure 3 above in the above referenced U.S. Patent No. 2,467,432. However this procedure did not take into account the individual finish position desired relative to the cranial-facial base.

In the preferred method, this repositioning is done mathematically by appropriate software programs which may be derived by conventional means for the particular method of treatment elected by the orthodontist. An "ideal" finish position is not based upon statistical averages and takes into account the variation and physical characteristics of the individual patient. Therefore, it is preferably that, the program be utilized to provide a customized finish position for the particular patient, so as to make the finish position ideal forthe patient, rather than attempting to have the patient duplicate the statistically average finish position.

After the finish position for the teeth in question has been calculated, the placement position of the orthodontic appliance, a bracket, for example, is calculated. In the presently preferred embodiment, a straight wire technique is utilized. The bracket manufacturers provide positioning information recommendations as to their brackets in the ideal position. This information is utilized together with the mathematical model of the finish position to calculate the bracket placement position on the teeth.

While it is possible to position the brackets on the teeth in a variety of methods, in the preferred embodiment there is carried out the step of calculating the shape of a bracket positioning jig from the mathematical model in order to ensure that the bracket

is accurately placed. A large variety of positioning jigs are known in the art, and such devices extend from rather simple direct application devices, such as is shown in U.S. Patent No. 3,686,762 to complex devices such as are shown in U.S. Patent Nos. 4,160,322, 4,183,141 and 4,360,341, which conform in shape to and overlay the tooth itself. In its broadest sense, the term "bracket positioning jig" as used herein includes devices utilized in the "indirect" method of bracket application, such as is described in U.S. Patent No. 4,160,322, to position simultaneously a plurality of brackets on the patients teeth. Thus, after the particular form of jig has been selected, the shape of the jig required to place the bracket or brackets in the previously calculated placement position or positions is calculated. Thereafter, in the preferred embodiment, the next step of the present invention is to form the positioning jig calculated in the previous step.

In as much as the mathematical model of the arch has been calculated in the preferred embodiment, another step which may be utilized is the preforming of an archwire for attachment to the bracket to conform to the orthodontic treatment to be undertaken. The particular details as to shape, size, and the like of the archwire are matters of choice of the orthodontist, depending upon the particular treatment and brackets involved. and normally on the subject of specification in the prescription, if the stepis to be undertaken.

Orthodontic brackets are generally manufactured in standard types in accordance with population averages. One method of creating individualized brackets is to cut custom bracket slots for each patient. The cost of that procedure is usually prohibitive. The computerized design method, according to the present embodiment utilizes modification of the angulation of the bracket/tooth interface on an individualized basis in order to cause the bracket to produce a desired force

vector on the tooth. Specific force vectors are prescribed, and an entire system or brackets/adhesive placement, pre-formed archwires, and peripheral appliances (head gear, elastics, etc.) is selected, if so desired.

In some instances a particular bracket may be selected and, for the particular case, modified in certain respects before calculating its placement position. In such an instance, the placement position is calculated for modified form of the bracket. In other instances, a selected bracket may, after calculation of its placement position, be determined to require modification in order to be placed in the required placement position. In such an instance, the bracket may be modified after calculation of the placement position to prevent its placement in accordance therewith.

In the method of the preferred embodiment, standard brackets are modified as appropriate to produce the required treatment force vectors by use of a structural adhesive system. The modification of standard brackets by use of a structural adhesive system is known in the art. The structural adhesive is initially a moldable putty which easily take on the contour of the dental surface to which the appliance will be fixed, and which provides the interface between that surface and the bracket base. A premachined archwire slot in the bracket face can thus be oriented with aix axes of freedom with respect to the dental surface so as to incorporate precisely the required force vectors. In practicing one embodiment the bracket is correctly positioned on a laboratory model of the tooth, and the adhesive is hardened to a rigid state by a irradiation with ultravoilet light, followed by oven post-cure. The adhesive is then an inseparable, integral part of the bracket, now customized for thatpatient's individual tooth.

While the use of a moldable putty to interface between the bracket and the tooth is satisfactory, the present method may be utilized in conjunction with computer-aided design and computer-aided manufacture (CAD/CAM), as described in the Rekow article referred to above, to provide a machined or cast base conforming to the tooth morphology and containing an appropriately positioned bracket receiving recess or fitting, so as to permit the base to be fixed to either the bracket or the tooth. The other of the two is then fixed to the base, thereby simplifying the attachment of the bracket to the tooth and its customized ideal position for the individual patient. By this method, standard brackets are readily adapted to customized use, so as to simplify the inventory retirements of the practitioner. Additionally, such customized brackets may be provided to the practitioner by a dental laboratory, where the digitized information is utilized in the process of providing the practitioner with the required dental appliances for the correction of the malocclusion.

As will be apparent, the practice of the present invention may be restricted to a single tooth, may be utilized with some or all of the teeth in a given dental arch, or utilized with teeth in both of the arches of the patient. Therefore, while the description of a prefered embodiment has been in certain instances, with respect to a single tooth for purposes of brevity and clarity, the practice of the invention is not so limited.

Furthermore, the present invention may also be utilized with respect to orthodontic diagnoses involving the requirement of movement of one arch, in its entirety, with respect to the other, as where the patient exhibits a lateral offset. In such an instance, a mathematical model is calculated for both arches in their relative positions with respect to one another. The prefered embodiments will take into account the

relative resistance to movement of various teeth or groups of teeth. Bracket positions can then be customized to accountfor these forces. Indications can be provided for the inter-dental arch force mechanics in order to correct or maintain the position of each individual arch over its respective jaw structure as well as relative to the opposing arch and jaw.

It will be appreciated that modifications to the methods set forth herein may be made by those skilled in the art.

CLAIMS

1. A method for producing an orthodontic bracket for placement on a malocclused tooth in a patient's jaw to correct the malocclusion, comprising the steps of generating digitized information representative of the shape of the tooth and its location with respect to the jaw; using data processing equipment to generate a mathematical model of the tooth as located in the jaw, from the digitized data, and to calculate the finish position in the jaw to which the tooth is to be moved; determining the form of the bracket and its placement position on the tooth in order to move the tooth to the finish position in a selected course of orthodontic treatment; and providing the bracket of such form.

2. A method as claimed in claim 1, wherein the form of the bracket is determined before its placement position is determined.

3. A method as claimed in claim 1, wherein the form of the bracket is determined after its placement position is determined.

4. A method as claimed in claim 1, 2, or 3, wherein the bracket has an initial shape, selected from standard shapes, that is modified to the determined form.

5. A method as claimed in any preceding claim, including the provision of means for enabling the correct placement of the bracket on the tooth.

6. A method as claimed in any claim 5, including the steps of determining the shape of, and providing, a jig to ensure correct placement of the bracket on the tooth.

7. A method as claimed in any preceding claim,

including the steps of determining the shape of, and providing, a preformed archwire for use with the bracket.

8. A method as claimed in any preceding claim, wherein the digitised information is generated for a plurality of teeth positioned in a dental arch, and a plurality of brackets are provided, each of whose form and placement position on a respective tooth is determined to achieve movement of the tooth to a respective finish position.

9. A method as claimed in claim 8, wherein digitised information is also generated for the other dental arch.

10. A method for determining orthodontic bracket placement on a malocclused tooth in a subject's jaw to correct the malocclusion, comprising the steps of generating digital information defining the shape and location of the malocclused tooth with respect to the patient's jaw; generating a mathematical model of the malocclused tooth as positioned in the jaw from the digitized information; calculating the finish position in the jaw to which the malocclused tooth is to be moved from the digitized information; and calculating the placement position of an orthodontic bracket on the malocclused tooth required in order to move the malocclused tooth to its finish position by a preselected orthodontic treatment.

11. A method for determining orthodontic bracket placement on a dental arch to correct a malocclusion, comprising the steps of generating digital information defining the shape and location of the teeth with respect to the arch; generating a mathematical model of the teeth as positioned in the arch from the digitized information; calculating the finish position in the arch of the teeth from the digitized information; and

calculating the placement position of orthodontic brackets on selected teeth required in order to move malocclused teeth to their finish positions by a preselected orthodontic treatment.

12. A method for determining orthodontic appliance placement on at least one dental arch to correct malocclusion between teeth in the arches, comprising the steps of generating digital information defining the shape and location of the teeth in each dental arch with respect to the other dental arch; generating a mathematical model of the arches as positioned in the head from the digitized information; calculating the finish position of the dental arches which is required to correct the malocclusion from the digitized information; and calculating the placement position of an orthodontic appliance on at least one of the arches required in order to correct the malocclusion by a preselected orthodontic treatment.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/00361

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5]: A 61 C 7/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC[5]	A 61 C

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4663720 (DURET) 5 May 1987 see the whole document --	1,4
A	EP, A1, 0025911 (HEITLINGER) 1 April 1981 see abstract --	1
A	EP, A1, 0091876 (DURET) 19 October 1983 see abstract --	1
A	Proceedings of the 38th Annual Conference on Engineering in Medicine and Biology, 30 September - 2 October 1985, Chicago, Illinois, volume 27, The Alliance for Engineering in Medicine and Biology, Publishers, (Washington, D.C., US), E.D. Rekow et al.: "CAD/CAM in dentistry", page 298 --------	1,4

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
10th May 1990	13. 06. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	MISS I TAYLOR

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9000361 SA 34550

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 12/06/90
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4663720	05-05-87	US-A- 4742464	03-05-88
EP-A- 0025911	01-04-81	DE-A- 2936847	19-03-81
		AU-A- 6231980	19-03-81
		CA-A- 1157299	22-11-83
		JP-A- 56045651	25-04-81
		US-A- 4324546	13-04-82
EP-A- 0091876	19-10-83	FR-A,B 2525103	21-10-83
		CA-A- 1233350	01-03-88
		DE-A- 3375757	07-04-88
		JP-A- 58187802	02-11-83
		US-A- 4611288	09-09-86
		US-A- 4742464	03-05-88

EPO FORM P0479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

DISPOSITIF POUR ETABLIR LE TRACE D'UNE PLAQUE DENTAIRE PARTIELLE AMOVIBLEDISPOSITIF POUR ETABLIR LE TRACE D'UNE PLAQUE DENTAIRE PARTIELLE AMOVIBLE

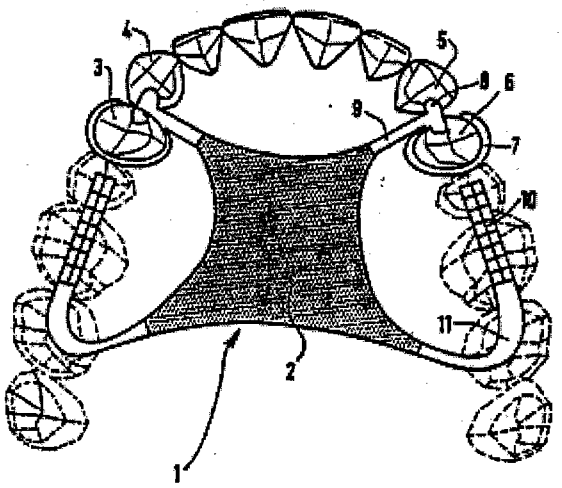
Patent number:	FR2652256
Publication date:	1991-03-29
Inventor:	GERARD JOURDA; JEAN GAILLARD
Applicant:	JOURDA GERARD;; GAILLARD JEAN
Classification:	
- international:	A61C13/01; A61C19/04
- european:	A61C19/04
Application number:	FR19890012814 19890926
Priority number(s):	FR19890012814 19890926

Also published as:

WO9104713 (A1)

Abstract of **FR2652256**

Device for tracing a removable partial dental plate characterized in that it is comprised of: means for displaying (15, 16, 19) the positioning of the teeth still in place in the mouth of the patient; calculation means (17) for the recurrent determination of the theoretical ideal tracing of the removable dental plate as a function, on the one hand, of the positioning of the teeth still in place, inputted during the preceding step, and on the other hand, brackets of physiological values previously inputted into said calculation means; input means (18) for introducing clinical particularisms proper to the mouth of the patient being treated; calculation means (17) for plotting the final theoretical tracing of the plate as a function, on the one hand, of the clinical particularisms and, on the other hand, of the physiological brackets of values.



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(19) RÉPUBLIQUE FRANÇAISE

INSTITUT NATIONAL
DE LA PROPRIÉTÉ INDUSTRIELLE

PARIS

(11) N° de publication : **2 652 256**
(à n'utiliser que pour les commandes de reproduction)

(21) N° d'enregistrement national : **89 12814**

(51) Int Cl[5] : A 61 C 19/04, 13/01

(12) DEMANDE DE BREVET D'INVENTION A1

(22) **Date de dépôt** : 26.09.89.

(30) **Priorité** :

(43) **Date de la mise à disposition du public de la demande** : 29.03.91 Bulletin 91/13.

(56) **Liste des documents cités dans le rapport de recherche** : *Se reporter à la fin du présent fascicule.*

(60) **Références à d'autres documents nationaux apparentés** :

(71) **Demandeur(s)** : *JOURDA Gérard* — FR et *GAILLARD Jean* — FR.

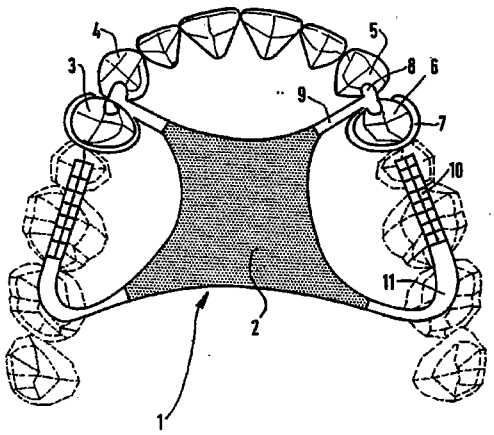
(72) **Inventeur(s)** : JOURDA Gérard et GAILLARD Jean.

(73) **Titulaire(s)** :

(74) **Mandataire** : Cabinet Laurent.

(54) Dispositif pour établir le tracé d'une plaque dentaire partielle amovible.

(57) Dispositif pour établir le tracé d'une plaque dentaire partielle amovible caractérisé en ce qu'il comprend:
- des moyens pour afficher (15, 16, 19) le positionnement des dents encore en place dans la bouche du patient;
- un moyen de calcul (17) pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul;
- des moyens d'introduction (18) des particularismes cliniques propres à la bouche du patient en cours de traitement;
- un moyen de calcul (17) pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.



FR 2 652 256 - A1

La présente invention concerne un dispositif pour établir le tracé d'une plaque dentaire partielle amovible.

Par "plaque dentaire partielle", on entend au sens de l'invention et des revendications une plaque dentaire destinée à être fixée de manière amovible sur au moins deux dents encore présentes dans l'une des deux arcades de la bouche d'un patient.

A ce jour, les plaques dentaires partielles amovibles sont réalisées à partir d'un tracé obtenu à partir d'une empreinte de l'arcade de la bouche du patient. Le tracé de la plaque proprement dite est normalement réalisé par le praticien en fonction des données cliniques et physiologiques de l'arcade considérée. Toutefois, les praticiens sont de moins en moins capables d'effectuer ce tracé et laissent généralement ce soin aux prothésistes. Cela suppose l'emploi d'un personnel très qualifié compte tenu des objectifs visés pour le tracé de la plaque. Ces objectifs se résument principalement à une parfaite adaptation morphologique à la bouche du patient d'une part et d'autre part à un maintien efficacec de ladite plaque dentaire sur les dents restant en place dans la bouche du patient, ce maintien laissant toutefois possible l'amovibilité de ladite plaque dentaire, notamment en vue de son nettoyage.

La présente invention vise à proposer un dispositif apte à permettre à tout praticien non spécialiste de réaliser des tracés de plaques dentaires amovibles, plus économiques dans leur réalisation d'une part et d'autre part mieux adaptés du point de vue morphologique.

Le dispositif pour établir le tracé d'une plaque dentaire partielle amovible conforme à l'invention se caractérise en ce qu'il comprend :

- des moyens pour afficher le positionnement des dents encore en place dans la bouche du patient ;
- un moyen de calcul pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul ;
- des moyens d'introduction de particularismes cliniques propres à la bouche du patient en cours de traitement ;
- un moyen de calcul pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.

En d'autres termes, la présente invention se caractérise en ce que l'on munit une installation de saisie de données, en l'occurence les dents restant encore dans la bouche du patient, d'un organe de calcul apte en fonction de critères pré-établis à délivrer de façon instantanée un tracé théorique de plaque dentaire, qui ne demande plus qu'à être adapté en fonction des particularismes cliniques d'un patient.

Dans une forme de réalisation avantageuse, le moyen pour afficher le positionnement des dents encore en place dans la bouche du patient est constitué par un écran sur lequel est susceptible de se déplacer un curseur, écran associé à un micro-ordinateur et à un organe de validation, validant les données en fonction de la position du curseur.

Le dispositif pour établir le tracé d'une plaque dentaire partielle amovible conforme à l'invention se caractérise en ce qu'il comprend :

- des moyens pour afficher le positionnement des dents encore en place dans la bouche du patient ;
- un moyen de calcul pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul ;
- des moyens d'introduction de particularismes cliniques propres à la bouche du patient en cours de traitement ;
- un moyen de calcul pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.

En d'autres termes, la présente invention se caractérise en ce que l'on munit une installation de saisie de données, en l'occurence les dents restant encore dans la bouche du patient, d'un organe de calcul apte en fonction de critères pré-établis à délivrer de façon instantanée un tracé théorique de plaque dentaire, qui ne demande plus qu'à être adapté en fonction des particularismes cliniques d'un patient.

Dans une forme de réalisation avantageuse, le moyen pour afficher le positionnement des dents encore en place dans la bouche du patient est constitué par un écran sur lequel est susceptible de se déplacer un curseur, écran associé à un micro-ordinateur et à un organe de validation, validant les données en fonction de la position du curseur.

Dans une autre forme de réalisation, le moyen de calcul destiné à déterminer le tracé idéal théorique et le tracé théorique final de la plaque dentaire est constitué par un micro-ordinateur dont les étapes de fonctionnement sont dictées par un logiciel adapté.

Selon l'invention, le moyen d'introduction des particularismes cliniques d'un patient est constitué par un clavier associé audit micro-ordinateur.

Les fourchettes de valeurs physiologiques introduites dans le moyen de calcul destiné à déterminer le tracé idéal théorique de la plaque concernent respectivement les crochets de fixation de la plaque, les épingles à cheveux destinées à solidariser la plaque à la selle de positionnement des dents, les caractéristiques dimensionnelles de la selle elle-même et la courbure de la plaque.

La manière dont l'invention peut être réalisée, et les avantages qui en découlent ressortiront mieux de l'exemple de réalisation qui suit donné à titre indicatif et non limitatif à l'appui des figures annexées.

La figure 1 est une vue schématique d'une plaque dentaire en place, réalisée selon la technique dite du "chassis amorti".

La figure 2 est également une vue schématique d'une plaque dentaire en place, réalisée selon la technique dite de KENNEDY, APPLEGATE.

La figure 3 est un schéma simplifié du dispositif conforme à l'invention.

Selon l'invention, et conformément à la représentation de la figure 1, la plaque dentaire portant la référence générale (1) est constituée de plusieurs éléments.

Outre la plaque dentaire proprement dite portant la référence générale (2) et destinée à épouser la morphologie du palais, qu'il s'agisse de l'arcade inférieure ou de l'arcade supérieure, la plaque dentaire est maintenue sur les dents restant encore dans la bouche du patient, et portant les références (3) à (6) par des crochets (7) et des appuis (8) par l'intermédiaire de potences (9). Ces différents éléments à savoir crochets, appuis et potences sont réalisés en alliage à base de cobalt, nickel et chrome, bien entendu non toxiques.

Les dents artificielles, donc manquantes, sont positionnées sur une selle (10) reliée à la plaque dentaire (2) par l'intermédiaire d'une épingle à cheveux (11) également réalisée dans le même alliage cobalt, nickel, chrome.

Selon l'invention, la manière dont sont reliées les potences (9) et l'épingle à cheveux (11) à la plaque dentaire (2), ainsi que le positionnement des points d'appui des crochets font l'objet de fourchettes physiologiques particulières, destinées d'une part à permettre une meilleure adaptation morphologique de la plaque dentaire à la morphologie de la bouche du patient et d'autre part à un meilleur maintien réversible de ladite plaque sur les dents restantes.

Selon la présente invention, lorsqu'un praticien désire procéder à la réalisation d'un tracé de plaque dentaire d'un patient déterminé, il procède tout d'abord au relevé des différentes dents restant en place dans l'arcade considérée de la bouche du patient. Il est muni d'un micro-ordinateur (17) auquel est associé un écran (15) visualisant une arcade complète, c'est-à-dire seize dents. Cet écran est associé à un organe de validation

(16), dans le cas d'espèces une souris associée à un curseur (19) se déplaçant sur l'écran selon le souhait du praticien. Le praticien peut déplacer le curseur (19) sur les dents manquantes et procède à la validation (16), par exemple par simple pression du bouton dudit organe de validation, afin d'introduire dans la mémoire du micro-ordinateur (17) le positionnement des dents restantes.

Ce micro-ordinateur comprend un micro-processeur géré par un logiciel spécialisé et adapté au tracé de plaque dentaire. Ce logiciel permet la restitution notamment à l'écran du tracé d'une plaque dentaire en fonction d'une part des données introduites par le praticien concernant les différentes dents restantes dans la bouche du patient, et d'autre part en fonction des fourchettes physiologiques sus-mentionnées, faisant partie intégrante des données du logiciel. Il est à noter que outre les fourchettes physiologiques déjà mentionnées, celles-ci concernent également les caractéristiques dimensionnelles de la selle et la courbure de la plaque dentaire elle-même.

Une fois ce tracé théorique restitué par le micro-ordinateur, notamment sur l'écran (15), le praticien introduit certains particularismes cliniques propres à chaque patient. Ces particularismes cliniques peuvent être de natures différentes, telles que des dents restant en mauvais état .

Ces particularismes cliniques étant introduits, et le tracé théorique précédent ayant été stocké en mémoire, le micro-ordinateur (17) restitue un nouveau tracé théorique, final cette fois, de la plaque dentaire destinée à être ensuite acheminée chez un prothésiste apte à réaliser effectivement cette plaque dentaire. Cette restitution est matérialisée soit sur l'écran (15) soit par l'imprimante (20).

L'introduction des particularismes cliniques par le praticien s'effectue par exemple par un clavier (18) associé au micro-ordinateur au moyen de codes pré-établis ou suivant un langage propre au logiciel.

Il va de soi qu'afin d'optimiser le rendu du tracé théorique de la plaque dentaire, un travail clinique préalable peut être effectué par le praticien en vue de consolider ou de supprimer certaines dents.

De plus, en fonction des différentes données introduites par le praticien d'une part et d'autre part des fourchettes physiologiques stockées par les mémoires du micro-ordinateur, le microprocesseur de ce dernier effectue de manière récurrente un calcul précis des différentes caractéristiques de la plaque dentaire et de ses différents éléments associés, notamment crochets, appuis, potences, épingles à cheveux et selles. De la sorte, il ne reste plus au prothésiste qu'à respecter scrupuleusement les différentes indications fournies par le micro-ordinateur pour réaliser une plaque dentaire s'adaptant parfaitement à la bouche du patient.

Le dispositif conforme à la présente invention permet indifféremment de réaliser des plaques dentaires amovibles, selon la technique dite du chassis amorti, ou selon celle dite de KENNEDY - APPLEGATE. Le choix de l'une ou de l'autre de ces techniques appartient au praticien. On a représenté en figure 2 une plaque dentaire amovible, réalisée selon la technique KENNEDY-APPLEGATE, avec le dispositif conforme à l'invention.

Il ressort de la présente invention des avantages fondamentaux par rapport à ce qui était connu de faire jusqu'alors. On peut notamment citer la possibilité pour

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tout praticien non spécialiste de prothèses de réaliser des tracés de plaques dentaires tout à fait exploitables par un prothésiste afin de réaliser les plaques dentaires proprement dites. Il ressort donc de ce dispositif le moyen d'effectuer d'importantes économies et surtout de réaliser des gains de temps appréciables.

REVENDICATIONS

1/ Dispositif pour établir le tracé d'une plaque dentaire partielle amovible caractérisé en ce qu'il comprend :

- des moyens pour afficher (15, 16, 19) le positionnement des dents encore en place dans la bouche du patient ;
- un moyen de calcul (17) pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul ;
- des moyens d'introduction (18) des particularismes cliniques propres à la bouche du patient en cours de traitement ;
- un moyen de calcul (17) pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.

2/ Dispositif selon la revendication 1, caractérisé en ce que le moyen pour afficher le positionnement des dents encore en place dans la bouche du patient est constitué par un écran (15) sur lequel se déplace un curseur (19) associé à un micro-ordinateur (17) et à un organe de validation (16) de données en fonction de la position dudit curseur (19).

3/ Dispositif selon la revendication 1, caractérisé en ce que le moyen de calcul (17) pour déterminer le tracé idéal théorique et le tracé théorique final de la plaque est constitué par un micro-ordinateur dont les étapes de fonctionnement sont dictées par un logiciel adapté.

4/ Dispositif selon l'une des revendications 1 à 3, caractérisé en ce que le moyen d'introduction des particularismes cliniques du patient est constitué par un clavier (18) associé à un micro-ordinateur.

5/ Dispositif selon l'une des revendications précédentes caractérisé en ce que les fourchettes de valeurs physiologiques introduites dans le moyen de calcul destiné à déterminer le tracé idéal théorique de la plaque dentaire concerne les crochets de fixation de la plaque, les épingles à cheveux destinées à solidariser la plaque à la selle de positionnement des dents artificielles, les caractéristiques dimensionnelles de la selle et la courbure de la plaque dentaire elle-même.

DEPOSANT : Monsieur Gérard JOURDA
Monsieur Jean GAILLARD

MANDATAIRE : Cabinet LAURENT

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1/2

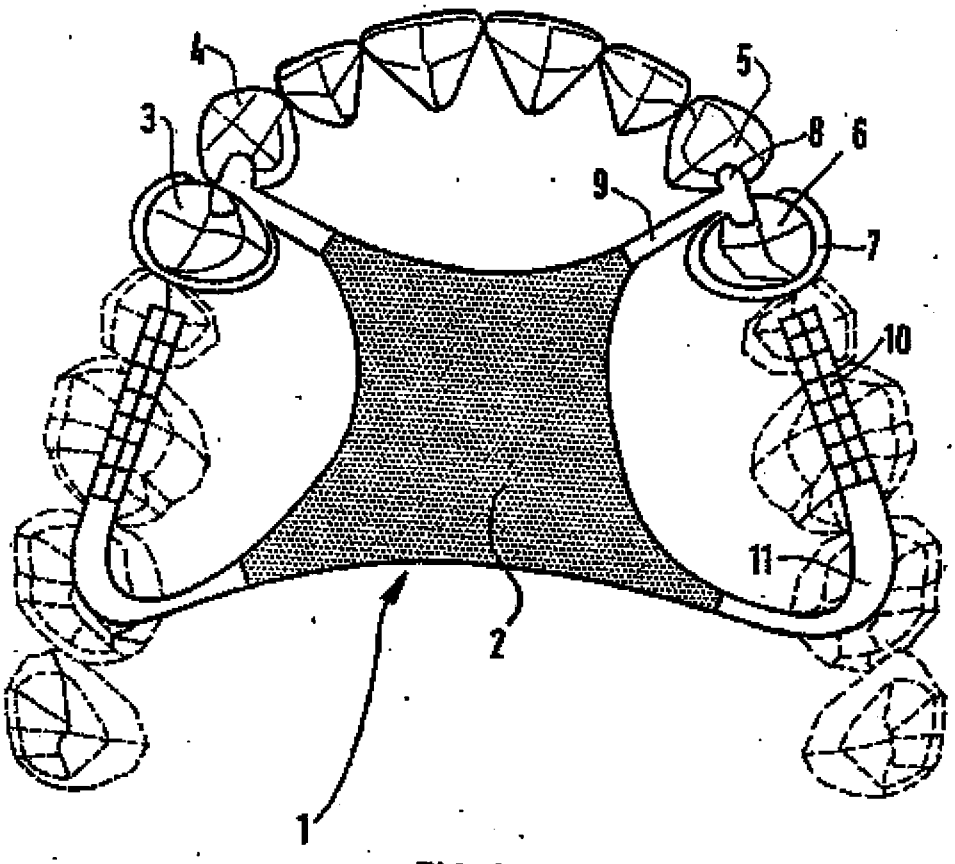


FIG.1

ALN116305

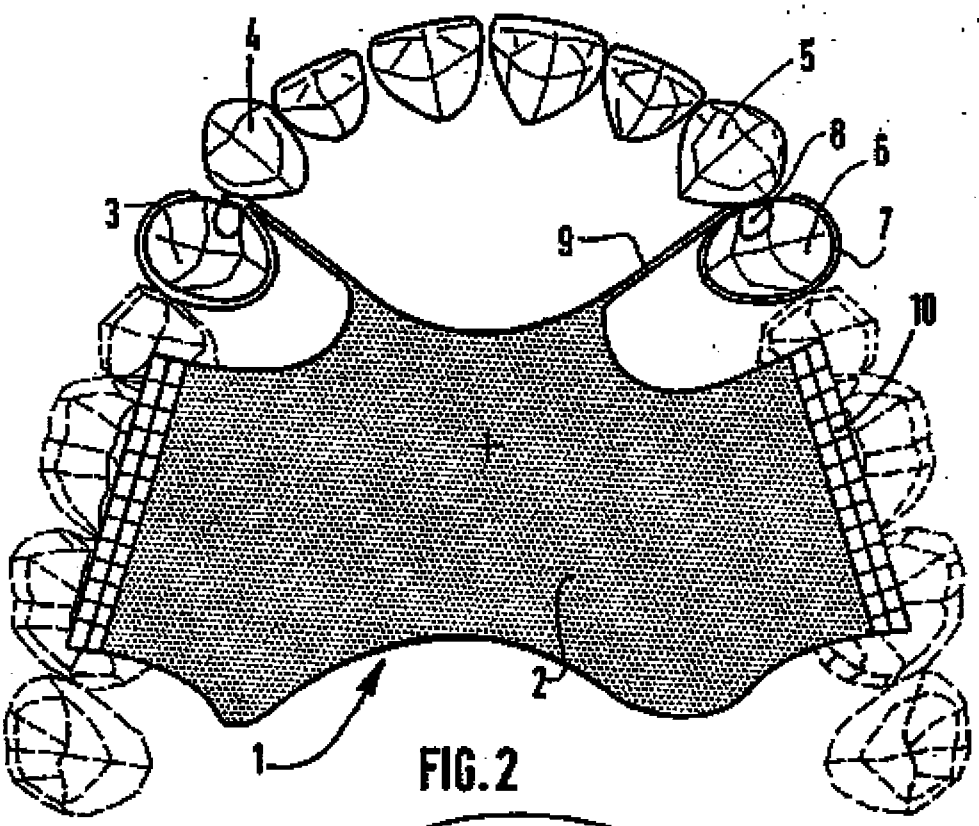


FIG. 2

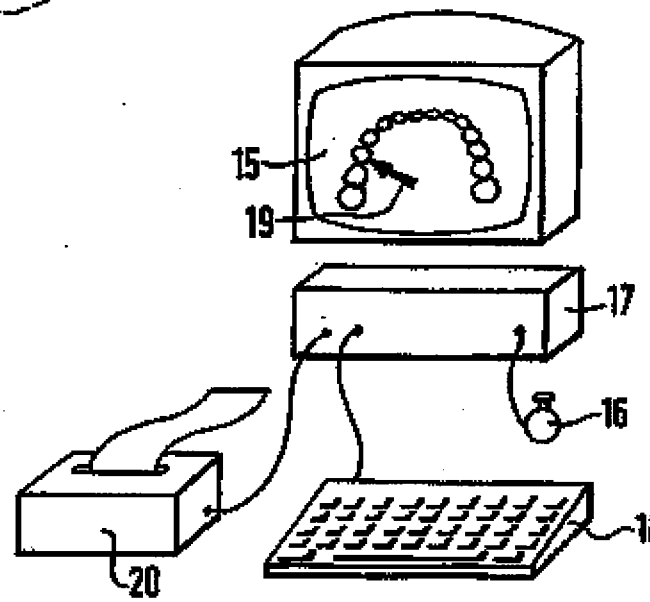


FIG. 3

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REPUBLIQUE FRANÇAISE

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de la
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2652256

N° d'enregistrement national

FR 8912814
FA 432026

RAPPORT DE RECHERCHE

établi sur la base des dernières revendications déposées avant le commencement de la recherche

DOCUMENTS CONSIDERES COMME PERTINENTS		Revendications concernées de la demande examinée
Catégorie	Citation du document avec indication, en cas de besoin, des parties pertinentes	
A	DE-A-3 320 395 (AICHER) * En entier * ---	1-4
A	FR-A-2 594 321 (INGLESE) * Page 4, ligne 20 - page 5, ligne 5; figure 1 * ---	1,2,4
A	EP-A-0 040 165 (MICHALLET) * Revendications * ---	1,3
A	US-A-4 663 720 (DURET) * Colonne 1, lignes 23-27; colonne 2, ligne 48 - colonne 4, ligne 53; figure 7 * -----	1-4

DOMAINES TECHNIQUES RECHERCHES (Int. Cl.5)

A 61 C

Date d'achèvement de la recherche	Examinateur
17-05-1990	KOUSOURETAS I.

CATEGORIE DES DOCUMENTS CITES

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EPO FORM 1503 03.82 (P0413)

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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 774 933 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
06.12.2000 Bulletin 2000/49

(21) Application number: **94917243.1**

(22) Date of filing: **27.05.1994**

(51) Int. Cl.[7]: **A61C 5/00**, A61C 5/10, A61C 13/00

(86) International application number:
PCT/SE94/00507

(87) International publication number:
WO 94/27517 (08.12.1994 Gazette 1994/27)

(54) METHOD OF MANUFACTURING CERAMIC TOOTH RESTORATIONS

VERFAHREN ZUR HERSTELLUNG KERAMISCHEN ZAHNERSATZES

PROCEDE DE PRODUCTION DE RECONSTITUTIONS DE DENTS EN CERAMIQUE

(84) Designated Contracting States:
AT CH DE DK ES FR GB IT LI SE

(30) Priority: **27.05.1993 SE 9301810**

(43) Date of publication of application:
28.05.1997 Bulletin 1997/22

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(56) References cited:
US-A- 5 080 589
US-A- 5 106 303

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EP 0 774 933 B1

Description

[0001] The present invention relates to powder metallurgical manufacturing methods of accurate-to-shape tooth restorations with an individually manufactured core in a densely sintered, high strength ceramic material, which fits against prepared tooth surfaces or artificial abutments. On these cores dental porcelain can be fired to tooth crowns, inlays, veneers or bridges.

[0002] Swedish patent application 8900620-9 discloses a method of manufacturing ceramic bodies with irregular shapes where the sintering shrinkage is considered.

[0003] US 5,080,589 discloses a method of manufacturing copings in densely sintered high strength ceramic material where the sintering shrinkage is considered. According to this patent the copings are premanufactured, which means that they have in advance given dimensions.

[0004] According to US 5,106,303 and Swedish patent application 9002959-6 inlays, onlay crowns and veneers can be manufactured in densely sintered high strength ceramic material by copy milling a green body or a presintered or sintered body from an impression of the prepared tooth surface considering the sintering shrinkage.

[0005] The object of the present invention is to provide rational manufacturing technique for manufacturing tooth crowns, inlays, veneers or bridges in densely sintered, high strength ceramic material by using modern powder metallurgical technique, reading technique and machining technique.

[0006] The present invention relates to a method of manufacturing artificial tooth restorations for natural teeth or implants containing an individual core in densely sintered, high strength ceramic material with dental porcelain fired to its outer surface. The inner surface of the core, which will fit to one or more prepared surfaces or artificial abutments is manufactured by forming a ceramic powder mixture against a surface of a body which surface is manufactured by registering with a three dimensional optical or mechanical reading method the prepared surfaces of the prepared teeth or artificial abutments and their mutual relationship, either directly in the mouth or on a model in e.g. plaster after which the registered surfaces are reproduced in an enlarged size into a carrier e.g. by using a computer controlled milling machine, the enlargement being calculated considering the shrinkage of the ceramic material during the sintering to full density with the addition of a desired gap for cement. The carrier is made from a model material e.g. plaster, graphite or a polymer.

[0007] In some cases the outer surface of the core can be surrounded by prepared tooth surfaces e.g. inlays. The core is manufactured in this case by first compacting a ceramic powder against a carrier, which partly has an outer shape, which is smaller than the outer surface of the core, which will fit against the prepared tooth surfaces. Then the outer shape of the core is made by milling the green body in the milling machine. In order to make it possible to machine the outer surface, the prepared surfaces are registered and their mutual relationship determined with a three dimensional optical or mechanical scanning technique, either directly in the mouth or on a model in some model material e.g. plaster or on an impression with some impression material e.g. addition-silicon or a wax impression, from the prepared surfaces. The registered surfaces are reproduced in an enlarged size onto a carrier, e.g. with a computer controlled milling machine, which machines the powder compacted against the carrier. The enlargement is calculated from the sintering shrinkage of the ceramic material upon sintering to full density. In this case a reduction is made for desired gap for cement.

Fig. 1 shows cross sections of natural tooth one with an artificial tooth crown (Fig. 1a), one with an inlay (Fig. 1b), and one with a veneer (Fig. 1c). In this figure A= dental porcelain, B= core, Y= outer surface of the core, I= inner surface of the core which will fit against the prepared surface, C= cement, P= prepared surface of the tooth, S= preparation border, E= enamel, D= dentine and F= pulp.

Fig. 2 shows a cross section of a bridge, which is cemented on two supporting teeth. These supporting teeth can have a vital abutment (U_1) or an artificial abutment (U_2) manufactured in a dental alloy, ceramic material or a strengthened polymer. The bridge in this figure contains two artificial dental crowns according to Fig. 1a and with a pontic (V) between as replacement for a lost tooth. The bridge contains a core (B) with dental porcelain (A). A bridge can contain more supporting teeth and also more pontics in between. The supporting teeth can also be prepared for inlays or veneers. Veneers can be made both on buccal and lingual surfaces. The supporting teeth can also be implants with artificial abutments.

Figs. 3a and b show a cross section of a cylindrical blank K_1 manufactured in e.g. plaster, graphite or a polymer. K_1 has the diameters Φ_1 and Φ_2, and a groove Q_1 for repositioning in a chucking fixture in a milling machine and a bevel Z_1.

Fig 3c shows K_{oc}, a model of a tooth prepared for a crown. P is the prepared tooth surface and S the preparation border.

Fig 3d shows K_2, is a cross section of a reproduction with enlarged size of K_{oc} produced in a computer controlled milling machine from a blank K_1. The enlargement is calculated considering the sintering shrinkage of the ceramic material. L_2 is a reproduction of the prepared tooth surface (P) and is defined as the surface above the preparation border S_2.

Fig 3e shows K_3 which is K_2 with a shell of 1-1,5 mm outside the enlarged surface (L_2). L_3 is the outer surface of this shell. L_3 is finished with the

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border S_3.

Fig. 4 shows a cross section of an example of a press for individual cores for tooth restorations. F is a cylindrical tube. G is a cylindrical plate with the diameters Φ 3 and Φ_4. H is a cylinder with diameter Φ_3. H, F, and G can be made in e.g. hardened steel E is made in a viscous elastic material as well as J and X. X is an impression from K_3 except the part with the diameter Φ_1. X has a cylindrical outer shape with diameter Φ_3. In Fig. 4 K_2 has been placed in X, M is a cavity with space for ceramic powder and P_K is the force with which H is pressed against G.

Fig. 5a shows K_{oi}, which is a cross section of an impression of an inlay. The surface P_i is an impression of the prepared surface of the inlay (P) (Fig. 1b) and S is the preparation border. Figs. 5b and 5c show a cross section of K_4 (Fig 5b) and K_5(Fig 5 c), which are used for manufacturing of cores for inlays. K_4 is a model of K_{oi} enlarged considering the sintering shrinkage. K_4 can be made by milling in a computer controlled milling machine from a blank K_1 in plaster, graphite or a polymer. In this figure the surface L'_4 (broken line) has been drawn. L'_4 is the enlarged surface of the inlay, which exactly fits against the prepared surface (P) of the tooth prepared for an inlay. S_4 marks the preparation border. L_4 is the milled surface of K_4. The distance between L_4 and L'_4 is equal to the thickness of the core in unsintered condition. K_5 consists of K_4 with a shell of 1,5 - 3 mm outside the continuous surface L_4. L_5 is the outer surface of this shell.

Fig. 6 shows K_{ob}, which is a cross section of a model of two supporting teeth c_1 and c_2 prepared for crowns and intermediate gingiva.

Fig. 7 shows K_6, which is an enlarged model of K_{ob}. The enlarged supporting tooth of K'_6 are C_1 and C_2. The model can be cut at the lines l_1. and l_2.

Fig. 8 shows the enlarged model from Fig. 7 with a shell with outer contour L_8, which surrounds the preparations C_1 and C_2 and intermediate gingiva.

[0008] As can be seen from Fig. 1 and Fig. 2 artificial tooth crowns, inlays, veneers or bridges are made as a core in densely sintered ceramic (B) with dental porcelain (A) fired to the outer surface (Y) or the core. The tooth restorations are fixed to the prepared surfaces(P) by e.g. adhesive (cement), as well as the bridge to the abutments U_1 and U_2. The thin layer of cement (C) connects the prepared tooth surface (P) with the inner surface of the core (I), which fits with desired precision to the prepared surface (P). On the outer surface (Y) of the core (B) dental porcelain can be fired. The layer of cement can have a thickness <100 µm, preferably 25-50 µm. The cement thickness can at some spots be > 100 µm depending on small irregularities in the preparation. The cementing of the restorations can be made with e.g. phosphate cement, glass ionomer cement or some resin cement in accordance with known techniques. In the latter instance, it can be an advantage to silane treat the inner surfaces (I) of the cores of the constructions, which are to be joined with the prepared surfaces (P). It also can be advantageous to etch the prepared surface (P), which consists of enamel (E) before the cementation of the veneer with resin cement. The etchant can be phosphoric acid. Parts of the prepared surface consisting of dentine can be treated with some bonding resin before the cementation.

[0009] The ceramic powder can be made by several well known methods. Traditional powder metallurgical technique can be used, where the different components are mixed and ground under dry or wet conditions with water or an inorganic solvent (e.g. alcohol) as grinding liquid. To the ceramic slurry lubricants or other organic binders are added, when needed at suitable time in the process in accordance with known techniques.

[0010] The ceramic base material in the core is suitably one or several biocompatible oxides, alternatively with additives of carbides and nitrides with or without binders. Examples of biocompatible oxides, which can form the base matrix for the ceramic body, are Al_2O_3, TiO_2, MgO, ZrO_2 and ZrO_2 with additives of smaller amounts of up to 10 mole% of Y_2O_3 or MgO (partly or totally stabilised ZrO_2). Included components can be present as particles with a size of <25 µ m, preferably <10 µm, and/or as whiskers (hair shaped single crystals) with a length of >10 µm, preferably >25 µm, and a length to diameter ratio >5, preferably >10 and/or fibres (polycrystalline) with a diameter >10 µm and/or as single crystal platelets with an approximate diameter of 5-50 µm and a thickness of 1-10 µm. The amount of whiskers, fibres and/or platelets should not exceed 60 volume%. In a preferred embodiment the ceramic material comprises >50% Al_2O_3 with additives of conventional sintering aids. In order to increase the strength <25 weight %, preferably 3-12 weight %, of ZrO_2, and/or 5-40 weight%, preferably 10-30 weight%, of SiC-, TiN- or ZrN-whiskers can be added. It is important that the ceramic material is sintered to closed porosity, which for an oxide material means at least 98% of theoretical density, but in order to ensure good mechanical strength the material should preferably have a density over 99%, while densities over 99.5% give the best strength.

[0011] In order to get a suitable colour of the core (B) coloured components can be chosen. Additives e.g. 0.1-1 weight % of TiN and/or ZrN will give Al_2O_3 based cores a faint yellow shade. Fe_2O_3 gives a yellow brown shade and MnO_2 gives a rose-coloured shade. Of course additives, which give unesthetic effects, should not be used.

[0012] According to the present invention artificial ceramic tooth crowns, inlays, veneers or bridges can now be made from a ceramic powder with additions of lubricants and/or other organic binders. When manufacturing the core of an individual tooth crown, the ceramic

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powder is compacted against the body K_2 to a core, which after sintering to full density fits to the prepared tooth surface and with an as close to desired wall thickness as possible. When manufacturing the enlarged model (K_2) the sintering shrinkage has to be considered by enlarging the surface (L_2) so that the compacted body during the subsequent sintering process to full density, with great accuracy will have desired final, inner geometrical shape (I), which fits against the prepared surface (P). The desired shape of the gap between the tooth crown and the prepared tooth for cementing the crown to the prepared tooth must also be considered. The size of this gap can be calculated e.g. to be as small as possible at the preparation border preferably as close to zero as may be achieved during the manufacturing process.

[0013] The manufacturing of an individual core of a tooth crown can be made in the following way: A body K_2 is manufactured from a blank K_1 by registering a prepared tooth surface with a three dimensional optical or mechanical reading method. The registered surface is transferred to a computer controlled milling machine, which gives the shape of K_2 based on the data from the registration and data about the sintering shrinkage and desired shape of gap for cement. A body K_3 is manufactured from the above registered surface, with the addition of a shell of 1,5 - 3 mm according to Fig. 3e. The tool X is manufactured by placing K_3 in a mould in which a viscous elastic material e.g. an Addition-silicone, which is allowed to harden. The tool X can also be made using the blank K_1 or a somewhat reduced K_1 instead of K_3. When using K_1 to manufacture X the amount of ceramic powder will increase and at the same time more compacted powder has to be milled. The advantage is that this tool X can be used for different sizes of preparations and the bevel Z_1 is not needed. Ready to press ceramic powder is placed in the cavity (M) of X and the body K_2 is placed in X. It can be an advantage to treat the surface L_2 of K_2 with a thin layer of an adhesive material to increase the adhesion of the ceramic powder to K_2. K_2 is fixed with help of the bevel Z_1. J is placed on K_2 and X with content in the tube F. E is put in place as well as the cylinder H whereupon the tube F with content is placed on the cylindrical end plate G. The whole tool according to Fig. 3 is placed in a uniaxial press e.g. a hydraulic press. During the compaction of the powder the cylinder H is pressed with the compaction force P_k into the tube F against the cylinder end plate G in contact with the elastic material J. During pressing, the powder is compacted against the body K_2. After the compaction, H, J and K_2 are removed with compacted powder, which adheres to K_2. If a dry bag isostatic press is used the tool X is not needed at all. The ceramic powder is just compacted against the body K_2 treated with an adhesive material.

[0014] After the compaction of the ceramic powder against K_2 this carrier is repositioned in the computer controlled milling machine. The groove Q1 and to this matching pin in the chucking fixture of the milling machine makes it possible to reposition in direction of rotation and the step between the diameters Φ_1 and Φ_2 in axial direction. The outer surface of the coping is machined after repositioning in the milling machine. The outer surface can be calculated by the computer, which controls the milling machine. The outer surface can also be made from data of a scanned coping, which is modelled in e.g. wax and which before the scanning is fixed on the model of the prepared tooth. The machining can be controlled by the computer so that the coping gets the desired outer form and be adapted to the preparation border. The shell thickness of the core can be 0,3 - 1 mm, however, in certain places shell thicknesses >1 mm can be needed for strengthening or other reasons. It is also possible from data of contact conditions with neighbouring teeth in the same or opposite jaw to machine a complete ready tooth or from scanned data from a crown, which is modelled in e.g. wax and which before the scanning is fixed on the model of the prepared tooth. During all machining in the milling machine the sintering shrinkage is taken into account.

[0015] The compacted body is presintered on the carrier K_2 manufactured in the milling machine. For alumina the presintering will be at 800°C - 1000°C on the carrier. During the presintering the model material (plaster) will dehydrate, which results in a shrinkage of about 15%. The ceramic material will shrink just a few percent during presintering. The presintered core will, thus, be too large on the plaster model and can be removed and be sintered to full density. Instead of plaster investment materials can be used provided that they have enough strength and will not deform during the powder compaction. The carrier K_2 can also contain a material e.g. graphite or a polymer which will burn slowly during the presintering period. It is important that the thermal expansion coefficient of the carrier material is less than the thermal expansion coefficient of the ceramic material, and the adhesive material must disappear during presintering without having any effects on the sintered copings.

[0016] In the same way as a tooth crown above a veneer can be manufactured.

[0017] A core (B) for an inlay can be manufactured by registering with a three dimensional optical or mechanical method the tooth prepared for an inlay (Fig. 1b) or an impression K_{oi}(Fig. 5a) from the prepared cavity. Data from the registered prepared surface guides a computer controlled milling machine for the manufacture of the body K_4(Fig. 5b) from a blank K_1(Fig. 3a) e.g. in plaster, graphite or a polymer. When the scanned impression from the inlay is enlarged taking into account both the shrinkage and the gap for cement, L'_4(Fig 5b) is obtained. From this surface L_4 is calculated. L_4 is the outer surface of the inlay, i.e. the surface at which porcelain can be fired in order to get the inlay ready. K_5 is manufactured in e.g. plaster or some easily machined shape resistant material.

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[0018] In the same way, as during the manufacturing of a core for a tooth crown an impression X for an inlay in some viscous elastic material (Fig. 4) can be manufactured. This impression (X) is then placed in the press in the same way, as described in Fig. 4 after the powder has been placed in the cavity (M) between the enlarged model (K_4) and the impression X. During the pressing procedure the powder is compacted against the body K_4. After the pressing procedure K_4 is repositioned in the computer controlled milling machine. The outer surface of the inlay (L'_4) is machined after the repositioning in the milling machine.

[0019] The compacted body is presintered on the enlarged plaster model K_4. The shape of L_4 gives the outer shape of the core of the inlay. Against this surface porcelain can be fired. In order to increase the aesthetics of the inlay the thickness of the core can be thinnest at the preparation border in order to be able to hide the core after the porcelain firing, if desired. During the modelling of the porcelain powder against the core, this is placed in the inlay preparation in the original model of the prepared tooth. The core is generally placed in a pinned and sawed model from the whole jaw.

[0020] The inlay is made in a conventional way with porcelain powders. During firing the inlay is removed from the model and is fired in a porcelain furnace. Several firings with subsequent adjustments may be needed before the inlay is ready for final adjustment. Against the core dental polymers can also be attached. These polymers then will give the inlay its final shape. It is an advantage if the outer surface of the core is silaniced before the polymer is joined together with the core. Finally, it is possible to give L_4 such a shape that the inlay contains only densely sintered ceramic material. It is then important that the outer surface, which has contact with other teeth, is polished so that the roughness of the surface will not give wear damage on teeth in the opposite jaw.

[0021] A bridge can be manufactured by first registering with a three dimensional optical or mechanical method the prepared surfaces of the supporting teeth and intermediate part from a model in plaster (Fig. 6) or directly in the mouth. Prepared teeth and intermediate part of the jaw are reproduced considering the sintering shrinkage in an enlarged size with e.g. a computer controlled milling machine (Fig. 7). At the sane time a gap for cement is calculated in the same way as for single crowns. Before the enlarged model is scanned, a pontics can be built up e.g. in wax on the fixture between C_1 and C_2. This substructure can also be calculated in the computer. Such a substructure can be seen in Fig. 7. The material in the enlarged models can be e.g. plaster, graphite or a polymer.

[0022] The compaction of the ceramic powder to a bridge is made in a similar way as for copings of crowns and inlays. When manufacturing a bridge an impression X is made, which leaves space for the powder both for a beam connecting the two copings and the two copings. The principal appearance of the body K_7, which is used for manufacturing of an impression X for manufacturing of a core of a bridge in densely sintered ceramic material, is shown in Fig. 8. The impression X is made in the same way, as is described for single cores for tooth crowns. In the empty space, which surrounds C_1, C_2 and the intermediate gingiva, ceramic powder is placed, whereupon the tool X is placed in a pressing tool in the same way as for a single crown and a pressure P_k is applied. The ceramic powder will be compacted against C_1 and C_2 and against that part of the enlarged model, which is between C_1 and C_2. After repositioning in the milling machine the outer surface of the compacted body is machined and the core is presintered in the same way as single copings. Before presintering the support, i.e. the enlarged model described in Fig. 7, can be cut at the lines l_1 and l_2 in order not to break the core during presintering if plaster is used in the carrier. This division can be made before or after the compacting of the powder. It is important that the three parts are fixed during compacting of the powder in order to maintain their mutual positions. After presintering the core is adjusted, especially on the parts which could not be machined before presintering. This final adjustment can be made with a hand piece whereafter the core is sintered.

[0023] A bridge can also be made, which is based on supporting teeth, which have a preparation on the buccal surface for a veneer or a preparation in the lingual side for a lingual plate. The manufacturing of such a bridge will be the same as has been described above for a bridge with supporting teeth prepared for crowns.

Claims

1. Method of manufacturing an artificial tooth restoration comprising a ceramic, densely sintered high strength individual core (B) with dental porcelain (A) by powder metallurgical manufacturing methods **characterised** in that the inner surface (I) of the core (B), which will fit against one or more prepared tooth surfaces (P) or artificial abutments are manufactured by forming a ceramic powder mixture against a surface of a body at which said surface is manufactured by registering the surfaces of the prepared teeth or artificial abutments and their mutual relationship with a three dimensional optical or mechanical reading method either directly in the mouth or on a model in e.g. plaster after which the registered surfaces are reproduced in an enlarged size e.g. with a computer controlled milling machine at which the enlargement is calculated from the shrinkage of the ceramic material during sintering to full density with adjustment of (I) considering desired gap for cement.

2. Method according to claim 1 **characterised** in that the core is manufactured by

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dry pressing a ceramic powder with a rubber tool X made from some viscous elastic material, close to desired size against the enlarged preparations K_2, K_4 and K_6 made by milling of premade plaster, graphite or polymer blanks.

3. Method according to claim 2 **characterised** in that the rubber tool X is made by taking an impression of the body K_3, K_5 or K_7, manufactured from the enlarged preparations K_2, K_4 or K_6, with the addition of a shell of 1,5 - 3 mm.

4. Method according to claims 2 and 3 **characterised** in that after compacting of the ceramic powder against K_2, K_4 or K_6, K_2, K_4 or K_6 are repositioned in the milling machine at which the outer contour of the core is milled to desired shape, whereupon the core is presintered on K_2, K_4 or K_6.

5. Method according to claims 2, 3 and 4 **characterised** in that the presintered core is removed from K_2, K_4 or K_6 and is sintered to full density.

6. Method according to claims 1, 2, 3 and 4 **characterised** in that the core material consists of high strength, densely sintered ceramic material with a relative density of >99%.

7. Method according to claim 5 **characterised** in that the ceramic material in the core is based on one or more of the oxides Al_2O_3, TiO_2, MgO, ZrO_2 or ZrO_2 with up to 25 mole% Y_2O_3 or MgO.

8. Method according to claims 5 and 6 **characterised** in that the core material also comprises whiskers and/or particles of SiC, TiN, ZrO_2 and/or ZrN.

Patentansprüche

1. Verfahren zur Herstellung eines künstlichen Zahnersatzes, der einen keramischen, dichtgesinterten Einzelkern hoher Festigkeit (B) mit Dentalporzellan (A) umfaßt, durch pulvermetallurgische Herstellungsmethoden, **dadurch gekennzeichnet,** daß die Innere Oberfläche (I) des Kernes (B), welche an eine oder mehrere präparierte Zahnoberflächen (B) oder künstliche Widerlager paßt, hergestellt wird, indem ein Keramikpulvergemisch an einer Oberfläche eines Körpers gebildet wird, an welchem diese Oberfläche durch registerhaltiges Anordnen der Oberflächen der präparierten Zähne oder der künstlichen Widerlager und ihrer wechselseitige Lage mit einer dreidimensionalen optischen oder mechanischen Lesemethode entweder direkt im Mund oder an einem Modell zum Beispiel aus Gips hergestellt wird, wonach die registerhaltig angeordneten Oberflächen in einem vergrößerten Maßstab zum Beispiel mit einer computergesteuerten Fräsmaschine reproduziert werden, bei welcher die Vergrößerung aus der Schrumpfung des keramischen Materials während des Sinterns zur vollständigen Dichte von (I) unter Berücksichtigung eines erwünschten Spaltes für Zement berechnet wird.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet,** daß der Kern durch trockenes Pressen eines keramischen Pulvers mit einem Kautschukwerkzeug X, das aus einem viskosen elastischen Material hergestellt ist, nahe der erwünschten Größe gegen die vergrößerten Präparate K_2, K_4 und K_6 hergestellt wird, die durch Fräsen vorher gefertigter Gips-, Graphit- oder Polymerrohlinge hergestellt wurden.

3. Verfahren nach Anspruch 2, **dadurch gekennzeichnet,** daß das Kautschukwerkzeug X hergestellt ist, indem man einen Abdruck des Körpers K_3, K_5 oder K_7, der aus den vergrößerten Vorpräparaten K_2, K_4 oder K_6 gefertigt wurde, unter Zusatz einer Schale von 1,5 bis 3 mm abnimmt.

4. Verfahren nach den Ansprüchen 2 und 3, **dadurch gekennzeichnet,** daß nach dem Verdichten des Keramikpulvers an K_2, K_4 oder K_6 K_2, K_4 oder K_6 in der Fräsmaschine wieder positioniert werden, bei welcher der Außenumriß des Kerns zu der erwünschten Form gefräst wird, worauf der Kern auf K_2, K_4 oder K_6 vorgesintert wird.

5. Verfahren nach Anspruch 2, 3 und 4, **dadurch gekennzeichnet,** daß der vorgesinterte Kern von K_2, K_4 oder K_6 entfernt und zu vollständiger Dichte gesintert wird.

6. Verfahren nach Anspruch 1, 2, 3 und 4, **dadurch gekennzeichnet,** daß das Kernmaterial aus dichtgesintertem Keramikmaterial hoher Festigkeit mit einer relativen Dichte von >99 % besteht.

7. Verfahren nach Anspruch 5, **dadurch gekennzeichnet,** daß das Keramikmaterial in dem Kern auf einem oder mehreren der Oxide Al_2O_3, TiO_2, MgO, ZrO_2 oder ZrO_2 mit bis zu 25 mol% Y_2O_3 oder MgO beruht.

8. Verfahren nach den Ansprüchen 5 und 6, **dadurch gekennzeichnet,** daß das Kernmaterial auch Whisker und/oder Teilchen von SiC, TiN, ZrO_2 und/oder ZrN umfaßt.

Revendications

1. Procédé de fabrication d'une reconstitution de

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dents artificielles comprenant un noyau individuel (B) de résistance mécanique élevée, fritté à densité maximale, avec de la porcelaine dentaire (A) grâce à des procédés de fabrication par métallurgie des poudres
caractérisé en ce que la surface intérieure (I) du noyau (B), qui s'adaptera contre une ou plusieurs surfaces de dents préparées (P) ou un ou plusieurs piliers artificiels est fabriqué en formant un mélange de poudres de céramique contre une surface d'un corps sur lequel ladite surface est fabriquée en repérant les surfaces des dents ou des piliers artificiels préparés ainsi que leur relation mutuelle au moyen d'un procédé tridimensionnel de lecture optique ou mécanique soit directement dans la bouche, soit sur un modèle par exemple de plâtre après quoi, les surfaces repérées sont reproduites à une taille agrandie par exemple avec une machine de fraisage commandée par ordinateur dans laquelle l'agrandissement est calculé à partir du retrait du matériau céramique durant le frittage jusqu'à une densité maximale avec un ajustement de (I), en prenant en compte l'interstice désiré pour du ciment.

2. Procédé selon la revendication 1,
caractérisé en ce que le noyau est fabriqué par pressage à sec d'une poudre de céramique avec un outil caoutchouteux X fait à partir d'un quelconque matériau élastique visqueux, de façon proche de la taille désirée contre les préparations agrandies K_2, K_4 et K_6 réalisées par le fraisage d'ébauches de plâtre, de graphite ou de polymère préfabriquées.

3. Procédé selon la revendication 2,
caractérisé en ce que l'outil caoutchouteux X est réalisé en prenant une empreinte du corps K_3, K_5 ou K_7, fabriqué à partir des préparations agrandies K_2, K_4 ou K_6, avec l'ajout d'une enveloppe de 1,5 à 3 mm.

4. Procédé selon les revendications 2 et 3,
caractérisé en ce que, après compactage de la poudre de céramique contre K_2, K_4 ou K_6, K_2, K_4 ou K_6 sont repositionnés dans la machine de fraisage dans laquelle le contour extérieur du noyau est fraisé à la forme désirée, à la suite de quoi le noyau est préfritté sur K_2, K_4 ou K_6.

5. Procédé selon les revendications 2, 3 et 4,
caractérisé en ce que le noyau préfritté est enlevé de K_2, K_4 ou K_6 et est fritté jusqu'a une densité maximale.

6. Procédé selon les revendications 1, 2, 3 et 4,
caractérisé en ce que le matériau du noyau est constitué de matériau céramique fritté à densité maximale, à résistance mécanique élevée, présentant une densité relative de > 99 %.

7. Procédé selon la revendication 5,
caractérisé en ce que le matériau céramique dans le noyau est à base d'un ou plusieurs des oxydes Al_2O_3, TiO_2, MgO, ZrO_2 ou ZrO_2 avec jusqu'à 25 % en moles de Y_2O_3 ou MgO.

8. Procédé selon les revendications 5 et 6,
caractérisé en ce que le matériau du noyau comprend également des barbes et/ou des particules de SiC, TiN, ZrO_2 et/ou ZrN.

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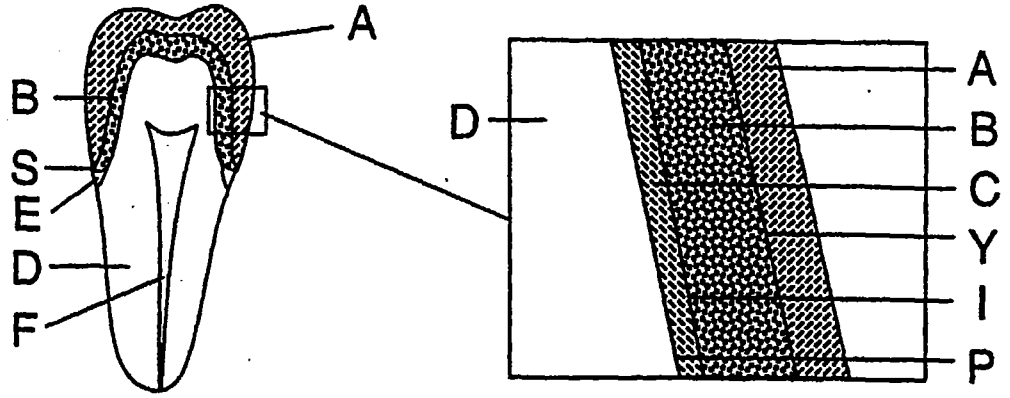


Fig. 1a

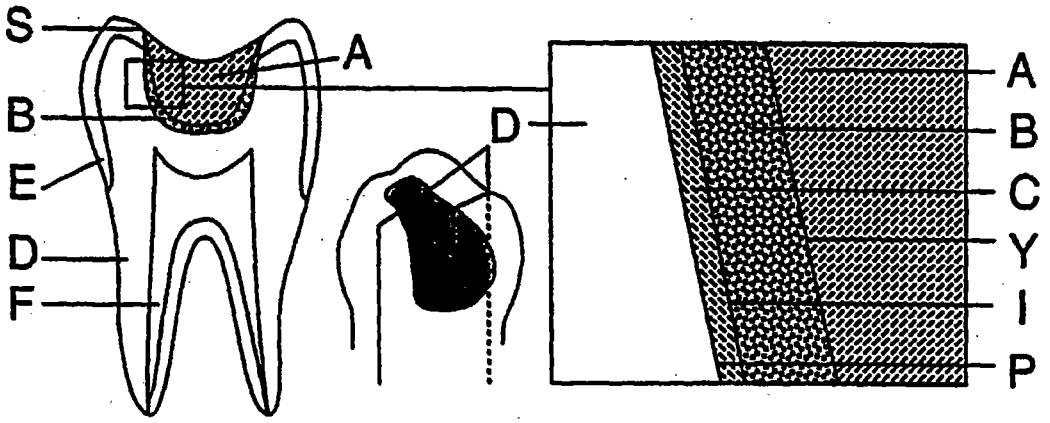


Fig. 1b

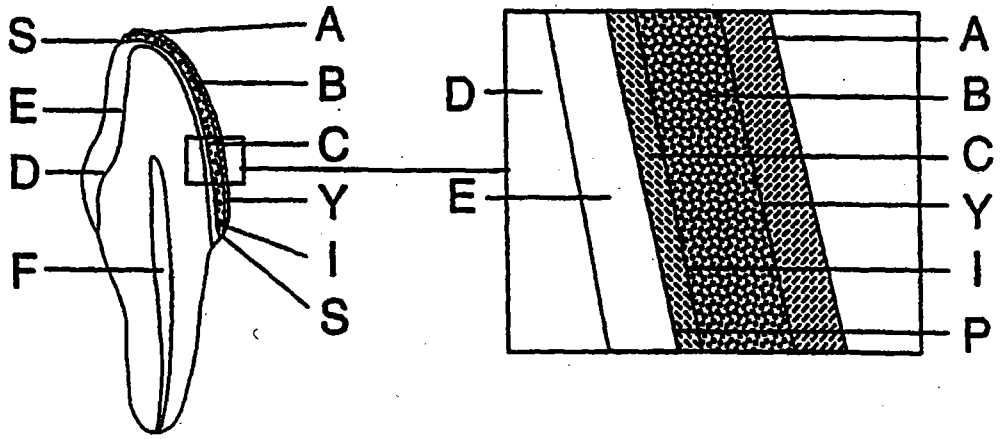


Fig. 1c

Fig. 1

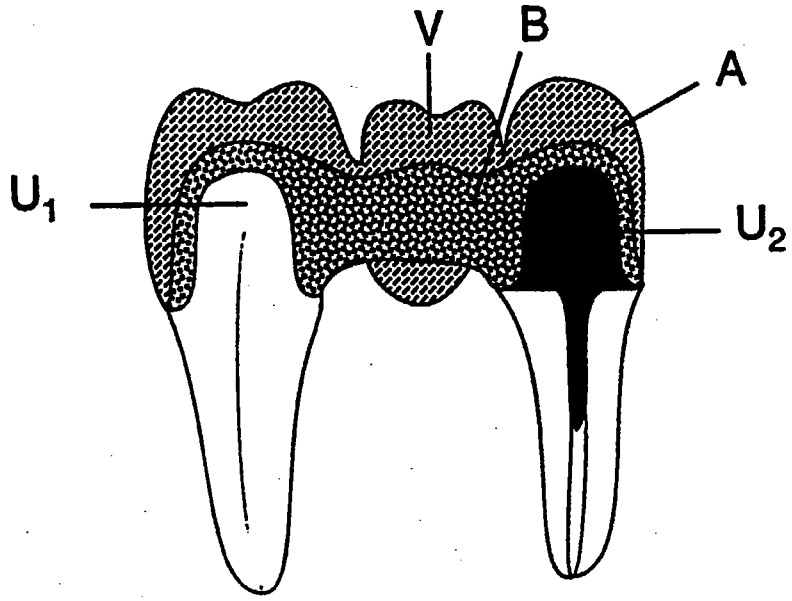


Fig. 2

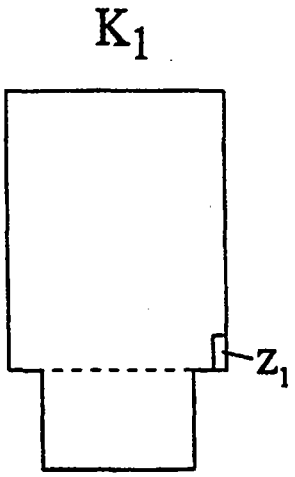


Fig. 3a

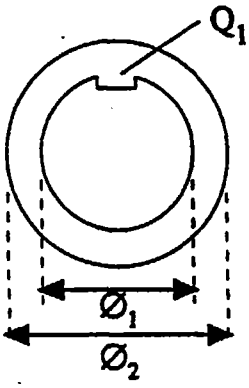


Fig. 3b

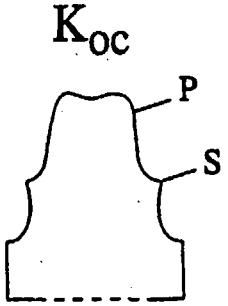


Fig. 3c

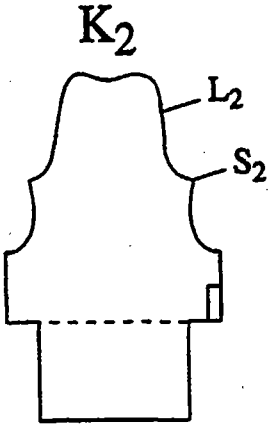


Fig. 3d

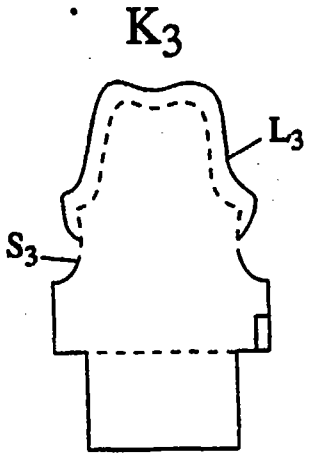


Fig. 3e

Fig. 3

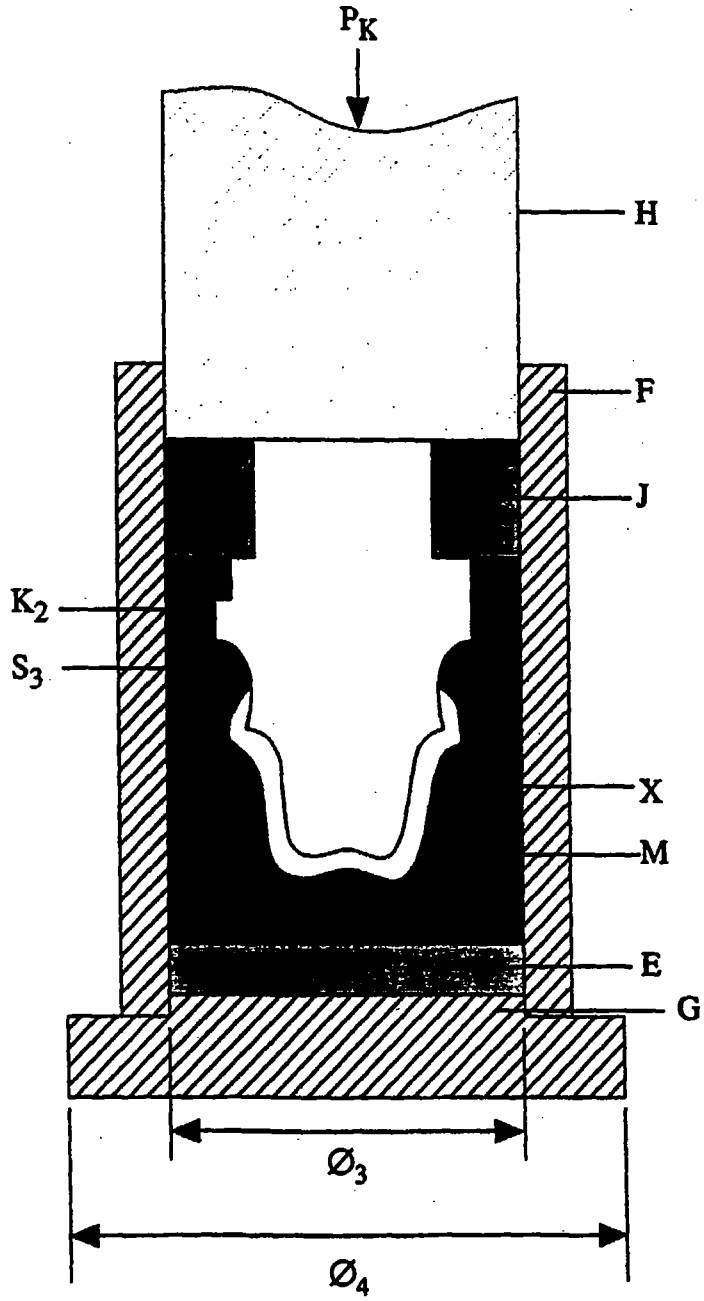


Fig. 4

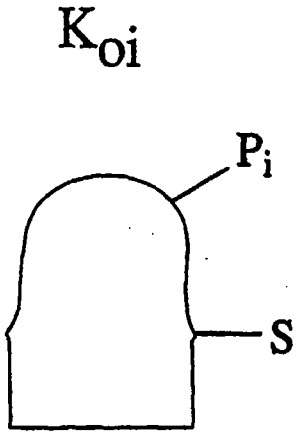


Fig. 5a

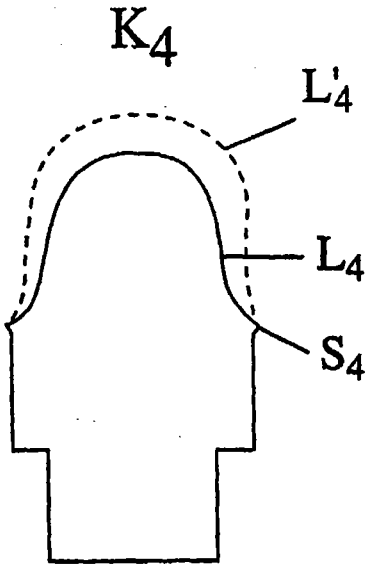


Fig. 5b

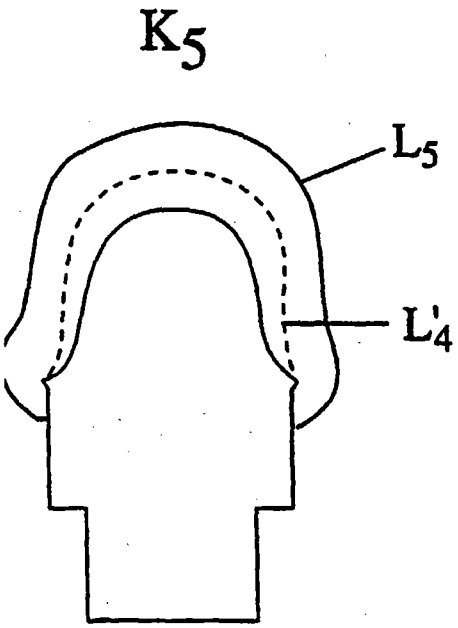


Fig. 5c

Fig. 5

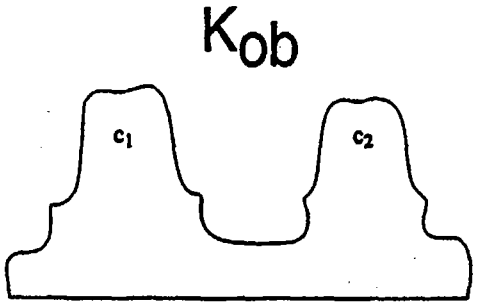


Fig 6

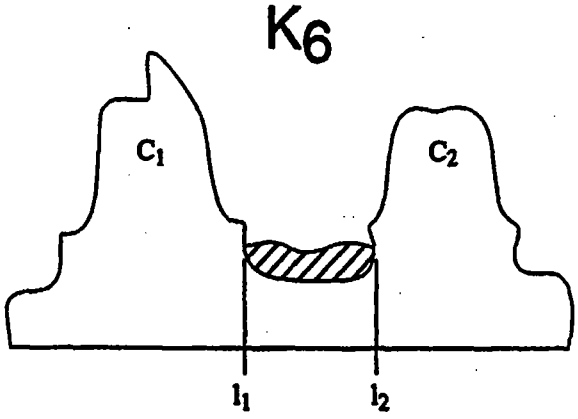


Fig 7

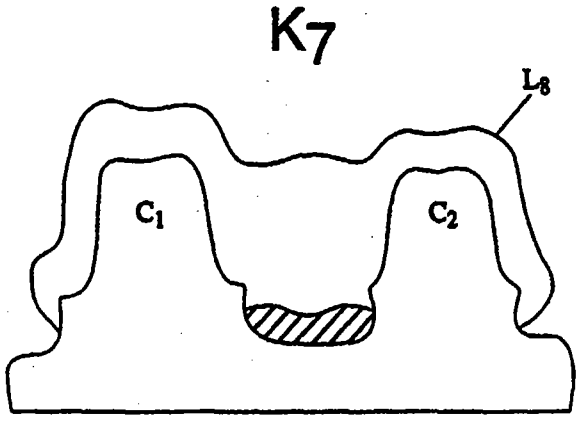


Fig 8

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : A61C 7/00, 13/00 — A1

(11) International Publication Number: WO 94/10935

(43) International Publication Date: 26 May 1994 (26.05.94)

(21) International Application Number: PCT/US93/10858

(22) International Filing Date: 9 November 1993 (09.11.93)

(30) Priority data:

07/973,844	9 November 1992 (09.11.92)	US
07/973,947	9 November 1992 (09.11.92)	US
07/973,965	9 November 1992 (09.11.92)	US
07/973,973	9 November 1992 (09.11.92)	US

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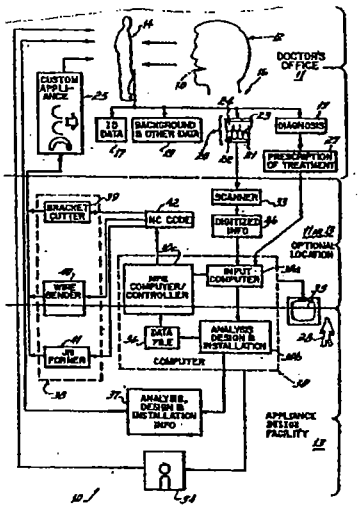
(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU, LV, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SK, UA, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: CUSTOM ORTHODONTIC APPLIANCE FORMING METHOD AND APPARATUS

(57) Abstract

A system (10) and method by which an orthodontic appliance (25) is automatically designed and manufactured from digital lower jaw and tooth shape data (26) of a patient (14) provides for scanning, preferably from a model (20) of the patient's mouth, to produce two or three dimensional images, and digitizing contours and selected point on the patient's teeth and jaw. From the scanned individual patient data, a computer (30) constructs archforms and calculates finish tooth positions, then designs an appliance (25), preferably including archwires and brackets, to move the teeth to the calculated positions. Lower teeth are positioned at the gums on an arch defined by the lower jaw bone and modified to best fit the tooth tips on a smooth curve. Then upper archforms are derived from the lower archform. Crown long axes of the teeth are derived and optimally inclined in the treatment which places all lower teeth but the cuspids in a plane and fits the occluding teeth to them. Overlaps for the upper incisors and cuspid rise are calculated. Brackets each have a base and an archwire support in which an archwire slot is to be cut to a custom inclination, depth, location and curvature, in a blank clamped to an inclinable holder, using a blade of a cutting machine (39). The holder and blade are moved by commands from a computer (30c). An archwire is automatically formed by a wire bender (40) into an optimize smooth arcuate shape and optimal low profile bracket design. Arch equations preferably start with a cubic spline equation and are converted to the form of a series of circle segments for machine control instructions for a numerically forming equipment. Placement jigs, simultaneously designed and automatically made with numerically controlled machinery (41) for positioning and orienting the appliance at connection points on the teeth, each have a surface custom shaped to the contour of a tooth. The machines (38-41) for making the brackets, wires and jigs are driven by commands derived from digitized tooth and jaw shape data and from digital representations of the tooth finish positions and appliance design.



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CUSTOM ORTHODONTIC APPLIANCE FORMING METHOD AND APPARATUS

The present invention relates to the design, manufacture and use of orthodontic appliances for the straightening of teeth, and more particularly, to the automated design, manufacture and use of custom orthodontic appliances based on individual patient anatomy and to the diagnosis of patients therefor and the treatment of patients therewith.

Background of the Invention:

The orthodontic treatment of patients has as its fundamental objective the repositioning or realignment of the teeth of a patient in the patient's mouth to positions where they function optimally together and occupy relative locations and orientations that define a pair of opposed and cooperating planar, or nearly planar, smooth arches. The teeth of the two arches, the maxillary arch of the teeth of the upper jaw and the mandibular arch of the teeth of the lower jaw, when in an optimal or ideal position, contact the teeth of the opposite arch along a surface that is usually flat or slightly upwardly concave and commonly referred to as the plane of occlusion.

The treatment applied to patients who have been diagnosed as having teeth insufficiently close to the ideal positions to require orthodontic correction includes an initial or rough procedure to overcome the more serious defects of tooth positioning followed by a finish treatment designed to bring the teeth as closely as possible or practical to their ideal positions. The rough treatment usually involves the movement of certain teeth through the use of any of a number of recognized techniques performed by an orthodontist, and sometimes procedures such as the extraction of certain teeth or surgery on the patient's jaw performed by an oral surgeon.

In the finish treatment, the orthodontist applies an appliance, or set of braces, to the teeth of the patient to exert continual forces on the teeth of the patient to gradually urge them toward their ideal positions. The application of the appliance usually involves the attachment of brackets to the teeth, either with the application of adhesive to the teeth or the securing of bands around the teeth. The brackets are usually each provided with a slot through which an archwire is extended. One archwire is provided for the upper teeth and one for the lower teeth. Typically, the slots in the brackets are of rectangular cross-section and the archwire is of rectangular cross-section. The archwire installed in the slots of the brackets interconnects the teeth, through the brackets, and exerts forces on the teeth to translate or rotate them toward a finish position envisioned by the orthodontist.

It has been recognized in the design and application of orthodontic appliances that an ideally designed and installed orthodontic appliance will present the slots of the brackets in a position to initially receive a preshaped archwire that will elastically deform to exert corrective forces on the teeth to urge them toward their finish positions. When in their finish positions, the archwire of the ideally designed appliance will no longer be elastically deformed, and will no longer exert forces upon the teeth. Achieving this objective has been inhibited by certain problems in the prior art.

One problem presented by the prior art is that current orthodontic products are designed and manufactured to average anatomy. As a result, orthodontists are faced with the need to select what they perceive to be the brackets and archwires of the closest design to those required by a particular patient, and to modify the designs for treatment of the patient. Some of this modification may be performed when the appliance is initially installed, but almost inevitably modification is required during the course of treatment of the patient. This modification may take the form of the replacement of brackets, but most commonly requires a periodic bending and reshaping of the archwire as the treatment progresses. Thus, the treatment of the patient has become a manual feedback system in which the orthodontist monitors the progress of the patient's treatment and then readjusts the appliance, usually by bending the archwires, to correct the forces being applied to the teeth to bring the teeth to their ultimate positions, which are less than ideal. As a result, the patient may be subjected to treatment over a period that is longer than would be necessary if the appliance were initially made to the optimum design. In addition, the time required of the orthodontist for implementation of the treatment may be several times greater than it would be if modification of the appliance were unnecessary. Thus, the orthodontist is able to treat fewer patients and the cost of the treatment to the patient or to the orthodontist is increased.

Location of the connection points for the appliance to the teeth also presents a problem in the prior art. Typically, brackets are bonded to the teeth and then interconnected by the installation of the archwires. This is done when the teeth are in their malocclusion positions, with the orthodontist having only a mental vision of where the finish positions of the teeth will be and where the brackets are to be placed to move the teeth to those finish positions. For more effective use of the appliance and to promote ease in cleaning the teeth, the orthodontist prefers to locate the brackets and archwires away from the gums. If they are placed to close to the tips of the teeth, however, they may interfere with the teeth of the opposite arch as the teeth approach their finish positions.

Another problem of the prior art that has inhibited the selection or design of an ideal orthodontic appliance for the patient is the difficulty in arriving at an expression of the ideal finish position of the teeth. Orthodontists typically make models of the patient's mouth and, with the models and the aid of x-rays, determine a treatment to move the teeth to finish tooth positions. This process is time consuming and presents a source of error and inaccuracy. From the measurements and based on the judgment of the orthodontist, appliance components are selected to implement the prescribed treatment. In reality, the treatment of patients is in many cases more of an art than a science, with results ranging from poor to excellent, and generally variable.

The need for custom manufactured orthodontic appliances and the use of automatic design techniques has been recognized by some, while others have advocated adherence to standard components and manual techniques in view of a perceived lack of practical custom appliance manufacturing and automated appliance design systems of the art.

The development of automated custom appliance design systems has encountered several difficulties. These difficulties have included the task of developing an automated system that includes reliable and efficient

decision making algorithms and techniques for automatically determining an ideal finish position of the teeth. Further, these difficulties have included arriving at an expression of appliance geometry in terms that can be efficiently produced by automated appliance manufacturing equipment. Furthermore, the prior art has not provided a way to accurately manufacture an appliance on an individualized basis in accordance with the appliance design. An additional problem in the automated design and manufacture of orthodontic appliances lies in the difficulty in designing the custom design system to take into account the professionally recognized parameters and criteria, derived over many years from the knowledge and experience of the practicing and clinical orthodontist, upon which diagnosis and treatment is based.

Accordingly, there is a great need in orthodontics for a practical, reliable and efficient custom appliance automated design and manufacturing system, and method of providing custom appliances and treating patients therewith.

Summary of the Invention:

A primary objective of the present invention is to provide a practical, reliable and efficient custom appliance automated design and manufacturing system and methods of automatically designing custom orthodontic appliances and treating patients therewith.

It is a particular objective of the present invention to provide an automated custom orthodontic appliance design and manufacturing system that can be easily and reliably used by practicing orthodontists and that will make best use of the skills, knowledge and experience that the orthodontist possesses. It is a further objective of the present invention to increase the accuracy of the orthodontist's treatment, to render the use of the orthodontist's time more efficient, to eliminate sources of error and guesswork from the orthodontist's treatment of patients, and to efficiently, repeatedly and reliably perform automatically the many of the routine steps in the diagnosis, prescription and implementation of orthodontic treatment and in the design and manufacture of orthodontic appliances.

It is a further objective of the present invention to improve the practice of orthodontics by aiding the practitioner in achieving optimal finish treatment of patients and in more accurately determining and precisely achieving the finish placement of a patient's teeth. An additional objective of the present invention is to provide for the accumulation of data from individual patients for the analysis of the data to advance the orthodontic art.

It is still another objective of the present invention to apportion the tasks involved in the design and manufacture of custom appliances most efficiently between orthodontist and appliance manufacturing facility in accordance with the scale and other particulars of the individual practitioner operation.

According to the principles of the present invention, a system and method are provided which depart from traditional design and manufacture by designing orthodontic appliances around the anatomy of the individual patient. Further, unlike current orthodontic products that are designed and manufactured to average anatomy, the orthodontic products of the present invention and the methods of manufacturing and using them are tailored to the individual anatomy of the patient.

In accordance with the preferred embodiment of the present invention, there is provided a computerized system and method with which finish positions of the teeth of a patient are derived from digitized information of anatomical shapes of the patients mouth, an orthodontic appliance is automatically designed from the digitized shape information and the derived tooth finish positions, machine code is

generated for production of the orthodontic appliance and communicated to NC machines, and the appliance is automatically fabricated with the machines in response to the machine code.

In accordance with the preferred and illustrated embodiment of the invention, the digitized information is generated from measurements from the mouth of the patient, either taken directly or from a model thereof, and preferably includes information of the shapes of the individual teeth of the patient and of the patient's lower jaw.

In the preferred embodiment, the finish tooth position derivation includes the derivation of one or more archforms, preferably conforming to a skeletal archform defined by the shape of the lower jaw. The appliance is also configured in accordance with the shape of the derived archform, preferably with a mandibular skeletal archform having size and shape conforming to that of the trough of the lower jaw. In the preferred embodiments, additional archforms are constructed using information of the shapes of the individual teeth and the lower jaw skeletal archform to define the positions of the buccal cusps and incisal tips of the mandibular teeth, the marginal ridges of the upper posterior teeth, and the lingual points of occlusion of the upper anterior teeth to position the teeth according to a preferred treatment plan.

In certain preferred embodiments of the invention, the digitized data is taken by measurements of the patient's individual teeth and the data is reduced to certain landmark data that becomes key to effective and efficient arrival at highly preferred finish tooth positions. The individual teeth are arranged on the various derived archforms with mesial and distal contact points of adjacent teeth in contact. The spacing between the opposite contact points of each tooth are preferably extracted from a computerized image formed in horizontal plan views of the patients teeth. Furthermore, relative locations of the incisal tips, marginal ridges, gingival contact points and the external surfaces of the teeth to which the appliance connects, for example, by the mounting of brackets, and which occlude with teeth of the opposite jaw, are determined by digitizing vertical profiles of the surfaces of the crowns of the teeth. This data is reduced to define contact points of the mandibular teeth with the lower jaw, such as the gingival center points, to define crown axes of the teeth, and other parameters that are amenable to manipulation with a simple and reliable algorithm in calculating the finish positions of the teeth. The landmarks also include intercusp and inter ridge spacing measurements that provide a basis for prescribing arch expansion treatment with exactness based on the computer aided calculation of precise finish tooth positions. Further, the tooth position calculations provided improve upon prior orthodontic practice by preserving crown long axis inclination angles and setting the teeth to preferred crown long axis inclination angles for population groups according to seed values that are statistically improved upon by the present invention.

In certain embodiments of the invention, images are digitized to produce the tooth and jaw shape data. Preferably, the images include a scanner which, in one form, generates a video image from which selected points are digitized to produce data from which finish tooth positioning and appliance design is carried out. Alternatively, three dimensional imaging of the teeth and jaw of the patient is carried out with laser or other scanner to form full three dimensional images of the teeth and jaw of the patient. The images may be formed from the patient's teeth and jaw or from a model thereof. Additional data is digitized by taking vertical profiles of the patient's teeth, either by tracing with a computer the three dimensional images generated with other scanners, or by scanning with a mechanical contact probe or with a non-contact probe the individual teeth of the patient, or model thereof. The data may be taken directly from the patient using CAT scans, MRI, positron emission tomography or other technique.

Also in accordance with certain embodiments of the invention, the finish tooth positioning includes the establishment of cuspid rise criteria by rigorous calculations made from measured and statistical anatomical data so that the height of the cuspids and other teeth can be adjusted relative to each other so that the teeth can be positioned to guide the jaws into proper occlusion. With the present invention, numerical relationships are provided for cuspid rise that are an improvement of the prior art.

In accordance with certain preferred embodiments of the invention, an archwire forming machine that is responsive to NC code is driven by signals generated by a computer that reads input data of anatomical shapes of the patient's mouth, is provided to automatically form an arcuate appliance that interconnects the teeth to move them toward their finish positions by rotational and translational forces applied in three dimensions each by the arcuate appliance. Generally, the arcuate appliance is an archwire, and the machine for forming the appliance includes an archwire forming machine that is responsive to NC code is driven by signals generated by a computer that reads input data of anatomical shape of the patient's mouth, preferably of the patient's jaw and teeth, derives the tooth finish positions and archwire and bracket designs that will move the teeth to the calculated finish positions, and generates the machine code to produce the archwire in accordance with the design. Preferably, the archwires have shapes that conform to archforms related to the finish tooth positions, particularly to the shape of the patient's lower jaw, and is represented as a series of segments of a continuous archwire that each have a constant radius of curvature over the length of the segment, and that preferably join adjacent segments in a smooth transition, with the segments tangent where they join.

Further in accordance with certain preferred embodiments of the invention, a bracket fabrication machine, also responsive to NC code, is driven by similar signals from a computer responsive to computer generated finish tooth position calculations and digitized tooth shape data. Preferably, the brackets have bases that mount on computer determined positions on the teeth and have slots to receive archwires that are inclined at computer determined angles. The fabrication of the brackets may include the formation of a slope and/or curvature to the mounting surfaces of the bases of the brackets, or, as with the illustrated embodiment, by cutting custom slots in the brackets. In the preferred embodiment, the design and manufacture of the archwires and brackets are interrelated so that the curve of the archwire is optimized to minimize curvature changes and the brackets are optimize to minimize their profiles, or the distances from the bases to the archwire slots. The calculations provide a basis for the selection of appropriate bracket blanks for the optimized appliance design.

Additionally, in accordance with other aspects of the invention, one or more placement fixtures are manufactured from the input data and the calculated tooth positions for locating points on the teeth, preferably determined by the computer, for the connection of the appliance to the teeth, such as for the mounting of the brackets to the teeth. The fixtures preferably include a set of bracket placement jigs, one for each bracket that is to be mounted on a tooth, to position and hold the bracket to the tooth so that it can be secured thereto in a precise mounting location. The jigs of the preferred embodiment include a tooth profile or three dimensional surface that fits against the tooth to precisely locate the jig on the tooth and hold a bracket at a precise position and inclination thereon so that it can be secured to the tooth with adhesive.

With the present invention, a custom orthodontic appliance is fabricated under the control of a computer directly from data taken from the teeth and/or jaw of a patient or a model thereof. The appliance so formed, when connected to the teeth of the patient, moves the teeth of the patient to precise calculated

finish positions without the need for the orthodontist to bend archwires over the course of the treatment. As a result, the orthodontist's time is conserved, the treatment of the patient is achieved in a shorter amount of time and the finish positions of the teeth are more nearly ideal, and consistently so, than those achieved with the procedures of the prior art. Furthermore, the appliance fabricating processes result in the generation of data useful in establishing treatment techniques and criteria that will improve the practice of orthodontics.

Further, movement of the teeth to the finish positions calculated in accordance with the present invention results in far more stable placement of the teeth than with other methods of the prior art which often experience movement of the teeth to inferior positions after the orthodontic treatment is terminated.

These and other objectives and advantages of the present invention will be more readily apparent from the following detailed description of the drawings in which:

Brief Description of the Drawings:

Figs. 1-1F are diagrams illustrating the preferred embodiments of the system of the present invention, of which:

Fig. 1 is a block diagram illustrating one preferred embodiment of an automated system for the design and manufacture of custom orthodontic appliances for the treatment of patients therewith according to the principles of the present invention.

Fig. 1A is an elevational diagram of a video graphics image forming embodiment of the data input portion of one embodiment of the scanner of the system of Fig. 1.

Fig. 1B is an elevational diagram of a laser scanner version of a three dimensional graphics imaging embodiment of a scanner of the system of Fig. 1.

Fig. 1C is an elevational diagram of a mechanical tooth profile probe scanner version of a two dimensional imaging portion of one embodiment of the scanner of the system of Fig. 1.

Fig. 1D is an isometric diagram of one embodiment of a bracket cutting device of the system of Fig. 1.

Fig. 1E is an isometric diagram of one embodiment of a wire forming device of the system of Fig. 1.

Fig. 1F is an isometric diagram of a bracket placement jig forming device of the system of Fig. 1.

Figs. 2-2Z are flow chart diagrams of the preferred methods of carrying out the present invention, of which:

Fig. 2 is a flow chart of one preferred embodiment of the process of the present invention performed with the system of Fig. 1.

Fig. 2A is a more specific flow chart illustrating the steps of the input procedure of automated tooth positioning and appliance design and manufacturing operation of the process of Fig. 2.

Fig. 2B is a more specific flow chart illustrating the steps of the analysis and tooth finish position calculating procedure of the automated tooth positioning and appliance design and manufacturing operation of the process of Fig. 2.

Fig. 2C is a more specific flow chart illustrating the steps of the custom appliance design procedure of the automated appliance design and manufacturing operation of the process of Fig. 2.

Fig. 2D is a more specific flow chart illustrating the steps of the custom appliance manufacturing procedure of the automated tooth positioning and appliance design and manufacturing operation of the process of Fig. 2.

Fig. 2E is a detailed flow chart illustrating the substeps of the identification data input step of the input procedure of Fig. 2A.

Fig. 2F is a detailed flow chart illustrating the substeps of the patient history and treatment data input step of the input procedure of Fig. 2A.

Fig. 2G is a detailed flow chart illustrating the substeps of the mandibular bone and horizontal tooth dimension data input step of the input procedure of Fig. 2A.

Fig. 2H is a detailed flow chart illustrating the substeps of the maxillary horizontal tooth dimension data input step of the input procedure of Fig. 2A.

Fig. 2I is a detailed flow chart illustrating the substeps of the individual tooth vertical profile data input step of the input procedure of Fig. 2A.

Fig. 2J is a detailed flow chart illustrating the substeps of the individual tooth profile analysis and landmark identification step of the analysis procedure of Fig. 2B.

Fig. 2K is a detailed flow chart illustrating the substeps of the cuspid rise calculation step of the analysis procedure of Fig. 2B.

Fig. 2L is a detailed flow chart illustrating the substeps of the mandibular preliminary horizontal tooth finish position calculation step of the analysis procedure of Fig. 2B.

Fig. 2M is a detailed flow chart illustrating the substeps of the best fit mandibular cusp arch equation calculation step of the analysis procedure of Fig. 2B.

Fig. 2N is a detailed flow chart illustrating the substeps of the calculation step of the mandibular tooth finish position on the best fit mandibular cusp arch equation of the analysis procedure of Fig. 2B.

Fig. 2O is a detailed flow chart illustrating the substeps of the maxillary horizontal tooth finish position calculation step of the analysis procedure of Fig. 2B.

Fig. 2P is a detailed flow chart illustrating the substeps of the mandibular archwire plane calculation step of the appliance design procedure of Fig. 2C.

Fig. 2Q is a detailed flow chart illustrating the substeps of the mandibular bracket slot inclination calculation step of the appliance design procedure of Fig. 2C.

Fig. 2R is a detailed flow chart illustrating the substeps of the maxillary archwire plane calculation step of the appliance design procedure of Fig. 2C.

Fig. 2S is a detailed flow chart illustrating the substeps of the maxillary bracket slot inclination calculation step of the appliance design procedure of Fig. 2C.

Fig. 2T is a detailed flow chart illustrating the substeps of the mandibular archwire and bracket slot in-out dimension calculation step of the appliance design procedure of Fig. 2C.

Fig. 2U is a detailed flow chart illustrating the substeps of the maxillary archwire and bracket slot in-out dimension calculation step of the appliance design procedure of Fig. 2C.

Fig. 2V is a detailed flow chart summarizing the substeps of the bracket placement jig shape calculation step of the appliance design procedure of Fig. 2C that is illustrated in more detail in the flowchart of the jig modification step of Fig. 2Z described below.

Fig. 2W is a detailed flow chart illustrating the substeps of the cubic spline curve fitting, spline to circle conversion and tooth placement calculation subroutines employed in placing teeth on calculated archforms in certain steps of the tooth positioning and appliance design and manufacturing operation of Fig. 2C.

Fig. 2X is a detailed flow charts illustrating the NC code generation and slot cutting substeps of the bracket manufacturing step of the procedure of Fig. 2D, and Figs. 2X-1 through 2X-4 are more detailed flowcharts illustrating substeps of Fig. 2X.

Fig. 2Y is a detailed flow chart of the substeps of the wire bending code generation and wire manufacturing step of the appliance manufacturing procedure of Fig. 2D.

Fig. 2Z is a detailed flow chart illustrating the substeps of the jig manufacturing step of the appliance manufacturing procedure of Fig. 2D. Figs. 2Z-1 through 2Z-6 are more detailed flowcharts illustrating details of substeps of Fig. 2Z.

Figs. 3-3C are illustrations of graphics computer images produced in the input procedure, in which:

Fig. 3 is a an example of a computer display of a video image generated by the scanner of the system of Fig. 1 illustrating in a top plan view a mandibular model produced by the scanner of the type shown in Fig. 1A.

Fig. 3A is a an example of a portion of a three dimensional digital image, illustrated in perspective, and produced by the scanner of the type shown in Fig. 1B.

Fig. 3B is an illustration similar to Fig. 3A of another portion of a three dimensional digital image produced by the scanner of Fig. 1B.

Fig. 3C is an example of a set of vertical tooth profile images produced by the scanner of Fig. 1C.

Figs. 4-4E are plan views of the teeth of the patient on tooth placement archforms at various stages of the tooth position calculation procedure of Fig. 2B, of which:

Fig. 4 is a geometric diagram illustrating a horizontal plan view data input screen showing diagrammatically the video image of Fig. 3 used as a template, with variables relevant to the digitization of data from the mandibular video image marked thereon.

Fig. 4A is a geometric diagram similar to Fig. 4 for the maxillary teeth.

Fig. 4B is a geometric diagram plotting horizontal mandibular archforms calculated through the analysis procedure of Fig. 2B.

Fig. 4C is a geometric diagram plotting horizontal maxillary archforms calculated through the analysis procedure of Fig. 2B.

Fig. 4D is a horizontal plan diagram showing the maxillary teeth in their finish positions.

Fig. 4E is a horizontal plan diagram showing the mandibular teeth in their finish positions and with the custom appliance in place.

Figs. 5-5P are mathematical calculation diagrams for reference in connection with spline to circle conversion and tooth placement routines of Fig. 2W, in which:

Fig. 5 is a horizontal plan diagram illustrating the placement of a tooth on an archform equation described in circle segment form.

Figs. 5A-5J are detailed diagrams of the spline to circle conversion and tooth placement subroutines.

Figs. 5K-5P are detailed diagrams of the tooth placement subroutine.

Figs. 6-6I are diagrams of tooth profiles illustrating landmark determination, tooth inclination and vertical positioning, in which:

Fig. 6 is an isometric image of a three-dimensional computerized representation, similar to Fig. 2B, of a molar showing the locations of alternative vertical labial-lingual profile planes and tooth profiles.

Fig. 6A is a mathematical tooth profile plot as illustrated on the computer screen of a the system of Fig. 1 of a mandibular molar showing selected landmark parameters.

Fig. 6B is a mathematical tooth profile plot, similar to Fig. 6A, of a mandibular cuspid or incisor showing selected landmark parameters.

Fig. 6C is a mathematical tooth profile plot, similar to Fig. 6A, of a maxillary molar or bicuspid showing selected landmark parameters.

Fig. 6D is a mathematical tooth profile plot, similar to Fig. 6A, of a maxillary cuspid or incisor showing selected landmark parameters relevant thereto.

Fig. 6E is representation of a display, similar to Fig. 3C, of an array of mathematical tooth profile plots of all of the teeth, angularly oriented, with landmark parameters marked thereon.

Fig. 6F is representation of a display of an array of mathematical tooth profile plots, similar to a portion of Fig. 6E, of the mandibular teeth with working horizontal placement planes marked thereon.

Fig. 6G is mathematical tooth profile plot, similar to Fig. 6A, of a mandibular posterior tooth with relevant dimensional variables for placement of the tooth marked thereon.

Fig. 6H is mathematical tooth profile plot, similar to Fig. 6B, of a mandibular anterior tooth with relevant dimensional variables for the placement of the tooth marked thereon.

Fig. 6I is mathematical tooth profile plot, similar to Fig. 6H, of a the tallest mandibular tooth.

Figs. 7-7D are diagrams for reference in connection with the finish tooth position calculation, of which:

Fig. 7 is an elevational diagram of the relationship of the jaws of a patient for illustration of cuspid rise occlusion calculation.

Fig. 7A is an enlarged view of a portion of Fig. 7.

Fig. 7B is a plan mathematical diagram illustrating certain of the mathematics of tooth placement on the mandibular offset arch.

Fig. 7C is a perspective diagram illustrating the relationship of the vertical tooth profile planes and relevant horizontal arch planes in the course of tooth finish position calculation.

Fig. 7D is a set of related elevational profiles of mandibular and maxillary teeth showing occlusal and overlap relationships in the course of tooth finish position calculations.

Figs. 8-8H are diagrams for reference in connection with the steps of the custom appliance design procedure, of which:

Fig. 8 is a diagram similar to Fig. 7D illustrating archwire plane and bracket slot design on positioned teeth.

Fig. 8A is an elevational diagram illustrating a bracket and slot configuration in connection with the diagram of Fig. 8.

Fig. 8B is a top view illustrating the relation of a tooth to an archform by placement routine of Fig. 2W.

Fig. 8C is a tooth profile diagram illustrating the slot in-out dimension calculation.

Fig. 8D is a perspective diagram illustrating the placement of a custom bracket onto a tooth with the use of a custom placement jig.

Fig. 8E is a plan diagram of a custom archwire for the appliance required to move the mandibular teeth to the finish positions illustrated in Fig. 4E.

Fig. 8F is a plan diagram illustrating the labial installated appliance on the teeth of the patient in their initial positions.

Fig. 8G is a plan diagram, similar to Fig. 8F, illustrating a lingual appliance installed on the teeth of the patient.

Fig. 8H is an elevational diagram illustrating an orthodontic lingual bracket of the appliance of Fig. 8G.

Fig. 8I is a top view of a bracket having a base slot curvature conforming to that of an archwire supported therein.

Figs. 9-9W are diagrams relating to appliance manufacturing steps, of which:

Figs. 9-9H relate to substeps of the bracket slot cutting code generation and bracket manufacturing step.

Figs. 9I-9W relate to the substeps of the bracket placement jig manufacturing step.

Detailed Description of the Drawings:

The preferred embodiment of the invention provides a system and method for designing and manufacturing orthodontic appliances and for employing the appliances to orthodontically treat patients for the straightening of teeth. Unlike traditional orthodontic products, however, the appliances resulting from the practice of the present invention are designed around the anatomy of the individual patients. It further incorporates in its design criteria the parameters and professional treatment approaches of the treating orthodontists, and applies automated decision making processes in the appliance design that take into account the professionally recognized characteristics and anatomical landmarks of the patients.

The overall configuration of the system 10 is illustrated diagrammatically in Fig. 1. The overall operations of the preferred method of the invention are illustrated in the flowchart of Fig. 2.

In accordance with the preferred embodiment of the invention as illustrated in Figs. 1 and 2, examination of a patient is performed by an orthodontist at the orthodontist's office for the purpose of assembling the information necessary to determine the patient's condition, prescribe the appropriate treatment, and specify the type of orthodontic appliance to implement the treatment. The information is then communicated to a remotely located appliance design and manufacturing facility where the design of a custom appliance for use in administering the treatment is carried out with the use of computer analysis. The appliance design, together with the information necessary for the orthodontist to install the appliance on the patient is then transmitted back to the orthodontist, who installs the appliance and administers the treatment in accordance with the appliance manufactures instructions and his own professional expertise.

In accordance with alternative embodiments of the invention, digitization of anatomical information for computer input is performed either at the appliance design and manufacturing facility, by the orthodontist at his office, or preferably divided between the two. Similarly, the present invention contemplates the manufacture of the appliance to be performed at either the appliance manufacturing facility, at the orthodontists office, or preferably divided between the two locations and in accordance with the analysis and design provided by the system of the present invention.

The practice of the present invention involves the use of certain system hardware, tangible records of information, and communications paths described below in connection with Fig. 1 and related illustrations, and the performance of operations, procedures and steps described in connection with the flowchart of Fig. 2 and related diagrams, all as set forth in detail below.

Terminology and Conventions

Throughout the description, references are made to tangible elements illustrated in the drawings and to actions performed by hand and by computer. In the description, numbers used to refer to structure or other tangible items illustrated in the drawings of the preferred embodiment appear in conventional form in the text, while numbers that refer to method steps in the illustrated flowchart are enclosed in parentheses in the following description. Letter symbols are used to refer to geometric or mathematical representations of variables, parameters, dimensions and values, input into or calculated by a computer, tie into equations and diagrams illustrated in the drawings, or correspond to computer codes or conceptual items set forth in the disclosure.

Throughout this description, the various teeth of the patient, up to thirty-two in number, may be identified as T_{JSI}, or $T(J,S,I)$, where J designates the jaw (upper: $J = U$; lower: $J = B$), where S designates the side (patient's right: $S = R$; patient's left: $S = L$), and I designates the tooth by position relative to the jaw centerline as follows:

$I = 1$: Central Incisor

$I = 2$: Lateral Incisor

$I = 3$: Cuspid

$I = 4$: First Bicuspid

$I = 5$: Second Bicuspid

$I = 6$: First (6 year) Molar

$I = 7$: Second (12 year) Molar

$I = 8$: Third (Wisdom Tooth) Molar

The wisdom teeth are, however, customarily not involved in orthodontic procedure and usually are not yet present in the mouth of patients of treatment age. Furthermore, the second molars are often not involved in orthodontic treatment. To simplify the description and drawings, however, these designations are eliminated except where they are necessary to avoid ambiguity. Instead, the description below states verbally when it relates to, for example, the lower jaw (thus making use of the J subscript unnecessary) or where it relates to data or calculations relevant to a particular or either side of a jaw (thus making use of the S subscript unnecessary).

Further, many values are calculated or measured for each tooth I, or for each of a limited group of teeth, as, for example, the mesio-distal width MDW or the mesial and distal extremities $M_{X,Y}$ and $D_{X,Y}$ as in the description of step (300) below. Wherever possible, the I designation is also eliminated and the description instead describes how the variables relate to the various teeth. In addition, where some values such as MDW discussed above relate to a tooth dimension or the distance between two points on a tooth (and may be represented by a scaler value in a computer), other values such as the points $M_{X,Y}$ and $D_{X,Y}$ relate to points M and D, respectively (and may be represented by a pair of X and Y coordinates in a computer). Usually, the subscripts designating the two coordinates are omitted, and where helpful to clarify the description, a single one of the subscripts X or Y may be used, such as with D_X or D_Y, to designate that only the X or Y coordinate is employed, for example, in a calculation.

SYSTEM CONFIGURATION

Referring to the system diagram of Fig. 1, an orthodontic appliance manufacturing and patient treatment system 10 is illustrated. The system components are distributed between two locations, a doctor's

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office 11, and an appliance design and manufacturing facility 13. At the doctor's office 11, a patient 12, who requires orthodontic treatment, is examined by an orthodontist 14, who makes a diagnosis 15 of the condition of the patient and of the treatment, if any, needed. The examination involves the traditional application of the skill, knowledge and expertise of the orthodontist 14, and results in the preparation of detailed records 16 of the anatomy and condition of the mouth 18 of the patient, of the treatment proposed, and of other information necessary to the preparation of an orthodontic appliance.

The records 16 prepared by the orthodontist include a physical model 20 from a mold of the patient's mouth 18, which includes a mandibular model 21 of the patient's lower jaw or mandible 22 and a maxillary model 23 of the patient's upper jaw or maxilla 24. The records 16 also include prescription 27 wherein the orthodontist sets forth a treatment to be applied to the patient and a result to be achieved by the treatment. The prescription 27 may also include a specification of techniques that are to be included in the treatment and a designation of an orthodontic appliance to be employed. The records 16 will further include identification information 17 and patient history information 19.

In the illustrated embodiment of the invention, the records 16 are transmitted to the appliance manufacturing facility 13, at which the finish position of the teeth are calculated and a custom appliance 25 is designed and manufactured. The facility 13 is provided with one or more trained operators 28. In some embodiments, the physical model 20 itself is transmitted in the information 16 to the facility 13. In such cases, one of the primary functions of the operators 28 is to input digital information 26 from the records 16 into a computer 30a. Another function is to operate the same or another computer 30b to design the custom appliance 25, and to operate NC equipment 38 controlled by one of the same or another computer 30c to manufacture the appliance 25. Where the inputing, design and manufacture are performed at the appliance facility 13, the computers 30a, 30b and 30c may be the same computer 30.

In other embodiments of the invention, the orthodontist 14 digitizes data from the model 20, in which case the inputing computer 30 is located at the orthodontist's office 11. In these embodiments, the digitized information 26, rather than the physical model 20, is transmitted to the appliance facility 13. The analyzing and appliance design computer is nonetheless preferably at the appliance facility 13.

The entry of the information into the input computer 30 involves a digitizing of the information 16 to produce the digitized anatomical information 26 in machine readable form for analysis by the analyzing computer 30b. The input computer 30 connected thereto by a scanner 33, which, in the alternative embodiments of the invention, includes equipment that employs one or more video cameras, mechanical probes, laser scanners, ultrasonic scanners, moire image scanners or other forms of imaging or measurement hardware that alone, or in combination with other such components, produce anatomical geometric information that describes the patient's teeth and jaw. The images may be three-dimensional or be made along a plurality of planes or other surfaces that can ultimately be combined to provide information in three dimensions.

The combined information from the scanner 33 of the illustrated embodiment provides a basis for three dimensional analysis of the patient's teeth and from which calculations of finish tooth positions can be made. From the final positional calculations and tooth anatomy data, automatic design and manufacture of the custom orthodontic appliance 25 is carried out. In the illustrated embodiment, the data is imaged in a plurality of differently oriented two dimensional planes in the computer 30, then mathematically manipulated

and combined in the computer 30b to construct a three dimensional solution to the tooth positioning and appliance design problems.

In a configuration in which the scanner 33 is connected to a separate dedicated inputing computer 30 is herein described, the functional equivalent of the inputing computer 30 may be included in circuitry within the scanner 33 itself.

Preferably, the digital input process utilizes interactive methods by which an operator 28 uses a pointing device and digitizer to select particularly useful orthodontic parameters from graphics images produced by the scanner 33 on a screen 35 of a display connected to the inputing computer 30.

In embodiments where some or all of the extraction of the digitized anatomical information 26 from the model 20, which may also be derived directly from the mouth 18 of the patient 12, is accomplished by the orthodontist 14 at the orthodontist's office 11, the information 26 is digitized by the orthodontist 14 then transmitted as part of the information 16 to the appliance design center 13. The transmitted information 16 is preferably transmitted from the orthodontist's office 11 to the appliance facility 13 by modem, but may be transmitted in any other available manner.

An analysis and design computer 30b, preferably at the appliance design facility 13, produces an archive diskette 34 that is formatted and written with all of the relevant information of the analysis and the history and prescribed treatment of the patient 14.

The computer 30b at the appliance facility 13 calculates, based on the digitized information 26, the final position of the patient's teeth, and the configuration of the appliance 25 required to move the patient's teeth to this final or finish position. As a result, calculated information for the patient is stored in a patient data file 36. From the calculations the computer 30c produces CNC machine readable code 42 for operating NC manufacturing equipment 38 to produce the appliance 25. An instruction document or file 37 is also produced, either by the computer 30b or the computer 30c, of information to aid the orthodontist 14 in treating the patient 14 with the custom appliance 25.

The manufacturing equipment 38 includes an appliance bracket cutting or forming machine 39 which produces custom brackets for the appliance 25 by cutting slots calculated angles and to calculated depths in slotless generic brackets. The machine 39 may also or alternatively shape the surfaces of the bracket bases. This provides the bracket design option of torquing the teeth by either the bracket slot or base, as may be best for various bracket materials.

The equipment 38 also includes an appliance archwire bending or forming machine 40 which produces custom shaped archwires for the appliance 25 by feeding and bending wire of any one of several available materials and stiffnesses into the custom archwire shape. The equipment 38 may also include a machine for forming patient treatment components and hardware to aid in the manufacture or installation of the appliance 25. In the illustrated embodiment, this includes a machine 41 for the making of bracket placement jigs, which cuts each tooth crown portion of the tooth profile into a plastic form, along with a superimposed cutout of the positioned bracket, for use in accurately installing the custom brackets in their calculated positions on the teeth.

The appliance manufacturing machines 38 may be connected directly to the analyzing computer 30b or one or more may be connected to a separate manufacturing equipment controlling computer or machine controller 30c. The computer 30c may be located at the appliance facility 13 or, together with one or more of the appliance manufacturing machines 38, 40 or 41, be located at the orthodontist's office 11. In one

preferred embodiment of the invention, one manufacturing computer 30c and the bracket cutting machine 40 are located at the orthodontist's office, along with the scanner 33 and input computer 30, which may be the same computer as the manufacturing computer 30c, while another manufacturing central computer 30c, which may be the analyzing computer 30b, the wire bending machine 40 and the jig forming machine 41 are located at the appliance facility 13. The optimum distribution of the computers 30, 30b and 30c and the scanner 33 and appliance manufacturing machines 38, 40 and 41 will be determined by the scale of the orthodontist's practice and the orthodontist's preferences. In the illustrated embodiment, the computers 30-30c are IBM PC clones, with Intel 80386 or 80486 microprocessors and equipped with 80387 or 80487 math coprocessors, respectively.

Certain components of the system 10 of Fig. 1 are described below in further detail.

Scanning Assembly 33

Three steps in the information input procedure (82), described below, involve the inputing into the computer 30, for analysis in digital form, of data concerning the shape of the mouth 18 of the patient 12 and of the shapes of the individual teeth therein. In these steps, digitized images and measurement data of the mouth 18 of the patient 12, preferably taken indirectly from the model 20, and digitized to form a three dimensional mathematical model of the patient's mouth 18. The mathematical model includes, in the preferred embodiment of the invention, the definition of certain parameters of the patient's lower jaw and individual teeth, and may include some information of the initial position and orientation of the teeth in the mouth 18 of the patient 12 for evaluating the magnitude of the treatment.

The input information 26 is, in some embodiments of the invention, input as a full three dimensional image, and then simplified by reducing it to a plurality of curves in a plurality of differently oriented planes or fairly flat curved surfaces, each defined in the independent *X-Y* coordinate system of the respective surface or plane. In subsequent analysis, these planes are oriented, translated and rescaled with respect to each other in arriving at a derivation of the ideal finish positions of the teeth and the design of the custom appliance 25. In accordance with the preferred embodiment of the invention, curves and points on the contours of the jaw and teeth of the patient 12 are expressed in terms of accepted or generally applicable orthodontic parameters so that manual and automated decision making can combine and coordinate the best of orthodontic knowledge and experience with the efficiency and precision of computer analysis to minimize the use of the orthodontist's time, shorten the patient's treatment period and optimize the final treatment result.

The various types of and components of the scanner 33 of various embodiments of the invention are described below.

Video Scanning Data Input Assembly 43:

One preferred form or component of the scanner 33 includes a video imaging assembly 43 as illustrated in Fig. 1A. The video imaging assembly 43 includes one or more video cameras 44 which each produce two dimensional images of the patient's mouth 18, preferably by forming an image of the model 20. When two or more are used together, the video assembly 43 produces stereo images capable of being resolved in three dimensions. In the illustrated embodiment of the invention, a single video camera 44 is employed to produce two dimensional video images of a plan view of the patient's lower or upper jaws 22 and 24, from the models 21 or 23, respectively, in generally horizontal *X-Y* planes. In accordance with this embodiment, other forms or components of the scanner 33 are preferably employed to produce information in a third dimension as described below.

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Referring to Fig. 1A, the video imaging assembly 43 is shown diagrammatically in side elevation at the appliance manufacturer's facility 13. The video imaging assembly 43, in its preferred form, is an operator-computer graphical interface that includes the video camera 44 connected to a video interface board 44a in the input computer 30. The camera 44 is mounted on a stand 45 to face downwardly to form a top plan view one of one of the halves 21 or 23 of the model 20, shown as the mandibular portion 21 in Fig. 3, on a horizontal support 46 attached to a base 45a of the stand 45. The model half 21 or 23 is positioned on the support 46 such that the teeth face upwardly toward the camera 44 and so that the tips thereof lie generally in a horizontal plane that is maintained at a known fixed distance from the camera 44, so that the scale of the image formed by the camera 44 is known. This may be accomplished by mounting the support 46 on springs 46a to urge the model half 21 or 23 upwardly against a transparent horizontal plate 45b.

The input computer 30 has connected thereto a pointing device which may be a mouse 47a or, as shown, a mouse equipped digitizer board 47. The camera 44 produces a graphics image display 48 on the screen 35 of the computer 30, which an operator 28 may align with the assistance of a positioning grid G (Fig. 4A). With the digitizer 47, the operator selects points by positioning a curser 48a on the screen 35 with the mouse 47a. The selection results in the storage of *X,Y* coordinate data for each of the points selected. The points selected, in the description of the preferred process below, correspond to preselected boundary points of the teeth and, from the mandibular model 21, the lower jaw. From these top view boundary points, tooth and mandibular jaw dimensions are calculated. The calculated dimensions are used in analysis steps to calculate equations for the mandibular bone structure or mandibular trough *MT* and to calculate from the trough equation and the calculated horizontal dimensions and relative positions of features on individual teeth the finish positions of the teeth.

In the alternative to selecting points from the video image display 48, the same points may be selected in the same manner from a plan view video image of a digitized three-dimensional computerized image of the teeth and jaws, such as an image formed by a laser scanner, moire interference pattern scanner, ultrasonic scanner, stereo video cameras, or other three-dimensional imaging apparatus. Sectional displays 55a and 55b of such a three-dimensional computerized image made with a laser scanner are shown in perspective in Figs. 3A and 3B, respectively. Such a laser scanner is described in connection with Fig. 1B below.

Laser Three-dimensional Image Input Assembly 51:

One preferred form or component of the scanner 33 is the laser generated three-dimensional image forming assembly 50 illustrated in Fig. 1B. Referring to Fig. 1B, one of the halves 21 and 23 of the model 20 is mounted on a support 51 while laser 52 directs a laser beam 52a onto the model 21 or 22. The laser beam 52a is reflected and the reflected beam is detected by a sensor 53 composed of a photoelectric pixel array which uses a triangulation method to convert a change in position on the sensor into a change in distance between the assembly 50 and the model 21 or 23 mounted to translate parallel to the model 21 or 23 on a support 54 so as to scan the model with the laser beam. Equipment for producing images using laser technology in this manner is commercially available for forming computerized representations in three dimensions of manufactured and other objects. An example of equipment suitable for this purpose are the Cyber Scan™ Measurement System manufactured by Cyber Optics Corporation of Minneapolis, Minnesota. The images formed by such equipment would preferably include full detailed three-dimensional image data of the patient's lower and upper jaws 22 and 24, taken from the model 20, with the teeth in their original

positions. The data is written in standard ASCII files by the equipment described and is readable by the input computer 30a into the digitized information files 26.

Illustrated in Figs. 3A and 3B are two sections of the mandibular digitized model, and include a section 55a showing the front mandibular incisors T_{RI} and T_{LI} of the patient 12, and a section 55b showing the right mandibular second bicuspid T_{RS} and first molar T_{RM} of the patient 12. When such images are rotated to a horizontal plan view, a derivation of the same information that is available from the video imager 43 of Fig. 1A may be derived, and points may be selected therefrom for digitization automatically with software, or through an operator/computer interactive process as with the video scanner 43. The three-dimensional image 55 may be rotated into other orientations for the derivation of other information in various planes such as vertical tooth profile information that is derived with the mechanical scanner 57 described below. Additionally, other computerized procedures may be used to automatically derive information from the three dimensional image 55 with or without intervention or interaction by an operator.

Mechanical Probe Digital Scanner Assembly 57:

The scanner may also include, alternatively or in combination with other scanning equipment such as the video scanner assembly 43 of Fig. 1A or the laser scanning assembly of Fig. 1B above, a mechanical probe assembly 57 as illustrated in Fig. 1C. This entire assembly 57 is used in the illustrated embodiment of the invention in combination with the video scanner 43 to derive labial-lingual vertical profiles of the individual teeth of the patient from the model 20 to supplement jaw and horizontal tooth dimensional and shape information derived from a video image produced by the video scanner 43 from the model 20. Alternatively, portions of this assembly can be used to produce the same information from a three dimensional image 55 produced by equipment such as the laser scanning assembly 50.

Referring to Fig. 1C, the probe assembly 57 includes a measurement probe 60 which is moveable over the individual teeth of the model 21 to produce an electrical signal that is digitized for computer input of point locations or profiles of the surfaces of the teeth in separate *X-Y* for each tooth. In the illustrated embodiment of the process of the invention, the information 26 preferably derived from the model 21 includes the tooth profiles curves PF_i in a labial-lingual plane viewed in a mesial-to-distal direction.

The probe assembly 57 further includes a magnetic base 59 upon which is mounted the model 20, and from which extends an upstanding vertical support 58 on which the probe 60 is mounted. The probe tip 60a is freely rotatable about a vertical axis on which its tip lies, while the probe itself is hooked to allow the tip to track recesses in the surfaces of the teeth of the model 21. The probe 60 is mounted on the support 58 to move in *X* and *Y* directions in a vertical plane preferably that extends through the support 58 and the probe 60. In this manner, the probe tip 60a is positioned to scan the surface of a tooth of the model 21 along this plane. The probe 60 is linked to the support 58 through a pair of orthogonal measurement position transducers 61, which respectively generate electrical analog measurements of the positions of the tip of the probe 60 along respective ones of the *X-Y* orthogonal coordinates. The outputs of the transducers 61 are connected to circuitry that generates a sequence of periodic readings of the transducer measurements of the probe tip positions which are then digitized. These outputs are sent in along lines 61a connected to input computer 30, preferably to a serial port thereof.

In use, a half of the model 20, for example, the mandibular model 21, is mounted upon the magnetic base 59 on a steel surveyor's mount 62 which slides on the base 59 when lightly urged, but which otherwise holds its place thereon for precise positioning. The mount can be raised, lowered or tilted for and for

leveling. In operation, the probe 60 is manually moved by an operator 28 or automatically to scan the surface of each selected tooth of the model 21 to produce profile curves *PF* of a section of each tooth as illustrated in Fig. 3C. The profile *PF* may be generated by any one of a number of commercially available off-the-shelf CAD/CAM or illustration software packages, such as VERSACAD™ available from Prime Computers, Inc. of Bedford, Massachusetts. The computer programs described in the flowcharts herein is written for use with VERSACAD™ in CPL™, the programming language of therefor. The video images 63 of the profiles *PF* are displayed on the screen 35 and the digitized profiles are stored as part of the input information 26 in non-volatile memory of the computer 30.

With the curves such as the profile *PF* so formed, an operator can, with the use of the pointing device 47, select, by positioning the cursor on the formed profile on the screen 35, point parameters of the tooth, the coordinates of which can be thereby input digitally into the computer 30.

Appliance Manufacturing Equipment 38

The manufacturing equipment 38 of the preferred embodiment of the invention includes: an appliance bracket cutting or forming machine 39 that custom forms the bracket bases to mount to the teeth and cuts archwire slots in the brackets at precise calculated positions and angles; an appliance archwire bending or forming machine 40 that precisely bends archwires to a shape that will cooperate with the custom brackets to apply corrective forces to the teeth until they are in their calculated finish positions; and a bracket placement jig forming machine 41 that manufactures bracket placement jigs that conform to the contours of the patient's teeth, as recorded in the profiles *PF*. These jigs are used by the orthodontist to precisely place the custom brackets at calculated positions on the teeth.

The manufacturing equipment 38 is controlled by NC computer generated programs based on the data from the digitized input information files 26 and the calculated patient data files 36.

Bracket Cutting Machine 39:

Referring to Fig. 1D, a bracket slot cutting machine 39 is illustrated. The machine 39 includes a stationary base 72 on which is fixed a pair of upwardly extending workpiece support brackets 72a to the top of which is pivotally mounted a workpiece or bracket support 73. On the support, a full set 80a of brackets 80 for the custom appliance 25 is mounted, prearranged in an assembly or cartridge of twenty or twenty-four brackets. The support 73 pivots about an axis 73a extending between the brackets 72a. Connected to the axis 73a is an angular positioning motor 74 which positions the support 73, and the brackets 80 mounted thereto, to any angular orientation with respect to the horizontal. The motor 74 has an input connected to the computer 30c to set the inclination to the slot inclination angle of the bracket design in response to NC command codes.

Also fixed to the base 72 and extending upwardly therefrom is a saw support bracket 72b. To the top of the support bracket 72b is a saw drive motor 75 and a set of three saw blade positioning linear drive actuator 76, including an X-drive actuator 76x, a Y drive actuator 76y, and a Z drive actuator 76z through which a saw support arm 77 is supported to move respectively in the X, Y and Z directions, that is, in an X direction horizontally perpendicular to the axis of rotation 73a of the bracket holder 73, in a Y direction horizontally parallel to the axis of rotation 73a of the workpiece holder 73, and in a vertical Z direction. The actuators 76 have inputs connected to the computer 30c to receive positioning signals from the computer 30c to cut arcuate slots in the X-Y plane of the machine 39 in response to NC commands generated in accordance with a custom appliance design.

At the remote end of the moveable arm 77 is a slot cutter assembly 77a, drivably linked to the motor 75. The assembly 77a has extending downwardly therefrom a rotatable cutter blade drive shaft 77b, which has fixed to the lower end thereof a circular slot cutter blade 77c. The blade 77c lies in the horizontal X-Y plane and is of the thickness of the slot needed for the thickness of archwire selected. The archwires are typically rectangular in cross-section so that they are able to exert torque on the bracket, which accordingly will be provided by the saw blade 77c with a slot of rectangular cross-section. The base of the slot will be cut, in accordance with the command signals from the computer 30c, at an angle in the X-Y plane of the machine 39 that is tangent to the final curve of the archwire that it will receive. The base of the slot will be convex to accommodate the curve of the wire in the horizontal plane. The base of the slot will be convex to accommodate the curve of the wire in the horizontal plane. The inclination of the bracket slot is achieved by the angle of the support 73 in response to control signals from the computer 30c. The computer 30c is programmed to account for changes in elevation of the bracket 80 due to the offset of the brackets from the support axis of rotation 73a.

Wire Bending Machine 40:

The wire bending apparatus 40 is illustrated diagrammatically in Fig. 1E. Primary control of the apparatus 40 is preferably by an IBM PC clone, preferably with an 80386 or 80486 microprocessor with a math coprocessor, and with motion controller board 65 installed. The controller board 65 is, for example, an MC300 Motion controller 3-axis card manufactured by Motion Engineering, Inc. The MC300 is a dedicated motion control card which sends and received signals to and from MC-OLS stepper interfaces 66a and 66b. MC-OLS stepper motor interfaces 66a and 66b send control signal commands to the stepper motor power supplies 67a and 67b, such as Compumotor S-Drive stepper power supplies #88-011483D, regarding rate and direction of motion of the motors.

The power supply 67a has an output connected to wire feed rollers 68, positioned on opposite sides of a wire guide 68a, which guides archwire 69 to feed it from a continuous coil supply. The power supply 67b has an output connected to a wire bending roller assembly or wire anvil 70.

The controller 66b additionally is adapted to receive feedback signals regarding position from a disc encoder 70a, such as a Dynapar/Veeder Root #E1000A76500, which monitors the position of wire forming roller 70b, providing closed loop control of a wire bending roller 70b. The roller is driven by a wire anvil motor 70c, such as a Compumotor #S/SX 57-102, through a drive screw 70d, such as an Industrial Devices Corp. Electric cylinder #X995A-2-M56-MT1-200-PS. The screw 70d converts the angular position of the motor 70c into linear motion of the roller 70b to deflect and bend the wire 69 as it is fed through the guide 68a by the rollers 68.

By coordinating the anvil 70 and the wire feed 68, formed archwires 64 of any planar shape are fabricated. The rollers 68 pinch the wire, forcing it to advance into the anvil 70. The roller 70b of the anvil 70 moves up and down varying the radius and thus controlling the radius to which the wire is permanently deformed. If the formation of archwires with inflection points, that is that have bends in opposite directions, a second anvil would be provided opposite the wire 69 from the anvil 70 and controlled in synchronism therewith.

A wire position sensor 71 is provided that inspects the finished archwire by comparing the width of the formed wire 64 to the desired width. The sensor 71 is mounted with respect to the anvil 70 and feed rollers 68 to detect the position of the formed archwire 64 when it is at the end of its forming cycle. This

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measurement provides a feedback signal that provides compensation for material property variations that effect the formed shape and the amount of overbending required. The sensor 71 sends information back to the computer 30c as to whether the wire 64 is acceptable or over-bent or under-bent. If the wire is either over or under-bent, the computer 30c calculates the correction required and incrementally modifies the signals through the interfaces 66a and 66b to provide compensation to progressively correct successive archwires 64 until the result of the signal from the sensor 71 is deemed acceptable by the computer 30c.

Bracket Placement Jig Forming Machine 41:

The bracket jig forming equipment 41 is preferably a standard NC mill configured as illustrated in Fig. 1F. The machine 41 includes the standard mill 81, having a downwardly projecting rotary tool head 81a on which is mounted an endmill tool 81b of, for example, 0.020 inches in diameter, where 0.022 inch archwire is used, and, for example 0.016 inches in diameter where 0.018 inch archwire is used.

The mill 81 is either connected to an controller which will have been loaded with CNC program code 42 prepared by the computer 30c or will be directly connected to the computer 30c. The mill 81 is provided with a tool support 81c to which a set of circular ABS plastic jig blanks 83, usually twenty or twenty-four in number, are fed by a feeding mechanism 81d, equipped with a magazine 81e of the sets 83a of jig blanks 83. The tool head 81a is moveable vertically to bring the tool 81b into contact with the blanks 83 and horizontally in the *X-Y* directions in accordance with the tool path instructions from the code 42.

GENERAL OPERATIONS AND PROCEDURES

In the preferred and illustrated embodiment of the invention, the overall configuration of which is illustrated diagrammatically in Fig. 1, the full custom system 10 is operated to produce the orthodontic appliance 25 based on the individual anatomy of the patient 12. One preferred method of the invention is represented by the operations and procedures illustrated in the flowchart of Figs. 2.

The method of the present invention, in its preferred embodiment, includes three general operations. The first operation, is (85) a patient evaluation operation performed by the orthodontist 14 at the doctor's office 11 on the patient 12. This operation includes the traditional professional diagnosis and general prescription of treatment. According to the present invention, the evaluation operation (85) is followed by (87) a computer aided analysis and appliance design and manufacturing operation performed, preferably at least in part, at the appliance facility 13 to produce the custom appliance 25, and in turn followed by a patient treatment operation (89), which includes treatment of the patient 12 by the orthodontist 14 at the doctor's office 11, with the installation and use of the appliance 25.

(85) Patient Evaluation Operation

Referring to the system diagram of Fig. 1 and the flow chart of Fig. 2, the orthodontic evaluation operation (85) is performed at a doctor's office 11. The operation (85) includes the procedures (90) of the examination of a patient 12, (91) the preparation of the model 20 of the patient's mouth and teeth, (92) the prescription by the orthodontist 14 of treatment, (93) and communication the appliance facility 13.

The examination procedure (90) the patient 12, who requires orthodontic treatment, is examined by an orthodontist 14, who makes a diagnosis 15 of the condition of the patient and of the treatment, if any, needed. Based on the diagnosis 15, the orthodontist or doctor 14 assembles the information 16 that is necessary to implement the prescribed treatment.

In assembling the information 16, the orthodontist 14 (91) prepares a model of the patient's mouth 18, usually a physical model 20 from a mold of the patient's mouth, in its initial condition at the time of the

diagnosis 15. The model 20 includes the mandibular model 21 of the patient's lower jaw or mandible 22 and the maxillary model 23 of the patient's upper jaw or maxilla 24.

Then, further based on the diagnosis 15, the orthodontist 14 (92) prescribes a particular treatment and generates a prescription 27 in a tangible record form.

The orthodontist 14 then (93) communicates the information 16, for example, by transmitting the model 20, the prescription for treatment 27, a record of information 17 identifying the doctor 14 and the patient 12, together with information 19 containing statistical and historic data of the patient 12, to an appliance design facility 13, at some remote location. At the appliance design facility 13, the information 16 is digitized and input into the computer 30 for analysis.

Alternatively, the orthodontist 14 may convert the information 16 to digital computer readable form and transmit the digitized information to the appliance design facility 13. In this alternative, the system 10 would be configured with the input computer 30 located at the orthodontist's office 11, and the orthodontist 14 or assisting personnel would perform portions of an data input procedure (94) described below.

(87) Analysis, Design and Manufacture Operation

When the information 16, which includes, for example, the model 20, the prescription 27 and the information 17 and 19, are received either at the appliance system manufacturer 13 or is ready to be digitized at the orthodontist's office 11, (87) an analysis, finish tooth position calculation, and orthodontic appliance design and manufacturing operation is begun. In the operation (87), the information 16 is processed and the custom appliance 25 for moving the patient's teeth to an optimum final or finish position in accordance with treatment prescribed by the orthodontist 14 is produced.

The operation (87) includes the procedures of (94) inputing into a computer the information 16 from the orthodontist 14, in digital form, (95) analyzing with the aid of computer 30b the input digitized information to arrive at the finish position of the teeth, (96) designing with a computer a custom orthodontic appliance in accordance with the computer analysis, (97) manufacturing the custom appliance 25 in accordance with the computer assisted design with the aid of computer controlled machinery, and (98) communicating the custom appliance 25 and accompanying instructions to the orthodontist 14.

In accordance with certain embodiments of the present invention, some or all of the appliance manufacturing step (97) can be performed at the facilities 11 of the orthodontist 14, in which case the communicating step (98) would involve the communication of machine readable code, in lieu of some or all of the completed custom appliance 25, from the design facility 13 to the orthodontist 14.

(94) Input Procedure:

In the input procedure (90) is illustrated in the flowchart of Fig. 2A. In the procedure (94), the received information 16 is input, in the illustrated embodiment by operator 28 at the design facility 13, into a computer 30 in digital form. Even where the inputing is performed by operator at the design facility 13, some information 16, such as the information 17 and 19, may be supplied by the orthodontist 14 in machine readable form and input directly into the computer 30. The input procedure (94) includes five steps (100)-(500), the substeps of which are described in detail in connection with the flowchart details of Figs. 2E-2I below. The steps of the input procedure (90), in the illustrated embodiment, also include certain substeps that are part of the function of the analysis step (92) but are more conveniently performed at the time of the information is entered into the computer.

The input steps (100) and (200) involve the entry of background information assembled by the orthodontist 14. In the input steps (300), (400) and (500), tooth and jaw positions and profiles are defined in terms of orthodontic parameters and landmarks that can be later analyzed by computer to best implement the orthodontic knowledge, skill and experience embodied in the prescription 27 and of the orthodontic profession while efficiently automatically producing a optimum result. These steps of the input procedure (90) include:

(100) The inputing of the doctor-patient identification information 17 in digital form into the computer 30a:

This information is used to identify the records of the patient and the products produced.

(200) The inputing of patient background information 19 in digital form into the computer 30a:

This information is used in part in the calculating the finish position of the patient's teeth in accordance with genetic characteristics. Sex and race, for example, are used to assign certain seed values such as the inclination of the axes of the individual teeth of the patient 12 to an arch plane in step (625), which is used to determine an offset for tips of the teeth from the jaw bone or gum line.

This information also includes diagnostic determinations and treatment option decisions made by the orthodontist 14, such as determinations to extract teeth, or employ optional treatment norms.

(300) The inputing into the computer 30, from a top view image of the patient's mandibular model 21, the mandibular jaw shape and tooth dimensional information:

In implementing a treatment to correct the tooth alignment of the patient 12, the mandible 22 is the logical starting point because it is a solid bone and has relatively little pliancy. By contrast, the maxilla or upper jaw 24 is composed of segments held together by sutures which do not fuse until mid or late teens. Furthermore, these sutures can be separated by the orthodontist even after the point of initial fusion by simple and commonly known clinical techniques. These anatomical factors require that the orthodontist 14 make relatively small changes in the mandibular bone 22 and the preponderance of skeletal changes in the maxilla 24. For this reason, the position of the mandibular trough *MT* therefore taken as a constraint on the positions of the roots of the lower teeth.

In step (300) information is input for use, in part, to define from the patient's lower jaw bone the shape of the mandibular trough *MT*, which serves as the first constraint in arriving at the finish position of the teeth. In one embodiment, this is accomplished by superimposing a predefined grid *G* on a video or graphics image of the mandibular trough (from Fig. 3) in the manner illustrated in Fig. 4. In addition, the distances between the mesiodistal extremities, or mesiodistal widths *MDW*, that is, their contact points with adjacent teeth, in a horizontal plane, are input. These determine the total length of the dental arch and the relative center-to-center spacings of the teeth along the arch.

A mandibular trough equation *MTE* is derived, and may be converted to a symmetrical equation *SMT*. As a starting point toward calculating finish tooth position, the mesio-distal widths of the mandibular teeth are mathematically placed on the trough equation. This is explained more fully below in connection with Fig. 4.

In the above and in many archform calculations below, a cubic spline equation form is used initially in fitting a curve to data points, then converted to a circle segment equation that provides advantages in the analysis and design process and in the final calculations needed to operate NC manufacturing equipment. This is explained below in connection with Figs. 5 et seq.

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Measured initial contra-lateral cusp spacing data are generated for use by the orthodontist 14 in evaluating the custom design and treatment parameters resulting from the final calculations below.

In some embodiments, horizontal profile data of the lower jaw may be input in this step, additional landmarks in the horizontal plane may be identified, or full three-dimensional images of the teeth and lower jaw may be made, for example, as discussed in the descriptions of Figs. 1A-1C above.

(400) The inputing into the computer 30, from a bottom view image of the patient's maxillary model 23, maxillary tooth dimensional information:

The shape of the maxilla, which is made of a segmented bone, is a variable capable of being altered orthodontically in response to final tooth position calculations as set forth below. Therefore, its initial shape and initial maxillary tooth position is relevant only in evaluating the feasibility of the amount of alteration required and the type of treatment to be used.

In step (400), information is input into the computer 30c of maxillary jaw shape and tooth dimensional information from the maxillary model 23. This information is used in part to determine the mesiodistal widths *MDW* of each upper tooth, in a horizontal plane, and to determine the total length of the dental arch and the relative center to center spacings of the teeth along the arch.

Measured initial contra-lateral cusp and central groove/fossa spacing data are generated for use by the orthodontist 14 in evaluating the custom design and treatment parameters resulting from the final calculations below.

As with step (300) above, in some embodiments, horizontal profile data of the upper jaw may be input in this step, additional landmarks in the horizontal plane may be identified, or full three-dimensional images of the teeth and lower jaw may be made, for example, as discussed in the descriptions of Figs. 1A-1C above. In these embodiments, techniques such as those described in step (500) may be employed in the horizontal plane in steps (300) and (400).

(500) The inputing of individual tooth elevational profile information from the two halves of the model 20:

The tooth profile information can be generated using computer analysis or interactive computer imaging from three-dimensional images, if employed, as illustrated in Fig. 3A formed with scanners such as illustrated in Fig. 1B, or with the use of the probe assembly 57 of Fig. 1C from the physical model 20 of the jaw. Use of the probe assembly 57 is herein described.

Rapid reduction of tooth shape information to important dimensions and landmark data for efficient and realizable calculations of finish tooth position is achieved by imaging carefully selected profiles of the teeth. Profiles are produced by outlining the tooth crown surfaces along a vertical plane or other similarly oriented surface that extends in a labial-lingual direction generally perpendicular to the arch of the teeth in the respective jaw. For the single cusp anterior teeth, this surface is generally a surface bisecting the tooth and through the crown long axis *CLA* of the tooth. For multiple cusp teeth, the same generally applies except modification or displacement of the surface is intelligently made on some teeth to pick up the highest cusp or a marginal ridge that is relevant to development of the proper occlusion.

For most calculations, as set forth in the detailed explanation below, the tooth features profile can be assumed to be on a plane through the tooth centerline, even when they are not. With the features selected herein, such assumptions result in errors that are still much smaller than those accepted in

conventional methods. In other calculations, the precise position of a feature must be considered, and provision for such considerations are made in the certain embodiments of the invention.

For each tooth, profile data is taken in separate *X-Y* coordinates that relate only to the selected surface or plane. In the course of the analysis and calculation of finish tooth position, these planes are separately translated and reoriented with respect to those of the other teeth and those of the trough and archforms, in several steps, until the ultimate interplane relationships are established.

(95) Analysis and Tooth Positioning Procedure:

The computer analysis procedure is illustrated in the flowchart of Fig. 2B. In the computer analysis procedure (95), the digitized information input by the input procedure (94) is analyzed to calculate the finish position of the teeth, so that the custom appliance 25 can be designed in computerized design procedure (96) and manufactured in computer controlled manufacturing procedure (97). The analysis procedure (95) includes six steps and subroutines (600)-(1100), the substeps of which are described in detail in connection with the flowchart details of Figs. 2J-2O below. These steps include the following:

(600) The dental analysis step in which the orthodontic landmarks of the teeth are identified:

A minimum number of points on the tooth profiles are selected that are sufficient for determining the contact points between teeth that are relevant to finish tooth position calculation and appliance design. These points are selected such that the calculations made from them are relatively insensitive to measurement errors in the input of the data in step (500). From the selected points, for each tooth, other parameters are derived, including an incisal center point *ICP*, a gingival center point *GCP* and the crown long axis *CLA* through the *ICP* and *GCP*, as explained below in connection with step (600) and Fig. 6 et seq.

In order to determine the relationship between the crown long axes and archwire planes, twenty-four of each crown type were removed from a set of orthodontic casts and sectioned along the mid-sagittal plane. These crowns were then mounted and projected at twenty times magnification on an optical comparator. Tracings were then made of these profiles. As a result, a procedure was determined for use to establishing the crown long axis inclination angles to produce the desired occlusion, and seed values were tabulated that and correlated with data such as the sex and race of the patient as entered in step (200). As a result of this analysis, preferred crown long axis inclination angles are produced with the present invention that are an improvement over the facial inclination angles employed in the prior art.

From the tabulated data, angles of inclination *LAIs* of the crown long axes *CLAs* of each of the teeth of each jaw are set relative to the plane that contains the mandibular trough equation *MTE*. This plane is parallel to a facial axis plane *FAP* used in clinical studies through a clinically defined facial axis *FA* of a tooth. These *LAIs* are later used to determine the horizontal offsets from the *MTE* of the tips of the lower teeth in step (1000) below, as well as the maxillary tooth placement in step (1100). The rotation of the inclination angle places new *Y* coordinates of each of the tooth profile planes established in step (500) parallel, and the *X* axes of these planes parallel to the same plane but of with their relative horizontal orientations and relative vertical positions yet to be determined. Once the teeth are rotated to their finish inclinations, precise crown heights, incisal and cusp tip locations, and other points and contours of the tooth surface are precisely defined for intertooth contact and appliance design and positioning calculations.

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As an example, for the maxillary bicuspids and molars, a marginal ridge elevation *MRE* is determined for later use in calculations relative finish positions of the upper and lower teeth.

(700) The cuspid rise determination step in which the occlusion of the upper and lower teeth is defined:

The orthodontist 14 will have selected the technique to be used to guide the teeth of the patient into occlusion as the jaws come together. Depending on the selected occlusion technique, either all or part of the occlusion is brought by a rise of the cuspids above that of the other teeth, to thereby initiate contact between the upper and lower teeth which aligns the two arches as the jaw closes. Most orthodontists prefer to accomplish this with the rise of the cuspids.

From anatomical studies, data is employed and the amount of cuspid rise, or other cusp rise if selected, that is necessary to clear the buccal cusp height *BHC* of the teeth, which is determined from the landmark data of step (600).

(800) The mandibular tooth placement step in which the plane of the mandibular teeth is defined and the teeth are positioned with respect to the mandibular trough:

The step (800) accomplishes the preliminary mathematical construction of the mandibular occlusion. This step first calculates the positions of the mandibular teeth to place their tips in an occlusal plane pending final refinement of the placement.

The starting point for the mandibular tooth placement is to assume tooth positions that place the teeth with their crown long axes *CLAs* intersecting the plane of the mandibular trough on the mandibular trough equation *MTE*. This satisfies the condition that the mandibular teeth are set in the bone of the lower jaw. The *CLAs* of the teeth are also inclined at the seed value angles *LAIs* established in step (600).

Next, the positions of the teeth are adjusted vertically to place the tips of all of the mandibular teeth, except the cuspids, in the same plane. The tips of the mandibular cuspids are set to extend above the plane of the tips of the other mandibular teeth by a distance according to the cuspid rise criteria selected, preferably by setting the distance equal to one third of the total cuspid rise, as calculated in step (700).

Then, a horizontal *OFFSET* from the *MTE*, generally in the labial direction, is calculated trigonometrically for each mandibular tooth from its crown height above the mandibular trough and its long axis inclination angle *LAI*. This calculation results in a mandibular trough offset equation *MO*, which is an outward radial expansion of the *MTE*. The *MTE* was defined in the form of a series of circle segments in step (300). The expanded *MO* equation is a discontinuous arch constructed by adding the respective *OFFSET* of each tooth to the radius of the circle segment of the *MTE* with which the midpoint of the width of the tooth is associated.

The teeth are then placed on the offset equation *MO* beginning with the placement of the central with its mesial contact point on the mandible centerline and the tooth midpoints on the *MO*. Then moving distally, the remaining teeth on the same side of the mandible are placed on the *MO* with their mesial contact points *MCP* in contact with the distal contact point *DCP* of the previous tooth. The same procedure is employed for the teeth on the other side of the mandibular arch.

An alternative further refinement would consider the vertical position on the teeth of their widest points and, considering the also the inclinations of the teeth, make a trigonometric adjustment so that the tooth contact points are spaced by the tooth widths *MDW* at the height of their actual widest points, rather than assuming the teeth contact in the plane of their tips.

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(900) The best fit cusp step in which the best fit equation is derived for mandibular arch:

In this step, a continuous curve is derived using statistical methods to produce a best fit buccal cusp equation *BFBCE* from the disconnected line segments of the *MO*. This is also illustrated in Fig. 4A. In the embodiment described below, a Bezier equation is used. A cubic equation is then generated from resulting data points that define the best fit equation. The cubic equation of the *BFBCE* is then converted to circle segment form as with the *MTE* above.

(1000) The mandibular teeth placement step in which the positions of the mandibular teeth are calculated for placement on the best fit arch equation:

The positions of the lower teeth are then recalculated to move the teeth horizontally, parallel to the *MOC*, such that the incisal center points *ICP* lie on the *BFBCE*. For incisors and cuspids, the *ICPs* are the tips of the teeth in the profile planes of steps (500) and (600). For the bicuspids and molars, the *ICPs* are the buccal cusp tips of the teeth. For purposes of placement of the teeth on the *BFBCE* or other archform, the *ICPs* are assumed to lie midway between the mesial and distal contact points of the respective teeth. Accordingly, tooth placement is achieved by moving the teeth normal to the circle segment associated with these *ICPs*. This recalculation of position has the effect of moving the roots of the teeth normal to the arch associated with their *ICPs*, either labially or lingually, such that their *ICPs* fall on *BFBCE*, when viewed from above.

This placement is the finish position of the mandibular teeth.

(1100) The maxillary placement step in which the maxillary arch is derived for occlusion with the placed mandibular teeth:

This step fits the positions of the maxillary teeth to the already positioned mandibular teeth. The maxillary teeth have not yet been positioned with respect to any equation, but the inclination angles of their dimensions and crown long axes *CLAs* have been determined in step (600). This positioning involves setting the tips of the maxillary teeth on the *BFBCE*, with certain modifications to the equation and the placement criteria to account for the way the different types of teeth occlude.

In adjusting maxillary tooth positions, the cuspids, the anterior teeth and the posterior teeth are treated separately to bring their relevant contact surfaces into three different respective arches that are then aligned relative to each other.

Since the anterior teeth do not occlude incisal edge to incisal edge, the *BFBCE* is modified to take into account the distance from the *BFBCE* to the labial contact points of the mandibular incisors and laterals, plus a horizontal or labial clearance, with the maxillary teeth. This defines the points of occlusion with the maxillary anteriors, at the intersection of their lingual surfaces with the plane of occlusion *MOC*. These points lie in a maxillary anterior contact arch form *MAAF*. This equation is calculated by expanding the *BFBCE*, by enlarging the radii of the circle segments of which it is made up, to account for these tooth dimensions and the clearances.

The vertical positioning of the maxillary anteriors and cuspids is then performed based on the vertical occlusion methods that have been prescribed, establishing an overlap for the incisors and cuspid rise as determined in step (700). This defines the vertical position of the maxillary cuspids and anteriors with respect to the *MOC*, and thereby defines the incisal overlap or overbite.

Placement of the maxillary posterior teeth places the intersections of the marginal ridges and the central grooves from steps (400) to (600) the cusps of the mandibular teeth with which they will occlude.

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The maxillary tooth movements needed to achieve this occlusion are applied to calculate a central groove marginal ridge arch form *CGMRAF* by modifying the *BFBCE*. The cusp tips of the maxillary cuspids are placed between the archforms of the incisors and of the posteriors, for example, by averaging the distance from the *BFBCE* to the *MAAF* and to the buccal cusp of the first maxillary bicuspid, by placing the cuspid mesial and distal contact points in contact with the adjacent teeth, by calculating a clearance as was done for the incisors or by some other criteria. The archforms for the maxillary tooth placement are illustrated in Fig. 4B.

The vertical positioning of the remaining teeth takes into account the occlusion and other prescription information input in step (200). The remaining calculations are set forth in detail below.

(96) Appliance Design Procedure:

The appliance design procedure (96), as illustrated in the flowchart of Fig. 2C, calculates the dimensions of the appliance components in a form capable of being translated into NC codes for operating NC machinery for production of the appliance components, such as the brackets and archwires and also placement jigs for installing the brackets in the proper positions on the teeth of the patient. In the appliance design procedure (96) includes the following steps (1200) through (1800), which are further illustrated in the detailed flowcharts of Figs. 2P-2V:

(1200) The mandibular archwire plane step in which the plane of the archwire for the mandibular teeth is defined in relation to the teeth of the mandible:

Where labial brackets are to be applied, as illustrated in Fig. 8, a plane is selected for the mandibular archwire that avoids interference with the mandibular archwire and brackets with the maxillary teeth, which overlap on the labial side of the mandibular teeth. Where lingual brackets are to be applied, this step is performed to define a maxillary archwire plane to avoid interference between the lingually mounted maxillary archwires and brackets with the mandibular teeth that overlap on the lingual side of the maxillary teeth.

This step involves the selection of the archwire plane and defines it in mathematical relation to the *MOC*. Once defined, the bracket positions on the teeth are determined such that the archwire slots will lie within the dimensional limits of the bracket. Where possible, it is preferable that the archwire lie in a literally flat plane and be symmetrical about the midline of the arch. As such, the archwire will be properly shaped for installation with either side facing upward.

(1300) The mandibular slot inclination step in which the angles of the slots of the mandibular tooth brackets of the appliance are calculated:

The slot inclination angle for the mandibular brackets is calculated from the angle between the mandibular archwire plane and the angle of the mandibular tooth surface to which the base of the bracket is to be mounted. The slot inclination angle may be achieved by cutting the full angle into the slot, by inclining the bracket base, or by both of these methods.

(1400) The maxillary archwire plane step in which the plane of the archwire for the maxillary teeth is defined in relation to the teeth of the maxilla:

The maxillary archwire plane in the case of labial appliances, and the mandibular archwire plane in the case of lingual appliances, has few constraints on its position and may be selected based on cosmetic considerations. It is usually selected as a plane midway on the crown of the maxillary teeth. It is therefore normally not parallel to the mandibular archwire plane. Once defined, the bracket positions

on the teeth are determined such that the archwire slots will lie within the dimensional limits of the bracket.

(1500) The maxillary slot inclination step in which the angles of the slots of the maxillary tooth brackets of the appliance are calculated:

The slot inclination angle for the maxillary brackets is calculated from the angle between the maxillary archwire plane and the angle of the maxillary tooth surface to which the base of the bracket is to be mounted. The slot inclination angle may be achieved by cutting the full angle into the slot, by inclining the bracket base, or by both of these methods.

(1600) The mandibular archwire and bracket in-out dimension calculation step in which the slot depth and bracket geometry is calculated for the mandibular tooth brackets:

For each bracket, the deepest and shallowest slot depths is determined to develop a window into which the archwire must pass, as illustrated in Fig. 8A. Then the smoothest archwire curve that will pass between the depth limits is determined. The smoothest curve is considered to be one with the least variation in radius changes along the curve, and preferably with no inflection points. A cubic spline equation is used to fit the points and the equation is then converted to one of circle segment form.

(1700) The maxillary archwire and bracket in-out dimension calculation step in which the slot depth and bracket geometry is calculated for the maxillary tooth brackets:

As with the mandibular slot depth calculations, for each maxillary bracket, the deepest and shallowest slot depths is determined to develop a window into which the archwire must pass. Then the smoothest archwire curve that will pass between the depth limits is determined. Here to, the smoothest curve is considered to be one with the least variation in radius changes along the curve. A curve with no, or the least number of inflection points is preferred. A cubic spline equation is used to fit the points and the equation is then converted to one of circle segment form.

(1800) The bracket placement jig designing step in which placement jigs are designed for use in properly positioning the custom designed brackets on the patient's teeth:

After the brackets and archwires are completely defined as in the above steps, with the depth and angle of the slots finalized for in the positioning of the brackets on the teeth and the shape of the desired archwires are described mathematically, bracket placement jigs are designed that will be used to assist the orthodontist in placing the brackets at the proper locations on the teeth. The designing of the jigs, in the preferred embodiment, is carried out in the software that generates the NC machine code in the performance of the jig manufacturing step (3500) below. This deferring of the jig design allows for consideration of appliance hardware modifications that may be made in the course of the bracket and archwire forming steps (3000) and (3200), respectively.

The provision of the bracket placement jigs furthers a goal of the practice of orthodontics to treat cases to occlusal perfection with the least amount of effort, discomfort and time expended. The portion of this goal that can be accomplished by appliance design and manufacture has been described above. While the individualized appliance geometries thus defined will be fabricated, the ability to place the bracket portion of the appliance system on the teeth with sufficient accuracy to allow the appliance system to deliver the desired orthodontic relationship, heretofore not realized clinically, is provided as follows:

The brackets are placed according to the three criteria:

1. Height: The height is established so that the appliance causes the upper and lower teeth to contact each other in the prescribed manner.

2. Mesio-Distally: The mesio-distal location is established so that the mesial and distal ridges of the teeth are parallel to the archform for that patient.

3. Long Axis: The bracket is aligned relative to the long axis of the tooth so that the appliance system tips the tooth to the desired angle relative to the archwire.

From the vertical profile data of step (500), and horizontal or three dimensional profile data of steps (300) and (400), the shape and size of each tooth is extracted, including particularly the profile in a mesio-distal view at the height of contour or along a plane perpendicular to the greatest prominence of the central developmental lobe of each tooth. Additionally, the geometry of the archwire slot has been accurately related to the respective teeth. This geometry includes the intersection of the archwire plane with the tooth profile curve, the slot inclination angle and the slot in-out dimensions. In addition, the wire size and bracket geometry information are assembled, and tool size and clearance information are taken into account.

With this information, a bracket placement jig is designed for NC controlled manufacture to position the slot, and thereby the bracket, precisely on the tooth.

In Fig. 8D, a plastic jig 82 is shown which engages the walls and bottom of the bracket slot fully. Additionally, the portion of the jig 82 contacting the tooth designed to be formed to precisely fit the known contour of the tooth, as determined by the profiles input in step (500). This assures that the bracket slot and hence the bracket is placed at precisely the correct height when bonded to the tooth.

Brackets are placed so that the slots are not necessarily perpendicular to the long axis of the tooth but at varying degrees of cant. The jig 82 accomplishes this goal by the use of an adapter 84 that fits into the bracket slot 82b and a coplanar slot 84a (Fig. 9T) to engage the plastic blade jig 82, as illustrated in Fig. 8D. The jig design substeps, which are preferably performed in step (3500) and included in the detailed flowchart of the jig manufacturing step of Fig. 2Z, are summarized in the flowchart of Fig. 2V. The design is converted into CNC code in step (3500) for controlling the jig forming machinery 41 primarily to cut a contoured surface that conforms the profiles of the tooth so that the jig fits in a precise position on the tooth to position the bracket for adhesion to the teeth.

In installation performed in the treatment operation (89), the jig 82 is lined up with the long axis of the tooth crown when viewed from either the front or facial surface of the tooth and from the biting or occlusal surface. A plastic blade form of jig 82 offers visual reference to the height of contour of the tooth and alignment of the bracket with the marginal ridges.

(97) Appliance Manufacturing Procedure:

The appliance manufacturing procedure (97), as illustrated in the flowchart of Fig. 2D, entails the generation of controller codes for NC machinery to produce the brackets, archwires and bracket placement jigs designed in the appliance design procedure (96), and the manufacture of the appliance components with the use of the machinery controlled by the codes. The procedure (97) includes the steps of:

(3000) Controlling and operating the bracket forming machinery 39 to produce the custom brackets:

The bracket manufacturing procedure of the preferred embodiment involves the generation of NC code for the bracket slot cutting mill 39 of Fig. 1D, as illustrated in the flowchart of Fig. 2X. The step

involves the geometric relating of the tooth profile information *PF* for each tooth, and other tooth contour information of the shape of the surface of the tooth to which the bracket is to be attached from steps (300) and (400), and the archwire plane, slot inclination angle and slot depth information from steps (1200) through (1700). In addition, the bracket forming step performs the function of selecting the bracket blank from which the bracket is to be fabricated. The bracket blank is made up of a base or pad that is attached to the tooth and an outwardly projecting support into which an archwire slot is formed.

The preferred embodiment includes the forming of brackets by cutting custom slots in bracket blanks while preserving the base inclination angle. Brackets could be alternatively fabricated by inclining the bracket bases or pads. Additionally, bracket bases may be contoured to conform to the surfaces of the teeth, or a bonding agent may fill the space between the bracket base and the tooth. Furthermore, while in the preferred embodiments, a mechanical cutter blade forms the bracket, other means such as wire EDM, machining, casting or stereo lithography may be employed.

(3200) Controlling and operating the Wire-bending machinery 40 to produce the custom archwires:

The software that operates the computer 30c to drive the wire bending apparatus 40 reads data files generated for the mandibular and maxillary archwires in steps (1600) and (1700) respectively. Also read by the computer 30c are data on the characteristics of the unformed wire 69, including that relating to the material of which the wire is made, as well as its cross-sectional shape and dimension. The file that is read contains coordinated data regarding calculated archwire segment lengths and radii which cumulatively describes geometrically the desired archwire shapes. As explained above, the archwires consist of a sequence of tangential arc segments with each segment a particular length and radius.

The arch forming software determines the position of the roller 70b of the anvil 70 that is required to produce a given radius in the particular wire material and cross-section by going to a look-up table, previously derived and stored in a file accessible by the computer 30c, containing constants necessary to correct for each wire material and cross-section. The anvil 70 is driven to the desired position to produce the required radius and the feed roll motor 70c is driven to create the desired length of wire at that radius. By adjusting the position of the anvil roller 70b and length of wire fed for with the roller 70b so adjusted, archwires 64 of the calculated final sequential tangential radii are fabricated.

(3500) Controlling and operating the jig forming machinery 41 to make custom placement jigs for the location of the brackets on the patient's teeth:

The machine control codes for controlling the jig forming machinery 41 are produced directly from the tooth profiles generated in step 500 and from the archwire plane location of steps (1200) and (1400), the slot inclination steps (1300) and (1500), and the slot in-out dimensions from the steps (1600) and (1700). As stated above, the jig design step (1800) is preferably performed in the course of, and is described herein as part of, the jig manufacturing step.

The profile data, which represents the profile curves with a fairly high resolution of data points is a series of straight line segments for developing the codes for driving the NC equipment. Tool and bracket dimensions and design clearances are also taken into account, and CNC codes are generated to cut jigs from circular plastic wafers on a standard CNC mill using a small carbide endmill tool. The details of the substeps of the step (3500) are included in the flowchart of Fig. 2Z.

(98) Appliance Transmission Procedure:

One of the ultimate objectives is to place the custom orthodontic appliance 25 into the hands of the orthodontist 14, along with the tools and information necessary for the proper installation of the appliance 25 in the mouth of the patient 12 to treat the patient by moving the patient's teeth to the calculated finish positions. This is best understood by reference to Fig. 1.

Referring to Fig. 1, as set forth above, the configuration of the preferred system 10 will vary depending on the nature and scale of the orthodontist's practice. Preferably, all or much of the appliance design portion of the procedure (87) takes place at an appliance design facility 13, although in a large scale orthodontic clinic, the entire process could be carried out at the patient treatment location. Usually, however, the functions performed in the design computer 30b, or design portion of the computer 30, are carried out at the appliance facility 13, together with some of the manufacturing functions performed by the manufacturing control computer 30c and the appliance manufacturing equipment 38.

In the configuration where, as illustrated, some or all of the appliance 25 is made at the appliance facility 13, the custom appliance 25 is transmitted to the orthodontist 14. Along with the appliance 25 is communicated documentation in the form of a hard copy printout of information 37 generated by the design computer 30b, which could also include documentation of the input data that made up the data 26 and the prescription information 27, and a printout of parameters recorded by the manufacturing computer 30c.

The transmitted appliance 25 includes a set of archwires 64, as illustrated in Figs. 8E and 8F, a complete set of custom brackets 80, as illustrated in Figs. 8D and 8F, and the placement jigs as illustrated in Figs. 8D and 9T through 9W. Along with the jigs 82 are included a set of adapters 84 that are used to align the slots 80b of the brackets 80 with coplaner slots 84a of the jigs 82. The appliance and the bracket placement jigs therefor are similar in the case of lingual appliances, a bracket for which is illustrated on a tooth in Fig. 8G while the lingual appliance is shown positioned on the mandibular teeth in Fig. 8H.

In addition, custom archwires 64 are transmitted to the orthodontist 14. These archwires include archwires in the exact form, as illustrated in Fig. 8E, to move the teeth to their finish calculated positions, as illustrated, for example for the lower teeth, in Fig. 4D. In Fig. 4D, the archwire 64 is shown in the unstressed state (or having nominal residual stress sometimes motivating some orthodontists to prescribe overcorrection) that it will attain when the appliance 25 has moved the patient's teeth to the calculated finish positions. This is the same shape as the archwire of Fig. 8E shipped to the orthodontist 14. This finish archwire will be of a material and stiffness determined to be appropriate for the final positioning of the teeth. Depending on the severity of the initial malpositioning of the patient's teeth, however, less stiff archwires, or temporary archwires may be desired for beginning the orthodontic treatment. Thus, additional archwires 64 of various properties but in the shape shown in Fig. 8E will be provided the orthodontist 14. In addition or in the alternative to the provision of these additional archwires, an actual size drawing or template having thereon the shape shown in Fig. 8E will be provided the orthodontist 14 to enable him to form archwires for preliminary treatment and rough positioning.

In alternative configurations, information may be sent from the design computer 30b in machine readable form, for example by diskette 34 or modem, to a manufacturing computer 30c to which is attached one or more of the appliance component manufacturing machines 38.

(89) Patient Treatment Operation

The patient treatment involves, first, the assembly of the respective bracket 80, jig 82 and adapter 84 combinations, as illustrated in Fig. 8D, and the application of the brackets 80 thereby to the patient's teeth. This involves the application of adhesive to the area generally in the center of the face of the tooth, either labial or lingual, to which the brackets 80 are to be applied. This is illustrated in Fig. 8D, for example, with the application of a bracket 80 to the labial face of a maxillary incisor $T_{p,i}$. The assembly is positioned on the tooth with the blade of the jig 82 positioned on a generally vertical labial lingual cross section through the approximate center of the tooth, in the plane that may be said to contain the crown long axis *CLA* of the tooth.

When the bracket adhesive has set, the bracket placement jig 82 is removed by first sliding out the adapter 84 mesiodistally and then sliding the jig 82 off of the incisal edge of the tooth, leaving the bracket in the calculated position.

Then, with the brackets 80 set on the teeth the archwire 64 is installed. Often, the first archwire installed will be one of lower stiffness than the final archwire. In the example of Fig. 8F, the mandibular teeth in their initial position as illustrated in Figs. 4 and 4A are shown. The brackets 80 are positioned on the teeth in the exact same positions as shown in the calculated finish position diagram of Fig. 4D. Because the teeth are not yet in this ideal finish position, the archwire 64, when inserted into the archwire slots and tied to the brackets 80, will be stressed into the elastically deformed condition shown in Fig. 8F. This stressed condition of the archwire 64 operates, without the need of the orthodontist to artfully bend the wire, to apply the forces to the teeth to urge them toward the ideal positions of Fig. 4D. This force will continue to be applied until the teeth have moved to the finish positions. In some prescribed forms of treatment, the wire and brackets are designed to move the teeth to a slightly overcorrected position to allow for a relaxation movement of the teeth when the appliance 25 is removed.

DETAILS OF STEPS OF APPLIANCE ANALYSIS, TOOTH POSITION CALCULATION, AND APPLIANCE DESIGN AND MANUFACTURING OPERATION (87)

The analysis, design and manufacturing operation (87), as stated above, includes the (94) input, (95) analysis, (96) design, (97) manufacturing, and (98) transmission procedures of a computerized custom designed appliance manufacturing operation. The steps of those procedures, as outlined above, include the following:

Digitized Input Procedure (94)

The input of digitized information includes the (100) input of patient and doctor identifying information, (200) the input of patient background information, (300) the input of digitized information of the horizontal dimensions of the mandibular teeth and the mandibular bone, (400) the input of horizontal dimensions of the maxillary teeth, and (500) the input of vertical labial-lingual profile information of each of the individual teeth.

(100) Identification Information Input Step:

The first step in the procedure (82), as illustrated in flowchart of Fig. 2A, is (100) to input the doctor-patient identification information 17. This step (100), as illustrated in the detailed flowchart of Fig. 2E, includes the substeps, performed by an operator 28 in response to prompts for text input at a terminal of the computer 30, of (105) input of the doctor's name, (110) input of the doctor's identification

number, and (115) input of the patient's name. Then, the computer 30 (120) assigns a patient identification number. With this information, (125) a patient-specific floppy disk or diskette 34 is automatically formatted.

(200) Patient Background Input Step:

The next step in the information input procedure (94), as illustrated in Fig. 2A, is (200) the entry, in response to prompts, of the patient background information 19, and the prescribed treatment information 27 from the doctor. This step, as illustrated in the detailed flowchart of Fig. 2F, involves the substeps of (205) entering, from the background information 19, the patient's age as numerical data, and selecting (210) the patient's sex and (215) the patient's race from options on the screen. Then, from the prescription information 27, the data are entered, by selecting choices from multiple choice prompts, from information such as the following:

(220) Whether or not the treatment is to include an extraction, and if so, which teeth are to be extracted;

(225) Whether the occlusion type is a group function or a cuspid rise, and if a cuspid rise, whether averages or individual head film is to be used;

(230) Whether the prescribed procedure is to preserve lower intercuspid distance or allow expansion, and if expansion is to be allowed, how much expansion;

(235) Whether or not the occlusion is mutilated;

(240) Whether a Steiner compromise is to be allowed to accommodate skeletal discrepancy;

(245) Whether a Roth or Ricketts inset is to be used on upper laterals, and if so which;

(250) Whether a Roth or Andrews upper lateral overbite is indicated, and if so, which;

(255) Which is the preferred slot size, from traditional sizes 0.018" or 0.022" (0.45 mm or 0.55 mm), or other available size, of which 0.20" (0.50 mm) would often be acceptable;

(260) Whether the case is to be treated with labial or lingual appliances;

(265) Whether the case is to be diagnosed using symmetry or not;

(270) How inter-incisal angle is to be determined, using the Andrews Norms, the Parallel Upper Central to Facial Axis Norm, or Ricketts Norm.

(300) Mandible Digitized Video Input Step:

The forming of the computerized mathematical model of the teeth of the patient 12 begins with (300) the inputing of video or other graphics top view image of the patient's lower jaw, including the teeth, as illustrated in the detailed flowchart of Fig. 2G. Such an image as input by the video scanner 43, is illustrated in Fig. 3.

The step (300) includes the digitizing and processing of the data of the widths of the mandibular teeth and size and shape of the mandibular bone or bone of the lower jaw 22 of the patient 12 from the horizontal plan view of the lower jaw as in Fig. 4. The mandible 22 is composed of hard or cortical bone on the external surface and soft or cancellous bone in the interior. This bone is not as orthodontically alterable as is the maxilla. Since the lower teeth must remain in the mandible, determination of its shape and boundaries is made so that a skeletal arch can be defined to be used as a starting point in the calculation of the finish position of the teeth.

The lower teeth must lie on the mandible 22 in an arch that may be defined as the mandibular trough *MT*, as illustrated in Fig. 4. The roots of the lower teeth of the patient are contained within the mandibular trough *MT*, which is defined as the space between boundaries B_L and B_B of Fig. 4. The outer, or buccal,

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and inner, or lingual, boundaries B_B and B_L, respectively, are preferably digitized by interactive selection by the operator 28 from an image 48 of the cortical bone of the mandible 22 on the screen 35. Furthermore, the mandibular teeth must lie in the arch in contact with one another. They each occupy a portion of the arch equal to the distances between their mesial and distal contact points with the adjacent teeth. These tooth extremities are also preferably digitized by interactive selection from the image 48.

To (300) input data of the patient's mandibular teeth and lower jaw 22, as illustrated in the detail flow chart of Fig. 2G, (305) a video graphics image 48 (Fig. 3) of mandibular model 21 is first input to the screen 35 of the computer 30c. Then (310) a grid G is overlaid on the video image of the mandibular 22 as illustrated in Fig. 4.. The grid G is presents grid lines that intersect the image 48 on the screen. The operator 28 (315) resizes the grid G, if necessary, and orients the image relative to grid G to define X,Y coordinates with a Y axis on a midline ML of the lower jaw 22 and an X axis perpendicular to the Y axis through a selected intersection point or origin $0,0$, preferably set at the mesial contact points of the lower central incisors.

Next, the computer 30 prompts the operator sequentially to select each point, first for the individual tooth contact points, then the jaw bone boundaries. With the pointing device 47, (320) the operator 28 moves the cursor on the screen 35 and selects (e.g., clicks with a mouse on) the prompted point, thereby initiating the software for digitizing the X,Y cartesian coordinates of the mesial and distal extremities $M_{X,Y}$ and $D_{X,Y}$, respectively, for each mandibular tooth. The mesial extremity $M_{X,Y}$ of a tooth is the point on its surface closest the midline ML along the mandibular arch (the mesial direction m) while distal extremity of a tooth is the point on its surface closest the rear of the mouth along the mandibular arch (the distal direction d). From the X,Y coordinates of $M_{X,Y}$, M_X and M_Y, and of $D_{X,Y}$, D_X and D_Y, (325) the mesio-distal width MDW_I of each tooth I, on each side of the mandible 22, is calculated using Pythagorean theorem:

$$MDW = \sqrt{(M_X + D_X)^2 + (M_Y + D_Y)^2}$$

where:

M_X is mandibular X coordinate.

M_Y is mandibular Y coordinate.

D_X is distal X coordinate.

D_Y is distal Y coordinate.

These widths are then summed to calculate the total length MAL required of the arch to accommodate the mandibular teeth. Since all of the teeth will be finally positioned to be in contact with the adjacent teeth, this length remains a constant length of any arch on which the mandibular teeth are placed in the calculations.

Then, by moving the pointing device 47 to the intersections of the lines of the grid G with the visible boundaries B_B and B_L and selecting the intersection points, data is input for determination of the shape of the mandibular trough MT. The point selection function can be made with conventional available CAD/CAM, imaging or illustration software and the pointing device 47. (330) From the selected intersections of the lines of the grid G with the mandible boundaries B_B and B_L, cartesian coordinates $La_{X,Y}$ and $Li_{X,Y}$ of labial and lingual limits, respectively, of cortical bone on both sides of mandibular jaw are generated. The X,Y coordinates La and Li so chosen are digitized as above on the boundary lines B_L and B_B of the cortical bone, between and interproximate the teeth.

After the points *La* and *Li* are chosen representing the cortical bone limits, (335) midpoint coordinates MP_{XY} are calculated between each of the individual labio-lingual pairs of *La* and *Li*. Also, calculated are the bone width distances between each of the respective labio-lingual pair *DLL*, as follows:

$$MP_X = La_X + \frac{Li_X - La_X}{2} \; ; \; MP_Y = La_Y + \frac{Li_Y - La_Y}{2}$$

$$DLL = \sqrt{(La_X + Li_X)^2 + (La_Y + Li_Y)^2}$$

where:

La_X is labial *X* coordinate of point *La*.

La_Y is labial *Y* coordinate of point *La*.

Li_X is lingual *X* coordinate of point *Li*.

Li_Y is lingual *Y* coordinate of point *Li*.

These midpoints MP_{XY}, one of which is the designated origin $MP_{0,0}$, lie on an arch that describes the size and shape of the center of the cancellous portion of the mandibular bone 22.

At this point, the beginning of the analysis for the calculation of the finish positions of the teeth is carried out. The coordinates of points MP_{XY} are recalculated relative to a new origin *0,0* at the calculated midpoint between the mandibular centrals, to normalize the mandibular trough equation to its own independent midpoint when calculated below. The sum of the individual mandibular tooth widths *MDW* equals the total dental length or mandibular arch length *MAL* contained in the mandibular trough equation *MTE* that will be constructed through the points MP_{XY}. *MAL* is referred to as the arch perimeter.

At this stage, (340) the midpoints are typically averaged right to left to eliminate any asymmetry that may be present due to slight measurement errors. If, however, the patient has been diagnosed by the orthodontist 14 to be of asymmetrical anatomy, the averaging process is not performed. Such a determination will have been made by the orthodontist 14 in the examination procedure (90) described above and specified of the prescription 27 in step (265) of the procedure (92) described above. An advantage of the averaging process is that, when used, it assists the final positioning of the teeth symmetrically about the midline *ML* and will make it easier for an archwire to be produced that is symmetrical from right to left, and thus can be made such that it can be installed in inverted orientation.

The midline *ML* shown in Fig. 4 is the axis of such symmetry corrections. These corrections for each point MP_{XY} are calculated as follows:

$$S_X = MP_X + \frac{PR_X - PL_X}{2} \; ; \; S_Y = MP_Y + \frac{PR_Y - PL_Y}{2}$$

where:

S_{XY} is the symmetricalized point MP_{XY}

MP_{XY} is mid-point of mandibular trough

PR_{XY} is a point MP_{XY} on the right side

PL_{XY} is the corresponding point on left side of the trough

With the completion of this symmetricali-zation process, a mathematical equation *MTE*, which describes the size and shape of the mandibular trough according to steps (345), (350) and (355), is derived by fitting a curve to the points $MP_{X,Y}$. Preferably, this curve is derived by fitting a series of cubic equations, such as a cubic spline equation, to pass smoothly through the points, for example, through the averaged midpoints $S_{X,Y}$. The cubic equations allow the determination of the slope of the curve at each of the midpoints.

The cubic equations are then preferably converted in form to a series of segments of tangent circle equations with slopes equal to the slopes of the cubic spline at the midpoints, and equal to the slopes of the adjacent circle segments at the segment end points, or their points of intersection, along the curve. To fit a cubic equation with quadratics, two circles *CS* and *CL* are used to describe each segment of the *MTE* between midpoints, as illustrated in Fig. 5. This allows a smooth curve consisting of tangential circles to represent the mandibular trough.

The cubic equation calculations are preferably those performed by (345) calculating cubic spline parameters required to pass a smooth curves through symmetricalized midpoints $S_{X,Y}$ as illustrated in Fig. 5A. This includes (350) calculating the slope of the cubic spline curve at each symmetricalized mid-point $S_{X,Y}$ or $S_{X,Y}$, and (355) calculating a series of tangential circle equations whose slopes are equal at the mid-points and at points of intersection along the curve.

(345) The cubic spline method preferred uses a cubic, or third degree, polynomial to interpolate between each pair of data points $S_{X,Y}$. A different polynomial is used for each interval, and each one is constrained to pass through the original data with the same slope as the data. (350) The slopes of the cubic equation are computed by solving the slope of a parabola that passes through each data point and its two nearest neighbors points. The cubic spline method is described in more detail in the discussion of the cubic spline subroutine (2000) below.

(355) Any point on the cubic spline equation can now be calculated by using a cubic spline interpolation. Using this, the cubic spline equation is subjected to a circle segment conversion by which the form of the equation *MTE* is converted to a series of circle segments that interconnect tangentially. Once the spline equation is derived, the slopes at each data point are calculated using the point slope method. These slopes are utilized to derive, between each pair of data points on the spline equation, the description of two circle segments, each from one of two circles as illustrated in Fig. 5, to convert the *MTE* to a series of circle segments throughout its length. This facilitates the setup of the teeth, the description of the configuration of archwires, and the generation of NC code for the manufacture of the appliance. The spline-to-circle conversion routine is described in further detail under routine (2100) below.

The input procedure continues. (360) Cartesian coordinates are input for right and left mandibular cuspid cusp tips *CR* and *CL*, respectively, as illustrated in Fig. 4. (365) A distance *DCT* between the cusp tips *CR* and *CL* of the two mandibular cuspids is then calculated:

$$DCT = \sqrt{(CR_X + CL_X)^2 + (CR_Y + CL_Y)^2}$$

where:

CR_X = right cuspid *X* coordinate.

CR_Y = right cuspid *Y* coordinate.

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CL_X = left cuspid X coordinate.

CL_Y = left cuspid Y coordinate.

This information is used to calculate if and how much the mandibular intercuspid distance is to be altered, and to evaluate whether the calculated final position is acceptable. Similarly, (370) cartesian coordinates or right and left mesio-buccal cusp tips, *MR* and *ML*, respectively, of mandibular first molars are calculated, and (375) the distance between these points *DMT* is calculated:

$$DMT = \sqrt{(MR_X + ML_X)^2 + (MR_Y + ML_Y)^2}$$

where:

MR_X = right first molar cusp X coordinate.

MR_Y = right first molar cusp Y coordinate.

ML_X = left first molar cusp X coordinate.

ML_Y = left first molar cusp Y coordinate.

This information is used to determine if and how much the mandibular intermolar distance is to be altered.

(400) Maxilla Digitized Video Input Step:

As with the mandibular jaw information described in connection with Fig. 4, (400) a computer image is made from input in the same manner from the upper model 23 of the maxillary jaw 24 of the patient 12, as illustrated in the flowchart detail of Fig. 2H. This involves the substeps of (405) inputing a video image 48a of maxillary model 23 to the computer screen 35. The image 48a is illustrated in Fig. 4A. With the maxilla, it is not necessary to overlay the grid *G* on maxillary image on the screen, since the bone of the maxilla is a variable that will be altered orthodontically to accommodate the finish positions of the teeth. The orientation of the axes and position of the origin are immaterial to the calculation of the relative distances such as *MDW* of the teeth. Only the scale must be maintained. As with the mandibular information, the image of the maxillary jaw 24 is displayed at a scale predetermined by the scanner 33. The scale is involved in the calculation of the maxillary tooth widths *MDW*.

(420) Cartesian coordinates of mesial and distal extremities $M_{x,y}$ and $D_{x,y}$ of each maxillary tooth are then input as with the mandibular teeth and (425) the mesio-distal width *MDW* of each maxillary tooth is calculated using Pythagorean theorem, thus:

$$MDW = \sqrt{(M_X + D_X)^2 + (R_Y + L_Y)^2}$$

where:

M_X is mesial X coordinate.

M_Y is mesial Y coordinate.

D_X is distal X coordinate.

D_Y is distal Y coordinate.

This information is used first to determine whether the maxillary and mandibular teeth are correct in proportion to the mesiodistal widths *MDW* of the other. If the proportions are incorrect, a tooth size discrepancy *TDS* is said to exist, and the information is recorded to report to the orthodontist. The *MDW*'s of the maxillary teeth are later used to place the maxillary teeth upon the mandibular arch.

Next, (430) coordinates of the central fossae of right and left maxillary first molars are input. Then, (435) the distance between central fossae *DCF* is calculated as follows:

$$DCF = \sqrt{(R_X + L_X)^2 + (R_Y + L_Y)^2}$$

where:

R_X is right side central fossa *X* coordinate.

R_Y is right side central fossa *Y* coordinate.

L_X is left side central fossa *X* coordinate.

L_Y is left side central fossa *Y* coordinate.

This information is recalculated after the tooth finish positions are calculated to coincide with the *DMT* spacing of the mandibular first molars, and compared with this initial measurement as an indicator of whether the intermolar width will be changed by treatment and the amount of such change, if any.

(500) Digitized Probe Tooth Profile Input Step:

The next input step (500) involves an analysis of the dentition, as illustrated in the detailed flowchart of Fig. 2I. In this step, selected profiles of each of the teeth are generated from either the model 20, or from a digitized three dimensional representation of the patient's teeth or the model 20 as illustrated in Figs. 3A and 3B. In the illustrated embodiment, the use of the probe assembly 57 of Fig. 1C is used in this step.

Where the full three dimensional scan has been employed in step (300), as could be produced with the use of the laser image generator (Fig. 1B), or as could be produced with moire image generator or other technique, a digitized computer model is produced. From such a computer model, which is an electronic version of the model 20 in the form illustrated in Figs. 3A and 3B, planes or other cross-sections through the teeth are selected that contain extremities of the teeth. The three dimensional images may be displayed on the screen 35 and profiles generated either with the pointing device 47 in a manner similar to the use of the mechanical probe described below, or automatically using available CAD or illustration imaging software. Whether the profiles are generated from a physical model 20 or an electronic version thereof, much of the input step (500) and/or the landmark selection step (600) may be similarly employed.

In the preferred use of the information from the probe assembly 57, a single digitized profile curve *PF* is constructed for each tooth in a generally vertical plane extending in an approximately labial-lingual orientation generally along the central developmental lobe perpendicular to the marginal ridges. While other profiles can be taken, the need to do so is reduced by intelligent plane selection made with an understanding of tooth anatomy, depending on the data required by the tooth positioning and appliance design criteria employed. The selection of the profile plane is illustrated in Fig. 6 where a first profile PF_A through the center of the tooth is shown as missing the buccal cusp tip which is the maximum crown highpoint of the tooth. Profile PF_B is then selected to include the buccal cusp, and the ridge of the profile is found to generally align with the lowpoint of PF_A. Alternatively, the profile may be non-planar to pick the important features of both planes. As such, the profile produced will be comparable to a projection onto a plane of the relevant tooth extremities.

The step (500) of analysis of the dentition includes, first (505) examination, by the operator 28 of the computer 30a, of the marginal ridges of the upper central and upper lateral teeth. If ridges are excessive, a determination is made to take a profile twice with the probe 60, once by smoothing the teeth, for example

with wax, for arch coordination and once without smoothing for placement jig geometry. Otherwise, a single profile taken across the buccal cusp will contain information of the crown height of the tooth as well as approximating the profile of the tooth through its mesiodistal center with accuracy that is usually sufficient. Then, (510) a determination is made as to whether one or two traces of maxillary incisor teeth are to be input as in step (505) above.

(515) The computer 30a is configured to receive sequential cartesian coordinate pairs through an RS-232C serial port representing tooth profile anatomy from the orthogonally positioned displacement transducers 61. (520) The computer 30a prompts the operator 28 to enter the profiles of each tooth sequentially. In response to the prompts, data points of each tooth are input, beginning with lower left molar $T(B,L,6)$ and ending with upper right molar $T(U,R,6)$, and a display 63 of profile PF_I image is generated. The output circuits associated with the transducers 61 are configured to digitize data values at periodic time intervals as the probe 60 is moved across the teeth from the time the probe first starts to move across the tooth until the operator enters a command or key stroke indicating that the scan is complete. Then (525) the input profile data of each of the teeth is stored in memory by the computer 30. The resulting profiles PF_I are illustrated in Fig. 3C. These profiles, at this stage, are not related to the positions of the teeth within the mouth or with respect to other teeth. Thus, each of the X-Y coordinates of the individual tooth profiles are independent of each other. In step (600) below, the coordinate axes of each tooth will be oriented with respect to each other, and thereafter, in later steps (800)-(1100), the coordinates of each profile are translated vertically for proper occlusion and horizontally for placement on their respective arches.

(95) Analysis and Finish Tooth Position Calculation Procedure

The calculation of the finish positions of the teeth, as illustrated in the flowchart of Fig. 2B, includes (600) determining the relative positions of geometric landmarks on the surfaces of the teeth and establishing the axis inclinations of the teeth, (700) calculating cuspid rise, (800) initially positioning the mandibular teeth vertically and in relation to the mandibular trough, (900) calculating a best fit cusp tip equation for the mandibular teeth, (1000) calculating the finish positions of the mandibular teeth on the best fit equation, and (1100) calculating the finish positions of the maxillary teeth on three arches related to the best fit equation.

(600) Tooth Landmark Identification Analysis Step:

After the individual teeth have been digitized, the inputing of tooth shape data (94) is complete, with the digitized information 26 stored a file. Then, referring again to the flowchart of Fig. 2, (95) the input data 26 is analyzed to develop or derive further parameters for calculating the final positions of the teeth and for (96) the design of the appliance 25. In the tooth positioning analysis (95), as illustrated in the flowchart of Fig. 2B, (600) a tooth profile analysis is made in which, for example, certain anatomical landmarks are chosen, depending on the tooth to be analyzed. The details of the tooth profile analysis are illustrated in the flowchart of Fig. 2J.

In the tooth profile analysis step, (605) individual images 63 of the profile curves PF_I of each tooth (Fig. 3C) are recalled separately to the screen of the computer 30b for selection of the landmarks.

Using the displayed images 63 of the profile curves PF_I, (610) specific landmark points are chosen, first on the mandibular molars and bicuspids. The selected points are digitized as illustrated in Fig. 6. The selected points are:

Point P_1: The Lingual (tongue side) gum/tooth intersection.

Point P_2: The prominence of the lingual cusp.

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Point P_3: The prominence of the buccal (cheek side) cusp.

Point P_4: The buccal gum/tooth intersection.

From these landmarks, (615) the crown long axis *CLA* of each molar and bicuspid profiled is determined. The determination is made by constructing a first line L_1 between points P_2 and P_3 and a second line L_2 between points P_1 and P_4. The crown long axis *CLA* of a tooth is the line between the midpoints of L_1 and L_2.

Line L_1 is constructed through point P_2 and point P_3 by the following equation:

$$\frac{Y - Y_2}{X - X_2} = \frac{Y_3 - Y_2}{X_3 - X_2}$$

where:

X_2, Y_2 = X and Y coordinates of point P_2.

X_3, Y_3 = X and Y coordinates of point P_3.

Line L_2 is constructed through point P_1 and point P_4 by the following equation:

$$\frac{Y - Y_1}{X - X_1} = \frac{Y_4 - Y_1}{X_4 - X_1}$$

where:

X_1, Y_1 = X and Y coordinates of point P_1.

X_4, Y_4 = X and Y coordinates of point P_4.

A point equidistant between points P_2 and P_3 along line L_1 is then calculated and defined as $P_{2\text{-}3}$:

$$P_{2\text{-}3_{X,Y}} = \frac{X_2 + X_3}{2} \; ; \; \frac{Y_2 + Y_3}{2}$$

where:

X_2, Y_2 = X and Y coordinates of point P_2.

X_3, Y_3 = X and Y coordinates of point P_3.

A point equidistant between points P_1 and P_4 along line L_2 is also calculated and defined as the Gingival Center Point *GCP*:

$$GCP_{X,Y} = \frac{X_1 + X_4}{2} \; ; \; \frac{Y_1 + Y_4}{2}$$

where:

X_1, Y_1 = X and Y coordinates of point P_1.

X_4, Y_4 = X and Y coordinates of point P_4.

The line defining the crown long axis *CLA* is constructed using the following equation:

where:

$X_{2\text{-}3}, Y_{2\text{-}3}$ = X and Y coordinates of the center point $P_{2\text{-}3}$.

$$\frac{Y - Y_{2-3}}{X - X_{2-3}} = \frac{Y_{GCP} - Y_{2-3}}{X_{GCP} - X_{2-3}}$$

X_{GCP}, Y_{GCP} = X and Y coordinates of gingival center point GCP_{XY}.

For molars and bicuspids, point P_3, the buccal cusp tip, is defined as the Incisal Center Point *ICP*.

Similarly, (610) the anatomical landmarks and crown long axis *CLA* for the mandibular cuspids, laterals and central teeth are determined, as illustrated in Fig. 6B. The points P_1 through P_4, as labeled in Fig. 6B, are selected as follows:

Point P_1: The lingual gum/tooth intersection.

Point P_2: The lingual aspect of the incisal edge.

Point P_3: The buccal aspect of the incisal edge.

Point P_4: The facial gum/tooth intersection.

As with the bicuspids and molars, lines L_1 and L_2 are constructed. The landmarks in the cases of the teeth as illustrated in Fig. 6B, are chosen because they are relatively tolerant to operator error in selection. This can be seen by the set of broken lines that are possible alternatives to L_2 in Fig. 6B. From these landmarks (615) the crown long axis *CLA* is determined as defined above, by connection of the midpoints of L_1 and L_2.

The next step in the analysis is the determination of maxillary dentition for each upper molar and bicuspid. (610) Anatomical landmarks are identified and chosen as illustrated in Fig. 6C, which requires (612) the selection of a fifth point, P_5, defined as follows:

Point P_1: The lingual gum/tooth intersection.

Point P_2: The prominence of the lingual cusp.

Point P_3: The prominence of the buccal cusp.

Point P_4: The buccal gum/tooth intersection.

Point P_5: The mesial marginal ridge of the tooth at central groove.

Referring to Fig. 6C, from the landmarks, (615) the crown long axis *CLA* of each applicable maxillary tooth is determined.

The (610) anatomical landmarks for the maxillary cuspids, laterals and central teeth are determined as illustrated in Fig. 6D. The points labeled P_1 through P_4 are selected, as follows as illustrated in Fig. 6D:

Point P_1: The lingual gum/tooth intersection.

Point P_2: The lingual aspect of the incisal edge.

Point P_3: The buccal aspect of the incisal edge.

Point P_4: The facial gum/tooth intersection.

From each of these sets of landmarks, the crown long axis *CLA* of each such tooth is also determined as described (615) above.

This completes the loop (620) for all of the teeth.

Next, as further illustrated in Fig. 6D, (620) seed values for setting the crown long axis inclinations *LAI* of the teeth. Initially, such seed values may be derived from analyses that identified the facial axis plane *FAP* through the facial axis point *FA* of the tooth (the midpoints of the height of the clinical crowns along the facial axes of the clinical crowns) as described by Dr. Lawrence Andrews. It is, however, contemplated

that *CLA* seed values for various population groups will be statistically derived in the course of the practice of the present invention, and will produce improved treatment results.

The seed values shown in Table 1 below are typical for caucasian males. These seed values for tooth *LAI*, tabulated in degrees from the horizontal lingual (-*X*) axis, will vary to reflect known variations due to such things as sex,

The preferred seed values are shown in Table 1 below are typical for caucasian males. These seed values will vary to reflect known variations due to such things as sex, race or treatment plan.

Tooth Type	Maxillary Crown *LAI*	Mandibular Crown *LAI*
Central	117	107
Lateral	112	107
Cuspid	108	100
1st Bicuspid	94	83
2nd Bicuspid	94	80
1st Molar	x	x
2nd Molar	x	x

TABLE 1

The computer images as summarized in Fig. 3C for each tooth (630) are then rotated so that the *CLA* is oriented at the angle *LAI*, the long axis inclination angle, to the mandibular trough plane *MT* according to the values in Table 1. This computes the final inclinations of the teeth that will be preserved in the calculations below. This produces the oriented profiles *PF* summarized in Fig. 6E.

In the analyses of Andrews referred to above, the *LAIs* were established with a line L_{FA} drawn tangent to the facial surface at *FA*, and line representing the relative inclination of the archwire plane drawn through *FA* point. The angle between the lines was established at the inclinations reported by Andrews for patients with no skeletal discrepancies. The angle *LAI* between the crown long axis *CLA* and a line representing the maxillary arch plane in which lies the mandibular trough equation *MTE* is related to the facial inclination angles of Andrews' studies by taking into account statistically the thicknesses and contours of the teeth. Table 1 above was derived, after statistical processing, to produce the seed value used for the final inclination of the crown long axis in preferred occlusal design.

Once the tooth profiles have been rotated to the inclination angles *LAI*, certain precise vertical dimensions and extremities can be determined. From the digitized profile curves, which are stored in memory in the form of a series of closely spaced points, the precise incisal tip *IC*, as illustrated in Figs. 6F, 6H and 6I, are identified on the cuspids, laterals and centrals.

Additionally the elevation of the marginal ridge P_3 is identified. The marginal ridge elevation *MRE*, which is the vertical distance from P_3 to P_5, is identified on the maxillary posterior teeth because they are the centric stops for the buccal cusps of the mandibular molars and bicuspids. In other words, point P_5 on the mandibular molars and bicuspids contacts point P_3 on the maxillary molars and bicuspids when the teeth are together, as illustrated in phantom line PH_1, in Fig. 6C. For a more precise placement in a less common

case where the maxillary ridge is narrow in relation to the mandibular tip (phantom line PH_2), a more detailed three dimensional analysis of the tooth shape can take into account additional correction needed. The calculation of *MRE* (Fig. 6C) is made after rotation of the teeth to their proper *LAI* inclinations so that *MRE* will be a vertical distance, where *LAI* is measured relative to the plane of the dental arch. The *MRE* is used as the buccal cusp height *BCH* in the calculation of cuspid rise and archwire plane placement as described below in the discussion of Figs. 7A and 8, respectively.

(700) Cuspid Rise Determination Step:

The next step of the analysis procedure (37) is (700) the calculation of cuspid rise, illustrated in detail in the flowchart of Fig. 2K.

Most orthodontists currently desire a cuspid rise occlusion, in which, in lateral movement of the lower jaw, the cuspids cause the other teeth to disclude or to come apart. In order for this to happen, the overlap of the cuspids must be greater than that of the other teeth when the teeth are together. This is complicated by the fact that the cuspids ($I=3$) are close to the front of the mouth and are therefore further from the condyle or pivot point PP of the jaw than are the posterior teeth ($I>3$), as illustrated by distances DJ_I in Fig. 7. This results in the teeth closer to the back of the mouth moving less than the cuspids on opening. This differential rate of movement must be included in the calculation of cuspid rise or the back teeth will remain in contact after the cuspids have cleared each other. Also, the distance *DPP* from the occlusal plane to the pivot point *PP* of the condyle of the jaws must be considered, as illustrated in Fig. 7. A failure to provide for this distance results in what is known as working interferences.

According to the preferred embodiment of the present invention, where cuspid rise is prescribed to control occlusion, the contribution of cuspid rise is distributed between the maxillary and mandibular cuspids, with two parts of the cuspid rise provided by the maxillary cuspids and one part by the mandibular cuspids. This distribution is applicable where occlusion is solely to be a cuspid rise function. Where occlusion is to be a group function, as specified by the orthodontist 14 in the prescription 27, the distribution between the upper and lower teeth is generally equal.

In the substeps performed in the calculation of the cuspid rise (700), illustrated in detail in the flowchart of Fig. 2K, the first substep is (705) to acquire the initial vertical distance or buccal cusp height *BCH* from P_3 to the marginal ridge for each of the right and left maxillary first bicuspids *T(U,4)*, second bicuspids *T(U,5)*, first molars *T(U,6)*, and second molars *T(U,7)*, as illustrated in Fig. 6C. This is the marginal ridge elevation *MRE* calculated for each of these teeth in substep (615) of step (600). Then, from anatomical study, (710) the cuspid rise vertical height *CR* required to clear each respective pair of teeth is determined by first computing the values in Table 2, which are derived from the jaw dimensions *DPP* and DJ_I in Fig. 7. required to clear each respective pair of teeth is determined by first computing the values in Table 2.

1.67 x BCH of T(U,7)

1.50 x BCH of T(U,6)

1.36 x BCH of T(U,5) and

1.20 x BCH of T(U,4).

TABLE 2

Then, (715) from the products of the buccal cusp height *BCH* for each such tooth multiplied by the rise factor listed above, the largest value is selected. This selected product is the cuspid rise required to clear

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the most prominent cusp and provide group function occlusion. This is illustrated as BCH_g in Fig. 7A for the case where the first molars are the last to clear.

(720) If the group function has been selected in the prescription 27 provided by the orthodontist 14, the calculated rise is used as is. If cuspid guidance has been selected in the prescription 27 of the orthodontist 14, the calculated cuspid rise factor must further be modified to give typically 0.5 to 0.75 mm of clearance over the largest rise factor by multiplying the buccal cusp height *BCH* for each tooth by the rise factor listed above and selecting the largest figure, then adding 0.5 to 0.75 mm additional cuspid overlap to obtain and adjusted cuspid guidance cuspid rise.

(725) Calculation of cuspid overlap or cuspid rise *CR* for maxillary and mandibular cuspids is preferably as follows: If group function has been selected, mandibular rise equals 50% total group function rise, and maxillary rise equals 50% of the total group function rise. If cuspid function has been selected, mandibular rise equals 34% of the total cuspid guidance rise, and maxillary rise equals 66% of the total cuspid guidance rise.

(800) Mandibular Tooth Placement Step:

The next step in the analysis procedure (87) is (800) the mathematical construction of the mandibular occlusion to calculate the position of the mandibular teeth. The details of this step are illustrated in the flowchart of Fig. 2L. The first calculation places the tips of the mandibular teeth on an occlusal plane pending final refinement of the placement, as diagrammatically illustrated in Fig. 6E. In this step, the inclinations of the mandibular tooth crown long axes *CLA* are preserved, and the teeth are moved upward along their *CLA*'s until their tips are in alignment with the plane of the top of the tallest tooth. The *CLA*'s are placed to intersect the *MTE* below the tooth *GCP*. Because the teeth are inclined at different *LAIs*, or long axis inclination angles, the tooth tips will each be differently offset from the *MTE*, and thus not in a smooth arch.

The substeps of the mandibular placement step (800), illustrated in the flowchart of Fig. 2L, are as follows:

(805) The tallest mandibular tooth, with the exception of the cuspids, is identified. In Fig. 6F this is illustrated as the left mandibular central. The tallest tooth is the tooth with the greatest crown height *CH*. The crown height *CH* is the distance, in the *Y* direction (with the teeth profiles oriented as described in step (600), from the *GCP*, the point of intersection of line L_2 and crown long axis *CLA*, to highest point on buccal cusp, e.g. P_3 (for posterior teeth) as illustrated in Fig. 6F and (for the anterior teeth) to either the incisal center point *ICP* or, preferably to the incisal tip *IC*, as illustrated in Fig. 6G. The crown height *CH* of the tallest tooth, shown as the left mandibular central incisor in Fig. 6F, is the maximum crown height *MCH* of the mandibular teeth.

Then, (810) three parallel planes are established:

a) an *MCH* reference plane *MCHP* parallel to the *X*-axis, and passing through an origin *0,0*, set at the *GCP* of the tallest tooth (Figs. 6F and 6I);

b) a Buccal Cusp Plane *BCP* parallel to *X*-axis and passing through coordinates *0, MCH* on the tallest tooth (Figs. 6F and 6I); and

c) a Cuspid Rise Plane *CRP* parallel to *X*-axis and passing through coordinates *0*, where *CR* is the cuspid rise calculated in step (700), where the cuspid rise option has been selected.

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With the planes defined, (815) the oriented mandibular teeth are placed such that the highest point on buccal cusp tip P_3 or incisal tip *IC* of each contacts the buccal cusp plane *BCP*, for all teeth except the cuspids, as illustrated further in Fig. 6F. The *BCP* thereby is established as the occlusal plane *MOC*. The reference plane *MCHP* is set equal to the plane of the mandibular trough *MT*. This sets the *GCP* of the tallest tooth on the *MT*, with the *GCP*'s of the remaining mandibular teeth above it. It also sets the occlusal plane *MOC* a distance *MCH* from the mandibular trough *MT*. The absolute highest point on a tooth crown is preferably used to align the teeth with the *BCP*. Such a point can be determined by additional point selection in step (500), such as by the direct selecting of the point *IC* for the precise incisal tip, or preferably by calculating the highest point directly from the profiles of Fig. 3C or from three dimensional images as in Figs. 2A, 2B after rotation of the teeth to their final inclination angles *LAI*, at the end of step (600).

The next stage in this step is to establish the mandibular component of cuspid rise. This involves (820) vertically moving the cuspids by, for example, sliding the cuspids along their crown long axes, such that the cuspid cusp tips are at the appropriate height above the mandibular occlusal plane, that is, in the plane *CRP*.

At this stage, the vertical positions of the mandibular teeth relative to each other are calculated, providing a basis for relating the *Y* coordinates of the individual mandibular tooth profiles with respect to each other as illustrated in Figs. 6F and 7C.

Then, with the mandibular teeth vertically positioned, the teeth are horizontally set at temporary positions with respect to the *MTE*, which lies in the plane of the mandibular trough *MT* (*MCHP*). This horizontal positioning, in effect, relates the *X* axes of the individual tooth profiles in a horizontal in-out direction with respect to the mandibular arch and special mesiodistally along the mandibular arch.

Because the preferred goal, however, is to position the tips of the teeth in the smoothest arch in an occlusal plane *MOC* rather than their gingival aspects in a smooth arch at the mandibular trough *MT*, (825), a horizontal distance *OFFSET* for each tooth is calculated, based on the tooth and the crown long axis inclination *LAI* determined in step (600). This offset is the horizontal distance from the *MTE* to the tooth tips when their *GCP*'s are placed on the *MTE*.

For mandibular centrals and laterals and cuspids, the *OFFSET* is calculated by dividing, by the tangent of *LAI*, the vertical distance from (1) the intersection of crown long axis *CLA* and the incisal tip *IC* to (2) the intersection of *CLA* and maximum cusp height reference plane *MCHP*. The vertical distance may be calculated from the *IC* to the *MCHP* (equal to the *Y* coordinate of point *IC*, producing the incisal center vertical distance *ICD*.) For mandibular laterals and centrals, *ICD* equals *MCH*. For mandibular cuspids, *ICD* equals the mandibular cuspid rise component, which is *MCH+(Total CR)/3* when cuspid rise function occlusion has been selected. The calculation of the *OFFSET* for centrals, laterals and cuspids would thus be as follows for the incisors and laterals:

$$OFFSET = ICD/\tan(LAI)$$

(831) For mandibular bicuspids and molars, referring to Fig. 6F, the *OFFSET* is calculated as the horizontal distance from point P_3 to the intersection of the *CLA* and the *MCHP* as follows:

$$OFFSET = [MCH/\tan(LAI)] + HD$$

where *HD* equals the horizontal distance from point P_3 to incisal center point *ICP*.

Then, (835) the mandibular trough placement point *MTPP* is defined as the intersection of *MCHP* and *CLA*, as illustrated in Figs. 6G and 6H. For the tallest tooth, *MTPP* is its *GCP*, as illustrated in

Fig. 61. The *MCHP* is at the level of the mandibular trough and contains the *MTE*. The *MTPP* is the point on the tooth that is initially placed on the *MTE*.

Next, referring to Fig. 7B and 7C, the teeth are placed with their *MTPP*'s on the mandibular trough, one side at a time. To achieve this, (840) the subroutine (2200) is called twice, once for the left side, and once for the right side, as follows:

The mandibular trough equation *MTE* is first adjusted for the mandibular centrals to increase the radii by the amount of the central *OFFSET* for that particular tooth, as defined above, to form a mandibular trough offset curve *MO(I)* of Fig. 4B. The radii of the *MTE* referred to are those of the *MTE* defined in the circle segment form of the equation generated in step (300) with the spline to circle conversion routine (2100). Since the *OFFSETs* of the teeth differ, the *MO* may be viewed as a discontinuous equation when constructed in this manner, made up of segments, each containing the tip of one tooth and spaced labial-lingually from the *MTE* by the amount of the individual tooth's *OFFSET*.

Beginning with the left side, the central is placed, as illustrated in Fig. 7B, by placing its mesial contact point *MCP* at the intersection of the midline *ML* with the offset curve *MO* for the tooth. This has the effect of the placing *MTPP* of the tooth, which is the intersection of the *CLA* with the *MCHP* or *MT*, on the *MTE* and the incisal tip *IC* of the tooth on MO_I. The tooth placement on the circle segment form of an equation is explained in detail in the description of the tooth placement routine (2200) below. In the placement of the central, a circle C_1 is constructed with a radius equal to the mesiodistal width *MDW*, of the central tooth and with the center of the circle C_1 at the mesial contact point *MCP* of the tooth at intersection of the midline *ML* with the offset curve MO_I. Then, circle C_2 is constructed with a radius equal to *MDW/2* and with its center coincident with the center of circle C_1. Then, the intersections of trough offset curve *MO* with the circles C_1 and C_2 are found, its intersection with the circle C_1 being the distal contact point *DCP* of the tooth and its intersection with the C_2 being the tooth midpoint *TMP* of the central tooth. The tooth midpoint *TMP* is here defined as the midpoint of the mesiodistal width of the tooth placed on an archform, which is the intersection of the archform with a vertical labial-lingual plane that contains the *CLA*. This midpoint *TMP* of the central tooth on the *MO* is the approximate position of the incisal tip *IC*.

Determining the intersections of the circles with the offset trough curve *MO*, or expanded mandibular trough, requires identification of which circle sector lines (Fig. 5) the circles C_1 and C_2 intersect. These are identified by comparison of the *X* coordinates of the intersections with the *X* coordinates of the distal contact points *DCP* of each of the central teeth to determine which segments of the trough equation will be used, as explained more fully in the description of the tooth placement routine (2200) below.

Finally, a distal contact point line *DCPL* is constructed for the central tooth through the *DCP*, at the intersection of circle C_1 with the *MO*, and through the center of the identified circle segment of the *MO*, the expanded *MTE*, on which the *DCP* of the tooth lies. This line lies along a radius of the circle segment of the *MO* curve through the distal contact point of the central tooth. Similar lines *DTMP* are constructed for the center of the tooth *TMP*.

(845) For each of the remaining mandibular teeth on the same side of the arch, in distal sequence, a new mandibular trough offset MO_I is calculated, by expanding the *MTE* with radii of curvature increased by the amount of the next tooth's *OFFSET* and with center of the circles C_1 and C_2 moved labially or outwardly from the *MTE* along the prior tooth's distal contact point line *DCPL* by the amount of the current this tooth's *OFFSET*. This is the *MCP* for the next tooth. Circle C_1 for the tooth is constructed with a

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radius equal to the mesiodistal width of the tooth and with its center at their center point *MCP*. Circle C_2 is constructed with a radius equal to *MDW/2* and with centers coincident with circles *C1*.

For bicuspids and molars, the tooth midpoints *TMP* can be considered as their points P_2. Then, as with the central, the intersections of *MO* and circles C_1 and C_2 are calculated for these teeth. The distal contact points *DCT* of these teeth are at the intersections of *MO* for the tooth and the respective C_1s. The centers of the teeth *TMP* are at the intersections of *MO* for the tooth and the respective circles C_2. The *MO* sector segments which the circles intersect are identified. Selection of the segments is made by comparing the *X* and *Y* coordinates of intersections to *X* and *Y* coordinates of distal contact points *DCPs*. Finally, a distal contact point line *DCPL* is constructed from selected segment center to the plane *DCP*. The same is done for the centers of the teeth *TMP*.

(848) The substeps (842) are repeated for all of the remaining mandibular teeth on the same side of the arch. Then, (849) substeps (840)-(848) are repeated for the teeth on the opposite side of arch.

(900) ***Best Fit Mandibular Arch Equation Step:***

The above step (800) leaves the crown long axes *CLA* of the mandibular teeth intersecting the *MCHP* reference plane, which is at the level of the mandibular trough *MT* at or just below the gingival center points *GCP* of the teeth, along the mandibular trough equation *MTE*. The discontinuous offset equation *MO*, however, contains the approximate tips of the teeth in the occlusal plane *MOC*, with the teeth irregularly offset as represented by the discontinuous *MO* lines in Fig. 4B. To place the tips of the teeth into an ideal arch, (900) a final equation for better placement of the buccal cusp tips and incisal edges of the mandibular teeth in a continuous arch is developed. The development of the best fit equation is illustrated in the detailed flowchart of Fig. 2M.

When viewed perpendicularly to the occlusal plane as in Figs. 4B and 7B, it can be seen that the buccal cusp tips and incisal tips of all of the individual teeth do not lie along either the mandibular trough equation or the same geometrical expansion of that equation. In fact, due to small anatomical variations, it is unlikely that the tips will fall on any smooth curve when the tooth *CLAs* intersect a smooth curve at the mandibular trough in the *MCHP* and the *LAIs* are preserved. To remedy this, the equation is statistically developed that best fits the cusp tips and incisal edges of the individual teeth; a Best Fit Buccal Cusp Equation *BFBCE*. In the formulation of the equation, the coordinates of the right and left tooth midpoints *TMP*, the *ICPs* or *ICs* in Fig. 7B, are preferably averaged. The equation *BFBCE* may be obtained (910) by use of polynomial or other bezier or least square statistical techniques to arrive at a best fit equation. These are available in any of a number of off-the-shelf software packages.

Such a *BFBCE* equation is plotted in Fig. 4B. Once the *BFBCE* is determined, it may be (915) converted to a circle segment equation in a manner such as with the spline to circle conversion routine (2100). This equation provides a basis for moving the teeth labially or lingually from the discontinuous offset equation *MO* to place the tips of the mandibular teeth in a smooth arch in the occlusal plane *CP*, as illustrated in Fig. 7C. To do this, in the next step the profile planes will be translated bodily in their own horizontal *X*-directions (which is an *X-Y* movement in the coordinates of the horizontal planes), moving their *MTPPs* off of the *MTE* in the *MCHP* (or *MT*).

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(1000) Mandibular Best Fit Arch Placement Step:

After statistically deriving a best fit equation *BFBCE*, (1000) positions of the individual mandibular teeth are calculated to translate them facially, either labially or lingually, so that their tips fall on the best fit curve. This step is illustrated in detail in the flowchart of Fig. 2N.

To achieve this, (1005) the mesiodistal contact point of the mandibular central, the point *MCP*, as in Fig. 7B, is first placed on the intersection of the midline *ML* with the *BFBCE* in the same manner as it was placed on the *MO* in step (800). Then (1010) circles *C1* and *C2*, as defined above, for the tooth are constructed and their intersections with the *BFBCE* curve are found. As with the placement in step (800) above, the intersection of C_1 with *BFBCE* is the distal contact point *DCP* of the tooth, and the intersection of C_2 with the *BFBCE* curve, is the center point *TMP* (which aligns with *IC*) of the tooth. This, in effect, moves the tooth normal to the circle segment of the *BFBCE* associated with the *TMP*. Then, (1015) new circles C_4 and C_3 are constructed with centers at the distal center points *DCP* and (1020) substeps (1005) and (1015) are repeated for all teeth on the same side of the mandibular arch. Then, (1025) steps (1005) through (1020) are repeated for the teeth on the other side of the mandibular arch. The placement uses the tooth placement routine (2200), the description of which below explains in detail the placement of the mandibular teeth on the *BFBCE*.

This step bodily translates the teeth in a generally horizontal direction, and rotates the teeth of the mandible about their *CLAs* to place incisal edges and cusp tips, as determined in step (800), on the *BFBCE*. With the completion of this step the finished positions of the mandibular teeth are calculated and the mandibular occlusion is finalized. At this point the mandibular occlusion can be envisioned as an ideal setup cast in stone, to which the maxillary occlusion will be fitted and related.

The finish positions of the mandibular teeth are illustrated in Fig. 7C in which the *X-Y* coordinates are those of the horizontal arch planes. A vertical *Z* coordinate, perpendicular to the horizontal X-Y plane, is aligned with the *Y* axes of the individual tooth profile planes. The *X* coordinates of the profile planes are aligned with the labial-lingual directions *La-Li* in Fig. 7B.

(1100) Maxillary Tooth Placement Step:

The construction of occlusion requires (1100) the fitting of the maxillary teeth to the already positioned mandibular teeth. This is accomplished by deriving a modified best fit buccal cusp equation *BFBCE* for the maxillary teeth in the step illustrated in detail in the flowchart of Fig. 2O. Unlike with the mandibular teeth, with the maxillary teeth, the cusp tips of the posterior teeth and incisal edges of the anterior teeth are not set in a single arch. The maxillary teeth are rather set: (1) with the central groove-marginal ridge points of the maxillary bicuspids and molars on the *BFBCE*, (2) with the maxillary anteriors spaced labially off of the *BFBCE* to allow for incisal overlap and a clearance between the lingual surfaces thereof and the labial surfaces of the mandibular teeth, and (3) with the cuspid tips in the arch generally between the first maxillary bicuspid and the lateral incisor. The arches on which the maxillary teeth are placed as illustrated in Fig. 4C, as explained above.

For the maxillary incisors, the modification of the *BFBCE* first involves an averaging the distances from point P_2 to point P_3 on the mandibular incisor incisal edge, and dividing by two, to locate the arch that will contain the labial surface of the tooth adjacent the incisal center point *ICP* of the tooth, which is generally the point P_5. This produces a uniform distance from the best fit equation to the contact point of the facial surface on the labial side of the mandibular anterior teeth with the facial point on the lingual side

of the maxillary anterior teeth. An additional distance, of typically one-quarter millimeter, is added to the averaged distance to provide a slight *Clearance* between the upper and lower anterior teeth. This is illustrated in Fig. 7D.

The maxillary anterior dentition is set for vertical position relative to the occlusal plane *MOC* according to occlusion criteria selected to provide a predetermined overlap. From the cuspid rise calculation of step (700), the vertical positions of the maxillary cuspids are known relative to the mandibular occlusal plane *MOC*. For maxillary laterals and centrals, the vertical positions provide the overlaps according to the prescribed criteria, putting their lingual facial contact points with their mandibular counterparts on the *MOC* plane. All teeth are inclined at the prescribed crown long axis *CLA* inclination values *LAI* from Table 1 in step (600).

In the (1100) placement of the teeth of the maxilla, or upper jaw 24, with respect to those of the mandibular, or lower jaw 22, (1105) three arch forms are mathematically defined. These are (1106) the maxillary anterior arch form *MAAF*, (1110) the central groove marginal ridge arch form *CGMRAF*, and (1115) the maxillary cuspid arch form *MCAF*, as illustrated in Fig. 4B. The *MAAF* is established to position the maxillary incisors with respect to the *BFBCE* so that their lingual faces contact or clear the labial faces of the mandibular incisors. The *CGMRAF* is established separate from the *MAAF* because the maxillary bicuspids and molars contact their mandibular counterparts with their central groove marginal ridge intersection points juxtaposed on the mandibular buccal cusps. The *MCAF* is established separate from the *MAAF* and the *CGMRAF* because the cuspids have a still different relation to their mandibular counterparts.

(1106) Location of the *MAAF* relative to the *BFBCE* requires a circle segment radius expansion of the *BFBCE* equation such that the lingual surfaces of the maxillary incisors, after being adjusted vertically to provide a predetermined overlap, will contact the labial face of the mandibular incisors at points spaced labially from the *BFBCE* with the predetermined *Clearance*. This expansion is calculated as the average distance between points P_3 and P_2 on the four maxillary incisors and adding the predetermined *Clearance* of typically 0.25 mm. This expansion, so calculated, is added to the *BFBCE* circle segment radii to define the maxillary anterior contact arch form *MAAF*. The *MAAF* is thus also expressed as a circle segment equation.

The calculation of the amount of circle segment radius expansion of the *BFBCE* needed to define the *MAAF* is made at the midpoint of the mesiodistal width of either maxillary central, *TMP*, in Fig. 4C. This would be the intersection with *BFBCE* of circle C_2 in Fig. 7C. The tooth is placed on the maxillary contact arch form equation *MAAF* such that the mesial contact point of the tooth is on intersection of the midline *ML* and the maxillary contact arch form *MAAF* (Fig. 4C). (1108) The *MAAF* is defined as follows with respect to upper laterals and centrals:

$$MAAF = BFBCE + \sum_{\{t\}} \frac{P_{3x} - P_{2x}}{\{Avg\}} + Clearance$$

where:

t = number of teeth (4),

Avg = 2 (to find midpoint), and

Clearance = 0.25mm, typically.

P_3 and P_2 are points on the maxillary central as defined in step (600). As described above, the crown long axes *CLA* of these teeth are angulated relative to the occlusal plane at the crown long axis seed values stated in Table 1.

(1109) The tooth placement proceeds in accordance with the tooth placement routine (2200) described below. The placement positions the lingual faces of the central teeth on the *MAAF*, with the central mesial contact point MCP_1 on *ML*. The midpoint TMP_2 of the mesiodistal width of the next maxillary tooth is then placed on the maxillary contact arch equation *MAAF* such that the mesial contact point MCP_2 touches a line normal to the curve *MAAF* and through the distal contact point DCP_1 of the previous tooth. This procedure applies on one side of the occlusion up to the cuspid. The other maxillary side is constructed similarly.

The next substep in the construction of the maxillary occlusion is (1110) the definition of the location of the arch for horizontal placement of the posterior teeth. The teeth are again set at the *LAI* values of Table 1 from step (600). (1111) The intersections of the marginal ridge and the central groove, which, if not separately selected in step (600) may be taken as point P_5 in Fig. 6C, are placed over the buccal cusp of the appropriate mandibular tooth whose cusps were previously positioned on the best fit buccal cusp equation *BFBCE*. Thus, the *CGMRAF* coincides with the *BCBFE* as shown in Fig. 4B.

For the maxillary cuspids, (1115) the cusp tips are placed on some smooth arch between the he *MAAF* and the *CGMRAF*. Preferably, their tips are placed on the *BFBCE* expanded by the average of the distances therefrom to the incisal tip of the lateral and to the buccal cusp tips of the first maxillary bicuspids. This labial distance from this point to the buccal cusp tip of the first bicuspid may alternatively be used to place the distal contact point of the cuspid, with its mesial contact point in contact with the distal contact point of the lateral. The point to which the *BFBCE* must be expanded to locate the buccal cusp tip of the first bicuspid for the two above alternatives is $P_{XY}(U,4) - P_{XY}(U,4)$. The cuspids will thereby be spaced out from the *BFBCE* by the average of a distance equal to the horizontal or *X* distance from P_5 to P_5 on the first maxillary molar, as illustrated in Fig. 6C, and the *MAAF*.

Alternatively, the cuspids may be placed with their mesial contact points MCP_3 on the *MAAF* and with their distal contact points *DCP* in line with the mesial contact points or with the buccal cusp tips of the first maxillary bicuspids.

A third alternative in placing the cuspids is to use the same criteria for clearance with the mandibular teeth used for the definition of the MAAF. Following the determination of the *MCAF*, the cuspids placed adjacent the laterals with the tips thereof on the *MCAF*, followed by the successive placement of the posterior teeth with the marginal ridges thereof on the *CGMRAF* (*BFBCE*), all according to routine (2200).

In relating the profile and archform drawings and equations above, it should be noted that the *X* dimension of the profiles on which P_5 and P_5 are defined are vertical planes, and that the *X* direction in these planes corresponds to the labial direction in the horizontal planes of the archforms, as was explained for the mandibular teeth in connection with Fig. 7C. Thus, addition of an *X* component of a point on a tooth profile to an archform curve results in a labial expansion of the archform, or an increase in the radius of the corresponding circle segment of the archform circle series equation.

At this point, information from the prescription 27 from the orthodontist 14 is retrieved to determine (1120) which maxillary anterior vertical occlusion method has been selected. The methods may include, for example, (1121) Roth occlusion, (1122) Ricketts occlusion, or (1123) the preferred method, referred to by the inventors as Elan occlusion. These are discussed below.

Where (1121) Roth occlusion has been selected, the maxillary cuspids will extend a distance CR_{03} equal to the cuspid rise *CR* below the occlusal plane *MOC*, and for laterals and centrals, the teeth will extend a distance CR_{02} equal to 0.5 the cuspid rise beyond the occlusal plane, as illustrated in Fig. 7D. From step

(725), the treatment is selected to apply either group function or cuspid rise function, and the respective cuspid rise quantities for maxillary cuspids are determined. From the lowest point on buccal (facial) cusp, a distance is measure vertically upward equal to 0.5 *CR* to find the intersection of occlusal plane *MOC* and central and lateral teeth. If two profiles were taken, the profile that includes marginal ridges is used. The intersections of *MOC* with each maxillary incisor are defined as follows:

Facial intersection with *MOC* = *FIMOC*,

Lingual intersection with *MOC* = *LIMOC*,

The distance from *LIMOC* to *FIMOC*, *DLF*, is computed as follows:

$$DLF = X_{FIMOC} - X_{LIMOC}$$

where *LIMOC* is the contact point with *MAAF*.

Where (1122) Ricketts occlusion is prescribed, the maxillary cuspids also extend below the *MOC* by a distance CR_{t3} equal to the cuspid rise *CR*. The laterals are positioned such that the tips are the distance CR_{t2} of 1.0mm above the cuspid tips, and the distance CR_{t1} is such that the tips of the centrals are 0.5mm above the cuspid tips. From step (725), in which either group function or cuspid rise function were selected, the respective cuspid rise quantities are applied for the maxillary cuspids. Then, from lowest point on buccal (facial) cusp, a distance of 1.0 mm is measured upward on the laterals and a distance of 0.4 mm is measured upward on centrals to find the intersection of *MOC* with the central and lateral teeth. If two profiles were taken, a profile that includes the marginal ridges is used. A line is then constructed through the points on the buccal cusps parallel to the *MOC*. The intersections with the teeth are defined as follows:

Facial intersection with *MOC* = *FIMOC*

Lingual intersection with *MOC* = *LIMOC*

Distance *DLF* from *LIMOC to FIMOC* = $X_{FIMOC} - X_{LIMOC}$

where *LIMOC* is contact point with *MAAF*.

Where (1123) Elan occlusion has been selected, the maxillary cuspids will extend a distance CR_{t3} equal to 0.67 of the cuspid rise *CR* below the occlusal plane *MOC*, laterals extend a distance CR_{t2} equal to 0.33 of the cuspid rise *CR* below the plane *MOC*, and the centrals extend a distance CR_{t1} equal to 0.50 of the cuspid rise *CR* below the plane *MOC*. As with the above, from step (725), in which either group function or cuspid rise function were selected, the respective cuspid rise quantities are applied for the maxillary cuspids. Then, from the lowest point on buccal (facial) cusp, a distance of 0.33 of the cuspid rise *CR* is measured upward on the laterals, and a distance of 0.50 of the cuspid rise *CR* is measured upward on the centrals, and the intersection of the teeth with the plane *MOC* is found. If two profiles were taken, a profile that includes marginal ridges is used. The *MOC* plane and the intersections with the teeth are defined as follows, as illustrated on the cuspid in Fig. 7D:

Facial intersection with *MOC* = *FIMOC*.

Lingual intersection with *MOC* = *LIMOC*.

Distance *DLF* from *LIMOC* to *FIMOC* = $X_{FIMOC} - X_{LIMOC}$.

LIMOC is contact point with *MAAF*.

The (1125) elected horizontal occlusion is selected. If (1126) the Roth maxillary anterior horizontal occlusion has been selected, no further changes are required. This results in the lingual surfaces of the teeth forming a smooth arc. If (1127) the Ricketts maxillary anterior horizontal occlusion has been selected, changes are made to cause the labial surfaces of the teeth to form a smooth arc. This requires finding the

largest *DLF*, or *LIMOC-FIMOC* distance for the centrals, subtracting the other *LIMOC-FIMOC* distances of the incisors from this largest distance, adding the respective differences to each tooth to extend the *LIMOC* point lingually along line *LIMOC-FIMOC*, and establishing a new point at which the *LIMOC* is to intersect the *MOC*.

If (1128) the Elan horizontal occlusion is selected, which is the preferred and illustrated embodiment, the horizontal tooth placement proceeds as set forth below. Because, given the overlap of the maxillary incisors, the labial-lingual thicknesses of the anterior teeth are greater in the plane of occlusion than the distance P_2-P_3 used to calculate the *MAAF* and the *MCAF*, offsets must be calculated and the maxillary teeth placed again on the offset versions of these archforms.

First, in calculating the positions of the teeth to provide the horizontal occlusion, (1130) a distance is calculated from *LIMOC* to *ICP* for the maxillary centrals and the laterals. This distance is referred to as the maxillary anterior offset *MAO*, thus:

$$ICP = \frac{X_2 + X_3}{2} \; ; \; \frac{Y_2 + Y_3}{2}$$

$$MAO = LIMOC_X - ICP_X$$

(1135) The maxillary first bicuspid offset *MBO* is calculated:

$$MBO = P_{3X} - P_{2X}$$

(1140) The maxillary tooth positions are then recalculated, one side at a time, with respect to the offset maxillary arch forms defined above that contain the buccal cusp tips and incisal edges of the maxillary teeth. This is achieved by sending the relevant parameters to the placement routine (2200) and calculating placement in the same manner as shown in Fig. 7B for the mandibular teeth. For the maxillary centrals, (1141) *MAAF* is adjusted such that the *MAAF* radii are increased by the amount of the *MAO*. This curve is now called maxillary contact archform offset *MAAFO* and is illustrated in Fig. 4C.

Calculation of the positions of the maxillary incisors on the *MAAFO*, preferably in accordance with the tooth placement routine (2200), closes the spaces between the teeth that results from expanding *MAAF* to *MAAFO*.

The intersection of *MAAFO* and the arch midline *ML* is the mesial contact point *MCP* of the tooth. A circle C_1 is constructed with a radius equal to the mesiodistal width *MDW* of the central incisor. Its center is at the intersection point of *MAAFO* and *ML*. The intersection of the circle C_1 with *MAAFO* is the distal contact point *DCP*. Then, circle C_2 is constructed with a radius equal to *MDW/2*, that is half the mesiodistal width *MDW*. Its center is coincidental with that of C_1. The intersection of the circle C_2 with the *MAFFO* curve is the mid-point of tooth *TMP* and the incisal center point *ICP*.

The intersection of *MAAFO* and circles C_1 and C_2 are then constructed. The curve defined by *MAAFO* and the intersection of circle C_1 is the distal contact point *DCP*. The intersections of *MAAFO* and *MAAFO* circle segment lines are found. The *X* coordinates of the intersections are compared to the *X* coordinates of *DCP* to determine which segment's center will be used.

A distal contact point line *DCPL* is constructed from the selected segment center to the *DCP*. Similarly a center of tooth line *TMPL* is constructed from the sector center to the *TMP*. Thus, the tooth

LIMOC is on *MAAF* and the tooth mesiodistal width line is on the *MAAFO* arch. The location of *FIMOC* is accordingly determined by adding *DFL* to the *MAFFO* circle segment radius through the *TMP*.

The *MAAFO*, like the *MO* for the mandibular teeth, is discontinuous, with the archform being offset differently for the different maxillary teeth. Accordingly, for the maxillary laterals, the prior *MAAFO* is replaced with the *MAAF* adjusted such that the *MAAF* radii are increased by amount of *MAO* for lateral. The tooth's *MCP* is the tooth's *MAO* distance from the *MAAF* along the prior tooth's distal contact point line *DCPL*. Circle C_1 is constructed with a radius the mesiodistal width of the tooth and with a center at the tooth's *MCP*. The intersection of C_1 with the *MAAFO* is the tooth's *DCP*. Circle C_2 is constructed with a radius equal to half of the tooth's *MDW* and with a center coincident with that of circle C_1. The intersection of circle C_2 with *MAAFO* is the tooth's *ICP*.

Then, the intersections of *MAAFO* and the *MAAFO* sector lines are found. The *X* and *Y* coordinates of intersections are compared to the *X* and *Y* coordinates of *DCP* to determine which segment's center will be used. A distal contact point line *DCP* is constructed from the selected segment center to the *DCP*. Similarly a center of tooth line *TMPL* is constructed from the sector to the *TMP*.

For the maxillary cuspids, the prior *MAAFO* is eliminated. A new arch form, the maxillary cuspid arch form *MCAF*, is computed to place the cuspid between the lateral and the first bicuspid. In one preferred approach, the *MCAF* is constructed offset from the *BFBCE* by the average of the *OFFSETs* of the first bicuspid and the lateral, as calculated in substep (1135) above. With exception of a new arch radius, the cuspid is placed as above.

For the maxillary bicuspids and molars, the arch form *CGMRAF*, which is the *BFBCE*, is offset by *MBO*. *CGMRAF* is adjusted by adding *MBO* for the respective teeth. The cuspid tips on the *MCAF*, which was offset from the *BFBCE* to align with the buccal cusp tips of the first bicuspids in (1115) above, are thus in line with the posterior buccal cusp tips. From the cuspid *DCP*, circles C_1 and C_2 are constructed and *DCPLs* are established. This sequence is repeated for remainder of the teeth, completing the relation of the maxillary and mandibular occlusions. The finish positions of the maxillary teeth are illustrated Fig. 4D.

At this point, the final positions of the maxillary teeth have been calculated, and thus, the finish positions of all of the teeth.

Appliance Design Procedure (96)

The appliance design procedure includes the steps of (1200) determining the location of the mandibular archwire plane relative to the calculated finish positions of the mandibular teeth, (1300) calculating the angle of each mandibular bracket slot relative to the mounting surface of the respective tooth, (1400) determining the location of the maxillary archwire plane relative to the calculated finish positions of the maxillary teeth, (1500) calculating the angle of each maxillary bracket slot relative to the mounting surface of the respective tooth, (1600) calculating the shape of the mandibular archwire and the slot in-out dimension of each mandibular bracket, (1700) calculating the shape of the maxillary archwire and the slot in-out dimension of each maxillary bracket, and (1800) calculating the contours of bracket placement jigs for each tooth.

(1200) Mandibular Archwire Plane Step:

The next step is (1200) to establish the position of the archwire plane for the mandibular teeth, which is illustrated in detail in the flowchart of Fig. 2P. The archwire plane can be located in an infinite number

of vertical positions since the brackets and archwire will be designed to accommodate any chosen location. Since the overlap of the maxillary teeth is known, for labial bracket placement, the mandibular archwire plane is set to provide bracket clearance for the maxillary teeth in the finished occlusion. For lingual bracket placement, this consideration is given to the maxillary archwire plane instead, in step (1300) below.

Since the maxillary teeth do not pose a bracket interference dilemma with labial bracket placement, the brackets can be positioned for ease of placement, cosmetic considerations and gingival health. This applies to the mandibular bracket positioning where lingual bracket placement is used. Typically, these brackets are located more centrally than the brackets of the other arch.

More particularly, as illustrated in the flowchart of Fig. 2P and Fig. 8, (1200) to establish the archwire plane, (1205) the selected vertical occlusion and respective vertical overlap from *MOC* for cuspids, laterals and centrals is recalled from (1110). Then, (1210) with the information from (705), the buccal cusp height *BCH* is recalled for each bicuspid and molar. Next, (1215) the maximum *BCH* or anterior vertical overlap is chosen as the maximum vertical overlap *MVO*. Then, (1220) a distance equal to the *MVO* is measured downward from the *MOC*. Finally, (1225) half of the bracket height (typically 3.0 mm) plus an additional 0.75 mm is added for occlusal clearance. This defines the mandibular archwire plane *MAWP*. This places brackets as occlusal as possible with an 0.75 mm clearance from the worst case from the maxillary occlusion.

(1300) Mandibular Slot Inclination Step:

Once the archwire planes have been defined with respect to the teeth, as illustrated in the flowchart of Fig. 2Q, (1300) the angle between the bracket mounting surface of the teeth and archwire plane is determined. This angle minus 90° is the facial torque or inclination angle to be formed into the brackets. This also defines the bracket slot placement height which is the distance from the top of the incisal edge to the archwire plane. This distance is calculated perpendicular to the archwire plane.

Slotless bracket bodies (vanilla brackets) have now been positioned appropriately. A smooth archwire is then designed such that it will pass through the bodies of the brackets. The archwire must not cut too deeply into the bracket or pass even partially outside the face of the brackets. Brackets are chosen having different heights according to need. Without modifying buccal tube assemblies, standard bracket distances from the tooth surface to the center of the slot may be used as a seed values. The archwire equation is then mathematically derived from cubic spline and tangential circle techniques as previously described and provided in the routines (2000) and (2100). Both archwires are developed similarly.

Bracket angle determination (1300), more particularly, is achieved by (1305) taking the intersection of the *MAWP* and labial (buccal) surface of each mandibular tooth in the case of labial appliances, and the intersection of the *MAWP* with the lingual surface of each tooth in the case of lingual appliances. Then, (1310) circles are constructed with centers at the intersections and with diameters that represent the occluso-gingival (vertical) dimensions of the bracket bonding pad (typically 3.0mm). Then, (1315) *X, Y* coordinates of the circle intersections with labial (buccal) tooth surface are taken, and, with the equations:

$$R^2 = (X_2 - h)^2 + (Y_2 - K)^2$$

$$Y_2 = mX_2 + b_2$$

$$Y_3 = mX_3 + b_3$$

(1320) The slopes between the points of intersection are calculated to produce the facial inclination angle *FIA*, where:

h,k = coordinates of circle center

X_2,Y_2,b_2 = definition of first line segment

X_3,Y_3,b_3 = definition of second line segment

Then, as illustrated in Fig. 8A for labial appliances, π/2 radians are then subtracted to produce the slot inclination angle *SIA*:

$$FIA=\frac{Y_2-Y_3}{X_2-X_3}$$

$$SIA = FIA - \pi/2$$

(1400) Maxillary Archwire Plane Step:

The next step is (1400) locating the maxillary archwire plane as illustrated in the flowchart of Fig. 2R and diagram of Fig. 8. For the maxillary centrals, this involves (1405) finding the vertical distance from incisal edge to point P_4. (1410) The smallest value is selected and divided by two to produce the slot placement height for the maxillary centrals. (1415) For terminal maxillary bicuspids the vertical distance from buccal cusp to point P_4 is found. (1420) Again, the smallest value is selected and divided by two. This produces the slot placement height *SPH* for the terminal maxillary bicuspids.

For maxillary centrals, (1425) the *Y* value of *FIMOC* is subtracted from the *Y* value for the slot placement height *SPH*. This is the distance from *MOC* to the slot centerline. For terminal maxillary bicuspids, (1430) the *Y* value of *MOC* is subtracted from the *Y* value for the slot placement height *SPH*. This is the distance from *MOC* to the slot centerline. Then, (1435) the *SPH* for the terminal bicuspid from *SPH* for the maxillary centrals. This is elevation change *DH* of the maxillary archwire relative to the *MOC* from the centrals to the terminal maxillary bicuspids. (1440) The elevation of the maxillary archwire *MXAWP* from the *MOC*, or archwire height *AHT* on each tooth, is calculated as follows:

$$AHT = K + DH + SPH - MOC_Y + \textit{Vertical overlap from (1110)}$$

where *K* is the conversion factor from Table 3.

Tooth Type	Non-Extraction	Extraction (e.g. 2nd Bicuspid)
Maxillary Central	0.0	0.0
Maxillary Lateral	-0.19	-0.28
Maxillary Cuspid	-0.42	-0.62
Maxillary First Bicuspid	-0.68	-1.00
Maxillary Second Bicuspid	-1.00	NA
Maxillary First Molar	-1.32	-1.46

TABLE 3

(1500) Maxillary Slot Inclination Step:

Once the archwire plane is determined, as illustrated in the flowchart of Fig. 2S, (1500) the slot inclination angle *SAI* for each of the maxillary tooth brackets is determined in a manner similar to the slot

inclination determination step for the mandibular brackets (1300). This step (1505) begins by finding the intersection of the maxillary archwire plane *MXAWP* with the labial or buccal surface of each maxillary tooth. Then, (1510) circles are described, for each maxillary tooth, having centers at this intersection point and having diameters equal to the occluso-gingival, or vertical, dimensions of the bracket bonding pad, which is typically 4.0 mm. From these circles, (1515) *X,Y* coordinates of the intersections of the circles with the labial or buccal tooth surface are found, as follows:

$$R^2 = (X_1 - h)^2 + (Y_1 - k)^2$$

$$Y_2 = mX_2 + b_2$$

$$Y_3 = mX_3 + b_3$$

Where: h,k = coordinates of the circle center

X_1,Y_1 = possible coordinates on the circle

X_2,Y_2,b_2 = definition of a first line segment

X_3,Y_3,b_3 = definition of a second line segment

Then, as illustrated in Fig. 8A, (1520) $\pi/2$ radians are then subtracted to produce the slot inclination angle *SIA*:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - \pi/2$$

(1600) Mandibular Archwire and Slot Depth Step:

The next step, as illustrated in the flowchart of Fig. 2T, is (1600) to determine the mandibular archwire and bracket in-out dimension. First, (1605) the circle segment of the *BFBCE* with which the *ICP* of the right central is associated is determined, as illustrated in Fig. 8B. Then, (1610) the incisal center point and circle segment center point plane *ICPCDCPP* is created normal to the arch planes. An incisal center point line *ICPL* is struck that will pass through the *ICP* and a particular circle segment center point *CSCP* associated with the tooth. Then (1615) the Pythagorean distance *PD* from *CSCP* to *ICP* is determined. Then, (1620) viewing the tooth in the *ICPCSCPP*, as illustrated in Fig. 8C, a line *NL* is struck normal to the *BFBCE* plane through the *ICP*, which is the intersection of *CLA* and *BFBCE*. Next, (1625) still viewing the tooth in this plane, the intersection point *XP* of *NL* and *MAWP* is determined.

Still viewing the tooth in the *ICPCSCPP*, (1630) the *X* distance *XD* to the labial surface of the tooth from the *XP* is determined, and (1635) *PD* is added to *XD* and the lower limit of the bracket slot *LLBS*. The *LLBS* is a distance associated with the particular bracket that will be placed on this tooth. It is the deepest slot allowable for that bracket. Then, the lower limit *LL* is calculated thus:

$$LL = PD + XD + LLBS$$

Similarly, (1640) *PD* is added to the *XD* and the upper limit of the bracket slot *ULBS*. The *ULBS* is also a distance associated with the particular bracket that will be placed on this tooth. It is the shallowest slot allowable for that bracket. The, the upper limit *UL* is calculated thus:

$$UL = PD + XD + ULBS$$

(1645) Then, viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *LL* distance, *X* and *Y* points, $AWLL_{X,Y}$, are determined relative to an origin at the

intersection of *BFBCE* and the mandibular midline *ML*. Then,(1650) viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *UL* distance, *X* and *Y* points, $AWUL_{X,Y}$ are determined relative to the intersection of *BFBCE* and the mandibular midline *ML*. Then, (1655) the mid-point of $AWLL_{X,Y}$ and $AWUL_{X<Y}$ is found and steps (1605) through (1650) are then repeated for all mandibular teeth.

Then, (1660) the average mid-point and distance from right to left is calculated to force mandibular archwire symmetry:

$$S_X = MP_X + \frac{PR_X - PL_X}{2}$$

$$S_Y = MP_Y + \frac{PR_Y + PL_Y}{2}$$

Where: $S_{X,Y}$ is the symmetricalized point.

MP is the mid-point of *BCBCE*.

PR is a point on the right side of the midline.

PL is a point on the left side of the midline.

The smoothest curve *SC* that will pass between all $AWLL_{X,Y}$ and $AWUL_{X,Y}$ points is then determined, as illustrated in Fig. 4E. This is accomplished by the following procedure:

a) The mid-point of each $AWLL_{X,Y}$ and $AWUK_{X,Y}$ pair is found.

b) Then, as described above, a cubic spline equation is passed through these points.

c) The existence of any inflection points is determined.

d) The curve with the least variation in radius changes along the curve is considered the smoothest curve. Preferably, it has no inflection points. If there are one or more inflection points, a logical alternative bracket solution will be derived based upon where the inflection occurred.

Then, (1665) the intersection point *XSCICPL* of the mandibular right central's *ICPL* is determined as well the smoothest curve as defined above in substep (1660). Next, (1670) the in-out *IO* of that particular tooth is determined as the distance along *ICPL* from *ICP* to *XSCICPL* minus that tooths' *XD*. Then, (1675) steps (1665) and (1670) are repeated until all in-out dimensions are calculated.

Finally, (1675) all *XCSICPL* points are passed into the cubic spline routine (2000) and to circle routine (2100) and (1680) all circle segment information gathered therefrom are converted to linear distance *LD* moves needed to bend the appropriate wire, as will be further explained in connection with the wire bending step (3200) below. The bracket slot cutting is described in connection with step (3000) below.

(1700) Maxillary Archwire and Slot Depth Step:

The next step, as illustrated in the flowchart of Fig. 2U, is (1700) to determine the maxillary archwire and bracket in-out dimension. As with the mandibular determination step (1600), (1705) the circle segment of the *BFBCE* with which the *ICP* of the right central is associated is determined. The step is similar to that for the mandibular slot in-out dimension calculation of Figs. 4E and 8C, except that the maxillary centrals and laterals are associated with the *MAAF* rather than the *BFBCE*, the maxillary cuspids are associated with *MCAF*, and teeth posterior to the cuspid are associated with the *BFBCE*.

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The calculation proceeds with (1710) the incisal center point and circle segment center point plane *ICPCDCPP* being created, with a line being struck that will pass through the incisal center point line *ICPL* which will pass through the *ICP* and a particular circle segment center point *CSCP* associated with the tooth. The plane passing through the *ICP* and the *CSCP* and normal to the mandibular trough *MT* is the *ICPCSCPP*. Then (1715) the Pythagorean distance *PD* from *CSCP* to *ICP* is determined. Then, (1720) viewing the tooth in the *ICPCSCPP*, a line *NL* is struck normal to the *BFBCE* through the intersection of *CLA* and *BFBCE*. Next, (1725) still viewing the tooth in this plane, the intersection point *XP* of *NL* and *MAWP* is determined.

Still viewing the tooth in the *ICPCSCPP*, (1730) the *X* distance *XD* to the labial surface of the tooth from the *XP* is determined, and (1735) *PD* is added to *XD* and the lower limit of the bracket slot *LLBS*. The *LLBS* is a distance associated with the particular bracket that will be placed on this tooth. It is the deepest slot allowable for that bracket. Then, the lower limit *LL* is calculated thus:

$$LL = PD + XD + LLBS$$

Similarly, (1740) *PD* is added to the *XD* and the upper limit of the bracket slot *ULBS*. The *ULBS* is also a distance associated with the particular bracket that will be placed on this tooth. It is the shallowest slot allowable for that bracket. The, the upper limit *UL* is calculated thus:

$$UL = PD + XD + ULBS$$

(1745) Then, viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *LL* distance, *X* and *Y* points, $AWLL_{X,Y}$, are determined relative to the intersection of *BFBCE* and the mandibular midline *ML*. Then, (1750) viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *UL* distance, *X* and *Y* points, $AWUL_{X,Y}$ are determined relative to the intersection of *BFBCE* and the mandibular midline *ML*. Then, (1755) The mid-point of $AWLL_{X,Y}$ and $AWUL_{X,Y}$ is found and steps (1705) through (1750) are then repeated for all mandibular teeth.

Then, (1760) the average mid-point and distance from right to left is calculated to force mandibular archwire symmetry:

$$S_X = MP_X \frac{PR_X - PL_X}{2}$$

$$S_Y = MP_Y \frac{PR_Y + PL_Y}{2}$$

Where:

$S_{X,Y}$ = the symmetricalized point.

MP = the mid-point of *BCBCE*.

PR = a point on the right side of the midline.

PL = a point on the left side of the midline.

Then the smoothest curve *SC* that will pass between all $AWLL_{X,Y}$ and $AWUL_{X,Y}$ points is determined. This is accomplished by the following procedure:

a) The mid-point of each $AWLL_{X,Y}$ and $AWUK_{X,Y}$ pair is found.

b) Then, as described above, a cubic spline equation is passed through these points.

c) The existence of any inflection points is determined.

d) If there are no inflection points, this is considered the smoothest curve. If there is an inflection point, a logical alternative bracket solution will be derived based upon where the inflection occurred. The relevant information necessary to determine a new pair of $AWLL_{X,Y}$ and $AWUL_{X,Y}$ and their midpoints is undertaken. It should be noted that there are varying *LLBS* and *ULBS* possibilities available for each tooth.

Then, (1765) the intersection point *XSCICPL* of the mandibular right central's *ICPL* is determined as well the smoothest curve as defined above in substep (1760). Next, (1770) the in-out of that particular tooth is determined as the distance along *ICPL* from *ICP* to *XSCICPL* minus that tooths' *XD*. Then, (1775) steps (1765) and (1770) are repeated until all in-out dimensions are calculated.

Finally, (1775) all *XCSICPL* points are passed into the spline to circle program and (1780) all circle segment information gathered therefrom are converted to linear distance *LD* moves needed to bend the appropriate wire, as will be further explained in connection with the wire bending step (3200) below. The bracket slot cutting is described in the discussion of step (3000) below.

(1800) Placement Jig Design Step:

With the shapes of the individual teeth determined, their finish positions calculated, and the brackets designed and their places on the individual teeth determined, the information necessary for the design of bracket placement jigs to aid the orthodontist in positioning the brackets in their proper positions on the individual teeth is available. In the preferred embodiment of the invention, the design of the placement jigs is carried out in the software associated with the jig manufacturing step (3500) described below, following a loading of the appropriate files with the necessary data from the calculations described above into the manufacturing control computer 30c. An abbreviated presentation of the jig design substeps is set forth in the flowchart of Fig. 2V.

Referring to Fig. 2V, (1805) a file containing data of the individual tooth profiles, the archwire plane location including data relating each of the tooth profiles to the relevant archwire plane, the bracket profiles relevant to each tooth, and the bracket design data including the slot size, inclination and depth, are prepared. Then, (1810) the tools that will form the jig are determined, and (1815) clearances are established. Then, (1820) data needed for instructions to cut an internal profile into each jig is assembled to hold a bracket and to locate the bracket at the proper position on the tooth by precise fitting of the jig over the tooth profile along a labial-lingual plane through the tooth midpoint *TMP*.

The details of the jig design step, as it is performed along with the jig manufacturing step, is described in detail in connection with the description of the flowchart of Fig. 2Z under step (3500) below.

Subroutines

Three subroutines are used in calculating various archforms and calculating the positions of the teeth thereon. These are (2000) the cubic spline equation curve calculation subroutine, (2100) the spline equation to circle segment equation conversion subroutine, and (2200) the tooth placement subroutine. These are illustrated in the flowchart of Fig. 2W.

(2000) Cubic Spline Equation Fitting Subroutine:

In the cubic spline interpolation, symmetrical data points are interpolated and a cubic spline equation is derived. As illustrated in Fig. 5A, a symmetrical mandibular trough or cubic spline equation *SMT* is shown for one side of the lower jaw. In Fig. 5A, the point $M_x M_y$ represents the intersection of the curve and the midline *ML*. The points $SI_x SI_y$ for *I = 1 to 6* represent the symmetricized points X_{MI} referred to above.

The cubic spline method uses a cubic (3rd degree) polynomial to interpolate between each pair of data points. A different polynomial is used for each interval, and each one is constrained to pass through the original data points with the same slope as the data. At these points, slopes are computed by finding the slope of the parabola that passes through each data point and its two nearest neighbors.

The iterations necessary to compute the cubic polynomial are as follows:

1) For each data point, the *X* and *Y* coordinates are made equal to zero and all other data points evaluated relative to this new original.

2) The slopes of the cubic spline are computed by first computing the coefficients of the above described parabola, then a first point of a slope array is filled followed by the remaining points through the final slope array point.

3) The spline coefficients are computed.

4) The polynomial is evaluated.

These steps are described in Science and Engineering Programs, Apple II Edition, Edited by John Heilborn, and published by Asborne / McGraw - Hill. Copyright, 1981, McGraw - Hill, Inc., and incorporated herein by reference.

Once the polynomial has been evaluated, it is possible to acquire additional data points. A *Y* value can be determined for any given *X* value, with the constraint that additional data points be within the upper and lower limits of the original *X* values. The following iterations are performed before circle conversion:

1) Determination of *X* and *Y* points on each side of the original data points. This is done by taking *X* points that are one thousandth (.001) to each side of original *X* data points. Then *X* values two thousandths (.002) less than the last data point are taken. Then *Y* points are determined for each arrayed *X* point by evaluation of the polynomial equation discussed above. Then the *Y* points of the array are calculated.

2) The slope array is then filled with slopes corresponding to data points on either side of the original data points.

3) The slope of the curve at each of the original data points is calculated. This involves retrieving *X* and *Y* points on either side of original data points, and calculating the slope at the original data points using the Point Slope method according to:

$$SLOPE = \frac{Y_2 - Y_1}{X_2 - X_1}$$

Where:

SLOPE = the slope of the curve at that point.

XI = the *X* point .001 to left of original data point.

YI = the *Y* point associated with *XI*.

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$X2$ = the X point .001 to right of original data point.

$Y2$ = the Y point associated with $X2$.

The slope is calculated using the arrayed point that is .002 less than the last data point and the last data point, and the slope is calculated using the point slope method as all array slopes are calculated.

(2100) Circle Segment Conversion Subroutine:

The circle segment conversion typically fits two circle segments into one spline segment. A spline segment is defined as the interpolated cubic spline equation which describes the shape of the curve between two original data points. A circle segment is defined as the arc associated with a beginning point, or end point, and the slope of tangency at that point. Two configurations of circle segments are possible when converting a spline segment into two circle segments, one where the first circle is larger than the second (Fig. 5B) and the other where the first circle is smaller than the second circle Fig. 5C, the variables in which are identified below. The iterations necessary to convert a spline segment into two circle segments are illustrated in Fig. 5D in which:

$P1_X,P1_Y$ = the beginning point of spline segment

$P2_X,P2_Y$ = end point of spline segment

$MT1$ = tangent slope of spline at point $P1_X,P1_Y$

$MN1$ = normal slope of $MT1$

$MT2$ = tangent slope at point $P2_X,P2_Y$

$MN2$ = normal slope of $MN2$

$P3_X,P3_Y$ = intersection of a line through point $P1_X,P1_Y$ with a slope of $MT1$ and a line though point $P2_X,P2_Y$ with a slope of $MT2$

CL = a Cord Line, a line connecting points $P1_X,P1_Y$ and $P2_X,P2_Y$

CNL = a Cord Normal Line, a line normal to CL through $P3_X,P3_Y$

hs,ks = the center of the smaller of the two circle segments

The iterations to convert a spline segment into two circle segments are, as follows:

1) Determine $MN1$ and $MN2$. They are the negative inverse of $MN1$ and $MT2$, respectively.
2) Determine the intersection point $P3_X,P3_Y$.
3) Determine the slope of the CL.
4) Determine the slope of CLN.
5) Determine the distance from $P1_X,P1_Y$ to $P3_X,P3Y$. This is defined as test one.
6) Determine the distance from $P2_X,P2_Y$ to $P3_X,P3_Y$. This is defined as test two.
7) Test to determine which length is smaller. If the test one result is shorter than the test result, the smaller circle is associated with $P1_X,P2_Y$, otherwise, the smaller circle is associated with $P2_X,P2_Y$.
8) Rename the variable associating to the size of the circle. See Fig. 5B in which:

$P1_X,P2_Y$ = the beginning point of spline segment

$P2_X,P2_Y$ = the end point of spline segment

MNS = the normal slope of small circle segment, equivalent to $MN1$ or $MN2$ depending on the relative results of test one and test two

MNL = normal slope of large circle segment

hs,ks = the center of the smaller of the two circle segments

hl,kl = the center of the larger of the two circle segments

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$P6_x,P6_y$ = a distance, defined by the radius of the small circle, to a point along *MNL* from the spline segment point associated with it

MNF = is the slope of the final line

9) Determine the intersection of the line described by slope of *CNL* and passing through $P3_x,P3_y$ and the line described by *MNS* through the spline segment point associated with it. The intersection point of these two lines is the center of the smaller circle *hs,ks*.

10) Determine the Pythagorean distance from the small circle center *hs,ks* to the spline segment points associated with it. This distance is the radius of the small circle *rs*.

11) Move along the line described by *MNL* and passing through the spline segment point associated with it by the radius of the smaller circle *rs*. This point is $P6_x,P6_y$.

12) Strike a line from $P6_x,P6_y$ to *hs,ks*.

13) The negative inverse of the slope of the line from $P6_x,P6_y$ and *hs,ks* is *mnf*.

14) Determine the midpoint of the line from $P6_x,P6_y$ to *hs,ks*.

15) Determine the intersection of the line described by a slope of *mnf* and passing the point described in step 14 and the line described by *MNL* and through the spline segment point associated with it. The intersection point of these two lines is the center of the larger circle *hl,kl*.

16) Determine the Pythagorean distance from the large circle center *hs,ks* to the spline segment points associated with it. This distance is the radius of the larger circle *rl*.

17) The intersection of the two circles is defined as the intersection of the line going through the large circle center *hl,kl* and the small circle center *hs,ks* and either of the circles. At this point the tangency of the two circles are equivalent.

18) Accommodate an arc length calculation dependent upon which spline point is closer to $P3_x,P3_y$:

If the test one result is greater than that of test two, then:

Theta1 = *ATN(m) - ATN(MSl)*

Theta2 = *ATN(MLl) - ATN(m)*

otherwise:

Theta1 = *ATN(msl) - ATN(m)*

Theta2 = *ATN(m) - ATN(mll)*

where:

$$m=\frac{k1-ks}{h1-hs}$$

Theta1 = the arc angle of the smaller circle

Theta2 = the arc angle of the larger circle.

19) Calculate arc length for each segment.

s1 = *rs (Theta1)*

s2 = *rl (Theta2)*

where:

s1 = arc length of smaller segment

s2 = arc length of larger segment

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20) Calculate the running arc length.

21) Continue distally until all spline segments are converted.

Figs. 5E-5J illustrate the building of the mandibular trough data points into circle segments.

(2200) Tooth Placement on Curve Subroutine:

The individual tooth placement upon an equation is required in many steps of the tooth finish position calculation procedure (94). The preferred method is described here in connection with the first occurrence in the procedure for the placement of the mandibular teeth.

There are four alternative equations upon which teeth can be placed: the mandibular trough *MT* equation, the maxillary anterior arch form *MAAF* equation, the maxillary cuspid arch form *MCAF* equation, and the central groove marginal ridge arch form *MGMRAF* equation. All occlusion equations will have been converted to circle segments before teeth are placed upon them. A typical tooth placement is illustrated in Fig. 5N, in which:

DCP = Distal Contact Point

ICP = Incisal Center Point

MCP = Mesial Contact Point

MCPL = is the Mesial Contact Point Line.

The *DCP* is the point at which the tooth contacts the proceeding tooth. The *ICP* is the center of the tooth being placed. The *MCP* is the point at which the tooth contacts the preceding tooth. The *MCPL* is defined as the line through the *DCP* of the tooth being placed and the center of the circle segment associated with the *DCP*. The *MCPL* is the line upon which the *DCP* of the proceeding tooth will be found.

The iterations to place the teeth onto the circle segments are:

1) Determine the offset distance for the mandibular central tooth on the side of the jaw under consideration.
2) Expand all circle segments about their centers by the offset amount.
3) Determine the intersection of the first circle segment and the midline. This is the mesial contact point *MCP* of the central, as illustrated in Fig. 5K.
4) Place the first circle C_1, whose radius is the mesio-distal width of the tooth, at *MCP*, as illustrated in Fig. 5K.
5) Determine which circle segment in the distal direction circle C_1 intersects and identify the intersection point. This is accomplished by performing an iteration which begins by transferring the coordinate system to the beginning point of the circle segment, as illustrated in Fig. 5L, in which:

X_{BEG}, Y_{BEG} = beginning coordinates of the circle segment

X_{END}, Y_{END} = End points of the circle segment

X_{INT}, Y_{INT} = coordinates of circle intersection

X and *Y* axes are oriented at X_{BEG}, Y_{BEG}.

The two following circle equations are then solved simultaneously:

$$R_1^2 = (x - h1) + (y - k1)$$

$$R_2^2 = (x - h2) + (y - k2)$$

Where:

h1,k1 = the center coordinates of the first circle

h2,k2 = the center coordinates of the second circle

R_1 = the radius of the first circle C_1

R_2 = the radius of a second circle C_2

X, Y = coordinates of possible intersection points

The following solutions are possible: (1) two real solutions which are labeled XI_{INT}, YI_{INT} and $X2_{INT}, Y2_{INT}$, respectively. (2) imaginary solutions, which are discarded, whereupon the next circle segment is evaluated. If intersections are real, the circle segment is rotated, as illustrated in Fig. 2M, such that X_{END}, Y_{END} is placed on the X axis. Then, X_{ZERO}, Y_{ZERO} is subtracted from the rotated X intersection point XI_{INT} or $X2_{INT}$, and rotated X_{END} is subtracted from the rotated X intersection point XI_{INT} or $X2_{INT}$. If the signs of the results of the two subtractions are opposite, the rotated intersection point is tested for a value less than zero. If it is not less than zero, the other rotated intersection point is tested to determine if it is valid. The testing continues until a segment is found such that the subtractions produce opposite sign results and the associated rotated Y intersection point is less than zero. This is the distal contact point *DCP* of the tooth, as illustrated in Fig. 5N.

6) Construct a line passing through the *DCP* and the center of the circle segment that intersects C_1.

7) Place circle C_2, whose radius is one half the mesio-distal width *MDW* of the tooth, at the *MCP*.

8) Determine which circle segment in the distal direction intersects circle C_2 and identify the intersection point. This is the incisal center point *ICP* of the tooth, as illustrated in Fig. 5N.

9) Eliminate all expanded circle segments.

10) Determine the offset distance for the mandibular lateral.

11) Expand all circle segments about their centers by the offset amount.

12) Determine the intersection point of the expanded circle segment *ECS* associated with the *DCP MCP Line*. The intersection point is the mesial contact point *MCP* of the lateral, as illustrated in Fig. 5O.

13) Place circle C_1, with radius the mesio-distal width *MDW* of the lateral, at the current *MCP* point.

14) Determine which circle segment in the distal direction circle C_1 intersects and identify the intersection point, which is the *DCP* of the lateral.

15) Construct a line passing through the *DCP* and the center of the circle segment that intersects C_1.

16) Place circle C_2, whose radius is one half the mesio-distal width *MDW* of the tooth, at the *MCP*.

17) Determine which circle segment in the distal direction intersects circle C_2 and identify the intersection point. This is the incisal center point *ICP* of the tooth, as illustrated in Fig. 5P.

18) Continue distally until all teeth are placed.

19) Perform the same iterations for the co-lateral side of the arch.

(97) Appliance Manufacturing Procedure

The appliance manufacturing procedure (97) includes the steps of (3000) manufacture of the custom brackets, (3200) manufacture of the custom archwires and (3500) manufacture of custom placement jigs for placement of the custom brackets on the patient's teeth. These steps are described in detail below for the embodiment in which all of the manufacturing is carried out at the appliance design facility 13.

(3000) Bracket Manufacturing Step:

The bracket manufacturing step (3000) produces the custom brackets, preferably by selecting bracket blanks and cutting a torque slot in the bracket for the archwire 64. This utilizes the modified CNC mill 40 illustrated in Fig. 2D. The bracket slot cutting step is illustrated in the detailed flowchart of Fig. 2X.

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Referring to Fig. 2X, the bracket manufacturing step (3000) begins with the computer 30c (3005) loading the data for each bracket from the patient data file 36.

For each tooth and bracket, as a default or initial selection, (3010) low profile brackets are assumed. Then, the slot angle *FAI* and the slot in-out dimension *IO* are read. Also, (3020) the radius of the archwire at the tooth midpoint is determined.

Then, (3025) a main CNC program is created and (3030) the program loops to generate the code for the cutting of each bracket, beginning with the calculation of the variables for the bracket, (3040) assigning the variables for each bracket to (3045)-(3050) set the cutting of the slot at the appropriate angle by rotating the bracket support 73 and setting the cutter 77c to a cooperating height *Z* and horizontal *X* position. If the position of the slot lies outside of the area of the bracket, a bracket of the appropriate higher profile is called for by the program, and loaded, either automatically or by an operator. The code is then generated (3055) to control the path of the cutter in the *Y* direction to cut the archwire radius in the slot bottom. (3060) then, the NC code is combined with the calculated variable values for the tooth and bracket and a subroutine is generated for the bracket, with (3065) the P-codes subroutines written the file. (3068) The program loops until codes for all of the brackets are complete.

Then, (3070) the CNC code is preferably downloaded to an NC controller and the brackets are formed by the cutting of the slots in the series of bracket blanks, and (3080) a report is written.

(3200) Archwire Manufacturing Step:

The archwire manufacturing step (3200) produces the archwire 64, as illustrated in Fig. 2E, preferably that is symmetrical about its archwire midline *AML*, having the appropriate terminal leg span *TLS*, formed of a series of circle segments.

As illustrated in the flowchart of Fig. 2Y, the archwire manufacturing step (3200) executes a program with the manufacturing control computer 30c to generate a CNC code to operate the wire forming machine 40. The program begins by (3215) opening one or more files from the calculated patient data 36 and reads therefrom the wire alloy and the wire cross-section prescribed, and an array of data that contains a series of *j* sets of data including the radius and sector length of each circle segment of which the archwire curve is formed, and the calculated total cumulative archwire length. To the archwire equation, (3220) a radii and sector lengths are added to produce a one half inch of straight segment at each end of the wire to form parallel terminal leg extensions. Then, calculating the cumulative slopes and sector lengths of the wire along the equation, (3225) the terminal leg span *TLS* is calculated.

Based upon the wire type selected, (3230) one of several data files or tables are read. For rectangle wire, for example, four files would include: (1) 0.022" thickness stainless steel (SS), (2) 0.025" thickness SS, (3) 0.022" thickness titanium molybdenum alloy (TMA), and (4) 0.025" thickness TMA. Other files are provided for round wires of various diameters and types.

Then, using the cubic spline subroutine (2000), (3235) the slopes of the cubic spline equation describing wire behavior are calculated by: (1) computing the coefficients of a parabola, (2) filling the first point of a slope array, (3) filling the intermediate points of the slope array, and (4) filling the last point of the slope array. Then, (3240) the cubic spline coefficients are calculated. Then, (3245) the vertical displacement of the bending lever arm *LA* (Fig. 2E) between the contact points of the roller 70b with the wire 69 and the contact point of the rollers 68 with the wire 69 is determined for each circle segment of the archwire equation, and data added to the array.

Then, (3255) temporary variables are defined for the sector length, lever arm displacement, radius and terminal leg span across the straight segments of the archwire, (3260) the controller card 65 of the computer 30c is initialized, (3265) the controller base address is set, and (3270) default parameters are set. Then, (3275) a sequential series of sector lengths and lever arm displacements are sent respectively (1) through the circuits 66a and 67a to the drive of the feed rolls 68, and (2) through the circuits 66b and 67b to the anvil assembly 70.

When all circle segments have been formed, (3280) the lever arm displacement is zeroed and (3285) the wire leg location is read by the sensor 71. This reading converted to a numerical value in the computer 30b and any difference in the actual measured terminal leg span and the desired terminal leg span *TLS* is calculated. If (3290) the difference is out of tolerance, a correction is made and another wire is formed.

(3500) Jig Manufacturing Step:

The jig manufacturing step (3500) produces bracket placement jigs custom designed for each tooth to aid in the placement of the custom designed brackets in the proper positions on the teeth so that the custom designed archwire will, when installed in the custom designed and custom placed brackets, move the teeth to their calculated finish positions.

The information necessary for the design of the custom placement jigs is contained in the patient data file of from the calculations made in the appliance design procedure (96) and in the tooth profile data file of digitized information read in step (500), in the illustrated embodiment of the invention. The design of the custom jigs involves, primarily, an assembly of the information already generated, and, in the preferred embodiment, takes place in the course of generating the code for control of the NC controlled manufacturing equipment 41 that produces the jigs.

In the preferred and illustrated embodiment, the jig manufacturing equipment 41 is a standard CNC mill equipped with a small carbide endmill tool of, for example, 0.020 inches in diameter (Fig. 1F). The jigs themselves 82 are made from circular ABS plastic wafers 83 of approximately one inch in diameter and approximately 0.040 inches in thickness, though considerable variation in size is acceptable.

The jig manufacturing step (3500), as illustrated in the detailed flowchart of Fig. 2Z, begins with the execution of a program or routine in the manufacturing computer 30b and the input of parameters identifying the patient or case. Upon beginning of the execution of the program, (3515) the file of patient data 36 generated in the tooth position calculation and analysis procedure (95) and the appliance design procedure (96) is opened and information is read for each tooth, as illustrated in the diagram of Fig. 9I, in relation to a tooth profile *PF*. The variables read are (a) the intersection of the archwire plane and the labial (or lingual, if prescribed) surface of the tooth *TS*, which is in the form of a pair of *X,Y* coordinates $TS_{X,Y}$ in the tooth profile vertical-labial/lingual plane, (b) the slot in-out dimension *Elan* or *IO*, (c) the type of bracket, which provides access to the appropriate place in a lookup table of bracket dimensions, such as bracket base thickness *BRel* and bracket pad height *BPH*, and (d) the torque slot width, 0.018 or 0.022 from the prescription.

Then, (3520) the bracket data file is opened and the bracket base thickness read, as illustrated in Fig. 9J. Then, a file name is assigned, (3530) a CNC file is created, and (3535) a CNC "main" program is written to it, as set forth, for example, in the flowchart of Fig. 2Z-1.

Then, (3540) a sequential file is identified that contains the beginning and ending object number for each tooth profile, and (3545) a CAD program file containing the tooth profiles PF_i is loaded. The profiles

PF, as illustrated in Fig. 3C, are made up of a series of closely spaced points in the profile plane, each represented by *X,Y* coordinates, connected by straight line segments to define the profile curve *PF*. The endmill tool diameter *Endmill* is also entered, which must be less than the archwire diameter or archwire slot width (0.018 or 0.022). Constants are declared, including the diameter of the jig blank 83, the cut clearance on the outside of the jig, the number of loops, set at 23, and the counter initial settings.

Then, (3560) the CNC P-code is generated for each tooth, by looping through substeps (3560) through (3639) until the code for each of the jigs 82 is generated. The loop begins by (3560) incrementing the tooth and P-code counters by 1. The loop begins with the lower left bicuspid, as brackets are usually not used on the molars, and proceeds left to right. Thus, (3565), when the incrementing of the counter advances the count to the lower right molar, (3565) the counter is advanced to skip to the upper left bicuspid.

Then, (3570) the parameters for the particular tooth are set up as illustrated in the flowchart detail of Fig. 2Z-2. This is followed by creating the profile and bracket clearance compensation tool paths *ITP* and *BCTP*, respectively, as illustrated in the flowchart detail of Fig. 2Z-3. This involves (3590) the creation of an initial inside tool path line *IITP* made up of a series of straight line segments, one parallel to each of the line segments of the tooth profile curve, spaced a distance equal to the tool radius on the inside of the profile curve, as illustrated in Fig. 9K, (3595) the creation of an initial bracket base compensation tool path line *IBCTP* made up of a series of straight line segments, one parallel to each of the line segments of the tooth profile curve, spaced a distance equal to the bracket base dimension minus the tool radius outside of the profile curve, as illustrated in Fig. 9L, and (3600) creation of the final bracket base compensation tool path *(d)* to cut from the inside tool path line to the base compensation line at the top of the bracket base pad to cut off the jig at the bottom of the pad, as illustrated in Fig. 9M ("top" and "bottom" being used as an example for the lower teeth, and being opposite for the upper teeth).

Next, (3605) the archwire slot tool path *ASTP* is created as illustrated in the flowchart detail of Fig. 2Z-4, which can be understood from the sequence set forth in the flowchart with reference to the diagrams of Figs. 9N, 9O and 9P. Then, as set forth in the flowchart detail of Fig. 2Z-5, (3610) a reference tool path *RefP* is created on an image of a jig blank 83, as illustrated in Fig. 9Q, and with reference to it, (3615) the outside jig boundary cutout *CTP* is added as illustrated in Fig. 2R, and (3620) the actual tool path *TP* is then generated as illustrated in Fig. 9S.

Then, (3625) the CNC machine code is generated, as illustrated in the detailed flowchart of Fig. 2Z-6, and written to the output file. Then, (3630) the variables are reset, (3635) the final results are displayed, and (3640) the program loops back to substep (3560) until all of the bracket jig code have been generated. Then, (3645) the completed CNC file is sent to the controller of the CNC mill and a pallet of wafers 83a (Fig. 1F) is cut into a set of bracket placement jigs 82. An example of one of the jigs is illustrated in Figs. 9T through 9W.

What is described above includes the preferred embodiments of the invention. Those skilled in the art will appreciate that additions to and modifications of the system and method of the invention, and the detailed manifestations thereof, may be made without departing from the principles of the inventive concepts set forth herein. Accordingly, the following is claimed:

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Claims:

1. A method of fabricating a custom orthodontic appliance to position teeth of a patient to preferred finish positions in the mouth of the patient, the method comprising the steps of:

measuring anatomical shapes from the mouth of the patient, and producing thereby digitized anatomical shape data;

deriving an archform from the digitized data with a specially programmed digital computer;

deriving with the computer tooth finish positions from the digitized data and the derived archform;

establishing appliance connection points, one on each of a plurality of the teeth;

designing, with the computer from the digitized data, the established appliance connection points and the derived tooth finish positions, an appliance configuration such that a custom appliance fabricated in accordance therewith and connected at the appliance connection points to the teeth, will exert substantially no tooth moving forces on the teeth when in the derived tooth finish positions, and will otherwise urge the teeth toward the derived finish positions;

producing machine code in accordance with the designed appliance configuration; and

automatically fabricating a custom orthodontic appliance with a NC machine in response to the machine code to conform to the designed appliance configuration.

2. The method of claim 1 wherein the teeth include mandibular teeth and maxillary teeth and wherein:

the dental anatomical shape measuring step includes the steps of the measuring the lower jaw of a patient and producing thereby digitized data of lower jaw shape, and measuring mandibular and maxillary teeth of the patient and producing thereby digitized data of individual mandibular and maxillary tooth shape;

the archform deriving step includes the step of deriving with the computer a mandibular skeletal archform from the digitized lower jaw shape data; and

the tooth finish position deriving step includes the step of deriving tooth finish positions from the tooth shape data and the derived mandibular skeletal archform to arrange the teeth with respect to the mandibular skeletal archform.

3. The method of claim 2 wherein each tooth has a crown, a root and a long axis extending generally vertically through the center of the crown, intersecting a gingival center point where the crown meets the root, and wherein:

the lower jaw measuring step includes the step of digitizing data points defining a mandibular trough in which mandibular tooth roots are to be confined;

the mandibular skeletal archform deriving step includes the step of fitting a smooth continuous mandibular trough equation to the digitized mandibular trough data points and producing a digitized representation of the mandibular trough equation;

the mandibular tooth finish position deriving step includes the deriving positions which center each mandibular tooth by placing the long axis thereof approximately on the mandibular trough equation near the gingival center point of the tooth, and which place the tips of the mandibular teeth on a smooth continuous curve derived by adjusting the mandibular trough equation; and

the appliance configuration designing step includes defining the appliance configuration by a series of digital values derived from the smooth continuous curve.

4. The method of claim 1 wherein:

the measuring step includes the step of digitizing data of the shape of the lower jaw of the patient by digitizing boundary points corresponding to boundaries of the patient's cortical bone;

the archform deriving step includes the step of deriving from the digitized data a skeletal archform mathemetically representing the shape of the patient's cortical bone by a smooth continuous equation derived from the digitized boundary points.

5. The method of claim 4 wherein:

the smooth continuous equation is a cubic spline equation through points related to the digitized boundary points.

6. The method of claim 1 wherein the archform deriving step comprises the step of:

defining a curve based on the digitized anatomical shape data and smoothing the curve by a best fit statistical method to produce smooth continuous archform equation, the finish position deriving step and the appliance configuration designing step being based at least in part on the archform equation.

7. The method of claim 1 further comprising the steps of:

digitally representing the derived archform by an archform equation in the computer;

representing the archform equation by a series of successively tangent circle segments;

the appliance configuration designing step includes the step of designing an arcuate appliance at least in part in accordance with a series of digital values representing circle segment lengths and radii derived from the circle segments of the archform equation;

the appliance fabricating step includes the step of converting the segment lengths and radii to a series of NC commands to produce the machine code, and, in response to the code, sequentially forming the appliance to a radius corresponding to each segment length thereof in response to the machine code to conform to the designed appliance configuration.

8. The method of claim 1 wherein:

the tooth measuring step includes the step of digitizing the distances between mesial and distal contact points for each tooth to define mesial-distal widths for each tooth;

the tooth finish position deriving step includes the step of deriving tooth finish positions to place adjacent mesial and distal contact points of adjacent teeth in mutual contact to form a tooth placement arch conforming in shape to the derived archform and approximately equal in length to the sum of the mesial-distal widths of the teeth placed thereon; and

the appliance configuration designing step includes the step of designing the appliance configuration in part from the mesial-distal widths and tooth placement arch.

9. The method of claim 1 wherein:

the measuring step includes the step of digitizing, for each tooth, tooth profile data in the form of a series of digitized data points representing the shape of the surface of the tooth at least along a profile thereof extending generally vertically and labial-lingually;

the connection point establishing step includes the step of locating an appliance connection point on the surface of each of the plurality of teeth along a profile thereof; and

the appliance configuration designing step includes the step of designing, from the series of digitized data points representing the shape of the surface of the teeth, the established connection points and the derived tooth positions.

10. The method of claim 1 wherein the archform deriving step includes the step of comparing corresponding contralateral points on opposite sides of the archform and, on the basis of the comparison, and calculating a modified archform that is laterally symmetrical about its center; and

designing the appliance configuration based at least in part on the modified archform.

11. The method of claim 1 wherein the measuring step includes the step of digitizing data of points on labial and lingual surfaces of each of a plurality of the teeth of the patient, and the method further comprises:

deriving from the digitized labial and lingual surface data a digital representation of the orientation of a crown long axis of each tooth with respect to the points;

calculating finish positions of the teeth from the digitized data and the digital representations of the crown long axes of the teeth, the calculated finish positions including preferred crown long axis orientations.

12. The method of claim 1 further comprising the steps of:

treating a plurality of patients while calculating the preferred crown long axis orientations and producing a record of the calculated preferred crown long axis orientations;

recording personal data of each of the treated patients, correllating the personal data with the calculated preferred crown long asis orientations and classifying the patients in population groups on the basis of the correllation; and

producing a statistical record of preferred crown long axis orientations for patients of the population groups.

13. The method of any one of claims 1-11 wherein:

the measuring step includes the step of measuring tooth shape data;

the appliance designing step includes the step of designing appliance placement jig configurations from the tooth shape data, each having a jig surface that will conform to the surface of a respective tooth for facilitating the location of the connection point thereon and the connection of the appliance thereto;

the machine code producing step includes the step of producing the machine code at least in part in accordance with the designed appliance placement jig configurations; and

the appliance fabricating step includes the step of automatically fabricating appliance placement jigs with the NC machine in response to the machine code to conform to the designed placement jig configurations.

14. The method of claim 13 wherein the appliance palcement jig configuration designing step comprises the steps of:

calculating, from the digitized tooth shape data and defined connection points, jig geometry defining a jig locating surface that conforms to a unique portion of the external surface of the crown of a tooth, and defining an appliance engaging surface having the same location relative to the jig locating surface as the unique portion of the external surface has to the connection point on the tooth, so that, the NC machine, when operated in response to the control signal, will form a jig that, when fit on the tooth, will position and orient an appliance engaged thereby at the connection point of the tooth for connection thereto.

15. The method of claim 14 wherein:

the connection point defining step includes the step of calculating the connection points from the digitized tooth shape data; and

the jig geometry calculating step includes the step of defining the appliance engaging surface such that the location relative to the jig locating surface is the same as that of the unique portion of the external surface to the calculated connection point on the tooth.

16. The method of claim 14 wherein:

the appliance includes a plurality of brackets, one for connection at each connection point to a tooth, each bracket having an archwire receiving slot therein;

the appliance configuration design includes bracket shape data including a digital representation of the position and inclination of the slot in the bracket; and

the jig geometry calculating step includes the step of defining the appliance engaging surface to include a part thereof that will align with the slot of the bracket when the bracket is engaged thereby.

17. The method of claim 16 wherein:

the appliance configuration designing step includes the step of calculating bracket design to accomodate arcuate archwire shape.

18. The method of claim 16 wherein:

the appliance configuration designing step includes the step selecting, from a plurality of bracket blanks, an optimum blank for the manufacture of the bracket in accordance with slot digital representation.

19. A method of any one of claims 1-11 wherein:

the measuring step includes the step of measuring the shapes of individual upper and lower teeth and the shape of the lower jaw of the patient and producing thereby digitized upper and lower tooth data and lower jaw shape data, the tooth shape data including data of the incisal tips of the lower anterior teeth and buccal cusp tips of lower posterior teeth and central ridge or marginal ridge locations of upper posterior teeth;

the finish position deriving step includes the steps of:

deriving a tooth-bearing lower jaw configuration based on assembly of the lower teeth along the lower arch configuration with adjacent teeth in contact with each other and the lower arch configuration;

vertically adjusting each lower tooth such that the incisal tips of the lower anterior teeth and buccal cusp tips of the lower posterior teeth are in substantially the same occlusal plane and are inclined at controlled angles of inclination;

adjusting the tooth-bearing lower arch configuration to provide a finished tooth bearing lower jaw configuration by labially-lingually positioning the lower teeth to place the incisal and buccal cusp tips thereof in a smooth arch in the occlusal plane with adjacent teeth in contact with each other; and

deriving a tooth-bearing finished upper tooth configuration in which:

the posterior teeth have their central grooves or marginal ridges lying horizontally on the finished tooth bearing lower jaw configuration and vertically on the occlusal plane;

the anterior teeth have their incisal tips positioned below the occlusal plane to achieve predetermined overlaps and are horizontally labially offset from the finished tooth bearing lower jaw configuration so as to establish a predetermined clearance between the lower anterior teeth lingual faces and the labial faces of the lower anterior teeth;

the appliance configuration desigining step includes the step of calculating a bracket configuration, including bracket slot angle and bracket slot depth, for individual upper and lower tooth brackets, and calculating upper and lower archwire shapes, based upon the calculated finished tooth positions, predetermined upper and lower archwire planes, the tooth shapes, and the positions of the brackets on the teeth;

the appliance fagricating step includes the steps of:

fabricating the upper and lower archwires to conform to the calculated archwire shapes; and

fabricating the brackets to conform to the calculated bracket configurations.

20. The method of any one of claims 1-11 further comprising the steps of:

providing criteria describing the distances of the individual teeth from the pivot axis of the lower jaw;

the finish position deriving step includes the steps of:

calculating from the criteria and the tooth shape data a component of cuspid rise; and

vertically adjusting the upper and lower cuspids such that their cusp tips are respectively below and above the occlusal plane a distance that has a predetermined relationship to the calculated cuspid rise.

21. The method of claim 20 wherein the tooth-bearing finished upper tooth configuration deriving step includes deriving the configuration in which:

the upper anterior teeth have incisal tips positioned below the occlusal plane so as to achieve predetermined overlaps that have a predetermined relationship to the calculated cuspid rise.

22. The method of claim 20 wherein the cuspid rise component calculating step includes the steps of:

identifying occluding pairs of respective upper and lower posterior teeth of the patient, and determining for each pair from the digitized tooth shape data a vertical distance from the highest extent of the lower tooth of the pair to the lowest extent of the upper tooth of the pair when the jaws are in a closed position;

adjusting each determined vertical distance by a factor proportionally related to a distance of each pair from the pivot axis, and selecting the largest adjusted vertical distance

calculating, from the digitized data, finish positions of the mandibular teeth of the patient at which highest points thereon are at vertical positions on an approximately flat occlusal surface; and

calculating finish positions of the upper and lower cuspids of the patient extend respectively below and above the occlusal surface.

23. The method of any one of claims 1-11 further comprising the steps of:

providing an orthodontic appliance designing and manufacturing system including:

a data input sub-system for digitizing input data of measured anatomical shapes and generating input signals carrying the digitized input data,

a data processing sub-system for processing the digitized input signals and generating, in response thereto, output signals carrying the machine control code, and

an NC appliance hardware manufacturing sub-system, including the NC mahine, for fabricating, in response to the output signals, a custom orthodontic appliance for the treatment of the patient by moving the teeth of the patient to the preferred finish positions;

generating, with the data processing sub-system, from the derived archform, output signals carrying numerical machine control code for operating the NC appliance hardware manufacturing sub-system to fabricate the custom orthodontic appliance; and

fabricating, with the NC appliance hardware manufacturing sub-system, in response to the output signal and in accordance with the numerical machine control codes, the custom orthodontic appliance of the custom configuration.

24. The method of claim 23 wherein:

the custom orthodontic appliance includes an archwire having an arcuate shape that is mathematically related to the mandibular trough skeletal archform;

the NC appliance hardware manufacturing sub-system includes a wire bending apparatus responsive to numerical machine control codes carried by the output signal;

the output signal includes a series of codes for operating the wire bending apparatus to feed a wire and to bend the fed wire into the custom archwire configuration for connection of the archwire to the teeth of a jaw at a respective connection points.

25. The method of claim 24 wherein:

the digitized input data contains information from which the connection point of the appliance and slope of the surface at the connection point can be derived;

the custom orthodontic appliance includes a plurality of brackets, one for each tooth connection point, each having a base securable to the respective connection point, and each having an archwire slot connectable to the archwire;

the NC appliance hardware manufacturing sub-system includes a bracket fabricating apparatus responsive to numerical machine control codes carried by the output signal;

the output signal includes a series of codes for operating the bracket fabricating apparatus to fabricate each bracket with the archwire slot positioned with respect to the base to support and orient a point on the archwire with respect to the connection point of the respective tooth to transfer force therebetween to urge the tooth toward its finish position.

26. The method of claim 25 wherein:

the digitized input data contains information of a contour on the surface of the tooth;

the custom orthodontic appliance includes a bracket placement jig for each bracket having a surface for uniquely positioning the jig with respect to the surface of the tooth and for positioning the bracket thereon at the connection point thereof;

the NC appliance hardware manufacturing sub-system includes a bracket placement jig fabricating apparatus responsive to numerical machine control codes carried by the output signal;

the output signal includes a series of codes for operating the bracket placement jig fabricating apparatus to fabricate the bracket placement jig.

27. The method of claim 25 wherein the appliance fabricating step includes the steps of:

providing a plurality of bracket blanks; and

forming a bracket from the bracket blank by forming an archwire slot in each of the bracket blank such that each slot will lie in an archwire plane when the bracket is mounted on the connection point of a tooth with the tooth in its derived finish position.

28. The method of claim 27 wherein:

the bracket slot cutting step includes the step of forming the slot to a depth defined by the intersection of the appliance archform equation with the bracket, when the bracket is mounted on the connection point of a tooth with the tooth in its derived finish position; and

the bracket slot cutting step includes the step of forming the slot to a slot bottom curvature of the radius of the intersecting circle segment of the appliance archform equation.

29. The method of any one of claims 1-11 wherein the connection position establishing step includes, to provide optimal spacing thereof from the gums of a patient and clearance with teeth of the opposite jaw of the patient, the steps of:

digitizing data of shapes of the teeth of the patient and of geometry of parts of an appliance to be connected thereto;

calculating from the digitized data finish positions of the teeth of the patient and the relationships of between points on surfaces of teeth of the opposite jaws;

calculating from the digitized data locations on the surfaces of the teeth of one jaw of the patient at which the appliance is to be connected to provide optimal spacing thereof from the gums of a patient and clearance with teeth of the opposite jaw of the patient; and

designing the appliance configuration in accordance with the calculated locations for connection of the appliance to the teeth of the patient.

30. A method of any one of claims 1-11 wherein:

the custom orthodontic appliance includes an archwire;

the appliance configuration designing step includes the step of deriving digital archwire shape data based at least in part on the the derived archform;

the machine code producing step includes the step of generating a wire shape control signal in response to the digital archwire shape data, such that, when communicated to an archwire former, the former will produce a custom orthodontic archwire based on the anatomical shapes from the individual patient's mouth; and

forming a length of orthodontic archwire material into a controlled shape in response to the wire shape control signal to produce the custom archwire.

31. The method of claim 30 wherein the machine code producing step includes the steps of:

providing archwire material property data of the archwire material; and

generating the wire bending control signal in response to the material property data of the archwire material.

32. The method of claim 30 further comprising the steps of:

measuring an archwire span between two points on the produced custom orthodontic archwire;

calculating a design archwire span from the derived archwire shape data;

comparing the measured archwire span with the design archwire span and signaling a result of the comparison; and

generating the wire bending control signal in response to the signaled result of the comparison.

33. A custom orthodontic appliance fabricating apparatus comprising::

means for measuring anatomical shapes from the mouth of the patient, and producing thereby digitized anatomical shape data;

a digital computer including program means for:

deriving an archform from the digitized data with a specially programmed digital computer;

deriving tooth finish positions from the digitized data and the derived archform;

designing, from the digitized data, established appliance connection points and the derived tooth finish positions, an appliance configuration such that a custom appliance fabricated in accordance therewith and connected at the appliance connection points to the teeth, will exert substantially no tooth moving forces on the teeth when in the derived tooth finish positions, and will otherwise urge the teeth toward the derived finish positions; and

producing machine code in accordance with the designed appliance configuration; and

an machine for automatically fabricating a custom orthodontic appliance in response to the machine code to conform to the designed appliance configuration.

34. The apparatus of claim 33 wherein the fabricating machine comprises::

an archwire former including means for forming a length of orthodontic archwire material into a controlled shape in response to a wire shape control signal communicated thereto; and

the program means including means for generating a wire shape control signal in response to the digital archwire shape data, such that, when the signal is communicated to the archwire former, the former will produce a custom orthodontic archwire conforming to the anatomical shape of the individual patient's mouth.

35. The apparatus of claim 34 wherein:

the derived digital archwire shape data includes wire length data correlated to a length component of the derived digital archwire shape data and wire curvature data correlated to a curvature component of the derived digital archwire shape data that is a function of the length component;

the wire shape control signal includes a wire feed control signal carrying the wire length data and a wire bending control signal carrying the wire curvature data;

the program means includes means for generating the wire feed control signal and means for generating a wire bending control signal and communicating the control signals to the archwire former; and

the archwire former includes means for longitudinally feeding the orthodontic archwire material in response to the wire feed control signal and means for transversely bending the archwire material fed by the wire feeding means in response to the wire bending control signal and in synchronism with the feeding of the archwire material.

36. The apparatus of claim 34 wherein:

the digital archwire shape data is a digital representation of a connected series of wire segments, each having a length component and a curvature component; and

the archwire former includes means for longitudinally feeding a series of lengths of the orthodontic archwire material corresponding to the respective wire length components in accordance with the wire length data and means for bending each fed length of archwire material to a curvature corresponding to the respective wire curvature component in accordance with the wire curvature data.

37. The apparatus of claim 36 wherein:

each wire segment is in the form of a circle segment with the length component thereof representing a tangential length of archwire material and with the curvature component thereof representing a constant radius of curvature of the material over the tangential length of the segment; and

the feeding means includes means for longitudinally feeding a series of tangential lengths of the orthodontic archwire material and the bending means includes means for bending each fed length of archwire segment to a constant radius in accordance with the wire curvature data.

38. The apparatus of claim 37 wherein:

the feeding means is operative to sequentially feed a series of lengths of the archwire material equal to the length components of the circle segments, in response to the wire feed signal, along a longitudinal path;

the bending means includes a bending element moveable in response to the wire bending signal transverse to the path to impart a transverse bending deflection to the segment and a transverse position sensor for producing a feedback signal responsive to the deflection; and

the computer includes means for modifying the wire bending control signal in response to the feedback signal to provide closed loop control of the bending element.

39. The apparatus of claim 34 wherein:

the program means includes means in communication with the wire shape control signal generating means for receiving material property data of the archwire material and for modifying the wire bending control signal in accordance with the property data to compensate for elastic properties of the material.

40. The apparatus of claim 34 further comprising:

means for measuring an archwire span between points on first and last segments of the series of the produced custom orthodontic archwire;

the program means including means for calculating a design archwire span from the derived archwire shape data;

means for comparing the measured archwire span with the design archwire span and for storing the results of the comparison; and

the program means being operative to generate the wire shape control signal in response to a stored result of the comparison.

41. The apparatus of any one of claims 33-40 wherein the fabricating machine comprises::

a bracket forming apparatus including:

a holder having means thereon for mounting a bracket blank thereon for fabrication;

means for forming at least one surface of a bracket blank mounted on the holder in response to a machine control signal communicated thereto in response to the control signal including means for shaping the bracket blank mounted on the holder to produce a bracket having a slot of a calculated geometric relationship to the mounting surface of the bracket base thereof.

42. The apparatus of claim 41 wherein:

each slot includes generally parallel upper and lower sides defining a slot inclination and includes a slot base at an end thereof nearest the bracket base defining a slot position;

each calculated geometric relationship of a slot to the mounting surface of a bracket includes the slot inclination and a slot position relative to the mounting surface;

the generated machine control signal carries machine control instructions for causing the forming means to shape the bracket blank to produce a bracket having a slot of the calculated slot inclination and slot position with respect to the mounting surface;

the slot of each bracket is adapted to receive an archwire having a custom curvature adjacent the tooth on which the bracket is to be secured;

each calculated geometric relationship of a slot to the mounting surface of a bracket includes a slot bottom curvature conforming to the custom curvature of the archwire adjacent thereto; and

the generated machine control signal carries machine control instructions for causing the forming means to shape the bracket blank to produce a bracket having a slot of the calculated slot bottom curvature.

43. The apparatus of claim 41 wherein:

the forming means includes means for cutting a slot in the support in response to the control signal.

44. The apparatus of claim 41 wherein:

the holder and the forming means are mounted on a stand; and

the apparatus further comprises means for angularly orienting the holder with respect to the stand and to the forming means, and means for translating the cutting means with respect to the stand and to the holder, in response to the control signal.

45. The apparatus of claim 33 wherein:

the fabricating machine comprises: a jig former including means for forming a jig for positioning a custom orthodontic appliance on a tooth of a patient, including means for shaping the contours of a surface of blank of jig forming material in response to a control signal communicated thereto;

the measuring means includes means for providing a digitized record of the shapes of the teeth of a patient and of the locations relative to the tooth shape record of appliance connection points on surfaces of the teeth;

the program means includes means for calculating, from the digitized tooth shape and connection point record, jig geometry defining a jig locating surface that conforms to a unique portion of the external surface of the crown of a tooth, and defining an appliance engaging surface having the same location relative to the jig locating surface as the unique portion of the external surface has to the connection point on the tooth; and

the generating means includes means for generating a machine control signal carrying machine control instructions for producing a jig in accordance with the calculated jig geometry.

46. The apparatus of claim 45 wherein:

the appliance includes a plurality of brackets, one for connection at each connection point to a tooth;

the apparatus further comprises means for providing digitized bracket shape data of an external surface of each bracket to be connected to a connection point; and

wherein the jig geometry calculating means includes means for defining the appliance engaging surface of the jig to conform, in response to the digitized bracket shape data, to the established appliance geometry.

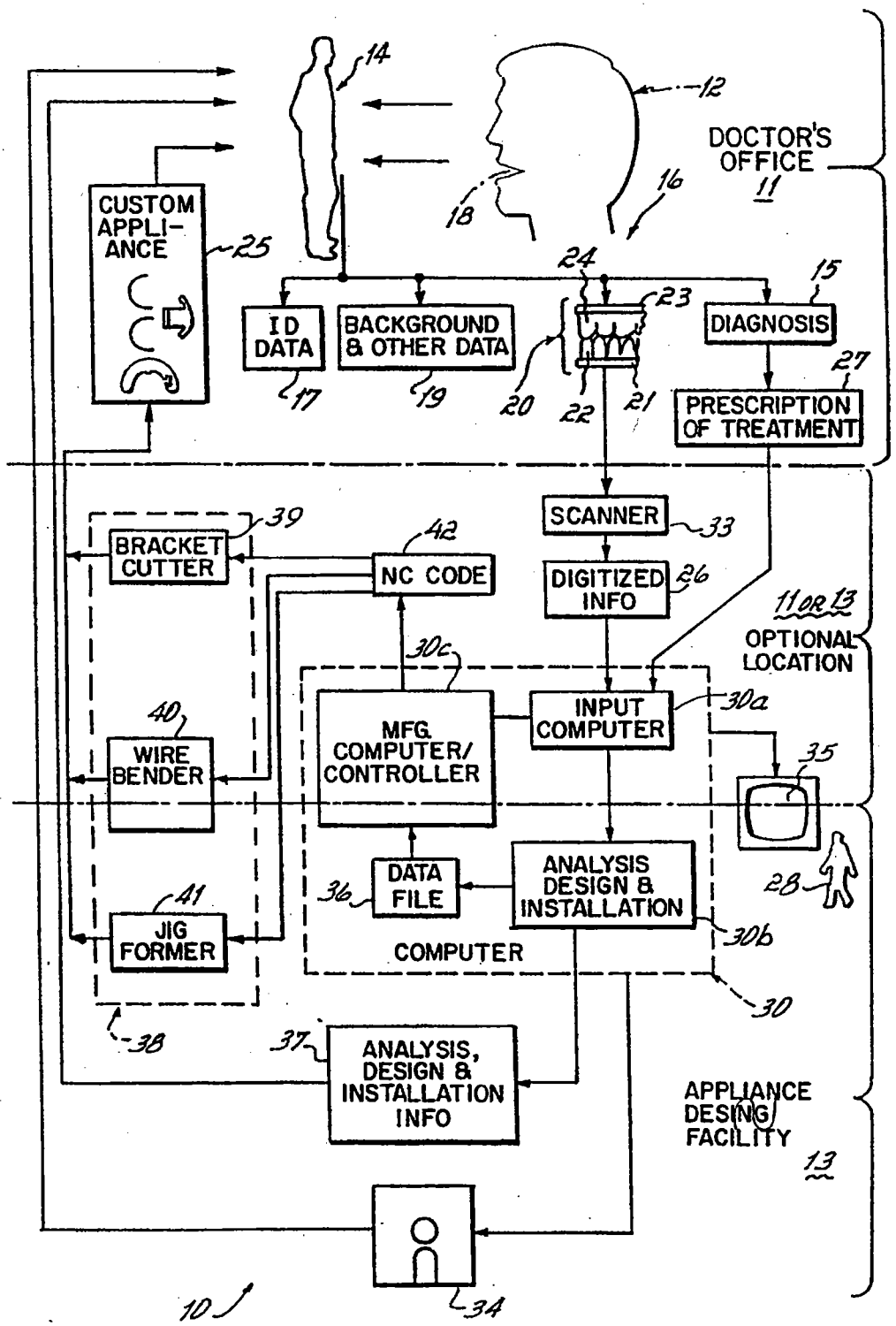

14
12
DOCTOR'S OFFICE
11
CUSTOM APPLI-ANCE
25
18
16
24
15
23
ID DATA
17
BACKGROUND & OTHER DATA
19
DIAGNOSIS
27
20
22
21
PRESCRIPTION OF TREATMENT
SCANNER
33
39
42
BRACKET CUTTER
NC CODE
DIGITIZED INFO
26
11 OR 13
OPTIONAL LOCATION
30c
INPUT COMPUTER
30a
40
MFG. COMPUTER/ CONTROLLER
35
WIRE BENDER
28
41
DATA FILE
36
ANALYSIS DESIGN & INSTALLATION
30b
JIG FORMER
COMPUTER
30
38
37
ANALYSIS, DESIGN & INSTALLATION INFO
APPLIANCE DESING FACILITY
13
34
10

FIG. 1

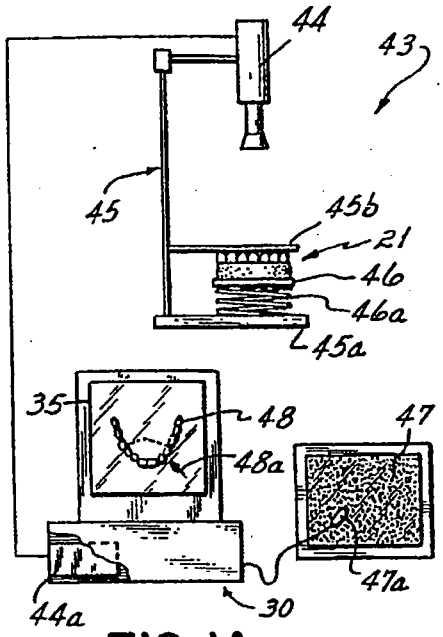


FIG. IA

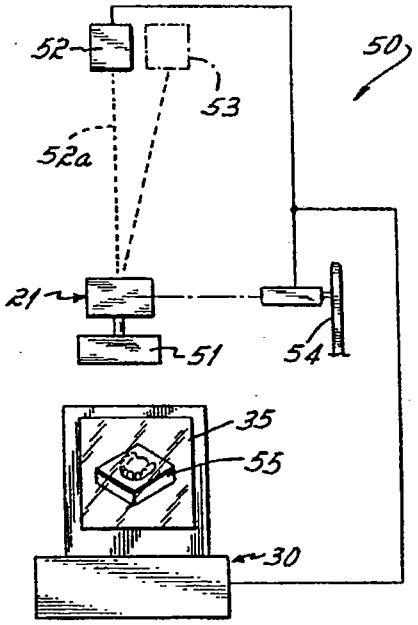


FIG. IB

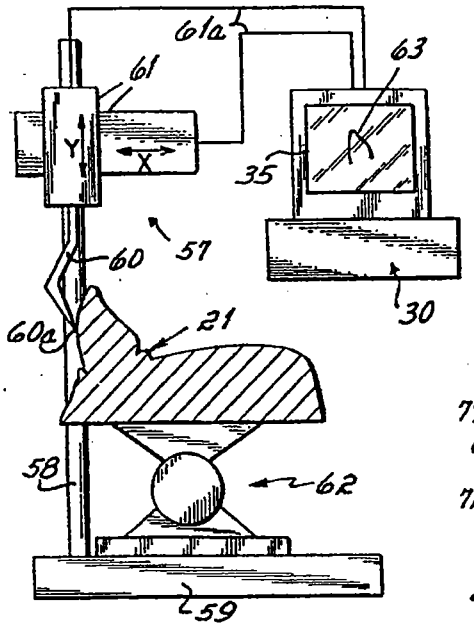


FIG. IC

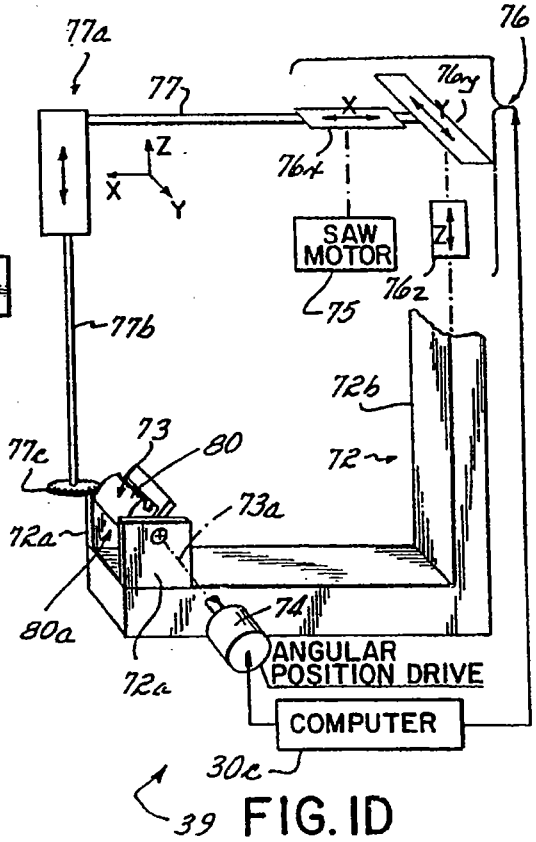


FIG. ID

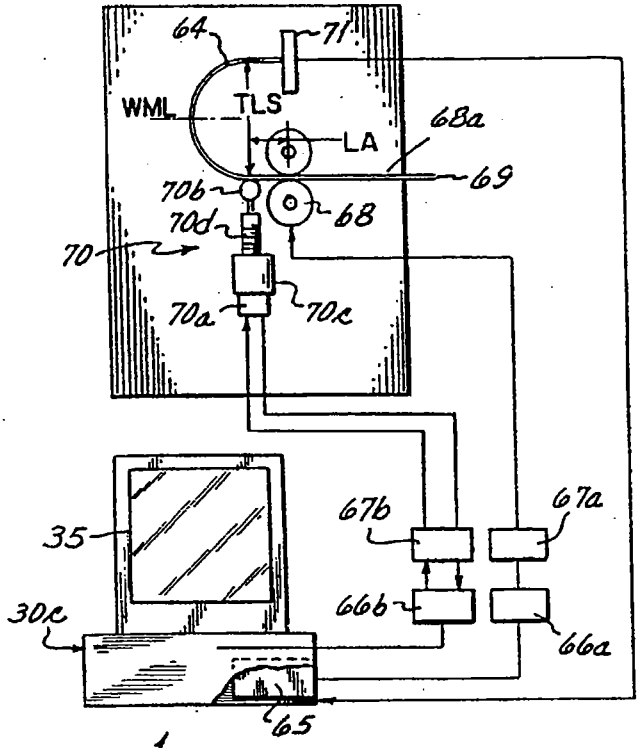

64
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70d
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30c
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FIG. IE

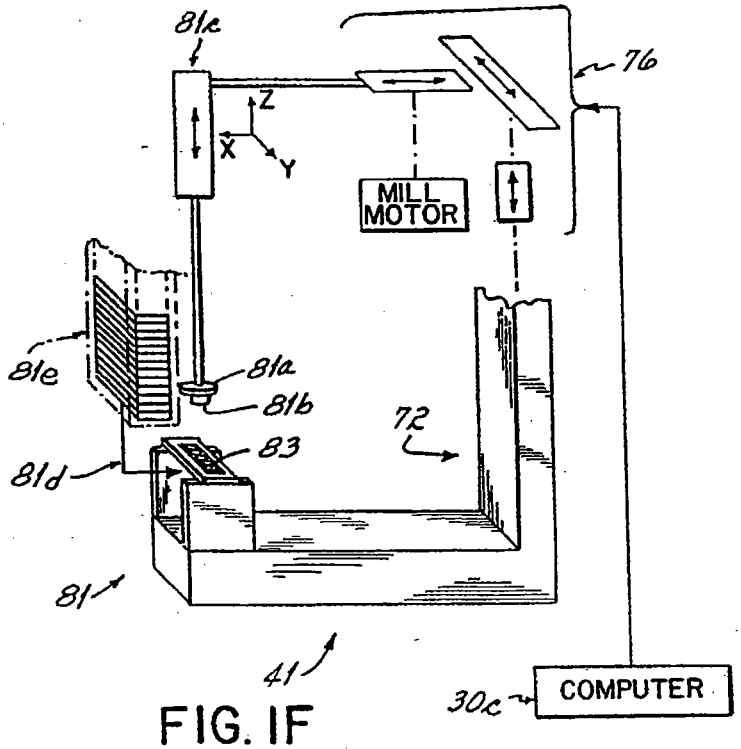

81c
76
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X
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MILL MOTOR
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81a
81b
72
83
81d
81
41
30c
COMPUTER

FIG. IF

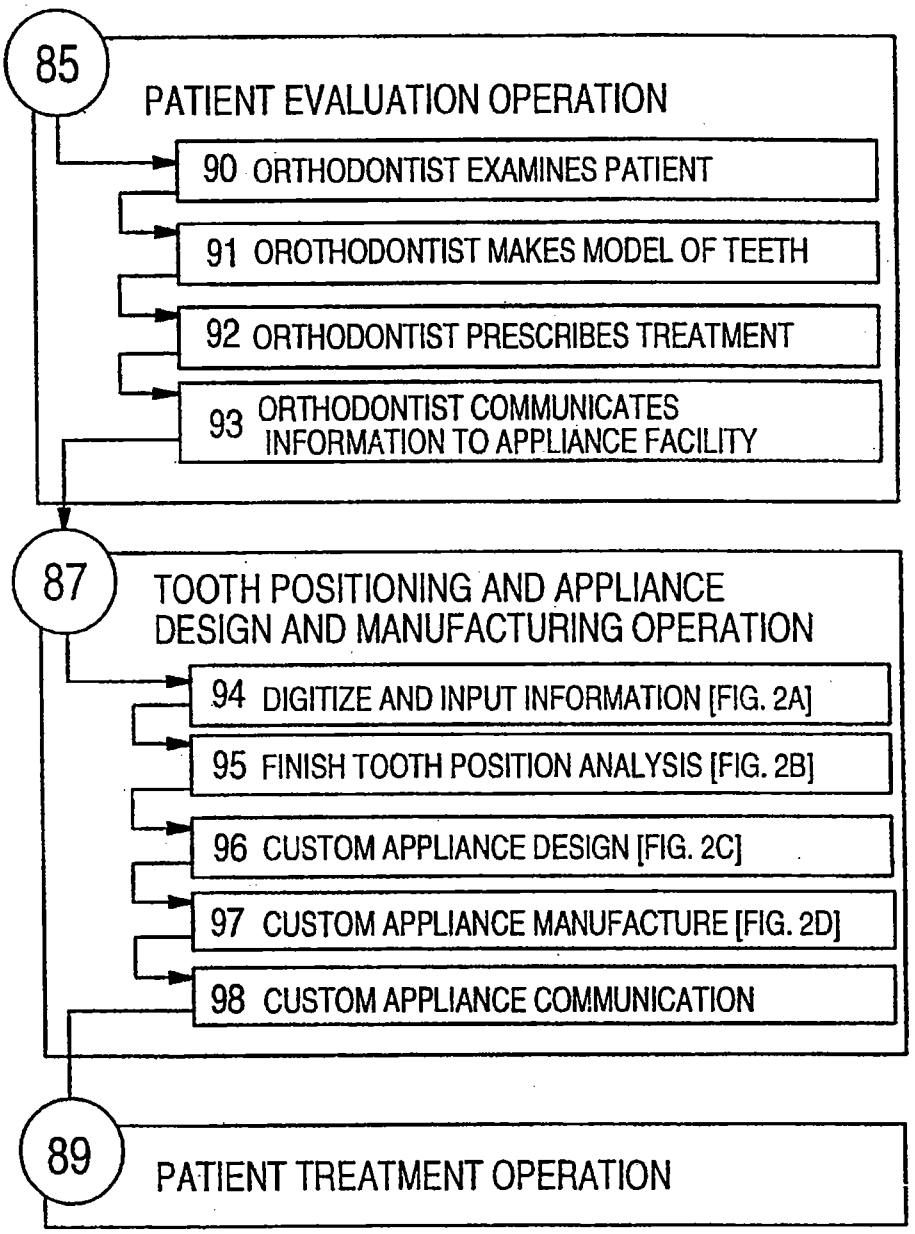

85
PATIENT EVALUATION OPERATION
90 ORTHODONTIST EXAMINES PATIENT
91 OROTHODONTIST MAKES MODEL OF TEETH
92 ORTHODONTIST PRESCRIBES TREATMENT
93 ORTHODONTIST COMMUNICATES INFORMATION TO APPLIANCE FACILITY
87
TOOTH POSITIONING AND APPLIANCE DESIGN AND MANUFACTURING OPERATION
94 DIGITIZE AND INPUT INFORMATION [FIG. 2A]
95 FINISH TOOTH POSITION ANALYSIS [FIG. 2B]
96 CUSTOM APPLIANCE DESIGN [FIG. 2C]
97 CUSTOM APPLIANCE MANUFACTURE [FIG. 2D]
98 CUSTOM APPLIANCE COMMUNICATION
89
PATIENT TREATMENT OPERATION

FIG. 2

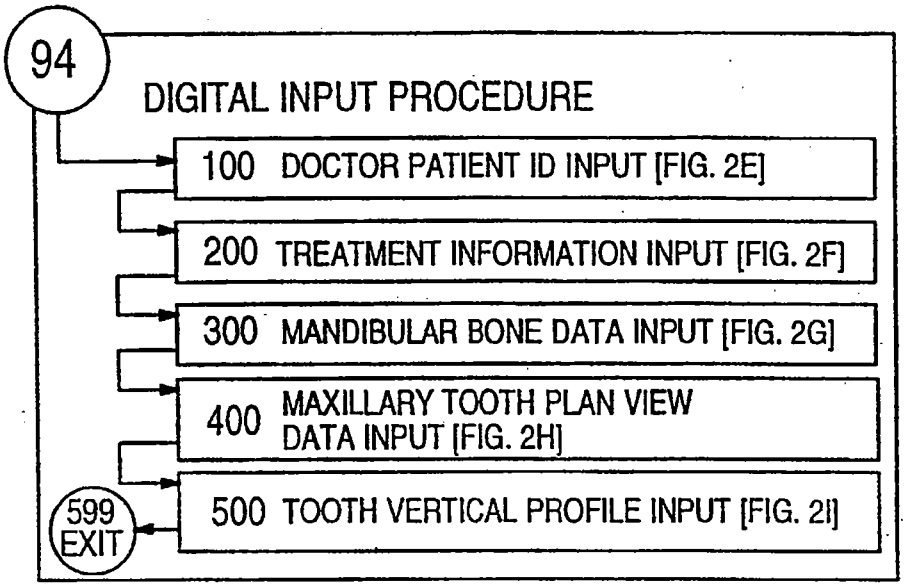

94
DIGITAL INPUT PROCEDURE
100 DOCTOR PATIENT ID INPUT [FIG. 2E]
200 TREATMENT INFORMATION INPUT [FIG. 2F]
300 MANDIBULAR BONE DATA INPUT [FIG. 2G]
400 MAXILLARY TOOTH PLAN VIEW DATA INPUT [FIG. 2H]
500 TOOTH VERTICAL PROFILE INPUT [FIG. 2I]
599 EXIT

FIG. 2A

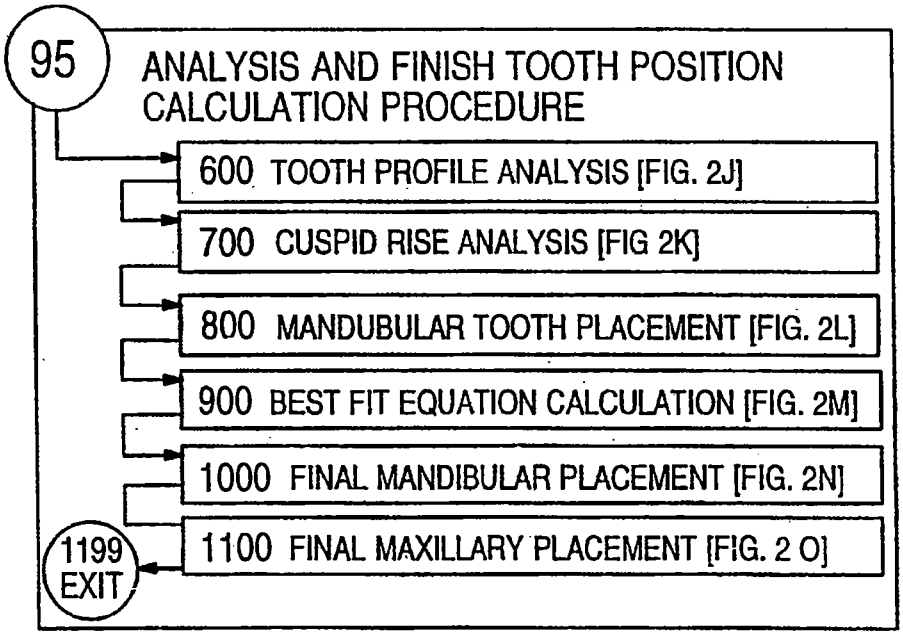

95
ANALYSIS AND FINISH TOOTH POSITION CALCULATION PROCEDURE
600 TOOTH PROFILE ANALYSIS [FIG. 2J]
700 CUSPID RISE ANALYSIS [FIG 2K]
800 MANDUBULAR TOOTH PLACEMENT [FIG. 2L]
900 BEST FIT EQUATION CALCULATION [FIG. 2M]
1000 FINAL MANDIBULAR PLACEMENT [FIG. 2N]
1100 FINAL MAXILLARY PLACEMENT [FIG. 2 O]
1199 EXIT

FIG. 2B

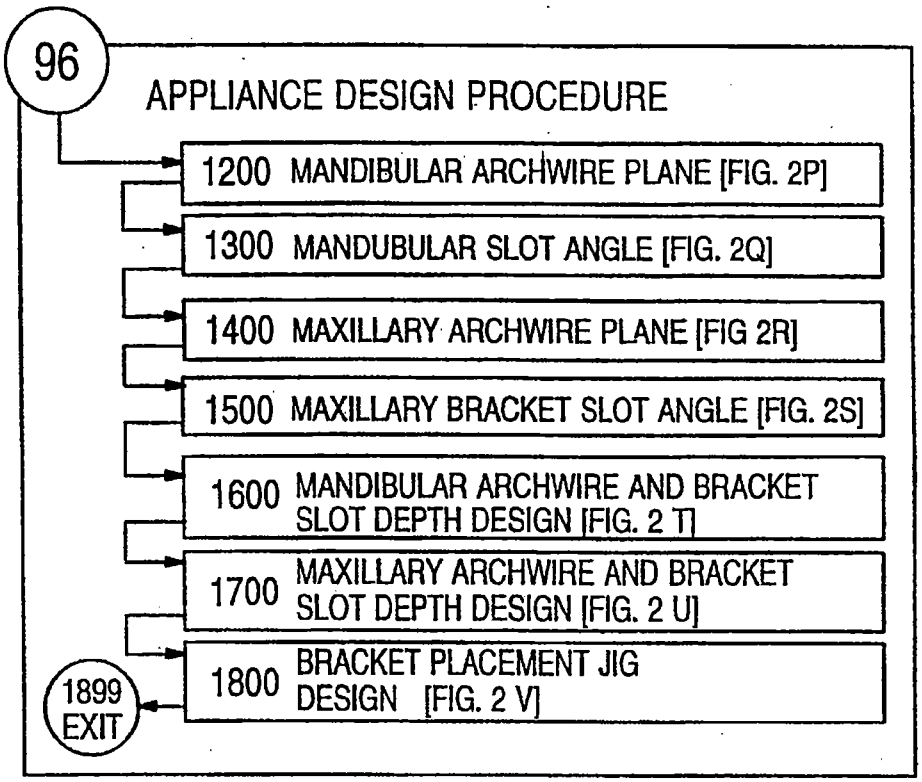

96
APPLIANCE DESIGN PROCEDURE
1200 MANDIBULAR ARCHWIRE PLANE [FIG. 2P]
1300 MANDUBULAR SLOT ANGLE [FIG. 2Q]
1400 MAXILLARY ARCHWIRE PLANE [FIG 2R]
1500 MAXILLARY BRACKET SLOT ANGLE [FIG. 2S]
1600 MANDIBULAR ARCHWIRE AND BRACKET SLOT DEPTH DESIGN [FIG. 2 T]
1700 MAXILLARY ARCHWIRE AND BRACKET SLOT DEPTH DESIGN [FIG. 2 U]
1800 BRACKET PLACEMENT JIG DESIGN [FIG. 2 V]
1899 EXIT

FIG. 2C

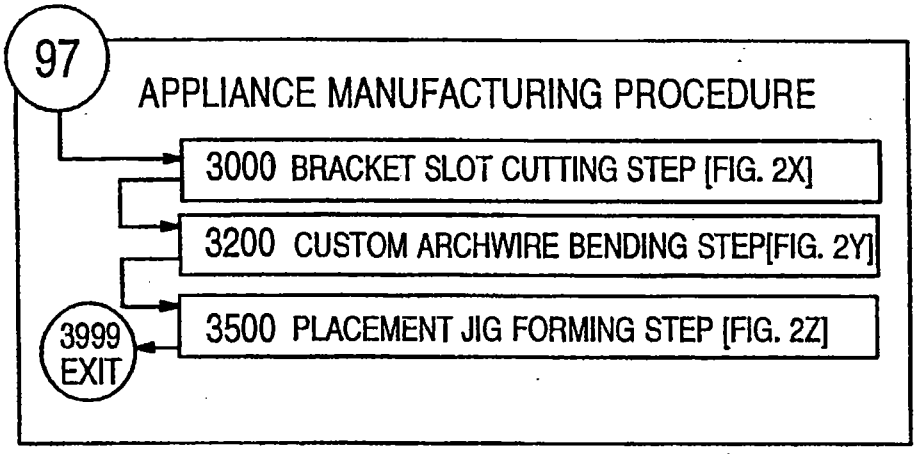

97
APPLIANCE MANUFACTURING PROCEDURE
3000 BRACKET SLOT CUTTING STEP [FIG. 2X]
3200 CUSTOM ARCHWIRE BENDING STEP[FIG. 2Y]
3500 PLACEMENT JIG FORMING STEP [FIG. 2Z]
3999 EXIT

FIG. 2D

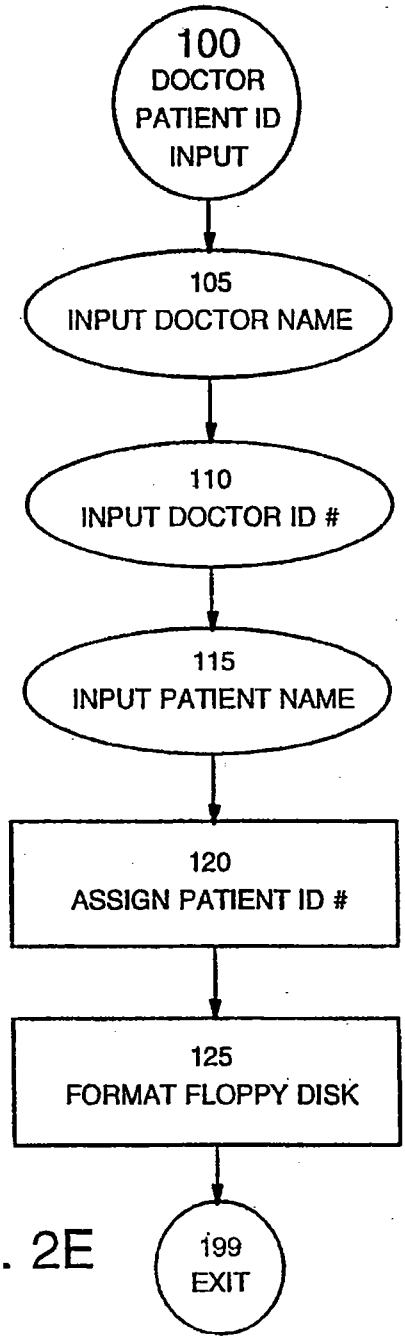

100
DOCTOR
PATIENT ID
INPUT
105
INPUT DOCTOR NAME
110
INPUT DOCTOR ID #
115
INPUT PATIENT NAME
120
ASSIGN PATIENT ID #
125
FORMAT FLOPPY DISK
199
EXIT

FIG. 2E

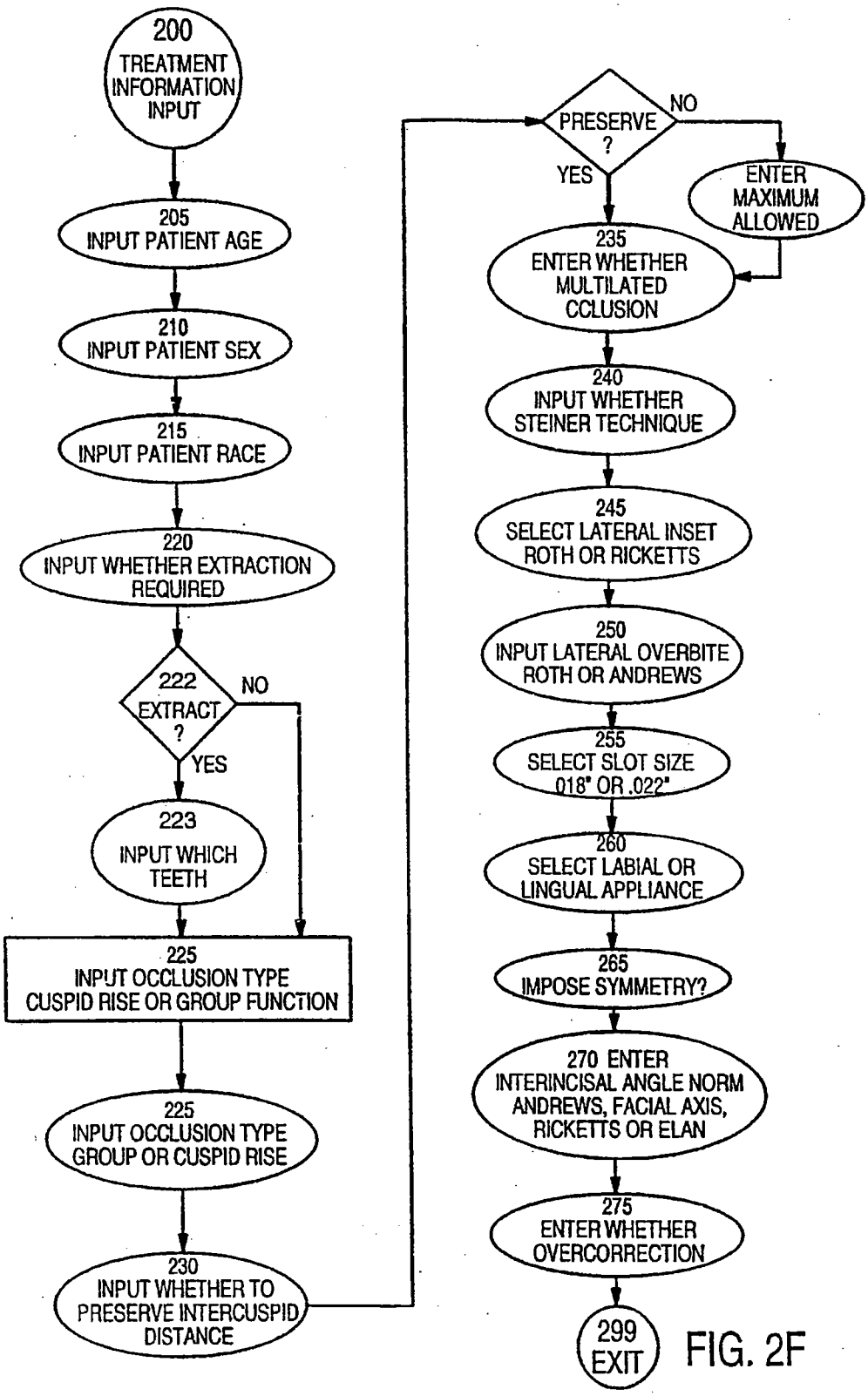

200
TREATMENT INFORMATION INPUT
205
INPUT PATIENT AGE
210
INPUT PATIENT SEX
215
INPUT PATIENT RACE
220
INPUT WHETHER EXTRACTION REQUIRED
222
EXTRACT ?
NO
YES
223
INPUT WHICH TEETH
225
INPUT OCCLUSION TYPE CUSPID RISE OR GROUP FUNCTION
225
INPUT OCCLUSION TYPE GROUP OR CUSPID RISE
230
INPUT WHETHER TO PRESERVE INTERCUSPID DISTANCE
PRESERVE ?
NO
YES
ENTER MAXIMUM ALLOWED
235
ENTER WHETHER MULTILATED CCLUSION
240
INPUT WHETHER STEINER TECHNIQUE
245
SELECT LATERAL INSET ROTH OR RICKETTS
250
INPUT LATERAL OVERBITE ROTH OR ANDREWS
255
SELECT SLOT SIZE 018" OR .022"
260
SELECT LABIAL OR LINGUAL APPLIANCE
265
IMPOSE SYMMETRY?
270 ENTER INTERINCISAL ANGLE NORM ANDREWS, FACIAL AXIS, RICKETTS OR ELAN
275
ENTER WHETHER OVERCORRECTION
299
EXIT

FIG. 2F

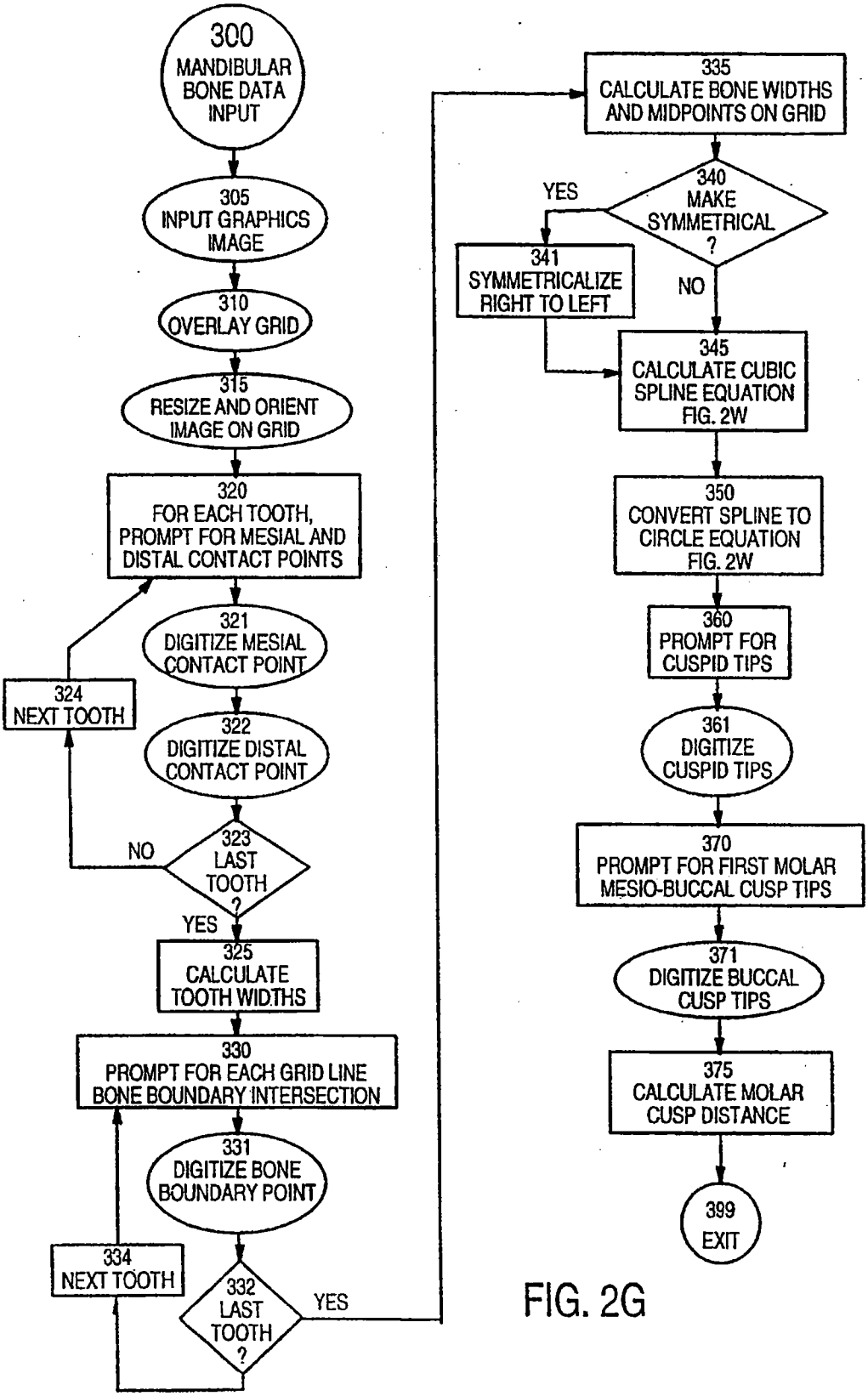

300
MANDIBULAR BONE DATA INPUT
305
INPUT GRAPHICS IMAGE
310
OVERLAY GRID
315
RESIZE AND ORIENT IMAGE ON GRID
320
FOR EACH TOOTH, PROMPT FOR MESIAL AND DISTAL CONTACT POINTS
321
DIGITIZE MESIAL CONTACT POINT
322
DIGITIZE DISTAL CONTACT POINT
323
LAST TOOTH ?
NO
YES
324
NEXT TOOTH
325
CALCULATE TOOTH WIDTHS
330
PROMPT FOR EACH GRID LINE BONE BOUNDARY INTERSECTION
331
DIGITIZE BONE BOUNDARY POINT
332
LAST TOOTH ?
YES
334
NEXT TOOTH
335
CALCULATE BONE WIDTHS AND MIDPOINTS ON GRID
340
MAKE SYMMETRICAL ?
YES
NO
341
SYMMETRICALIZE RIGHT TO LEFT
345
CALCULATE CUBIC SPLINE EQUATION FIG. 2W
350
CONVERT SPLINE TO CIRCLE EQUATION FIG. 2W
360
PROMPT FOR CUSPID TIPS
361
DIGITIZE CUSPID TIPS
370
PROMPT FOR FIRST MOLAR MESIO-BUCCAL CUSP TIPS
371
DIGITIZE BUCCAL CUSP TIPS
375
CALCULATE MOLAR CUSP DISTANCE
399
EXIT

FIG. 2G

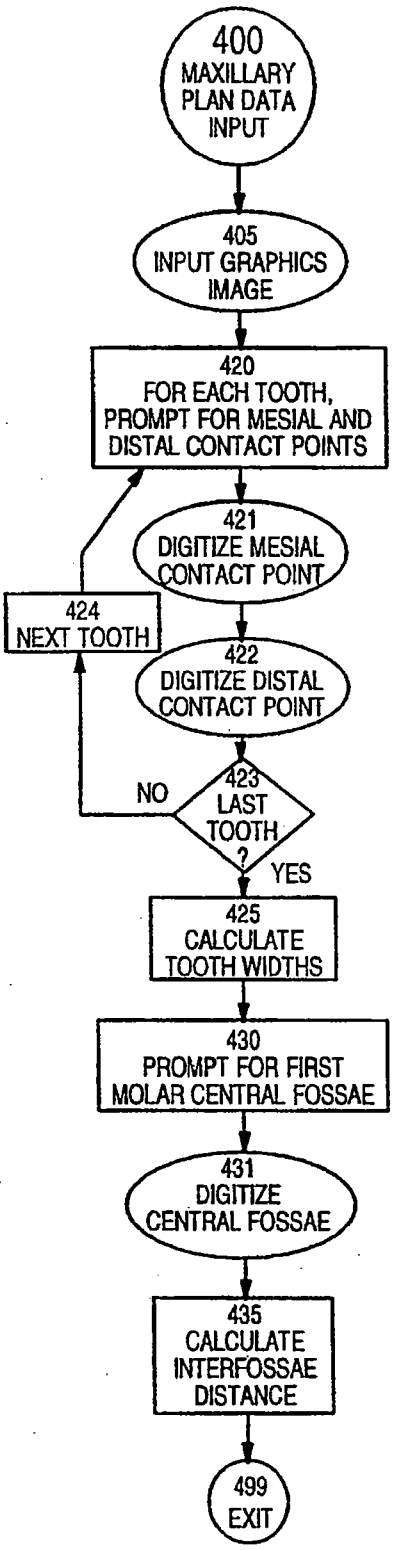

400
MAXILLARY PLAN DATA INPUT
405
INPUT GRAPHICS IMAGE
420
FOR EACH TOOTH, PROMPT FOR MESIAL AND DISTAL CONTACT POINTS
421
DIGITIZE MESIAL CONTACT POINT
422
DIGITIZE DISTAL CONTACT POINT
423
LAST TOOTH ?
NO
YES
424
NEXT TOOTH
425
CALCULATE TOOTH WIDTHS
430
PROMPT FOR FIRST MOLAR CENTRAL FOSSAE
431
DIGITIZE CENTRAL FOSSAE
435
CALCULATE INTERFOSSAE DISTANCE
499
EXIT

FIG. 2 H

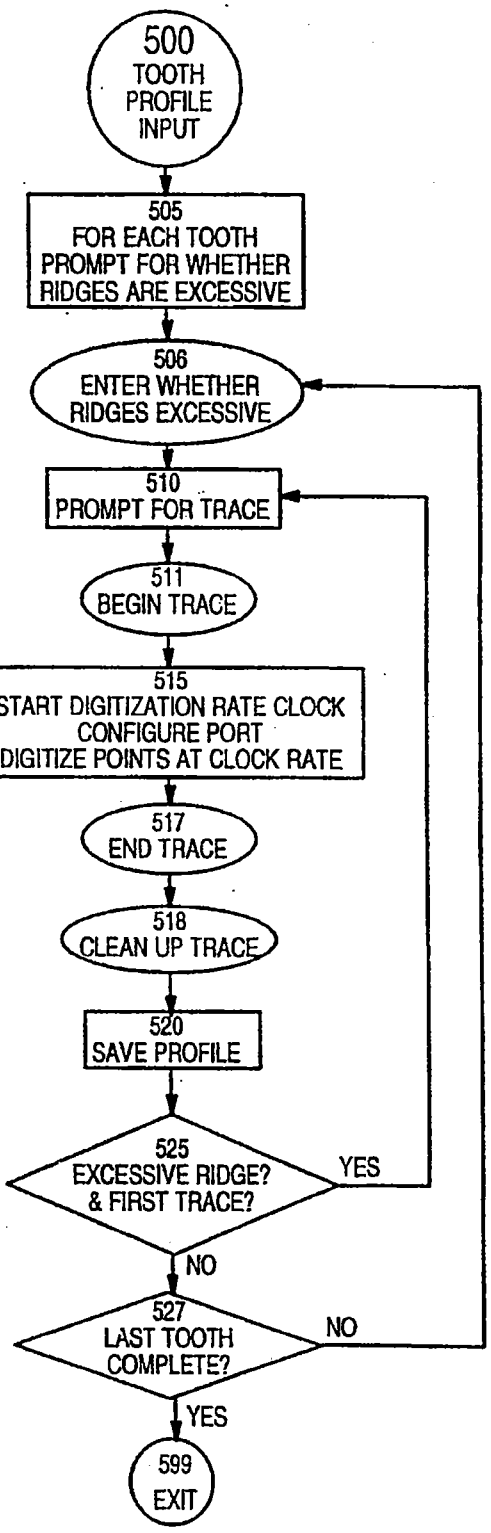

500
TOOTH PROFILE INPUT
505
FOR EACH TOOTH PROMPT FOR WHETHER RIDGES ARE EXCESSIVE
506
ENTER WHETHER RIDGES EXCESSIVE
510
PROMPT FOR TRACE
511
BEGIN TRACE
515
START DIGITIZATION RATE CLOCK
CONFIGURE PORT
DIGITIZE POINTS AT CLOCK RATE
517
END TRACE
518
CLEAN UP TRACE
520
SAVE PROFILE
525
EXCESSIVE RIDGE? & FIRST TRACE?
YES
NO
527
LAST TOOTH COMPLETE?
NO
YES
599
EXIT

FIG. 2 I

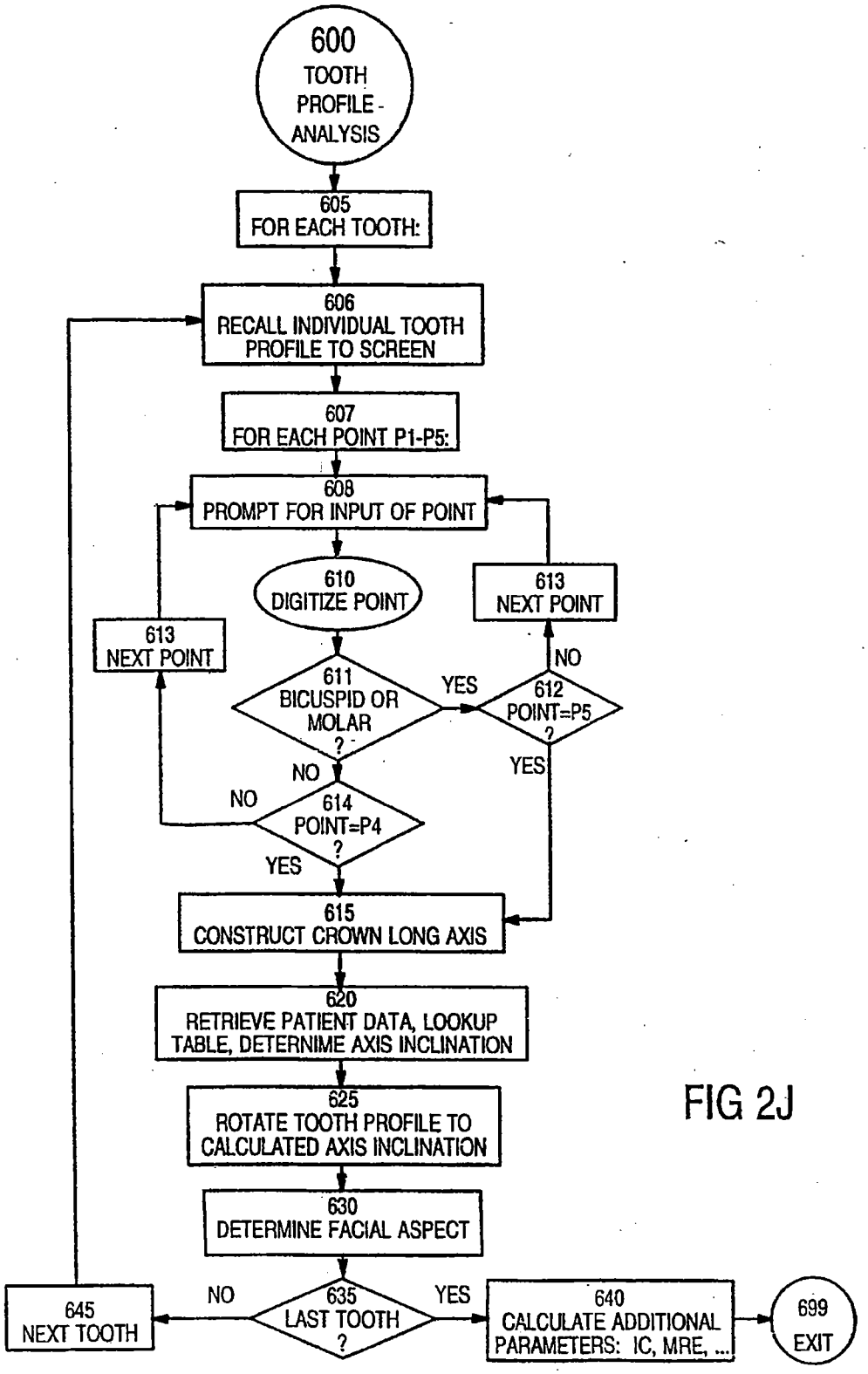

600
TOOTH PROFILE - ANALYSIS
605
FOR EACH TOOTH:
606
RECALL INDIVIDUAL TOOTH PROFILE TO SCREEN
607
FOR EACH POINT P1-P5:
608
PROMPT FOR INPUT OF POINT
610
DIGITIZE POINT
611
BICUSPID OR MOLAR ?
YES
612
POINT=P5 ?
NO
613
NEXT POINT
NO
614
POINT=P4 ?
YES
613
NEXT POINT
YES
615
CONSTRUCT CROWN LONG AXIS
620
RETRIEVE PATIENT DATA, LOOKUP TABLE, DETERNIME AXIS INCLINATION
625
ROTATE TOOTH PROFILE TO CALCULATED AXIS INCLINATION
630
DETERMINE FACIAL ASPECT
635
LAST TOOTH ?
NO
645
NEXT TOOTH
YES
640
CALCULATE ADDITIONAL PARAMETERS: IC, MRE, ...
699
EXIT

FIG 2J

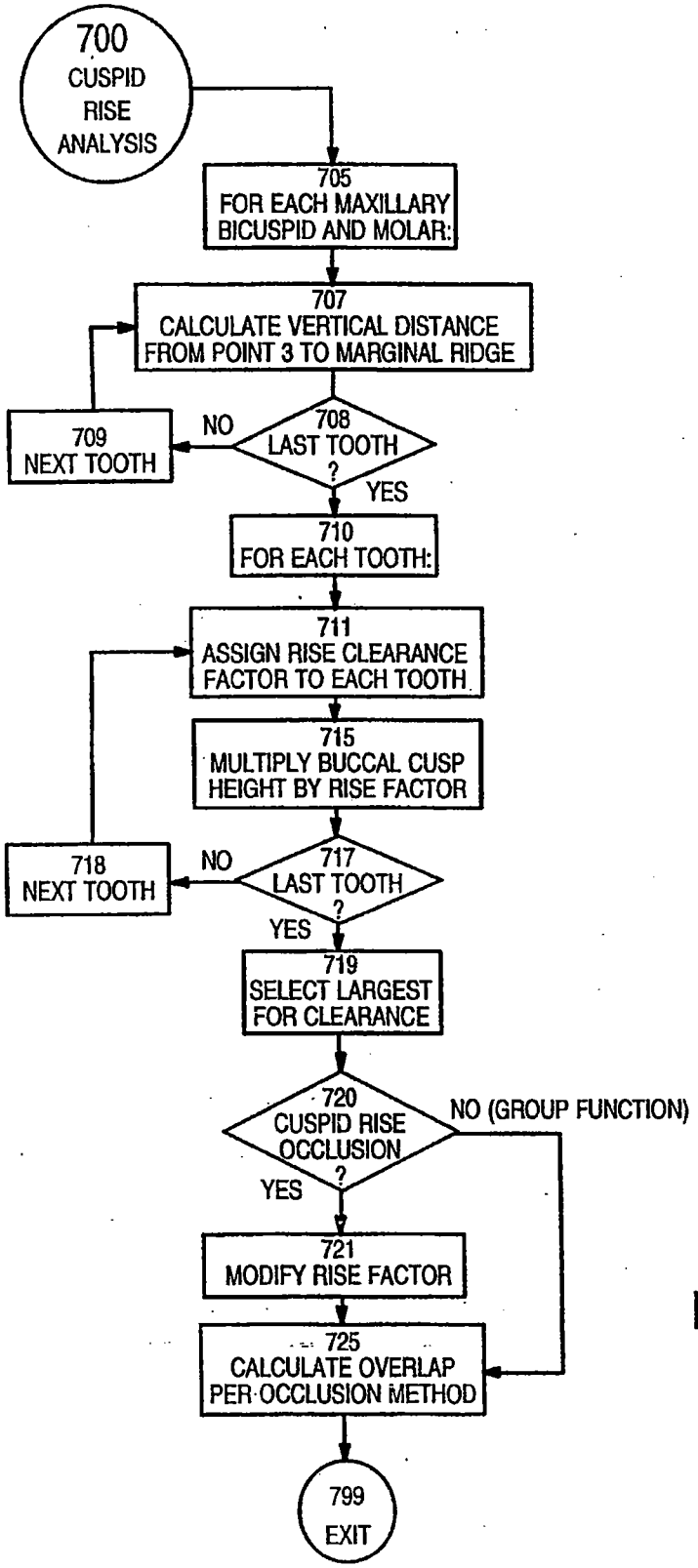


FIG. 2K

ClearCorrect Exhibit 1010, Page 254 of 1447

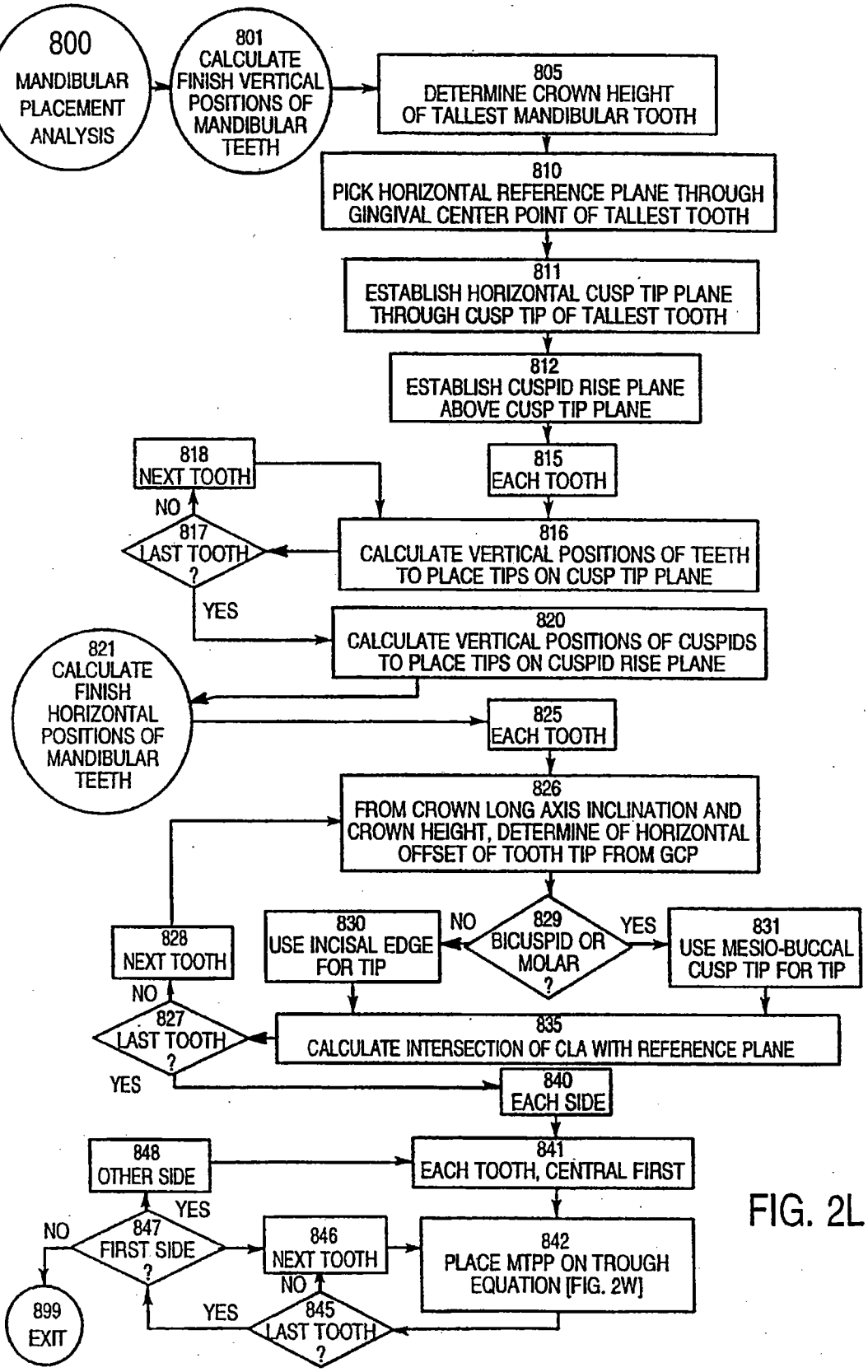

800
MANDIBULAR PLACEMENT ANALYSIS
801
CALCULATE FINISH VERTICAL POSITIONS OF MANDIBULAR TEETH
805
DETERMINE CROWN HEIGHT OF TALLEST MANDIBULAR TOOTH
810
PICK HORIZONTAL REFERENCE PLANE THROUGH GINGIVAL CENTER POINT OF TALLEST TOOTH
811
ESTABLISH HORIZONTAL CUSP TIP PLANE THROUGH CUSP TIP OF TALLEST TOOTH
812
ESTABLISH CUSPID RISE PLANE ABOVE CUSP TIP PLANE
815
EACH TOOTH
816
CALCULATE VERTICAL POSITIONS OF TEETH TO PLACE TIPS ON CUSP TIP PLANE
817
LAST TOOTH ?
NO
818
NEXT TOOTH
YES
820
CALCULATE VERTICAL POSITIONS OF CUSPIDS TO PLACE TIPS ON CUSPID RISE PLANE
821
CALCULATE FINISH HORIZONTAL POSITIONS OF MANDIBULAR TEETH
825
EACH TOOTH
826
FROM CROWN LONG AXIS INCLINATION AND CROWN HEIGHT, DETERMINE OF HORIZONTAL OFFSET OF TOOTH TIP FROM GCP
829
BICUSPID OR MOLAR ?
NO
YES
830
USE INCISAL EDGE FOR TIP
831
USE MESIO-BUCCAL CUSP TIP FOR TIP
828
NEXT TOOTH
827
LAST TOOTH ?
NO
YES
835
CALCULATE INTERSECTION OF CLA WITH REFERENCE PLANE
840
EACH SIDE
841
EACH TOOTH, CENTRAL FIRST
842
PLACE MTPP ON TROUGH EQUATION [FIG. 2W]
845
LAST TOOTH ?
NO
YES
846
NEXT TOOTH
847
FIRST SIDE ?
NO
YES
848
OTHER SIDE
899
EXIT

FIG. 2L

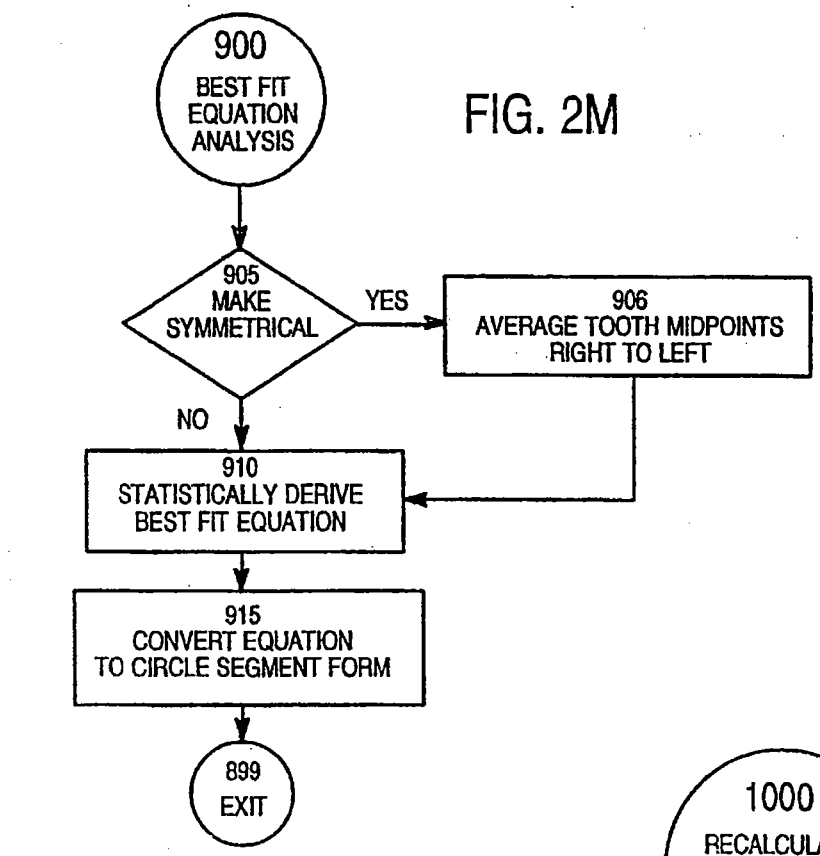

900
BEST FIT EQUATION ANALYSIS
905
MAKE SYMMETRICAL
YES
906
AVERAGE TOOTH MIDPOINTS RIGHT TO LEFT
NO
910
STATISTICALLY DERIVE BEST FIT EQUATION
915
CONVERT EQUATION TO CIRCLE SEGMENT FORM
899
EXIT

FIG. 2M

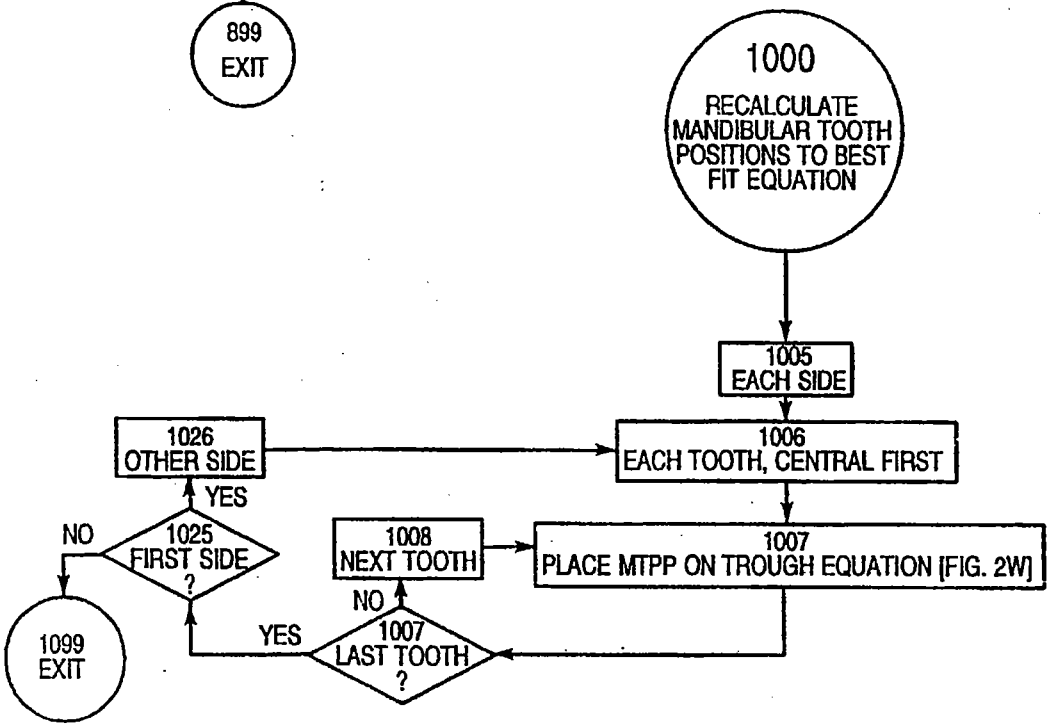

1000
RECALCULATE MANDIBULAR TOOTH POSITIONS TO BEST FIT EQUATION
1005
EACH SIDE
1026
OTHER SIDE
1006
EACH TOOTH, CENTRAL FIRST
YES
NO
1025
FIRST SIDE ?
1008
NEXT TOOTH
1007
PLACE MTPP ON TROUGH EQUATION [FIG. 2W]
NO
YES
1007
LAST TOOTH ?
1099
EXIT

FIG. 2N

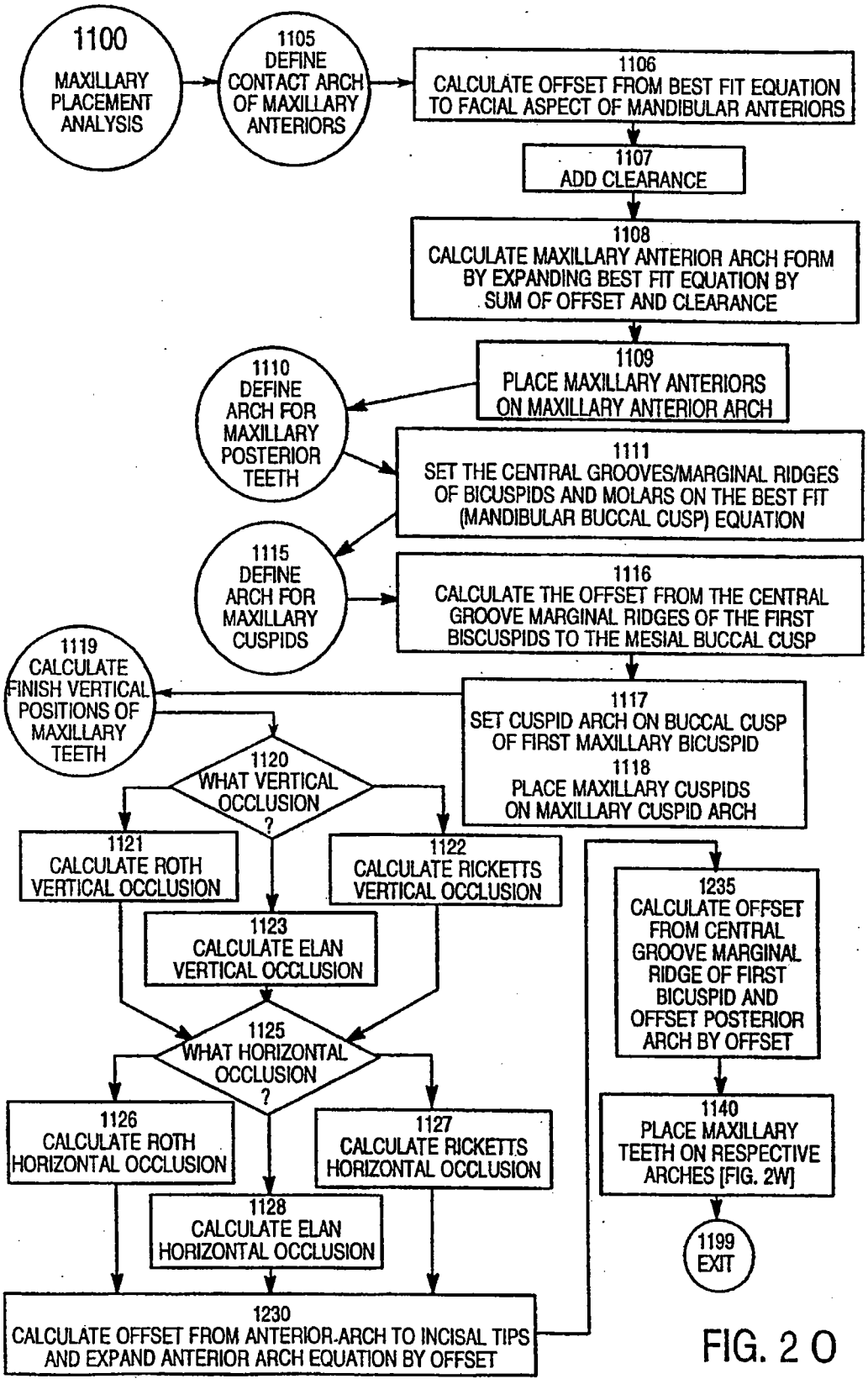

1100
MAXILLARY PLACEMENT ANALYSIS
1105
DEFINE CONTACT ARCH OF MAXILLARY ANTERIORS
1106
CALCULATE OFFSET FROM BEST FIT EQUATION TO FACIAL ASPECT OF MANDIBULAR ANTERIORS
1107
ADD CLEARANCE
1108
CALCULATE MAXILLARY ANTERIOR ARCH FORM BY EXPANDING BEST FIT EQUATION BY SUM OF OFFSET AND CLEARANCE
1109
PLACE MAXILLARY ANTERIORS ON MAXILLARY ANTERIOR ARCH
1110
DEFINE ARCH FOR MAXILLARY POSTERIOR TEETH
1111
SET THE CENTRAL GROOVES/MARGINAL RIDGES OF BICUSPIDS AND MOLARS ON THE BEST FIT (MANDIBULAR BUCCAL CUSP) EQUATION
1115
DEFINE ARCH FOR MAXILLARY CUSPIDS
1116
CALCULATE THE OFFSET FROM THE CENTRAL GROOVE MARGINAL RIDGES OF THE FIRST BISCUSPIDS TO THE MESIAL BUCCAL CUSP
1119
CALCULATE FINISH VERTICAL POSITIONS OF MAXILLARY TEETH
1117
SET CUSPID ARCH ON BUCCAL CUSP OF FIRST MAXILLARY BICUSPID
1118
PLACE MAXILLARY CUSPIDS ON MAXILLARY CUSPID ARCH
1120
WHAT VERTICAL OCCLUSION ?
1121
CALCULATE ROTH VERTICAL OCCLUSION
1122
CALCULATE RICKETTS VERTICAL OCCLUSION
1123
CALCULATE ELAN VERTICAL OCCLUSION
1125
WHAT HORIZONTAL OCCLUSION ?
1126
CALCULATE ROTH HORIZONTAL OCCLUSION
1127
CALCULATE RICKETTS HORIZONTAL OCCLUSION
1128
CALCULATE ELAN HORIZONTAL OCCLUSION
1230
CALCULATE OFFSET FROM ANTERIOR ARCH TO INCISAL TIPS AND EXPAND ANTERIOR ARCH EQUATION BY OFFSET
1235
CALCULATE OFFSET FROM CENTRAL GROOVE MARGINAL RIDGE OF FIRST BICUSPID AND OFFSET POSTERIOR ARCH BY OFFSET
1140
PLACE MAXILLARY TEETH ON RESPECTIVE ARCHES [FIG. 2W]
1199
EXIT

FIG. 20

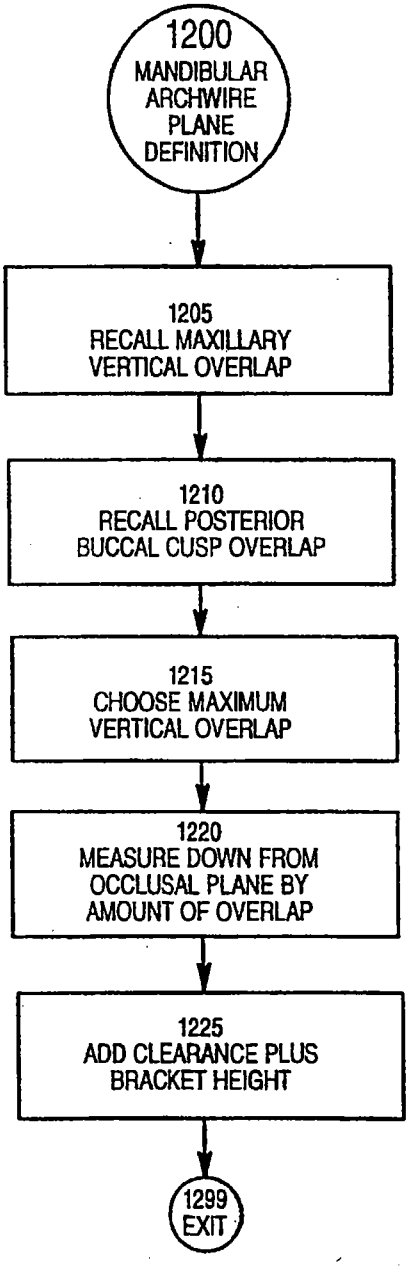

1200
MANDIBULAR ARCHWIRE PLANE DEFINITION
1205
RECALL MAXILLARY VERTICAL OVERLAP
1210
RECALL POSTERIOR BUCCAL CUSP OVERLAP
1215
CHOOSE MAXIMUM VERTICAL OVERLAP
1220
MEASURE DOWN FROM OCCLUSAL PLANE BY AMOUNT OF OVERLAP
1225
ADD CLEARANCE PLUS BRACKET HEIGHT
1299
EXIT

FIG. 2P

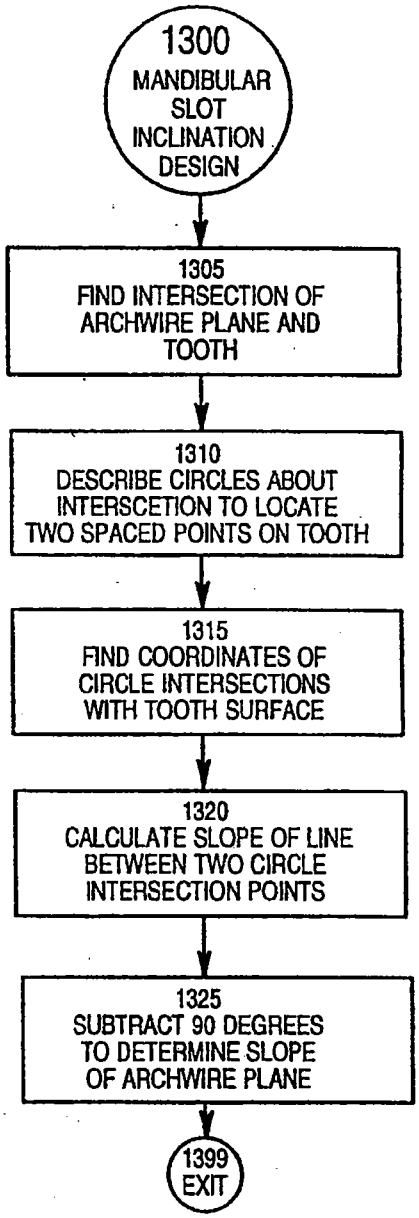

1300
MANDIBULAR SLOT INCLINATION DESIGN
1305
FIND INTERSECTION OF ARCHWIRE PLANE AND TOOTH
1310
DESCRIBE CIRCLES ABOUT INTERSCETION TO LOCATE TWO SPACED POINTS ON TOOTH
1315
FIND COORDINATES OF CIRCLE INTERSECTIONS WITH TOOTH SURFACE
1320
CALCULATE SLOPE OF LINE BETWEEN TWO CIRCLE INTERSECTION POINTS
1325
SUBTRACT 90 DEGREES TO DETERMINE SLOPE OF ARCHWIRE PLANE
1399
EXIT

FIG. 2Q

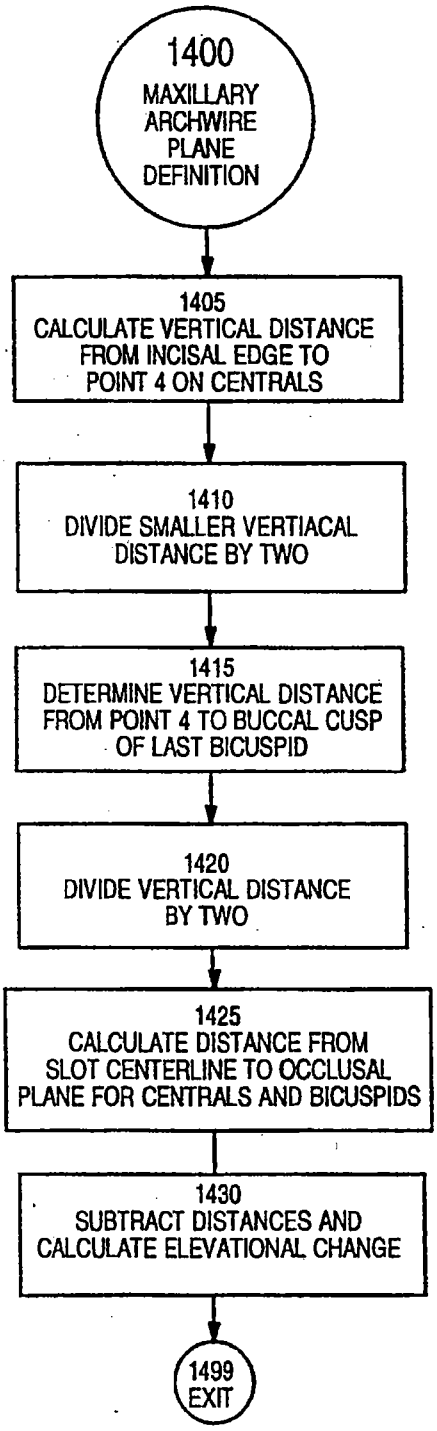

1400
MAXILLARY ARCHWIRE PLANE DEFINITION
1405
CALCULATE VERTICAL DISTANCE FROM INCISAL EDGE TO POINT 4 ON CENTRALS
1410
DIVIDE SMALLER VERTIACAL DISTANCE BY TWO
1415
DETERMINE VERTICAL DISTANCE FROM POINT 4 TO BUCCAL CUSP OF LAST BICUSPID
1420
DIVIDE VERTICAL DISTANCE BY TWO
1425
CALCULATE DISTANCE FROM SLOT CENTERLINE TO OCCLUSAL PLANE FOR CENTRALS AND BICUSPIDS
1430
SUBTRACT DISTANCES AND CALCULATE ELEVATIONAL CHANGE
1499
EXIT

FIG. 2R

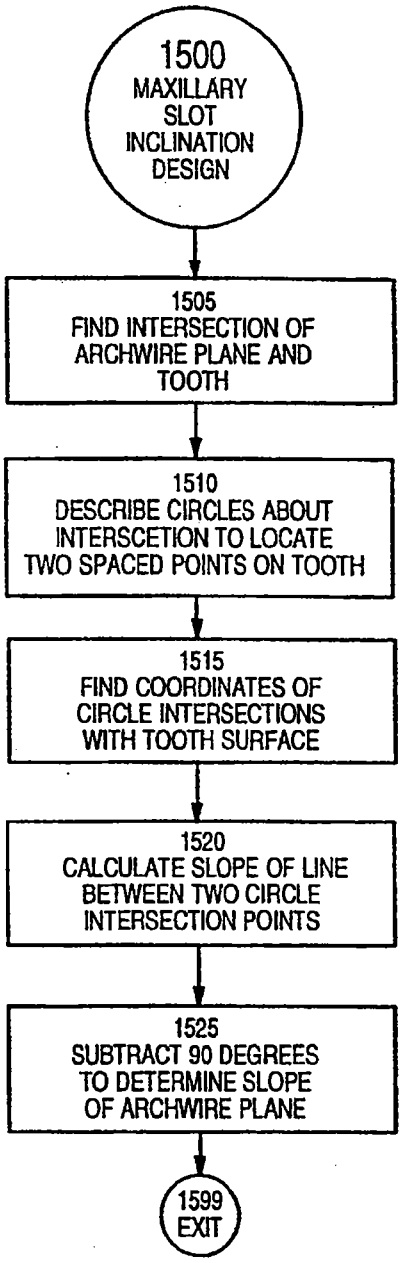

1500
MAXILLARY SLOT INCLINATION DESIGN
1505
FIND INTERSECTION OF ARCHWIRE PLANE AND TOOTH
1510
DESCRIBE CIRCLES ABOUT INTERSCETION TO LOCATE TWO SPACED POINTS ON TOOTH
1515
FIND COORDINATES OF CIRCLE INTERSECTIONS WITH TOOTH SURFACE
1520
CALCULATE SLOPE OF LINE BETWEEN TWO CIRCLE INTERSECTION POINTS
1525
SUBTRACT 90 DEGREES TO DETERMINE SLOPE OF ARCHWIRE PLANE
1599
EXIT

FIG. 2S

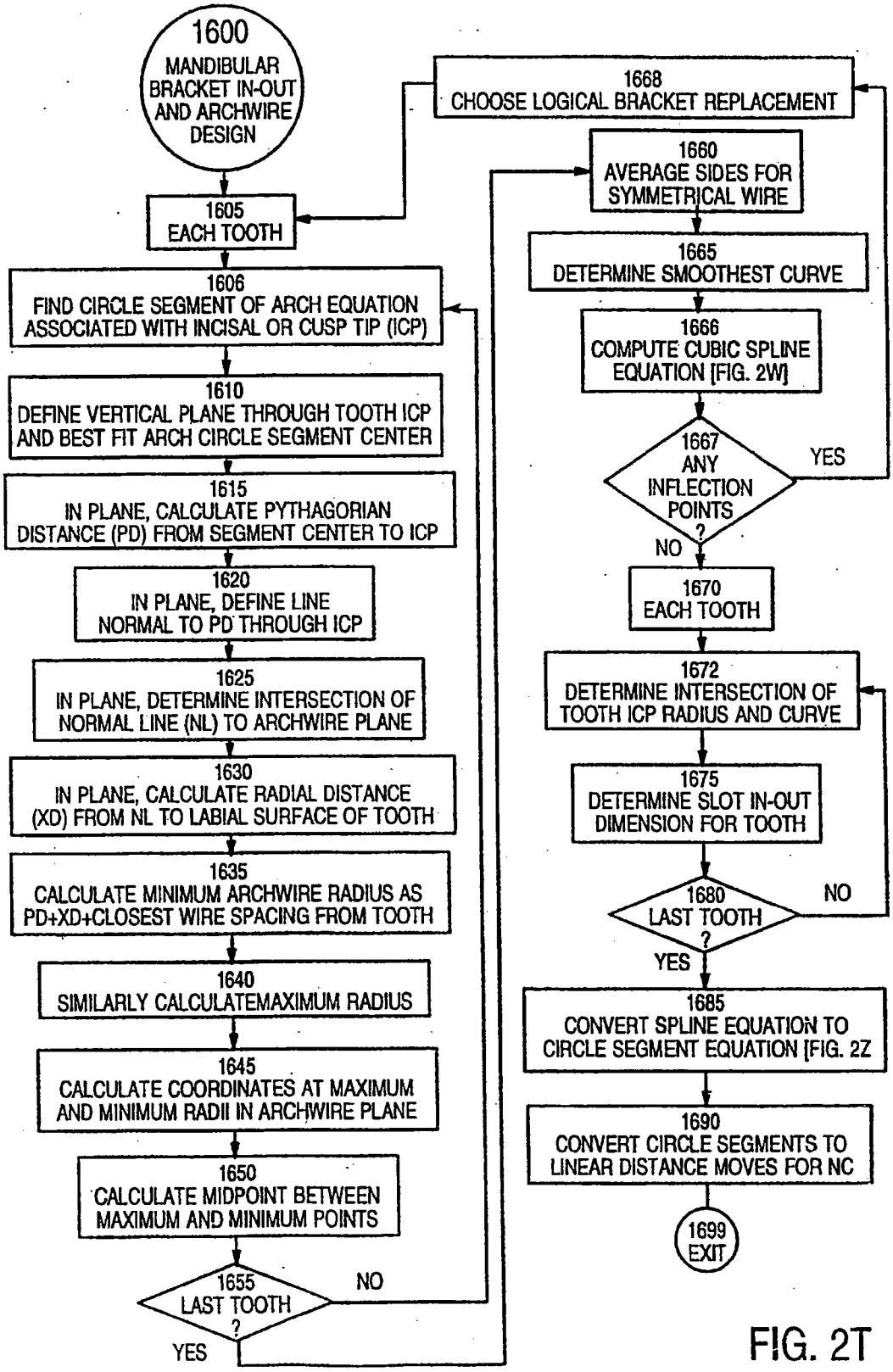

1600
MANDIBULAR BRACKET IN-OUT AND ARCHWIRE DESIGN
1605
EACH TOOTH
1606
FIND CIRCLE SEGMENT OF ARCH EQUATION ASSOCIATED WITH INCISAL OR CUSP TIP (ICP)
1610
DEFINE VERTICAL PLANE THROUGH TOOTH ICP AND BEST FIT ARCH CIRCLE SEGMENT CENTER
1615
IN PLANE, CALCULATE PYTHAGORIAN DISTANCE (PD) FROM SEGMENT CENTER TO ICP
1620
IN PLANE, DEFINE LINE NORMAL TO PD THROUGH ICP
1625
IN PLANE, DETERMINE INTERSECTION OF NORMAL LINE (NL) TO ARCHWIRE PLANE
1630
IN PLANE, CALCULATE RADIAL DISTANCE (XD) FROM NL TO LABIAL SURFACE OF TOOTH
1635
CALCULATE MINIMUM ARCHWIRE RADIUS AS PD+XD+CLOSEST WIRE SPACING FROM TOOTH
1640
SIMILARLY CALCULATEMAXIMUM RADIUS
1645
CALCULATE COORDINATES AT MAXIMUM AND MINIMUM RADII IN ARCHWIRE PLANE
1650
CALCULATE MIDPOINT BETWEEN MAXIMUM AND MINIMUM POINTS
1655
LAST TOOTH ?
NO
YES
1660
AVERAGE SIDES FOR SYMMETRICAL WIRE
1665
DETERMINE SMOOTHEST CURVE
1666
COMPUTE CUBIC SPLINE EQUATION [FIG. 2W]
1667
ANY INFLECTION POINTS ?
YES
NO
1668
CHOOSE LOGICAL BRACKET REPLACEMENT
1670
EACH TOOTH
1672
DETERMINE INTERSECTION OF TOOTH ICP RADIUS AND CURVE
1675
DETERMINE SLOT IN-OUT DIMENSION FOR TOOTH
1680
LAST TOOTH ?
NO
YES
1685
CONVERT SPLINE EQUATION TO CIRCLE SEGMENT EQUATION [FIG. 2Z
1690
CONVERT CIRCLE SEGMENTS TO LINEAR DISTANCE MOVES FOR NC
1699
EXIT

FIG. 2T

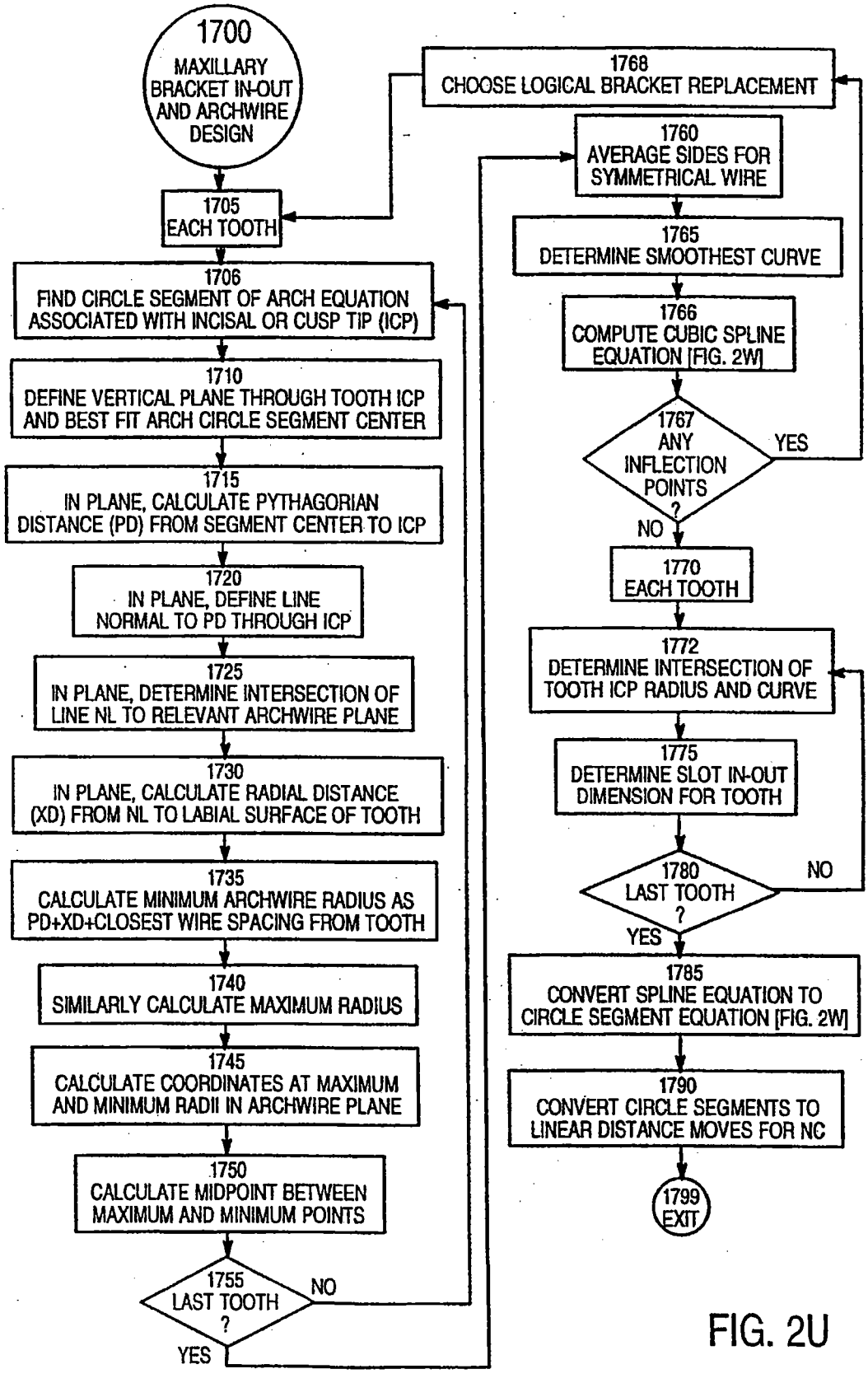

1700
MAXILLARY BRACKET IN-OUT AND ARCHWIRE DESIGN
1705
EACH TOOTH
1706
FIND CIRCLE SEGMENT OF ARCH EQUATION ASSOCIATED WITH INCISAL OR CUSP TIP (ICP)
1710
DEFINE VERTICAL PLANE THROUGH TOOTH ICP AND BEST FIT ARCH CIRCLE SEGMENT CENTER
1715
IN PLANE, CALCULATE PYTHAGORIAN DISTANCE (PD) FROM SEGMENT CENTER TO ICP
1720
IN PLANE, DEFINE LINE NORMAL TO PD THROUGH ICP
1725
IN PLANE, DETERMINE INTERSECTION OF LINE NL TO RELEVANT ARCHWIRE PLANE
1730
IN PLANE, CALCULATE RADIAL DISTANCE (XD) FROM NL TO LABIAL SURFACE OF TOOTH
1735
CALCULATE MINIMUM ARCHWIRE RADIUS AS PD+XD+CLOSEST WIRE SPACING FROM TOOTH
1740
SIMILARLY CALCULATE MAXIMUM RADIUS
1745
CALCULATE COORDINATES AT MAXIMUM AND MINIMUM RADII IN ARCHWIRE PLANE
1750
CALCULATE MIDPOINT BETWEEN MAXIMUM AND MINIMUM POINTS
1755
LAST TOOTH ?
NO
YES
1760
AVERAGE SIDES FOR SYMMETRICAL WIRE
1765
DETERMINE SMOOTHEST CURVE
1766
COMPUTE CUBIC SPLINE EQUATION [FIG. 2W]
1767
ANY INFLECTION POINTS ?
YES
NO
1768
CHOOSE LOGICAL BRACKET REPLACEMENT
1770
EACH TOOTH
1772
DETERMINE INTERSECTION OF TOOTH ICP RADIUS AND CURVE
1775
DETERMINE SLOT IN-OUT DIMENSION FOR TOOTH
1780
LAST TOOTH ?
NO
YES
1785
CONVERT SPLINE EQUATION TO CIRCLE SEGMENT EQUATION [FIG. 2W]
1790
CONVERT CIRCLE SEGMENTS TO LINEAR DISTANCE MOVES FOR NC
1799
EXIT

FIG. 2U

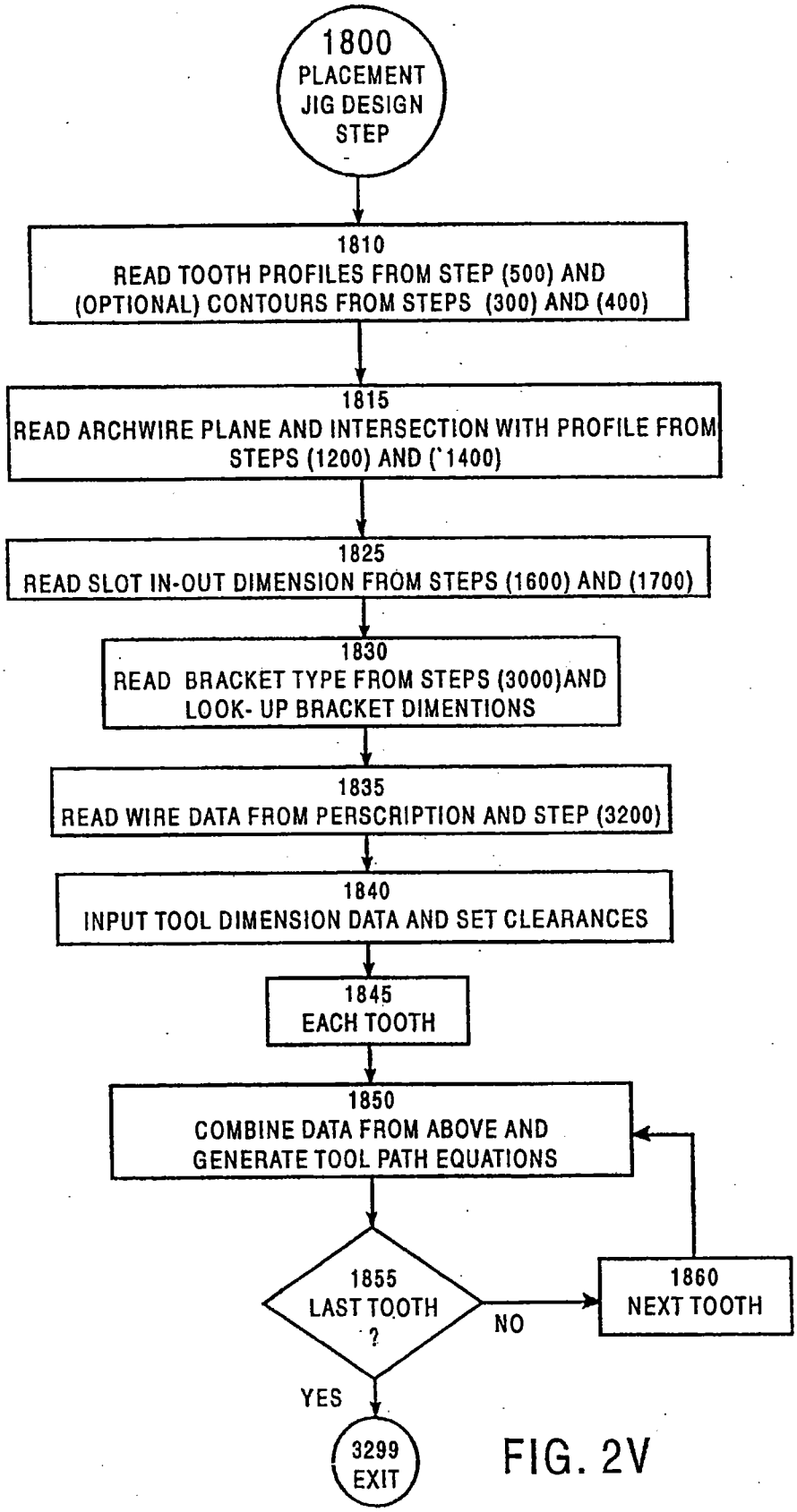

1800
PLACEMENT JIG DESIGN STEP
1810
READ TOOTH PROFILES FROM STEP (500) AND (OPTIONAL) CONTOURS FROM STEPS (300) AND (400)
1815
READ ARCHWIRE PLANE AND INTERSECTION WITH PROFILE FROM STEPS (1200) AND (`1400)
1825
READ SLOT IN-OUT DIMENSION FROM STEPS (1600) AND (1700)
1830
READ BRACKET TYPE FROM STEPS (3000)AND LOOK- UP BRACKET DIMENTIONS
1835
READ WIRE DATA FROM PERSCRIPTION AND STEP (3200)
1840
INPUT TOOL DIMENSION DATA AND SET CLEARANCES
1845
EACH TOOTH
1850
COMBINE DATA FROM ABOVE AND GENERATE TOOL PATH EQUATIONS
1855
LAST TOOTH ?
NO
1860
NEXT TOOTH
YES
3299
EXIT

FIG. 2V

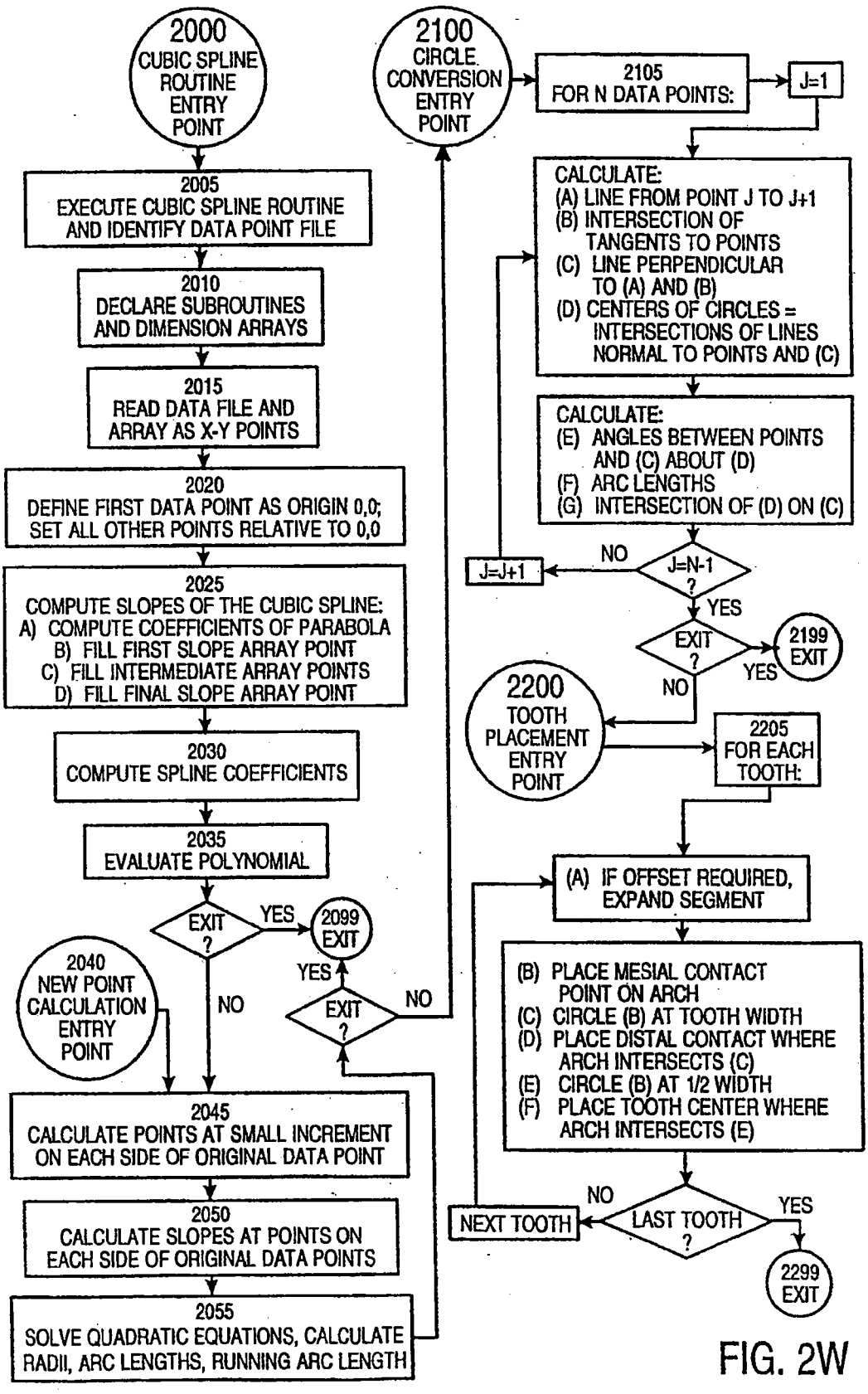

2000
CUBIC SPLINE ROUTINE ENTRY POINT
2005
EXECUTE CUBIC SPLINE ROUTINE AND IDENTIFY DATA POINT FILE
2010
DECLARE SUBROUTINES AND DIMENSION ARRAYS
2015
READ DATA FILE AND ARRAY AS X-Y POINTS
2020
DEFINE FIRST DATA POINT AS ORIGIN 0,0; SET ALL OTHER POINTS RELATIVE TO 0,0
2025
COMPUTE SLOPES OF THE CUBIC SPLINE:
A) COMPUTE COEFFICIENTS OF PARABOLA
B) FILL FIRST SLOPE ARRAY POINT
C) FILL INTERMEDIATE ARRAY POINTS
D) FILL FINAL SLOPE ARRAY POINT
2030
COMPUTE SPLINE COEFFICIENTS
2035
EVALUATE POLYNOMIAL
EXIT ?
YES
2099 EXIT
NO
2040
NEW POINT CALCULATION ENTRY POINT
YES
EXIT ?
NO
2045
CALCULATE POINTS AT SMALL INCREMENT ON EACH SIDE OF ORIGINAL DATA POINT
2050
CALCULATE SLOPES AT POINTS ON EACH SIDE OF ORIGINAL DATA POINTS
2055
SOLVE QUADRATIC EQUATIONS, CALCULATE RADII, ARC LENGTHS, RUNNING ARC LENGTH
2100
CIRCLE CONVERSION ENTRY POINT
2105
FOR N DATA POINTS:
J=1
CALCULATE:
(A) LINE FROM POINT J TO J+1
(B) INTERSECTION OF TANGENTS TO POINTS
(C) LINE PERPENDICULAR TO (A) AND (B)
(D) CENTERS OF CIRCLES = INTERSECTIONS OF LINES NORMAL TO POINTS AND (C)
CALCULATE:
(E) ANGLES BETWEEN POINTS AND (C) ABOUT (D)
(F) ARC LENGTHS
(G) INTERSECTION OF (D) ON (C)
NO
J=N-1 ?
J=J+1
YES
EXIT ?
YES
2199 EXIT
NO
2200
TOOTH PLACEMENT ENTRY POINT
2205
FOR EACH TOOTH:
(A) IF OFFSET REQUIRED, EXPAND SEGMENT
(B) PLACE MESIAL CONTACT POINT ON ARCH
(C) CIRCLE (B) AT TOOTH WIDTH
(D) PLACE DISTAL CONTACT WHERE ARCH INTERSECTS (C)
(E) CIRCLE (B) AT 1/2 WIDTH
(F) PLACE TOOTH CENTER WHERE ARCH INTERSECTS (E)
NO
NEXT TOOTH
LAST TOOTH ?
YES
2299 EXIT

FIG. 2W

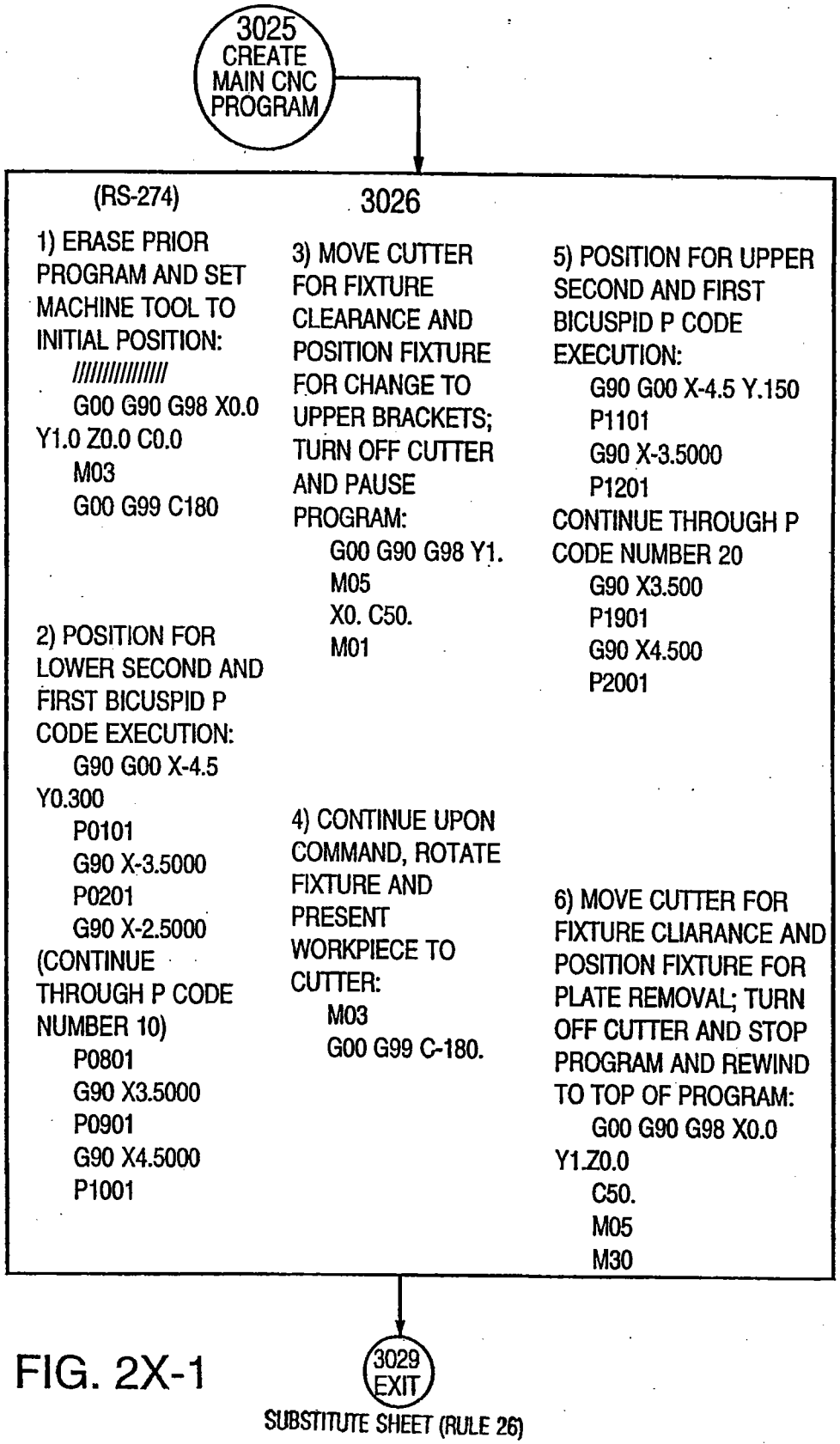


FIG. 2X-1

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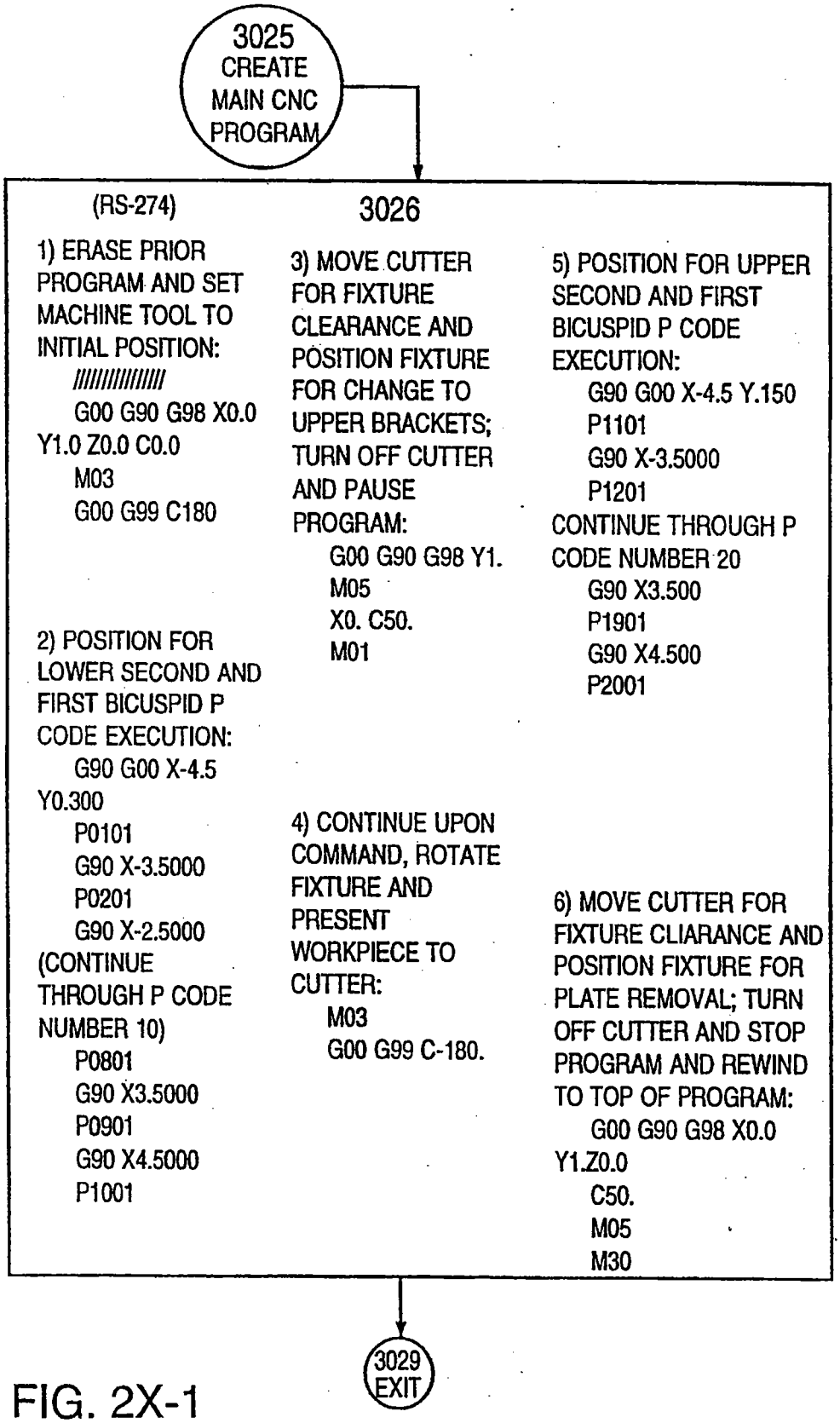
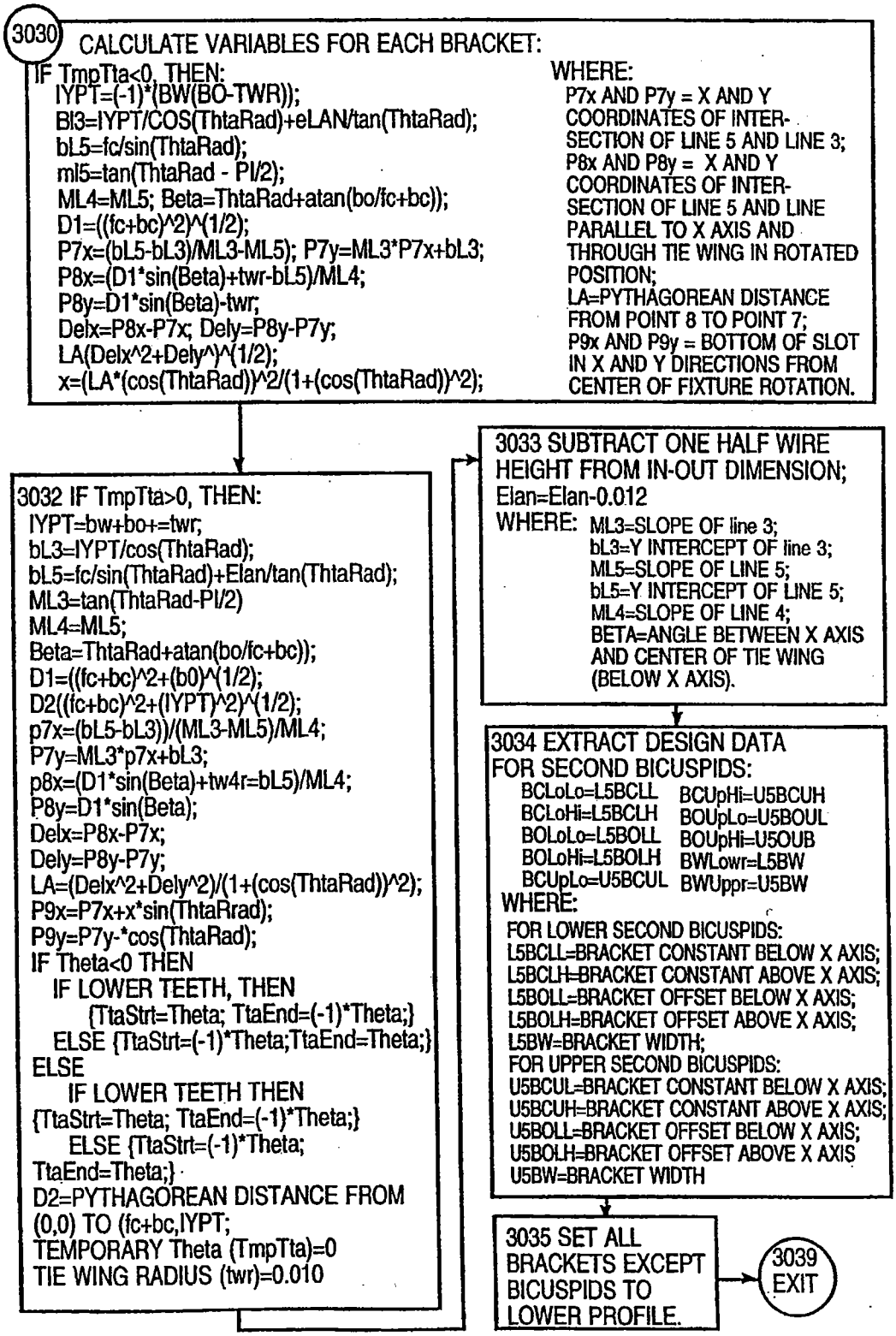

3025
CREATE
MAIN CNC
PROGRAM
(RS-274)
3026
1) ERASE PRIOR PROGRAM AND SET MACHINE TOOL TO INITIAL POSITION:
////////////////
G00 G90 G98 X0.0 Y1.0 Z0.0 C0.0
M03
G00 G99 C180
2) POSITION FOR LOWER SECOND AND FIRST BICUSPID P CODE EXECUTION:
G90 G00 X-4.5 Y0.300
P0101
G90 X-3.5000
P0201
G90 X-2.5000
(CONTINUE THROUGH P CODE NUMBER 10)
P0801
G90 X3.5000
P0901
G90 X4.5000
P1001
3) MOVE CUTTER FOR FIXTURE CLEARANCE AND POSITION FIXTURE FOR CHANGE TO UPPER BRACKETS; TURN OFF CUTTER AND PAUSE PROGRAM:
G00 G90 G98 Y1.
M05
X0. C50.
M01
4) CONTINUE UPON COMMAND, ROTATE FIXTURE AND PRESENT WORKPIECE TO CUTTER:
M03
G00 G99 C-180.
5) POSITION FOR UPPER SECOND AND FIRST BICUSPID P CODE EXECUTION:
G90 G00 X-4.5 Y.150
P1101
G90 X-3.5000
P1201
CONTINUE THROUGH P CODE NUMBER 20
G90 X3.500
P1901
G90 X4.500
P2001
6) MOVE CUTTER FOR FIXTURE CLIARANCE AND POSITION FIXTURE FOR PLATE REMOVAL; TURN OFF CUTTER AND STOP PROGRAM AND REWIND TO TOP OF PROGRAM:
G00 G90 G98 X0.0 Y1.Z0.0
C50.
M05
M30
3029
EXIT

FIG. 2X-1

FIG. 2X-2



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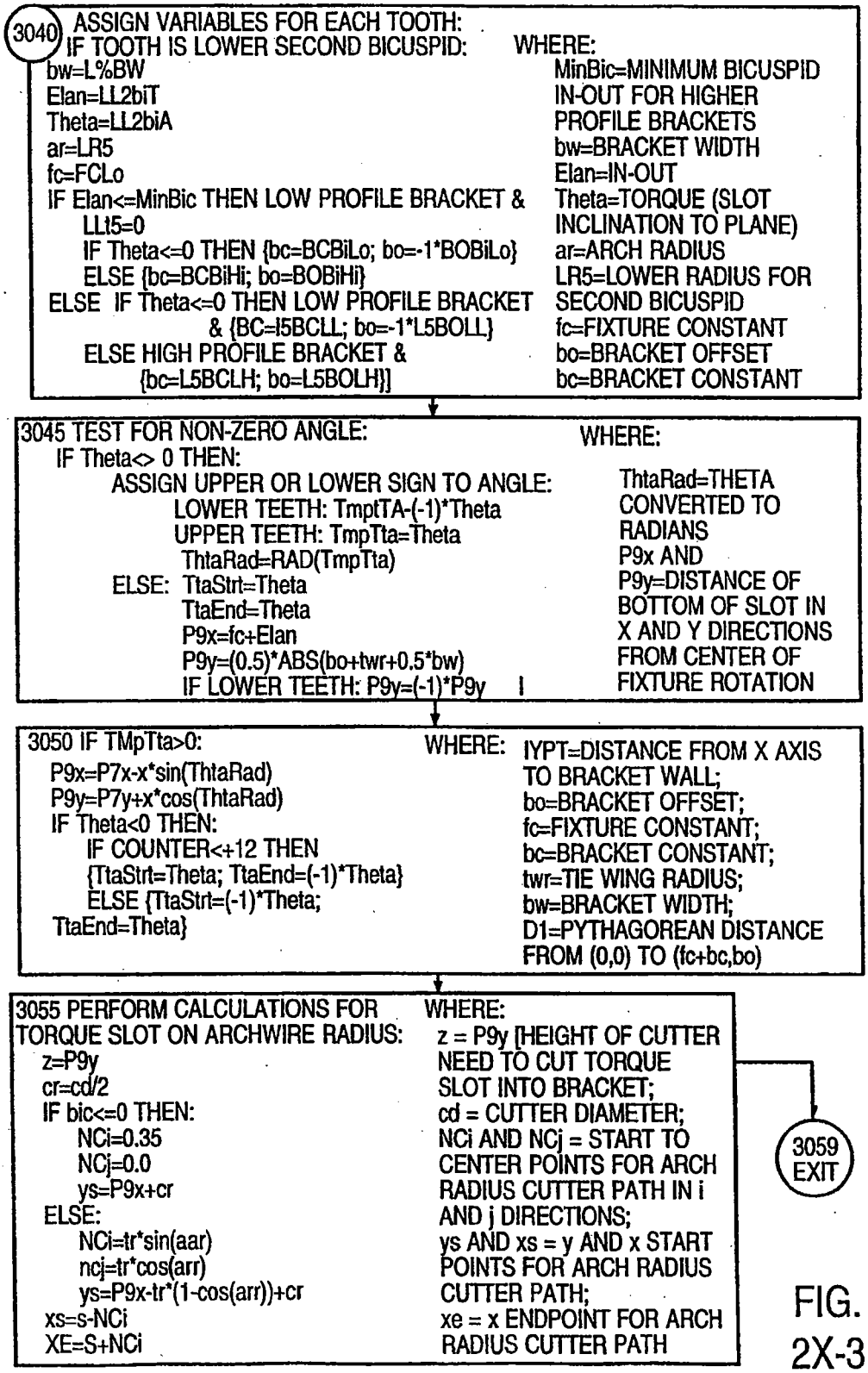


FIG. 2X-3

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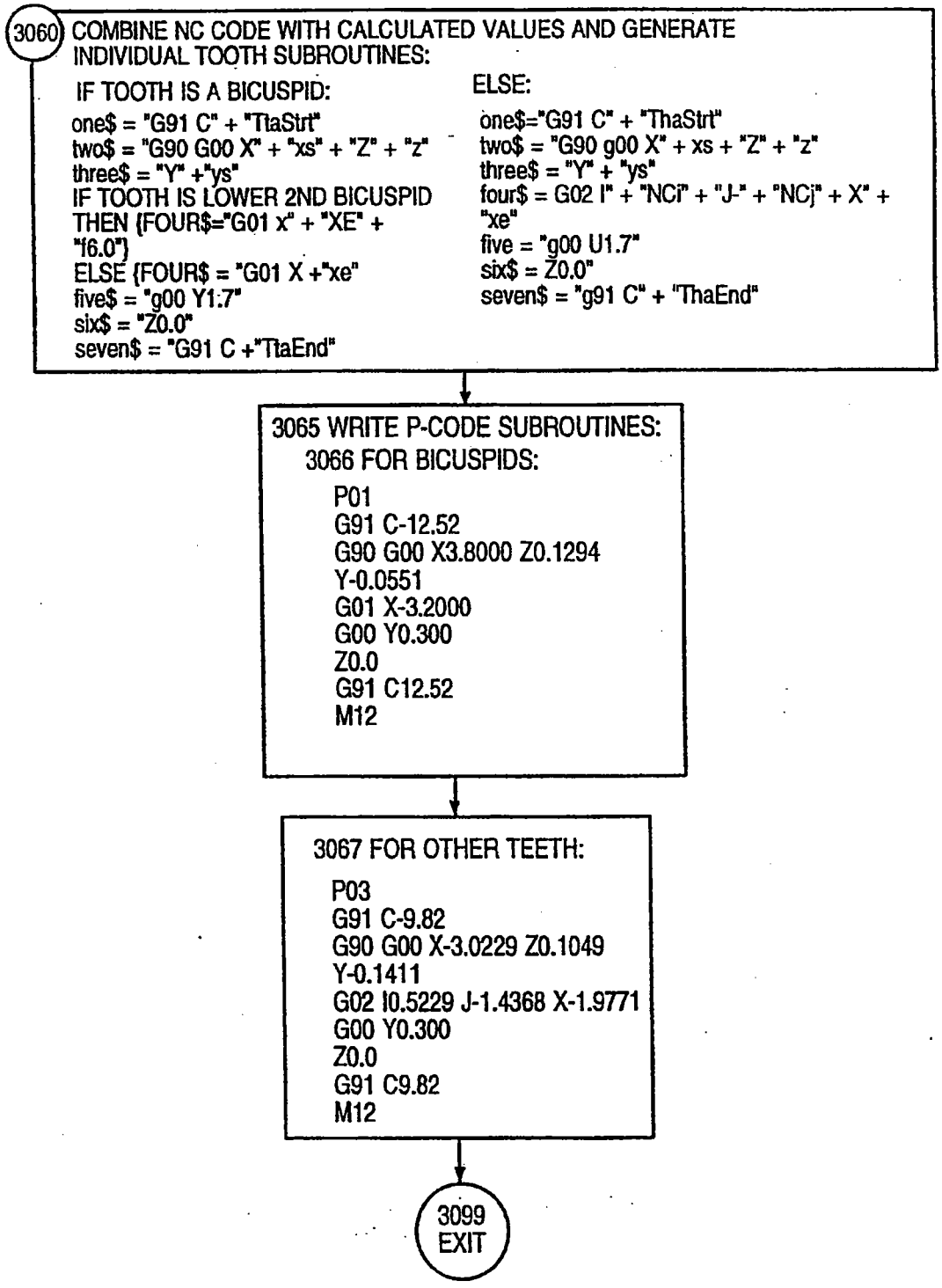

3060
COMBINE NC CODE WITH CALCULATED VALUES AND GENERATE INDIVIDUAL TOOTH SUBROUTINES:
IF TOOTH IS A BICUSPID:
one$ = "G91 C" + "TtaStrt"
two$ = "G90 G00 X" + "xs" + "Z" + "z"
three$ = "Y" +"ys"
IF TOOTH IS LOWER 2ND BICUSPID THEN {FOUR$="G01 x" + "XE" + "f6.0"}
ELSE {FOUR$ = "G01 X +"xe"
five$ = "g00 Y1:7"
six$ = "Z0.0"
seven$ = "G91 C +"TtaEnd"
ELSE:
one$="G91 C" + "ThaStrt"
two$ = "G90 g00 X" + xs + "Z" + "z"
three$ = "Y" + "ys"
four$ = G02 I" + "NCi" + "J-" + "NCj" + X" + "xe"
five = "g00 U1.7"
six$ = Z0.0"
seven$ = "g91 C" + "ThaEnd"
3065 WRITE P-CODE SUBROUTINES:
3066 FOR BICUSPIDS:
P01
G91 C-12.52
G90 G00 X3.8000 Z0.1294
Y-0.0551
G01 X-3.2000
G00 Y0.300
Z0.0
G91 C12.52
M12
3067 FOR OTHER TEETH:
P03
G91 C-9.82
G90 G00 X-3.0229 Z0.1049
Y-0.1411
G02 I0.5229 J-1.4368 X-1.9771
G00 Y0.300
Z0.0
G91 C9.82
M12
3099
EXIT

FIG. 2X-4

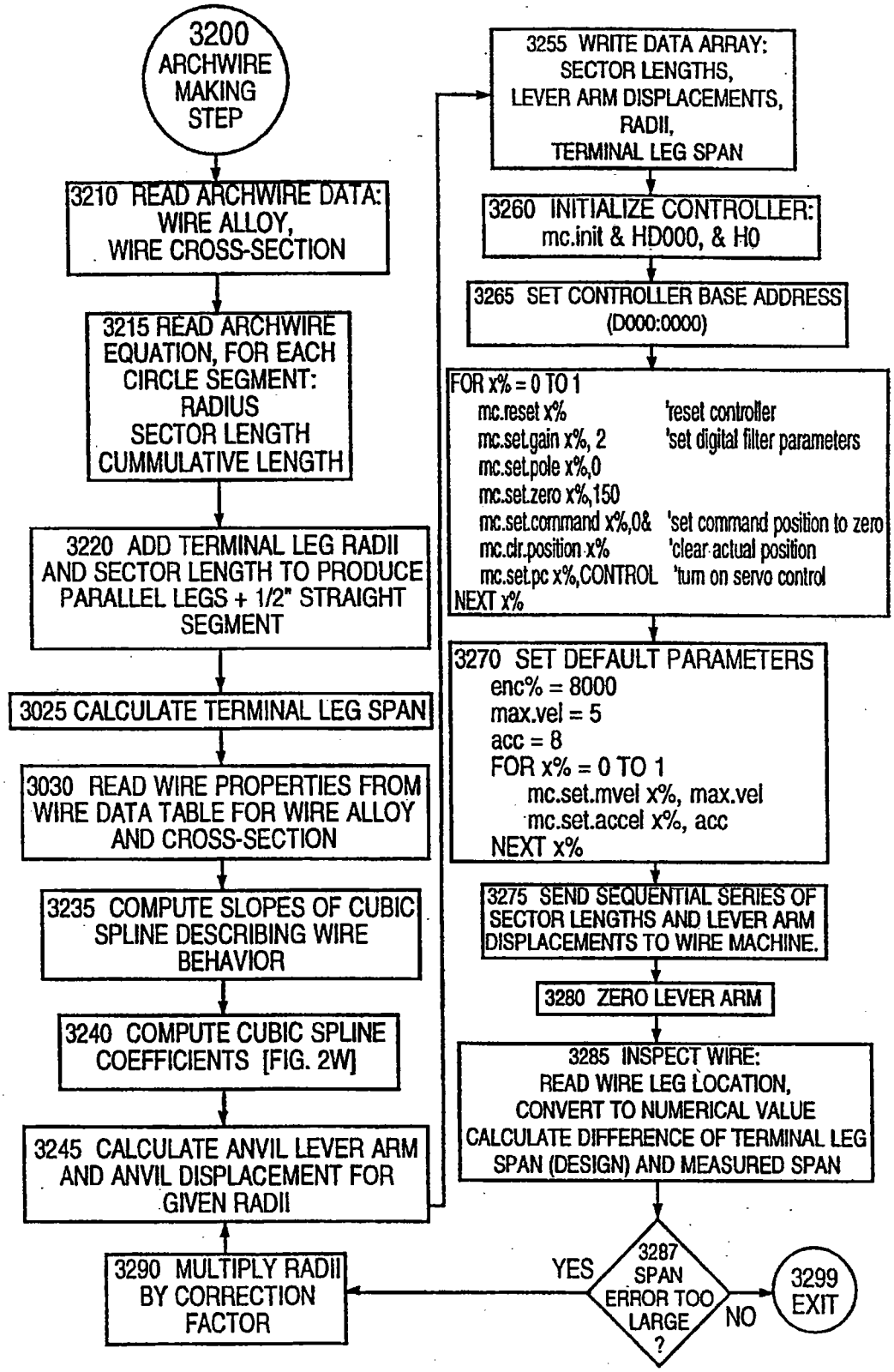

3200 ARCHWIRE MAKING STEP
3210 READ ARCHWIRE DATA: WIRE ALLOY, WIRE CROSS-SECTION
3215 READ ARCHWIRE EQUATION, FOR EACH CIRCLE SEGMENT: RADIUS SECTOR LENGTH CUMMULATIVE LENGTH
3220 ADD TERMINAL LEG RADII AND SECTOR LENGTH TO PRODUCE PARALLEL LEGS + 1/2" STRAIGHT SEGMENT
3025 CALCULATE TERMINAL LEG SPAN
3030 READ WIRE PROPERTIES FROM WIRE DATA TABLE FOR WIRE ALLOY AND CROSS-SECTION
3235 COMPUTE SLOPES OF CUBIC SPLINE DESCRIBING WIRE BEHAVIOR
3240 COMPUTE CUBIC SPLINE COEFFICIENTS [FIG. 2W]
3245 CALCULATE ANVIL LEVER ARM AND ANVIL DISPLACEMENT FOR GIVEN RADII
3290 MULTIPLY RADII BY CORRECTION FACTOR
3255 WRITE DATA ARRAY: SECTOR LENGTHS, LEVER ARM DISPLACEMENTS, RADII, TERMINAL LEG SPAN
3260 INITIALIZE CONTROLLER: mc.init & HD000, & H0
3265 SET CONTROLLER BASE ADDRESS (D000:0000)
FOR x% = 0 TO 1
mc.reset x% 'reset controller
mc.set.gain x%, 2 'set digital filter parameters
mc.set.pole x%,0
mc.set.zero x%,150
mc.set.command x%,0& 'set command position to zero
mc.clr.position x% 'clear actual position
mc.set.pc x%,CONTROL 'turn on servo control
NEXT x%
3270 SET DEFAULT PARAMETERS
enc% = 8000
max.vel = 5
acc = 8
FOR x% = 0 TO 1
mc.set.mvel x%, max.vel
mc.set.accel x%, acc
NEXT x%
3275 SEND SEQUENTIAL SERIES OF SECTOR LENGTHS AND LEVER ARM DISPLACEMENTS TO WIRE MACHINE.
3280 ZERO LEVER ARM
3285 INSPECT WIRE: READ WIRE LEG LOCATION, CONVERT TO NUMERICAL VALUE CALCULATE DIFFERENCE OF TERMINAL LEG SPAN (DESIGN) AND MEASURED SPAN
3287 SPAN ERROR TOO LARGE ?
YES
NO
3299 EXIT

FIG. 2Y

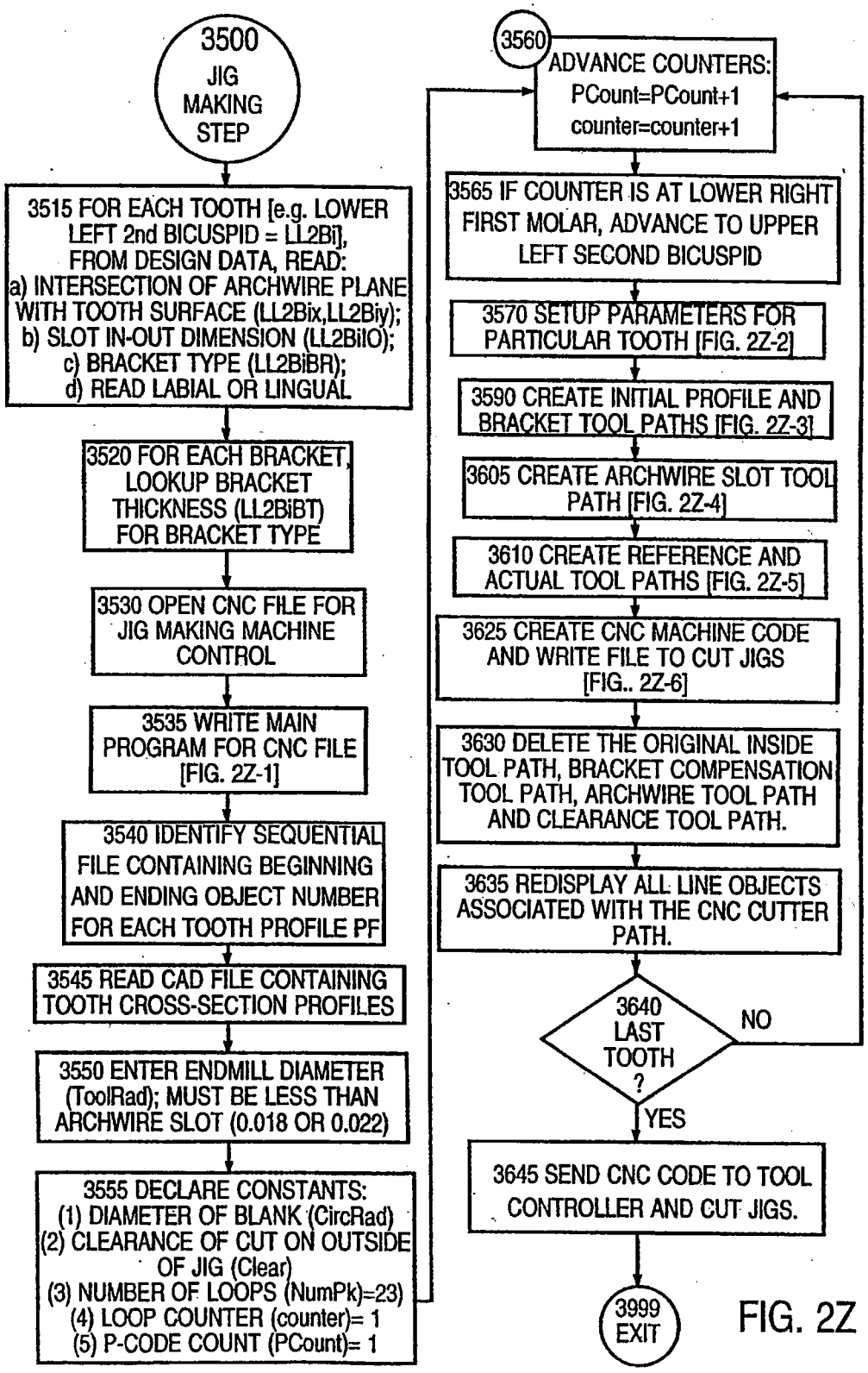


FIG. 2Z

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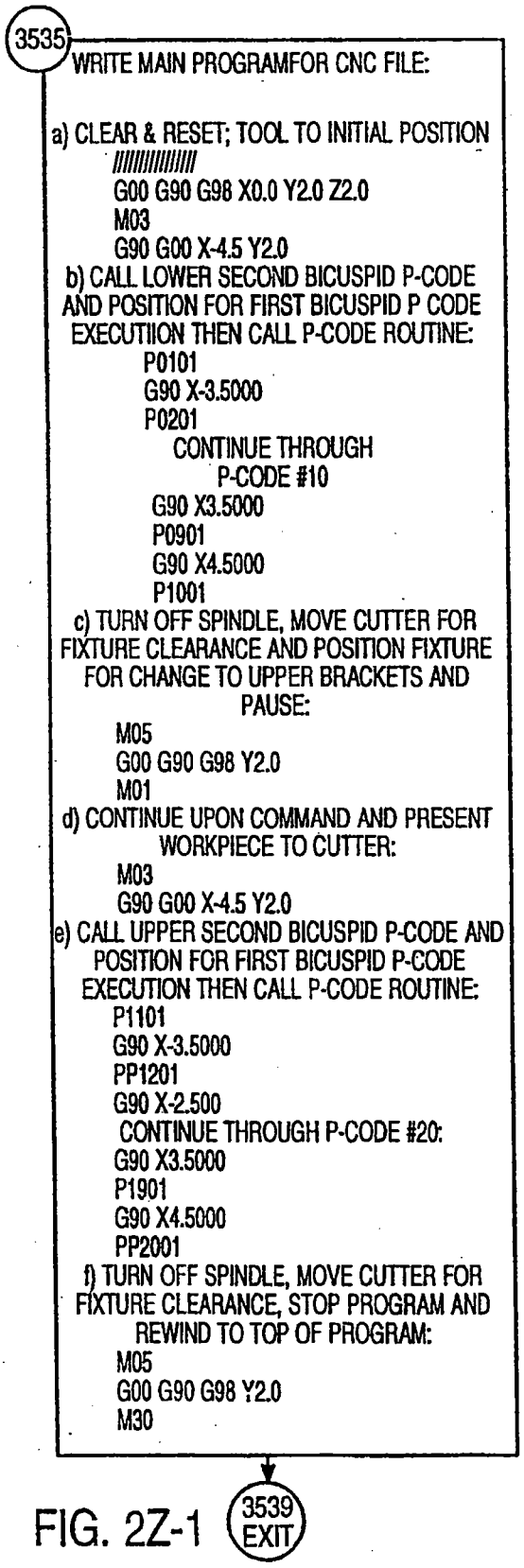


FIG. 2Z-1

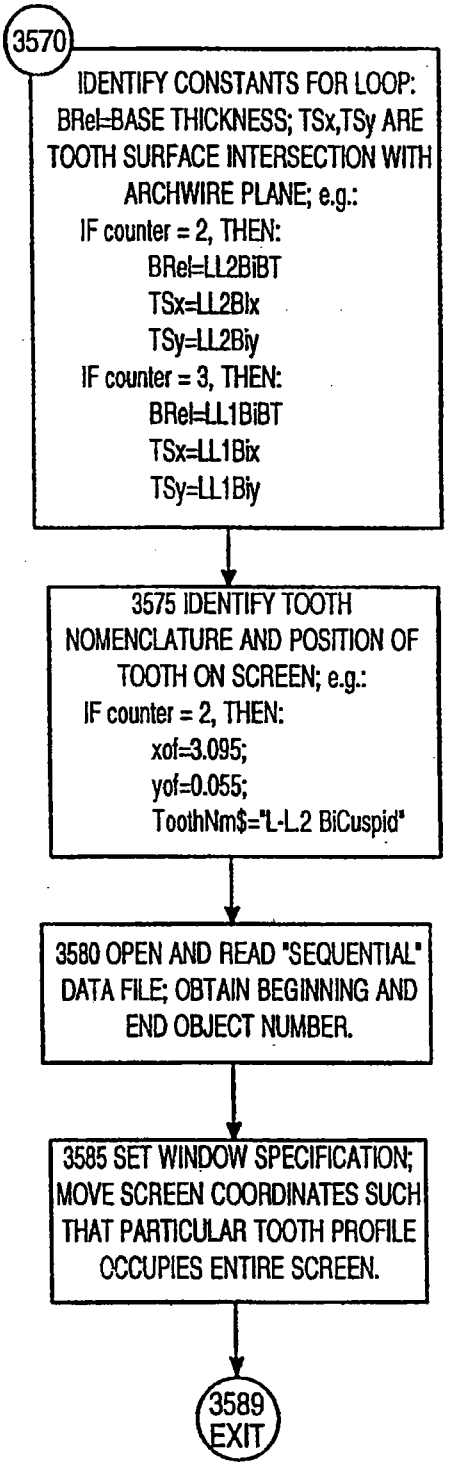


FIG. 2Z-2

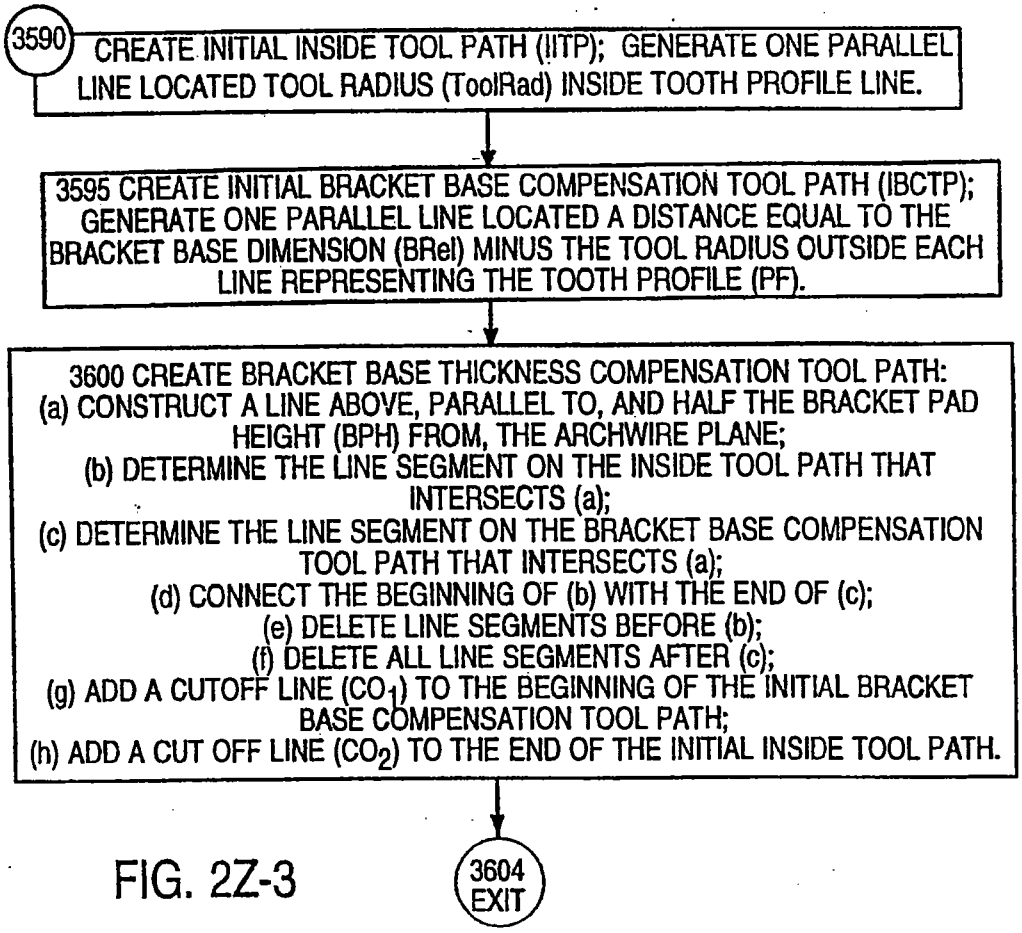


FIG. 2Z-3

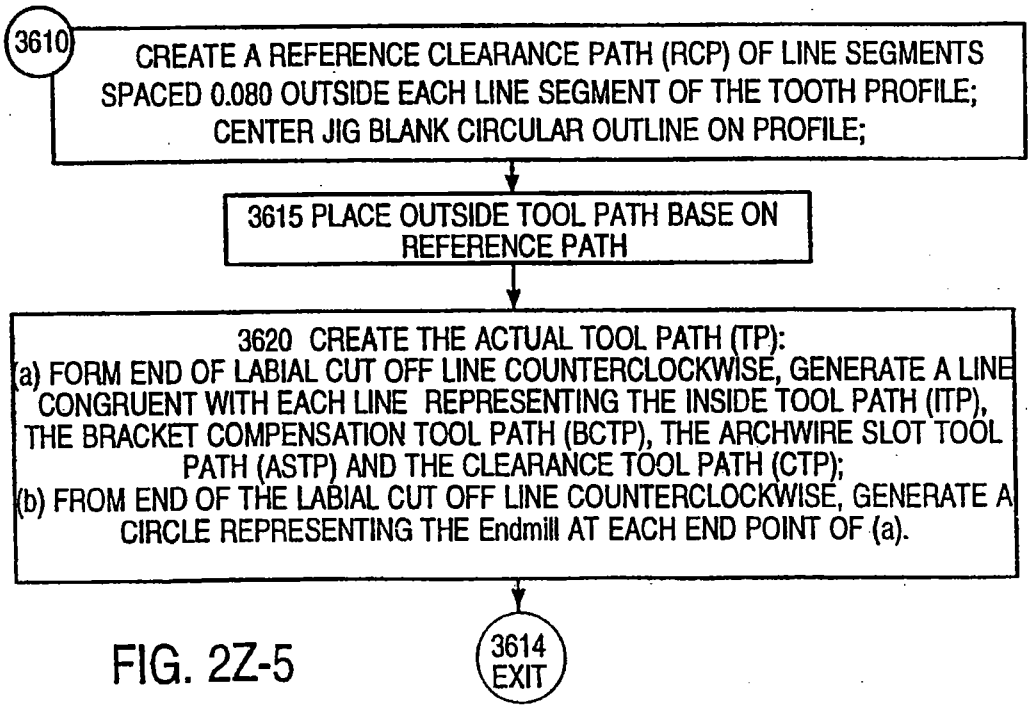


FIG. 2Z-5

3605

CREATE AN ARCHWIRE SLOT TOOL PATH (ASTP):

(a) DETERMINE THE DISTANCE FROM THE SURFACE OF THE TOOTH IN THE x DIRECTION THAT WILL ALLOW A PLASTIC SHIM TO FIT INTO THE TORQUE SLOT: THE DIMENSIONS OF THE SHIM ARE:
(torque slot width) x 0.085 x 0.100;
LnEnd=TSx+Elan-0.012+0.085-ToolRad
WHERE: LnEnd=x LOCATION
Elan = BRACKET In-out (IO)

(b) CONSTRUCT A LINE ABOVE AND PARALLEL TO THE ARCHWIRE PLANE SUCH THAT THE ENDMILL WILL GENERATE A LINE CONGRUENT WITH THE BRACKET TORQUE SLOT WALL; THE HEIGHT ABOVE THE ARCHWIRE PLANE IS:
(torque slot width)/2 - ToolRad;

(c) DETERMINE THE LINE SEGMENT ON THE BRACKET BASE COMPENSATION TOOL PATH THAT INTERSECTS (a);

(d) DELETE (b);

(e) CONSTRUCT A LINE BELOW AND PARALLEL TO THE ARCHWIRE PLANE SUCH THAT THE ENDMILL WILL GENERATE A LINE CONGRUENT WITH THE BRACKET TORQUE SLOT WALL:
THE HEIGHT ABOVE THE ARCHWIRE PLANE IS:
(torque slot width)/2 - ToolRad.

(f) DETERMINE THE LINE SEGMENT ON THE BRACKET BASE COMPENSATION PATH THAT INTERSECTS (a):
THIS IS POINT 8: P8x,P8y;

(g) DELETE (e);

(h) CONSTRUCT A LINE FROM POINT 1 (P1x,P1y) TO POINT 2 (P1X, LnEnd - 0.001);

(i) CONSTRCUT A LINE FROM POINT 2 (P1x, LnEnd - 0.001) TO POINT 3 (P1x + 2.5ToolRad, LnEnd - 0.001);

(j) CONSTRUCT A LINE FROM POINT 3 (P1x + 2.5ToolRad, LnEnd - 0.001) TO POINT 4 (P1x + 2.5ToolRad, LnEnd);

(k) CONSTRUCT A LINE FROM POINT 3 (P1x + 2.5ToolRad, LnEnd- 0.001) TO POINT 4 (P1x + 2.5ToolRad, LnEnd);

(l) CONSTRUCT A LINE FROM POINT 5 (P2x - 2.5ToolRad, LnEnd) TO POINT 6 (P2x - 2.5ToolRad, LnEnd - 0.001);

(m) CONSTRUCT A LINE FROM POINT 6 (P2x - 2.5ToolRad, LnEnd - 0.001) TO POINT 7 (P2x, LnEnd - 0.001);

(n) CONSTRUCT A LINE FROM POINT 7 (P2x, LnEnd - 0.001) TO POINT 8 (PIx,P8y)

3609
GO TO 3610
[FIG. 2Z-4]

FIG. 2Z-4

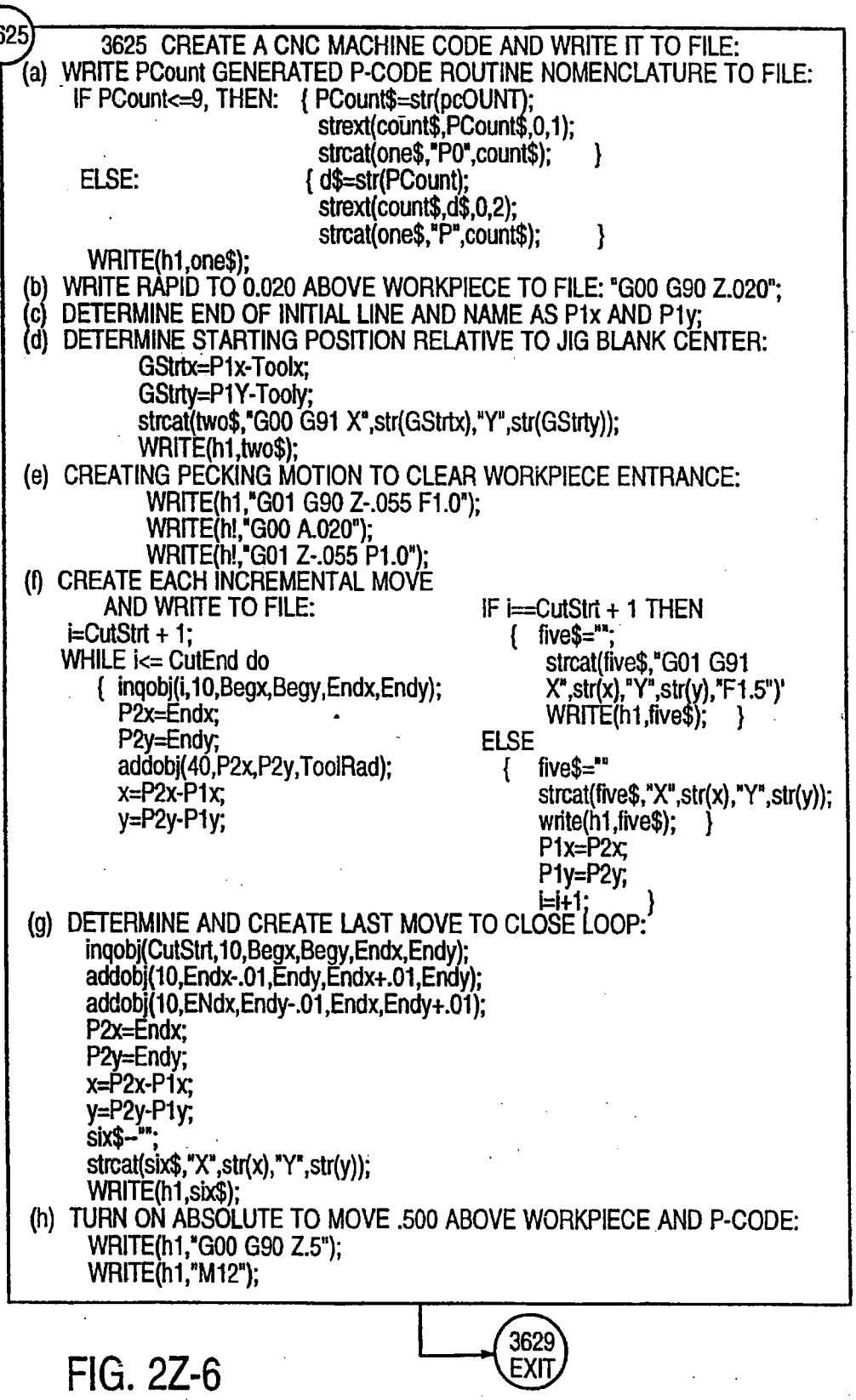

3625
3625 CREATE A CNC MACHINE CODE AND WRITE IT TO FILE:
(a) WRITE PCount GENERATED P-CODE ROUTINE NOMENCLATURE TO FILE:
IF PCount<=9, THEN: { PCount$=str(pcOUNT);
strext(count$,PCount$,0,1);
strcat(one$,"P0",count$); }
ELSE: { d$=str(PCount);
strext(count$,d$,0,2);
strcat(one$,"P",count$); }
WRITE(h1,one$);
(b) WRITE RAPID TO 0.020 ABOVE WORKPIECE TO FILE: "G00 G90 Z.020";
(c) DETERMINE END OF INITIAL LINE AND NAME AS P1x AND P1y;
(d) DETERMINE STARTING POSITION RELATIVE TO JIG BLANK CENTER:
GStrtx=P1x-Toolx;
GStrty=P1Y-Tooly;
strcat(two$,"G00 G91 X",str(GStrtx),"Y",str(GStrty));
WRITE(h1,two$);
(e) CREATING PECKING MOTION TO CLEAR WORKPIECE ENTRANCE:
WRITE(h1,"G01 G90 Z-.055 F1.0");
WRITE(h!,"G00 A.020");
WRITE(h!,"G01 Z-.055 P1.0");
(f) CREATE EACH INCREMENTAL MOVE
AND WRITE TO FILE:
i=CutStrt + 1;
WHILE i<= CutEnd do
{ inqobj(i,10,Begx,Begy,Endx,Endy);
P2x=Endx;
P2y=Endy;
addobj(40,P2x,P2y,ToolRad);
x=P2x-P1x;
y=P2y-P1y;
IF i==CutStrt + 1 THEN
{ five$="";
strcat(five$,"G01 G91
X",str(x),"Y",str(y),"F1.5")'
WRITE(h1,five$); }
ELSE
{ five$=""
strcat(five$,"X",str(x),"Y",str(y));
write(h1,five$); }
P1x=P2x;
P1y=P2y;
i=i+1; }
(g) DETERMINE AND CREATE LAST MOVE TO CLOSE LOOP:
inqobj(CutStrt,10,Begx,Begy,Endx,Endy);
addobj(10,Endx-.01,Endy,Endx+.01,Endy);
addobj(10,ENdx,Endy-.01,Endx,Endy+.01);
P2x=Endx;
P2y=Endy;
x=P2x-P1x;
y=P2y-P1y;
six$--"";
strcat(six$,"X",str(x),"Y",str(y));
WRITE(h1,six$);
(h) TURN ON ABSOLUTE TO MOVE .500 ABOVE WORKPIECE AND P-CODE:
WRITE(h1,"G00 G90 Z.5");
WRITE(h1,"M12");
3629
EXIT

FIG. 2Z-6

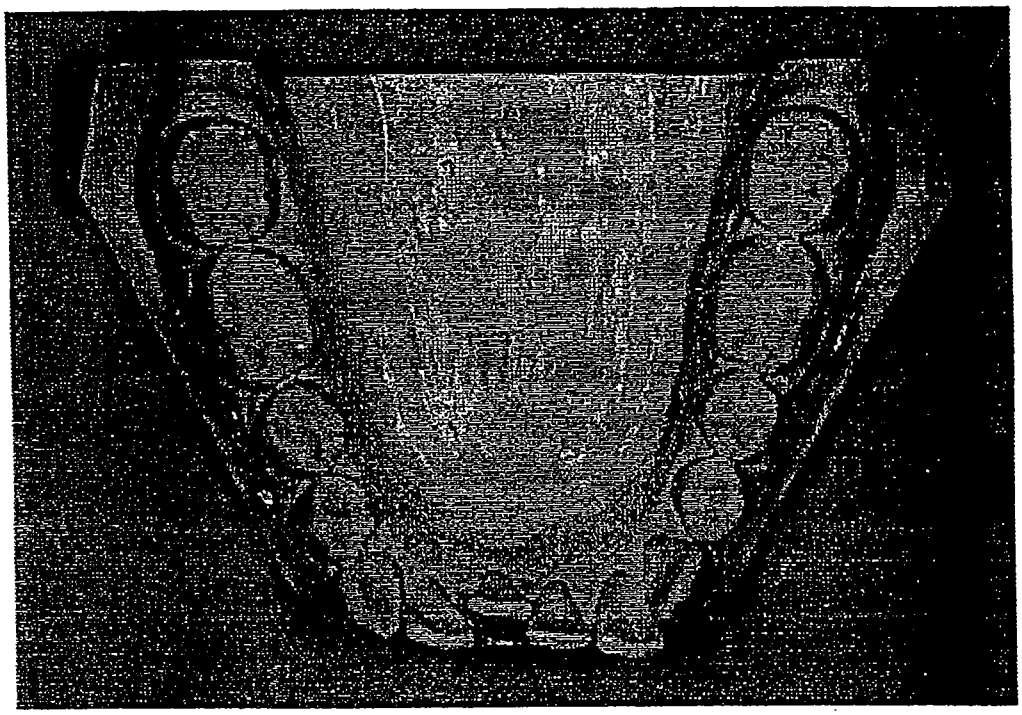


FIG. 3

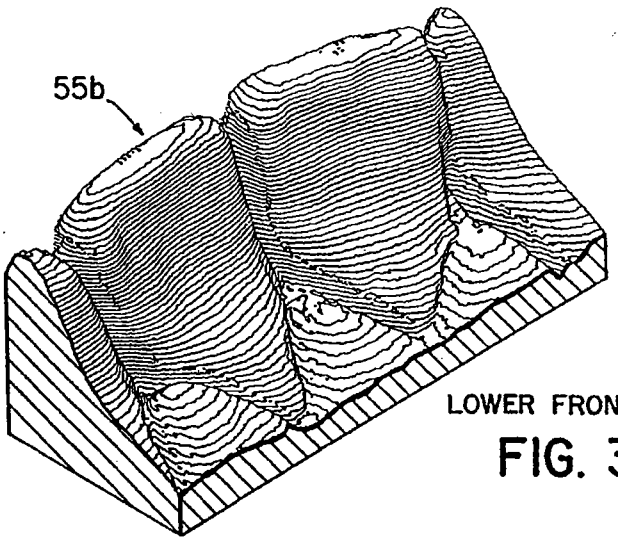


FIG. 3B

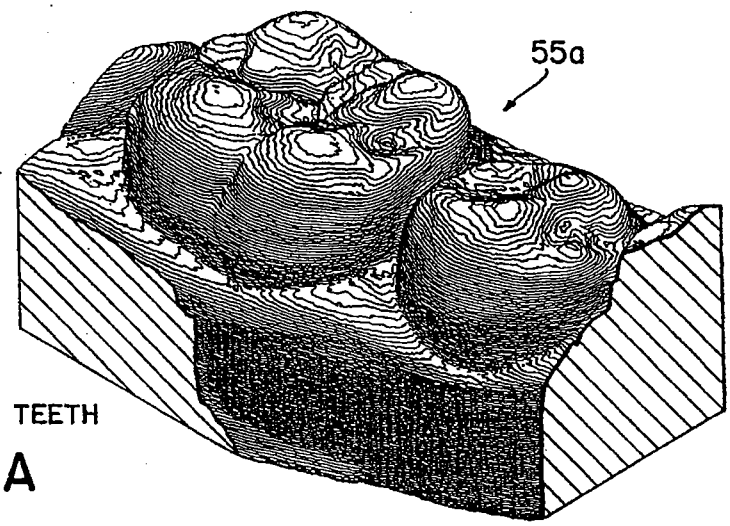


FIG. 3A

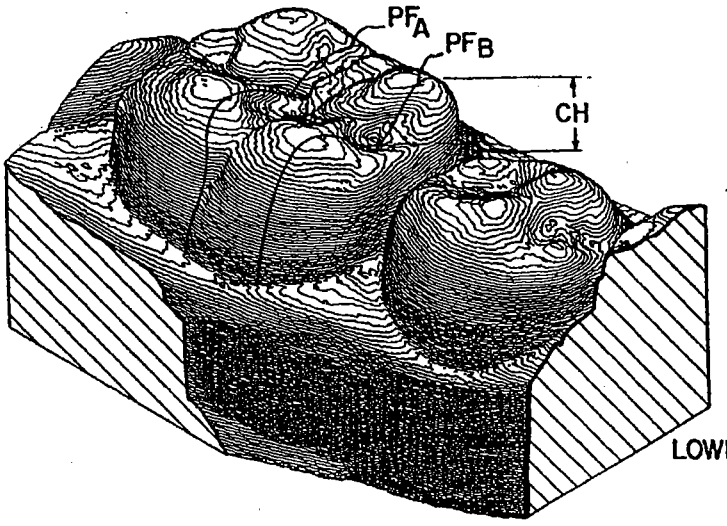


FIG. 6

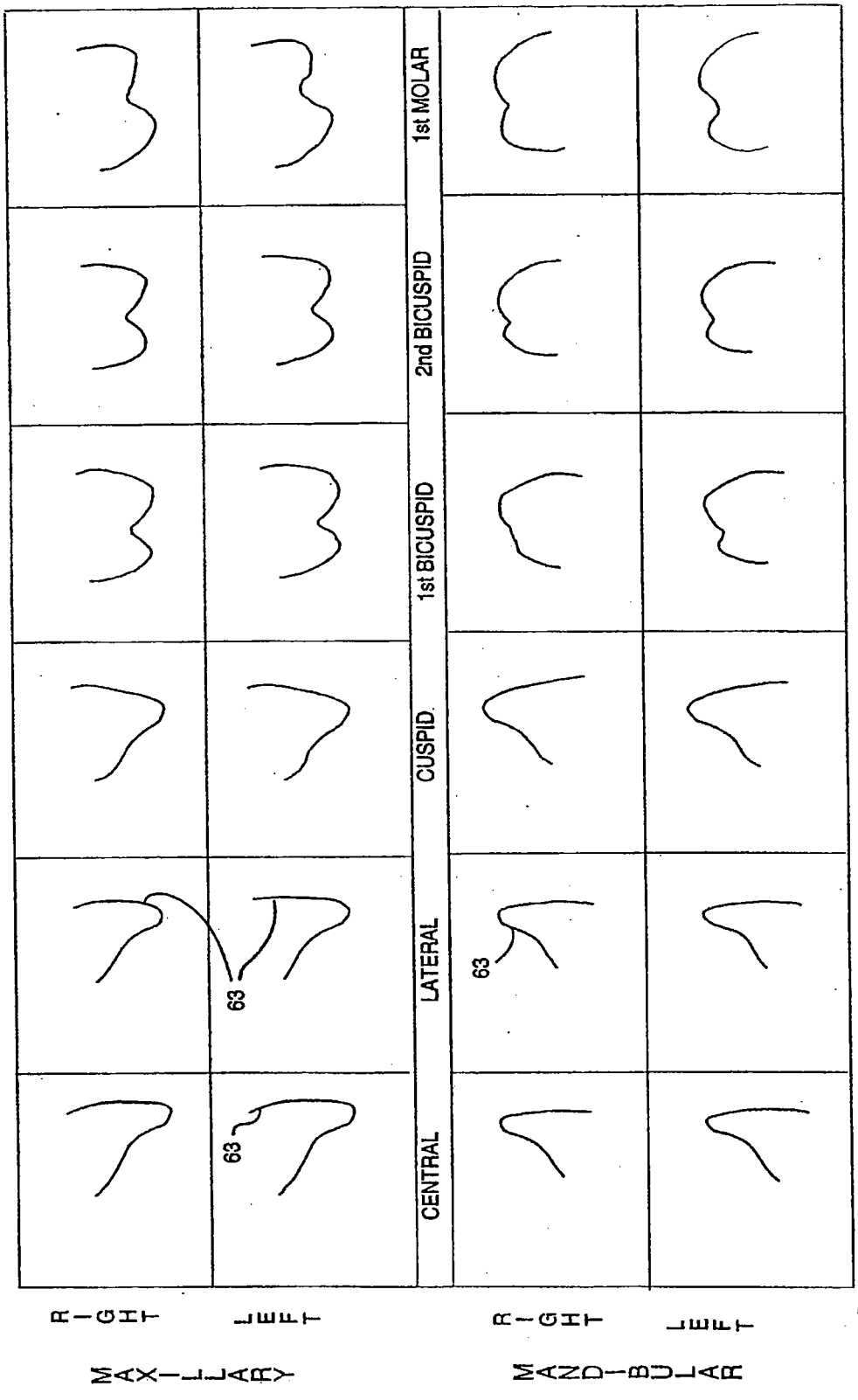


FIG.3C

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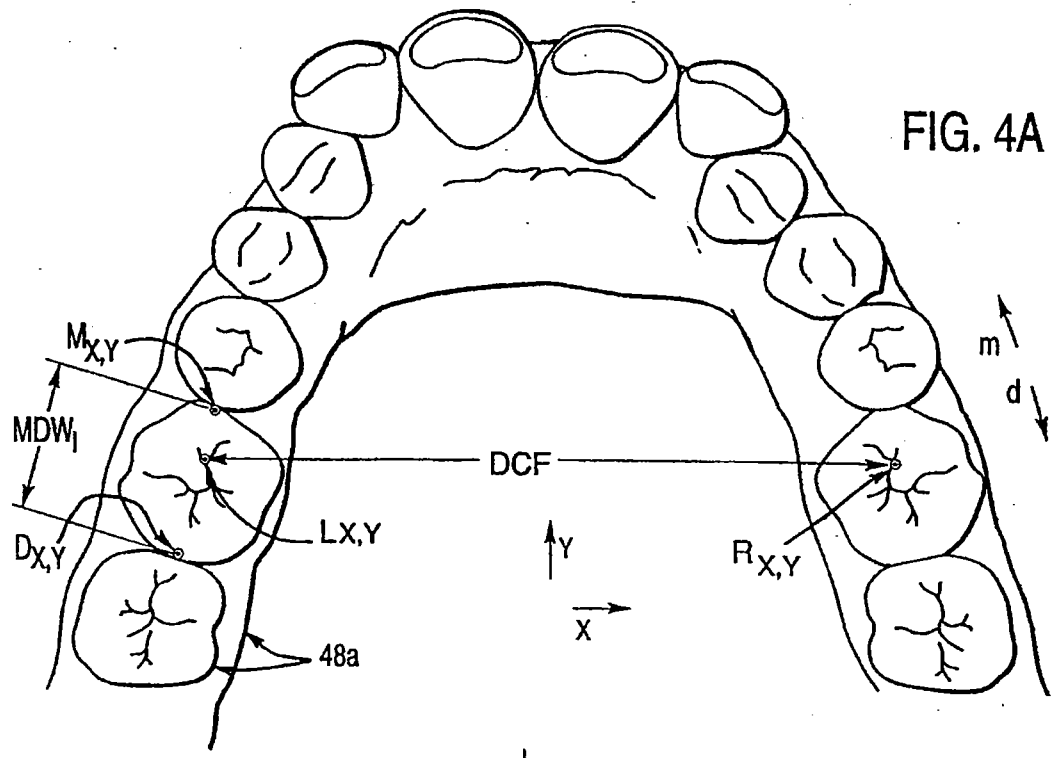

$M_{X,Y}$
MDW_I
$D_{X,Y}$
DCF
$L_{X,Y}$
Y
X
$R_{X,Y}$
48a
m
d

FIG. 4A

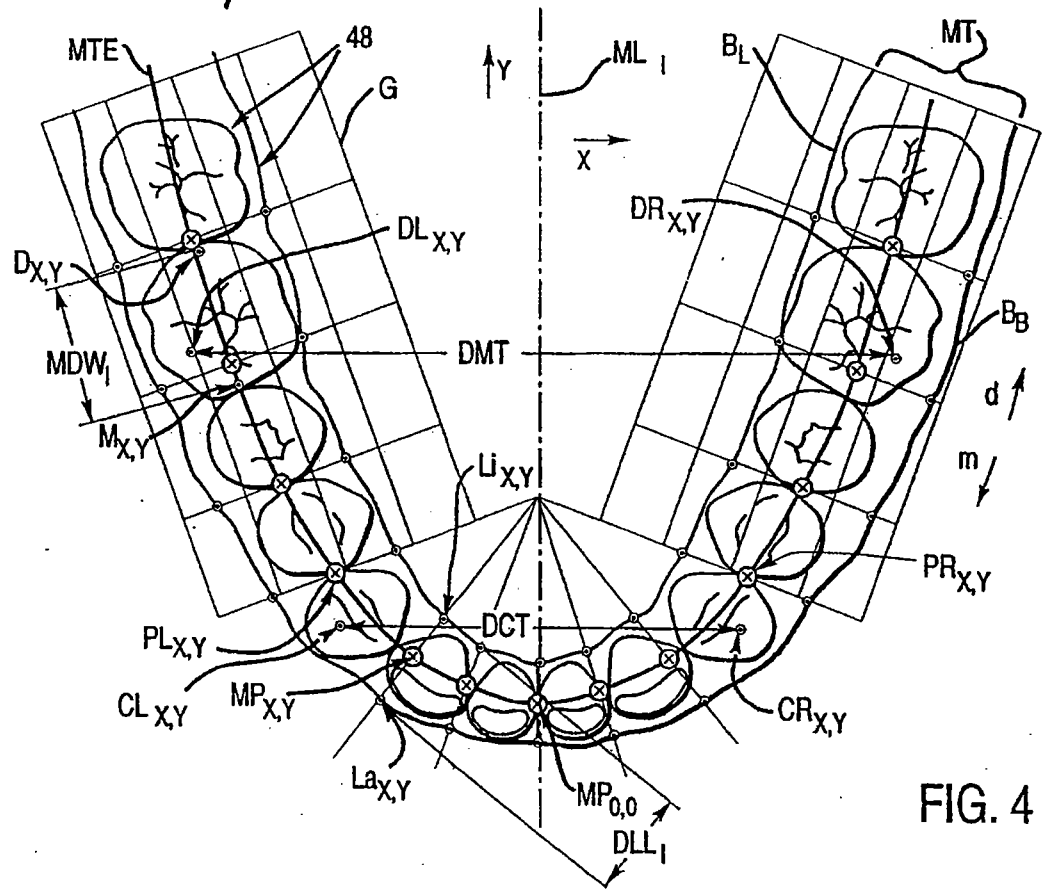
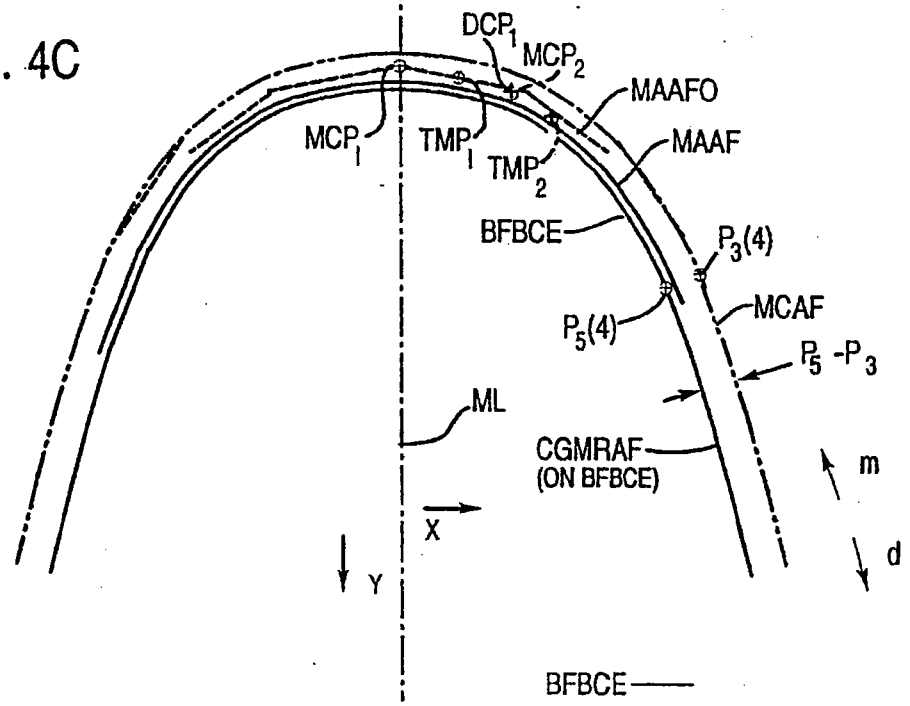

MTE
48
G
Y
ML_I
X
B_L
MT
$DR_{X,Y}$
$DL_{X,Y}$
$D_{X,Y}$
MDW_I
DMT
B_B
d
m
$M_{X,Y}$
$Li_{X,Y}$
$PR_{X,Y}$
$PL_{X,Y}$
DCT
$CL_{X,Y}$
$MP_{X,Y}$
$CR_{X,Y}$
$La_{X,Y}$
$MP_{0,0}$
DLL_I

FIG. 4

FIG. 4C


DCP1
MCP2
MAAFO
MCP1
TMP1
TMP2
MAAF
BFBCE
P3(4)
MCAF
P5(4)
P5 -P3
ML
CGMRAF
(ON BFBCE)
m
X
Y
d
BFBCE

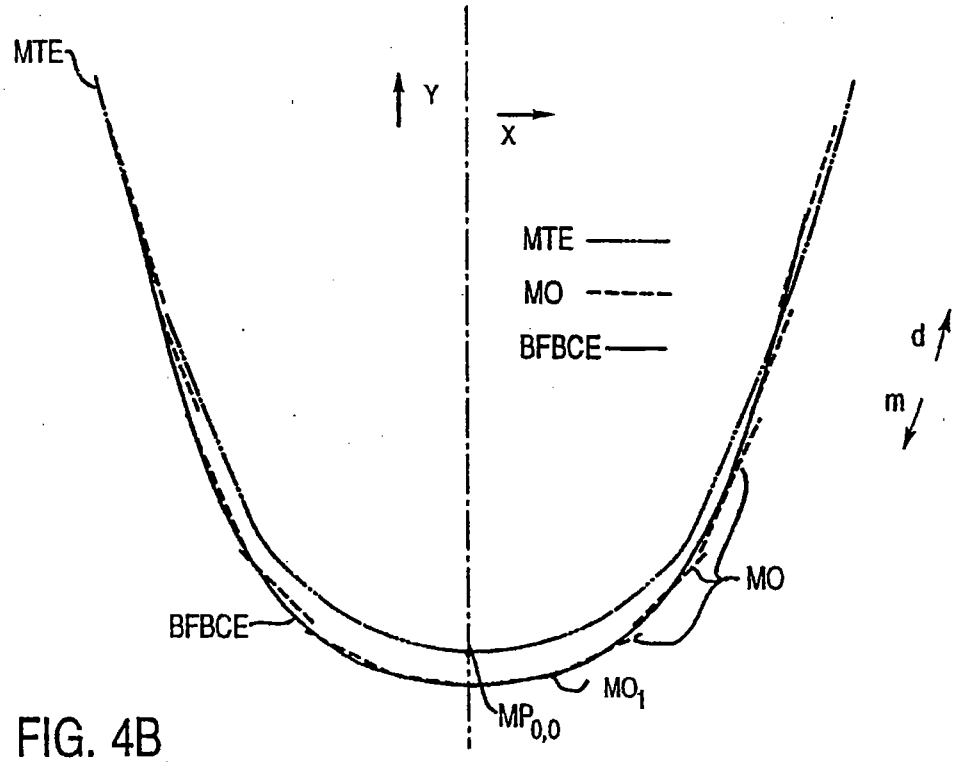
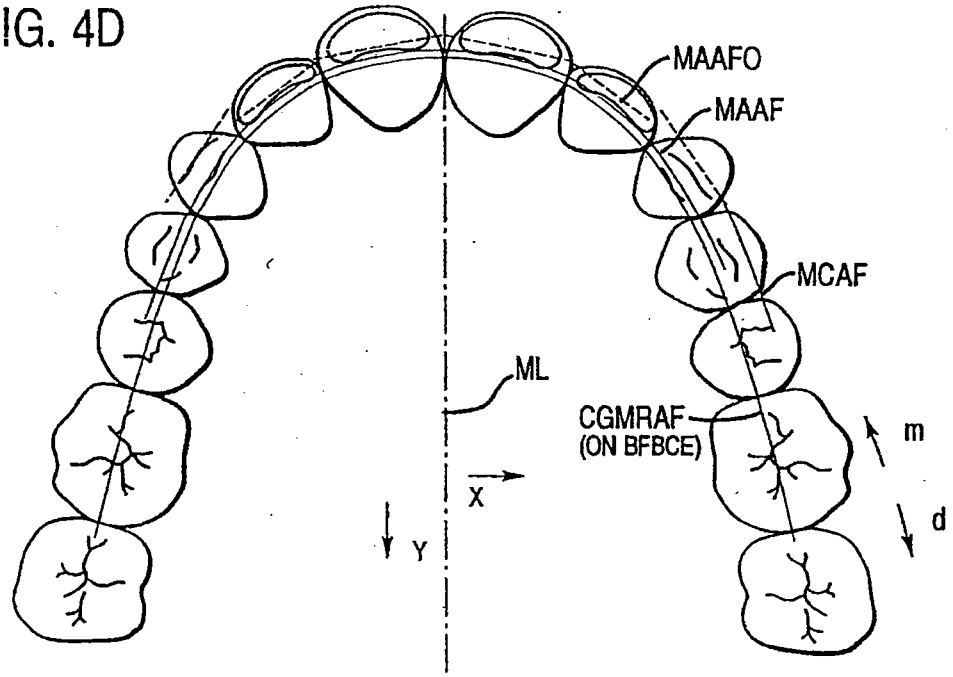

MTE
Y
X
MTE
MO
BFBCE
d
m
MO
BFBCE
MO1
MP0,0

FIG. 4B

FIG. 4D


MAAFO
MAAF
MCAF
ML
CGMRAF
(ON BFBCE)
m
d
X
Y

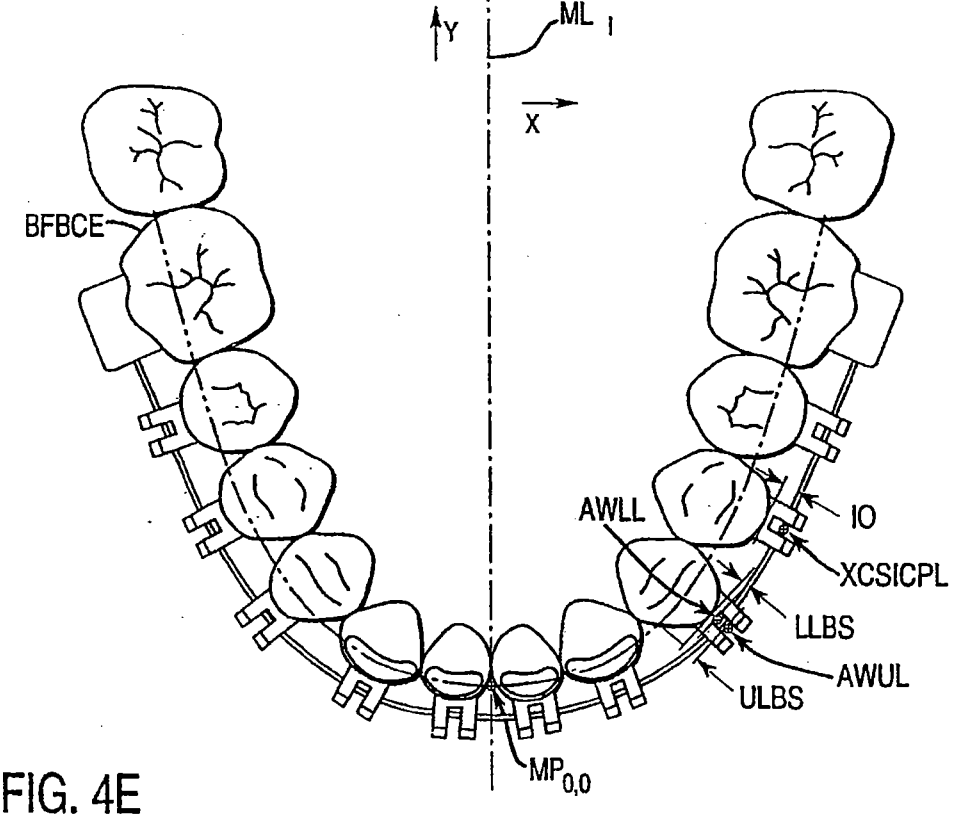

Y
ML
X
BFBCE
AWLL
IO
XCSICPL
LLBS
AWUL
ULBS
MP0,0

FIG. 4E

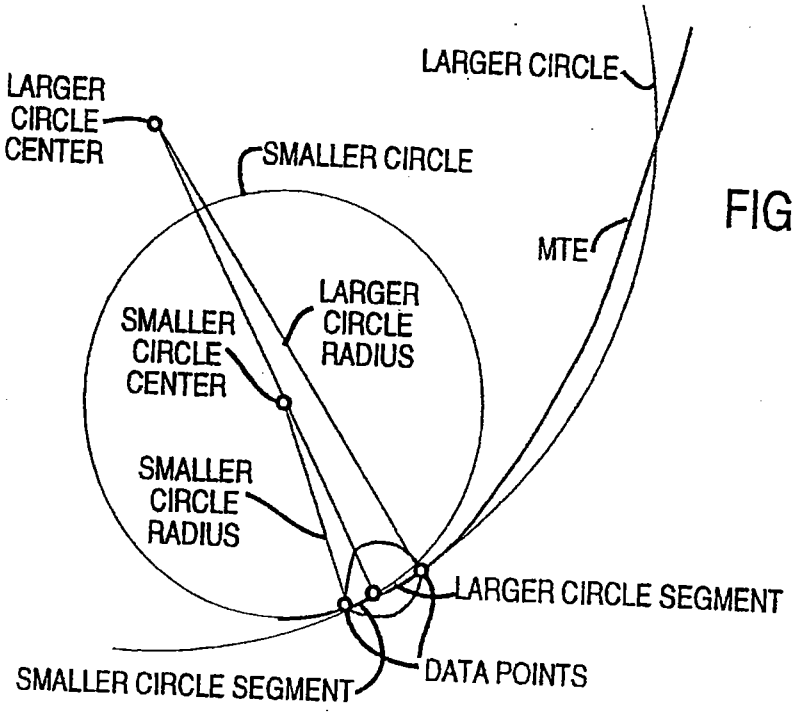

LARGER CIRCLE
LARGER CIRCLE CENTER
SMALLER CIRCLE
MTE
LARGER CIRCLE RADIUS
SMALLER CIRCLE CENTER
SMALLER CIRCLE RADIUS
LARGER CIRCLE SEGMENT
DATA POINTS
SMALLER CIRCLE SEGMENT

FIG. 5

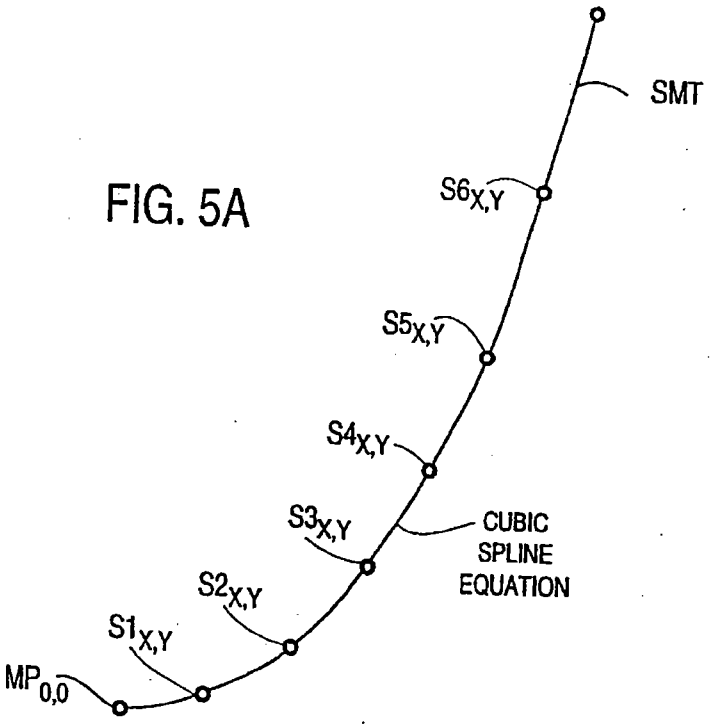

SMT
S6X,Y
S5X,Y
S4X,Y
S3X,Y
CUBIC SPLINE EQUATION
S2X,Y
S1X,Y
MP0,0

FIG. 5A

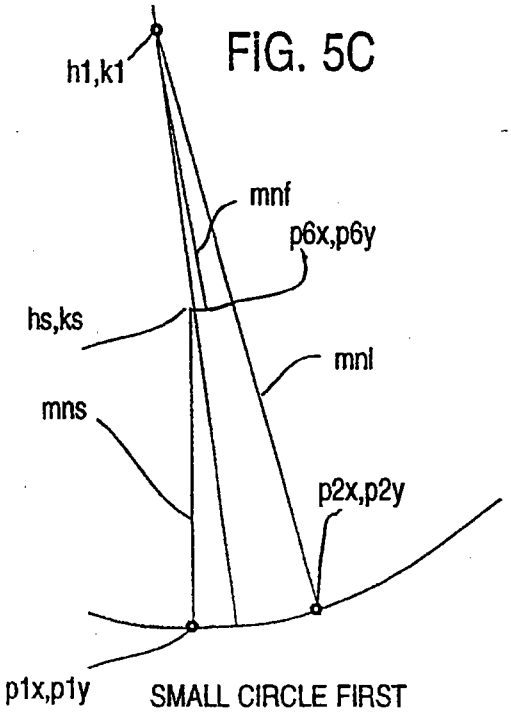


FIG. 5C

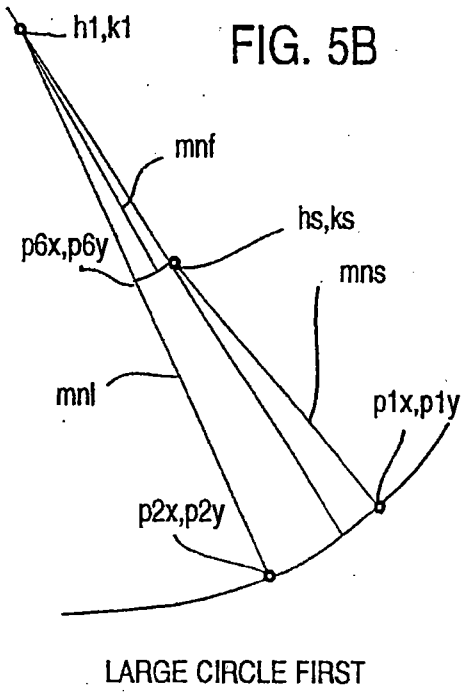


FIG. 5B

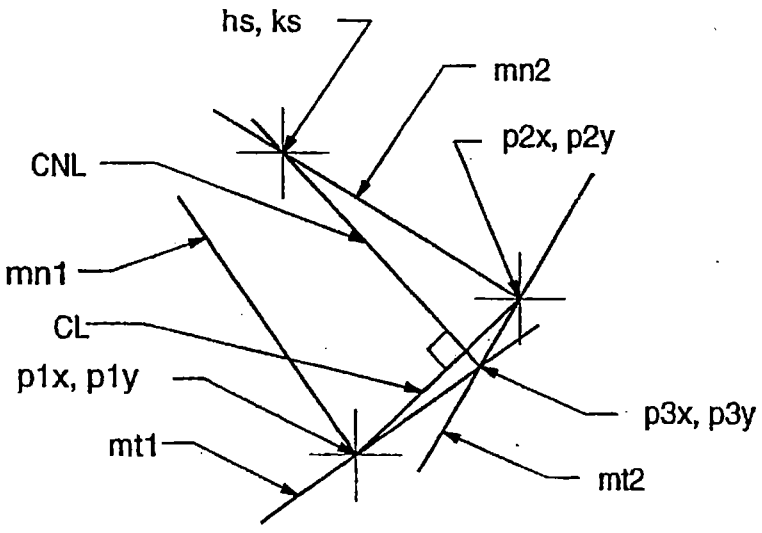
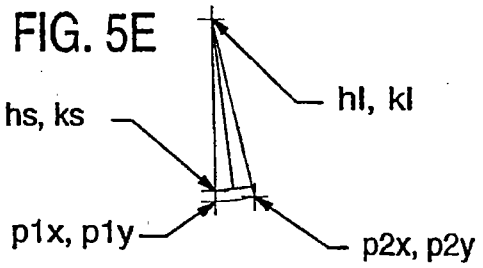


FIG. 5D

FIG. 5E



Spline Seg. No. 1
Circle Seg. Nos. 1 and 2

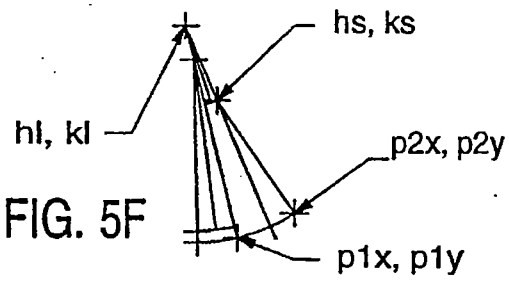
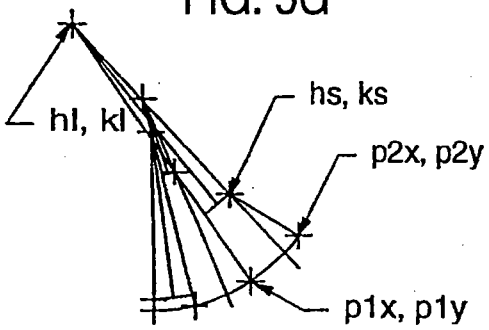


FIG. 5F

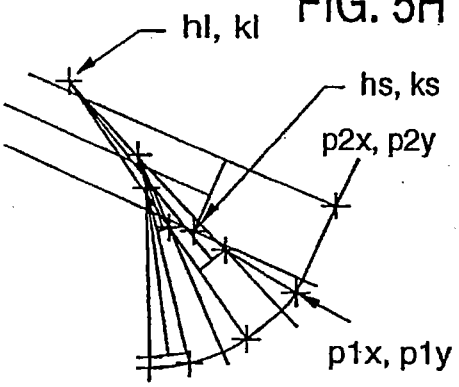
Spline Seg. No. 2
Circle Seg. Nos .3 and 4

FIG. 5G

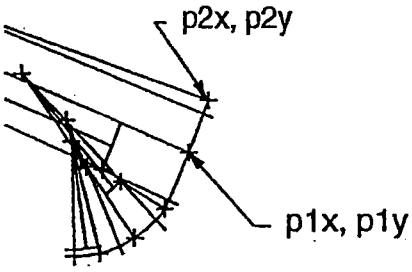


Spline Seg. No. 3
Circle Seg. Nos. 5 and 6

FIG. 5H

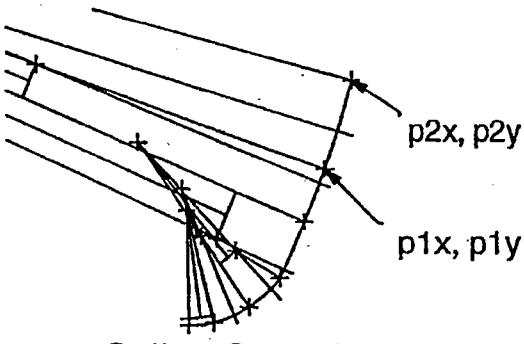


Spline Seg. No. 4
Circle Seg. Nos. 7 and 8



Spline Seg. No. 5
Circle Seg. Nos.9 and 10

FIG. 5I



Spline Seg. No. 6
Circle Seg. No.'s 11 and 12

FIG. 5J

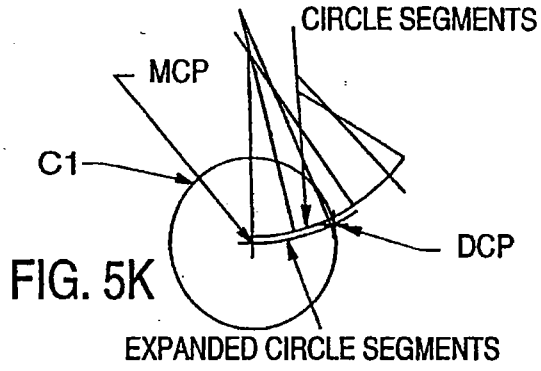


FIG. 5K

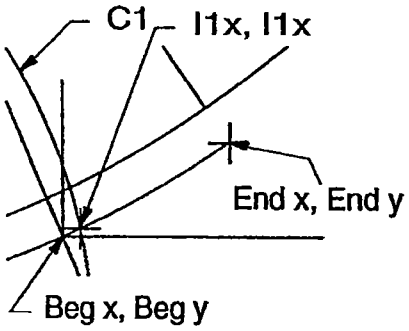


FIG. 5L

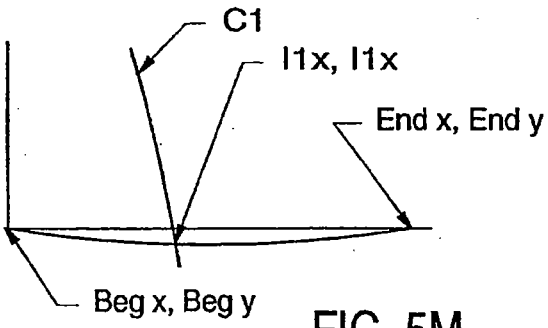


FIG. 5M

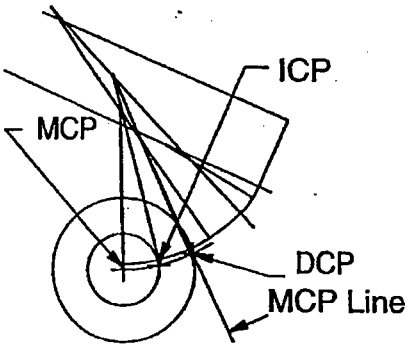


FIG. 5N

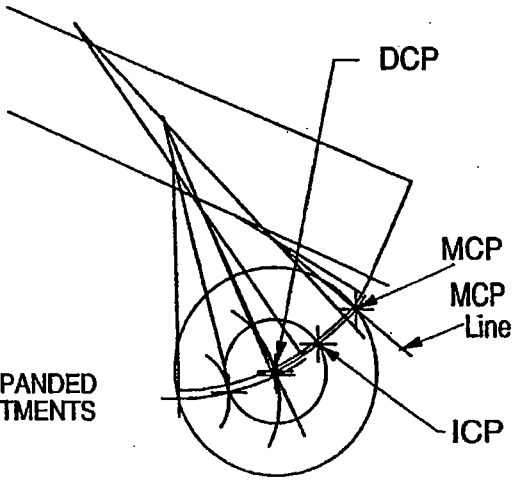


FIG. 5P

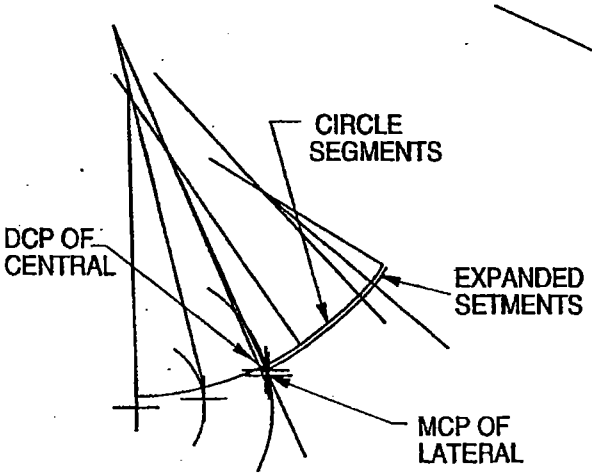


FIG. 5O

ClearCorrect Exhibit 1010, Page 284 of 1447

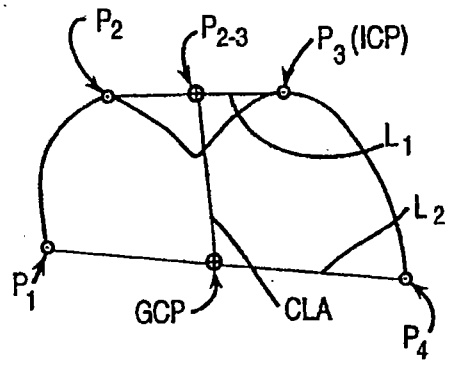


FIG. 6A

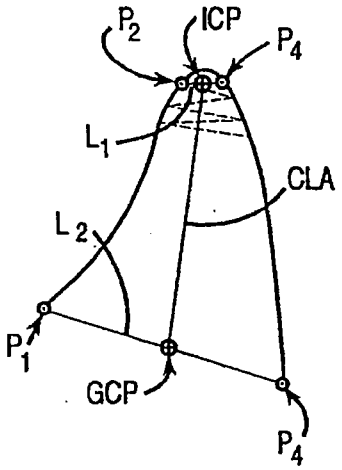


FIG. 6B

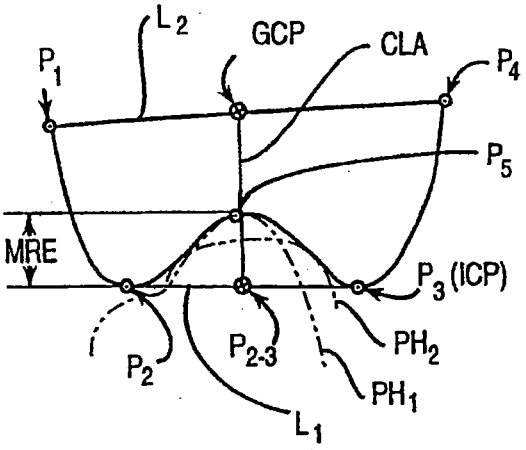


FIG. 6C

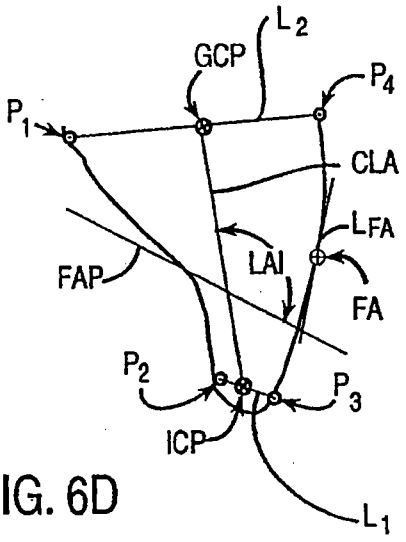


FIG. 6D

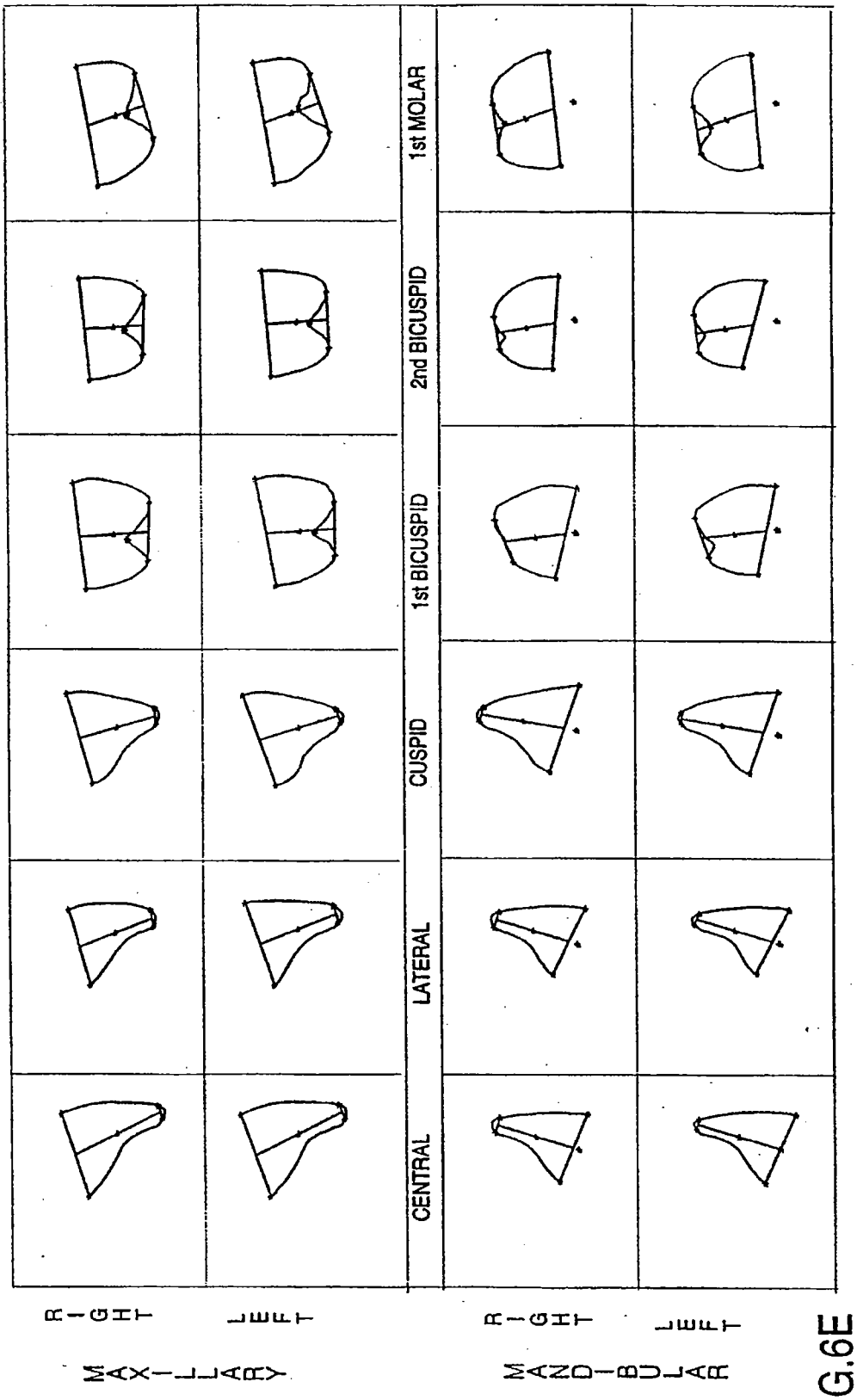

1st MOLAR
2nd BICUSPID
1st BICUSPID
CUSPID
LATERAL
CENTRAL
RIGHT
LEFT
MAX-LLARY
RIGHT
LEFT
MAND-BULAR

FIG.6E

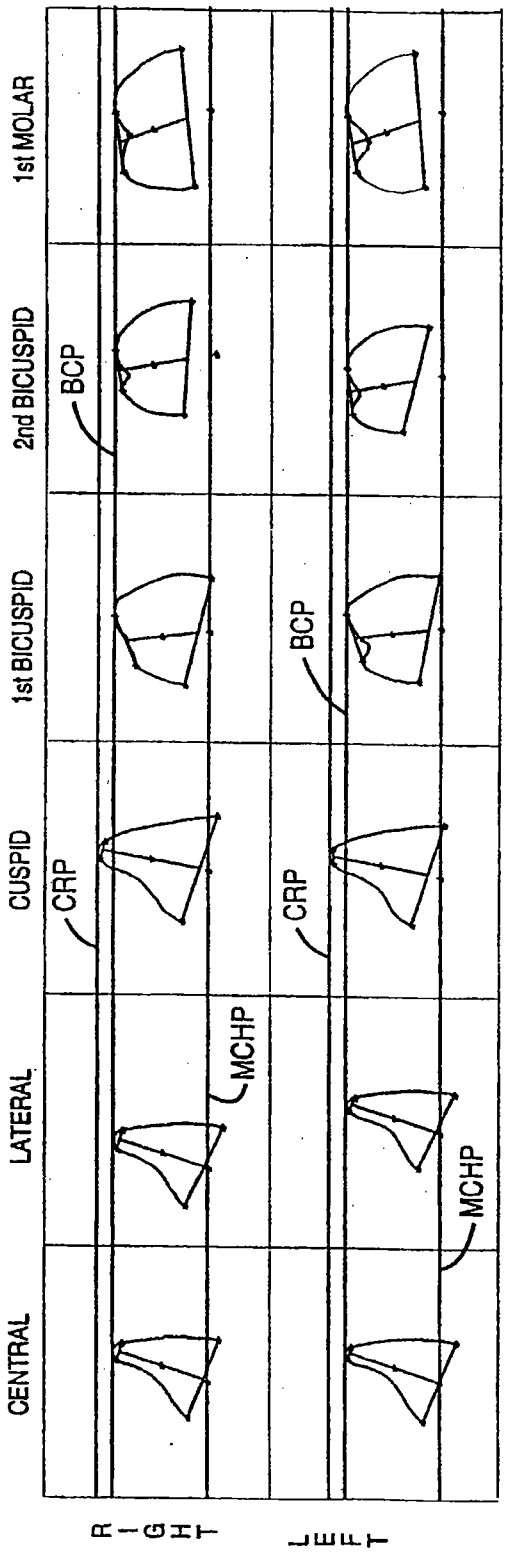


FIG. 6F

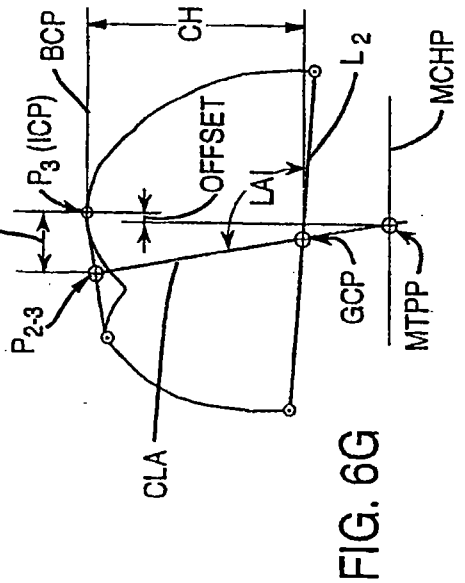


FIG. 6G

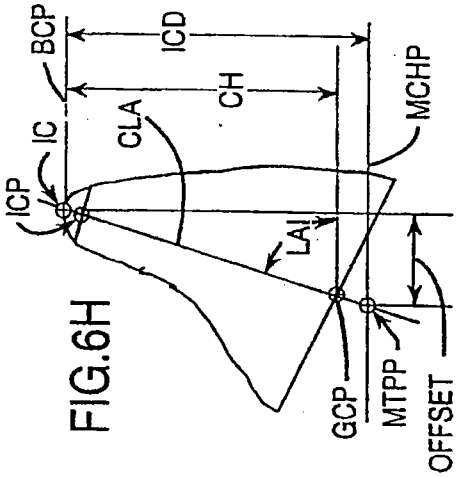


FIG.6H

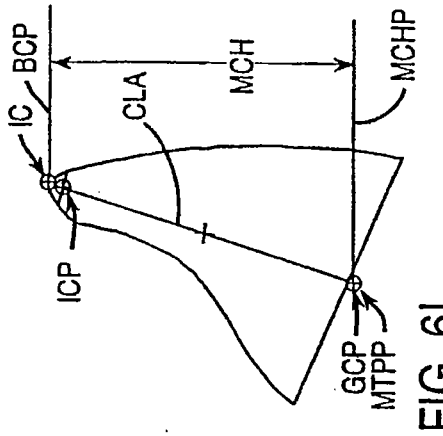


FIG. 6I

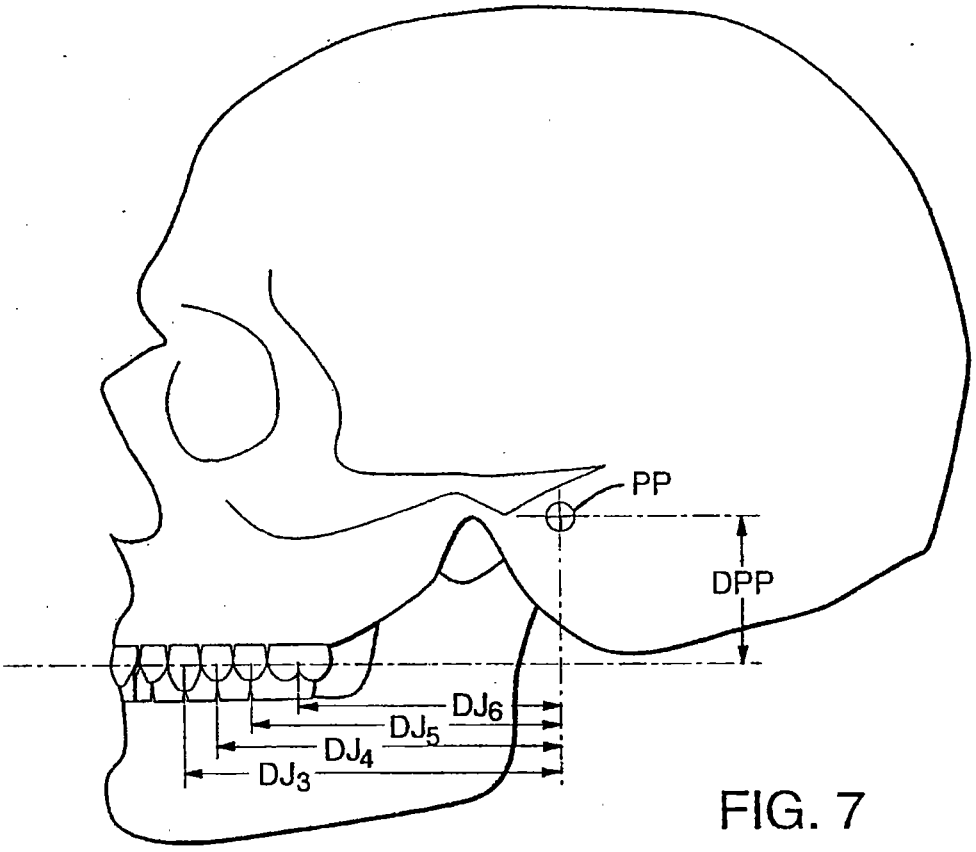


FIG. 7

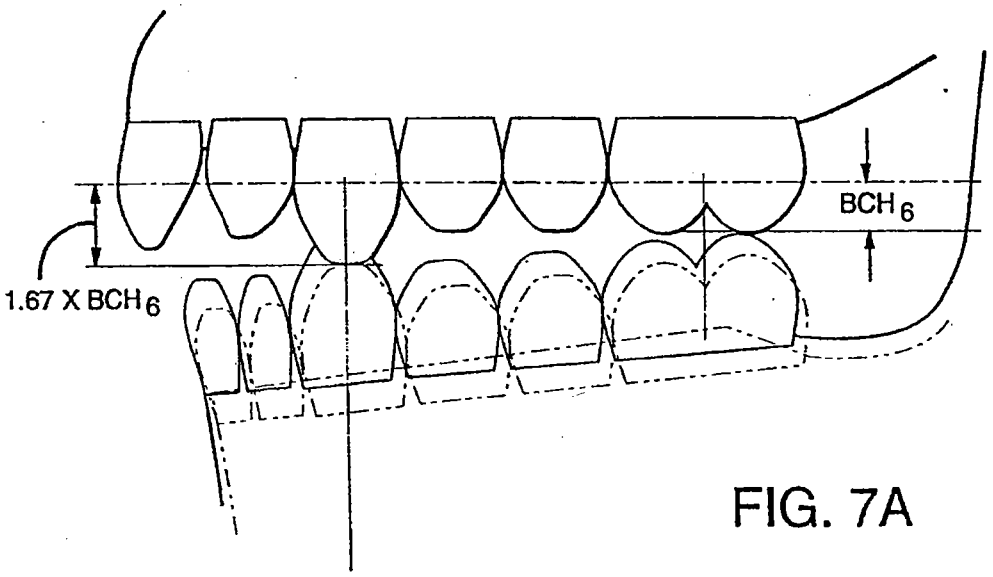
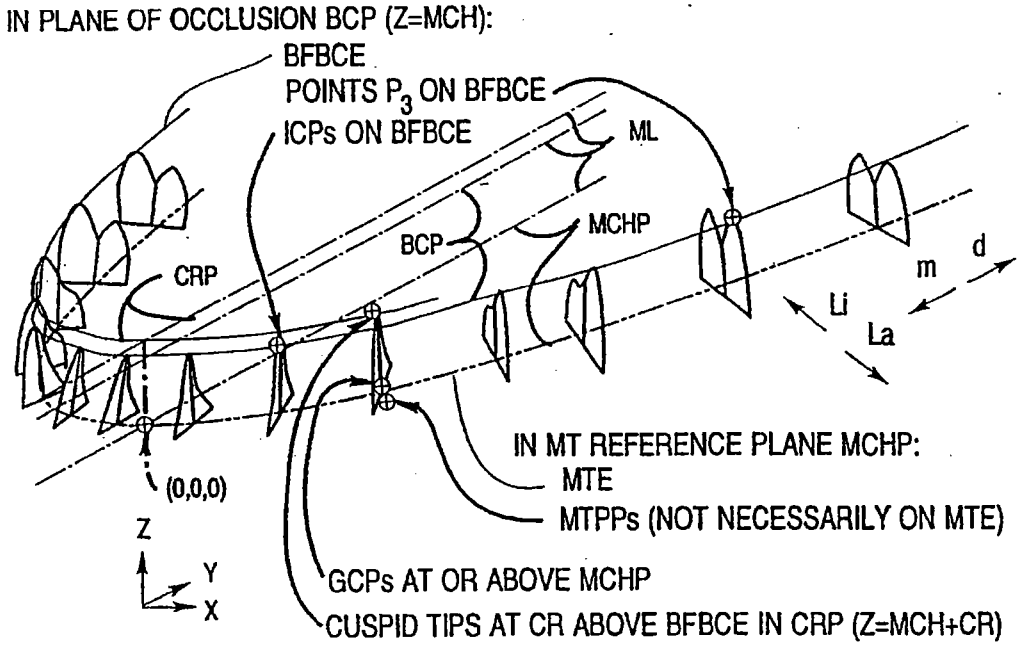


FIG. 7A



PROFILE PLANE COORDINATES:
Y COORDINATE = Z IN ARCH PLANES
X COORDINATE = LABIAL (La) DIRECTION IN ARCH PLANES

FIG. 7C

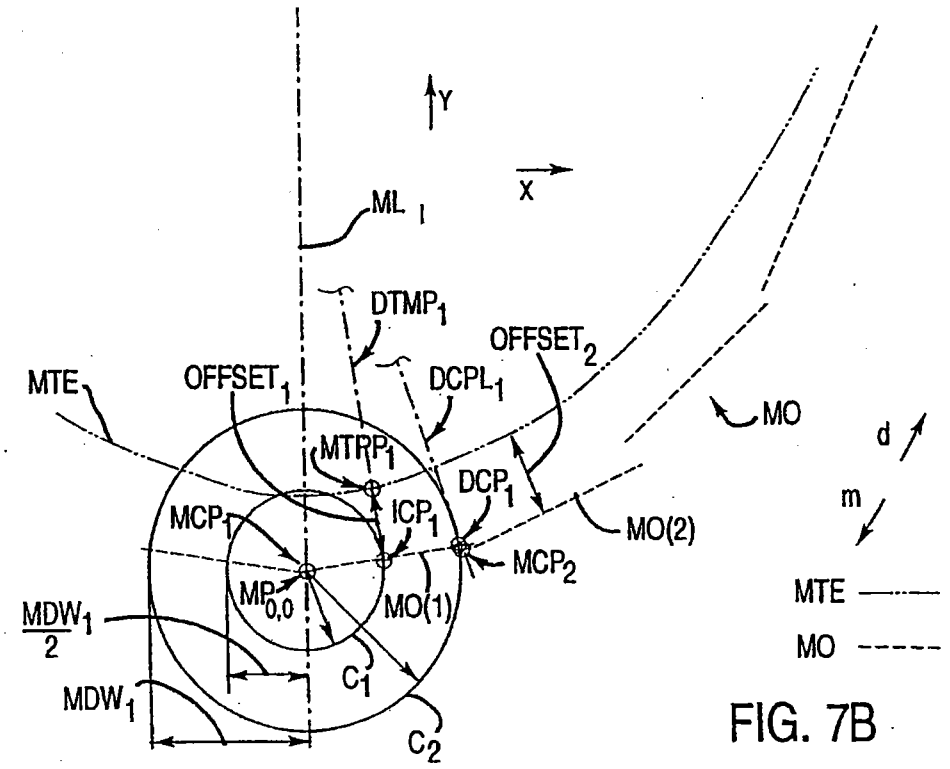


FIG. 7B

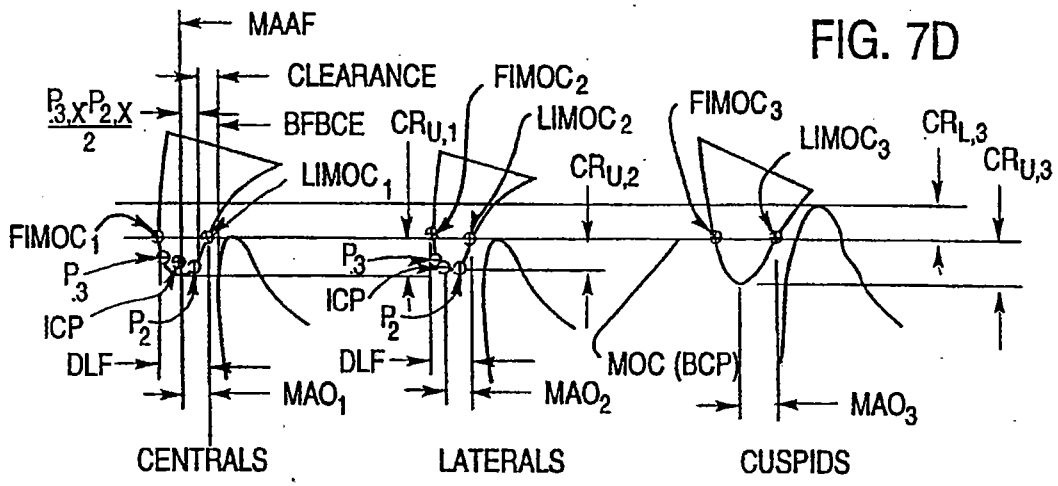


FIG. 7D

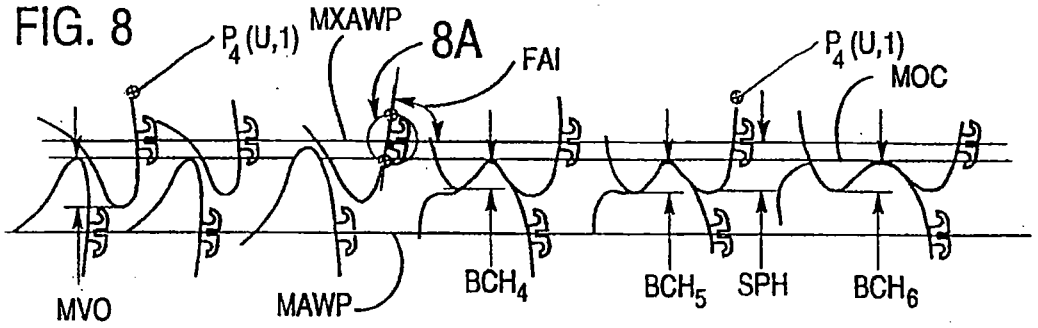


FIG. 8

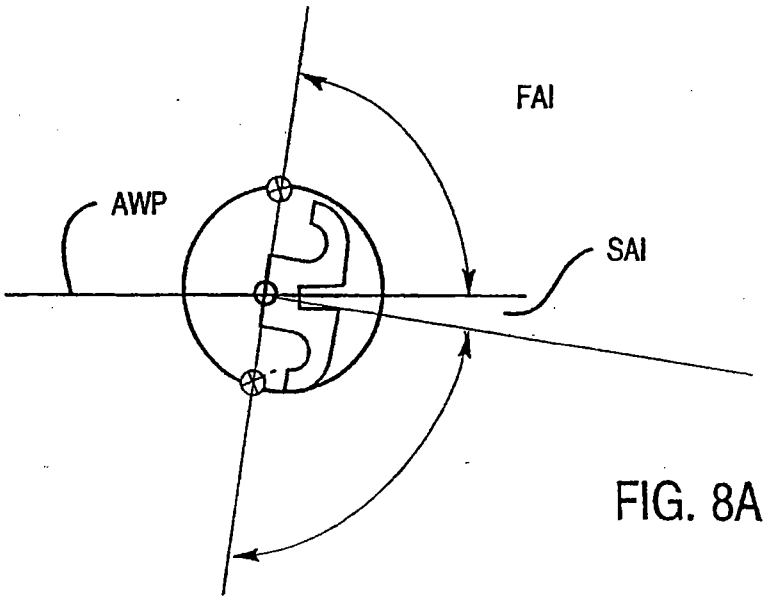


FIG. 8A

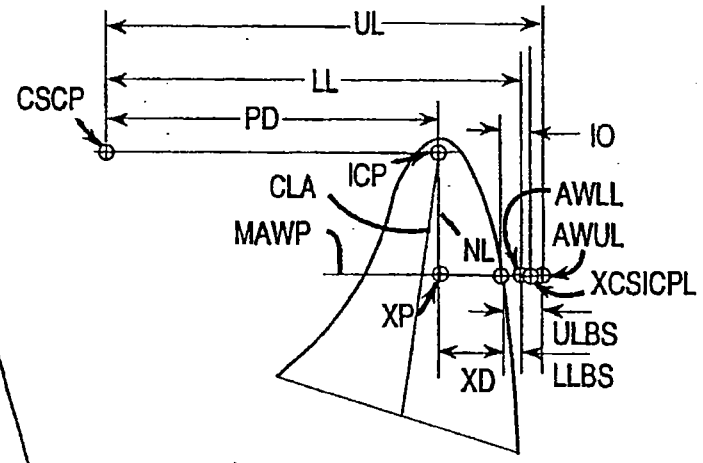

UL
LL
CSCP
PD
IO
CLA
ICP
AWLL
MAWP
NL
AWUL
XCSICPL
XP
ULBS
XD
LLBS

FIG. 8C

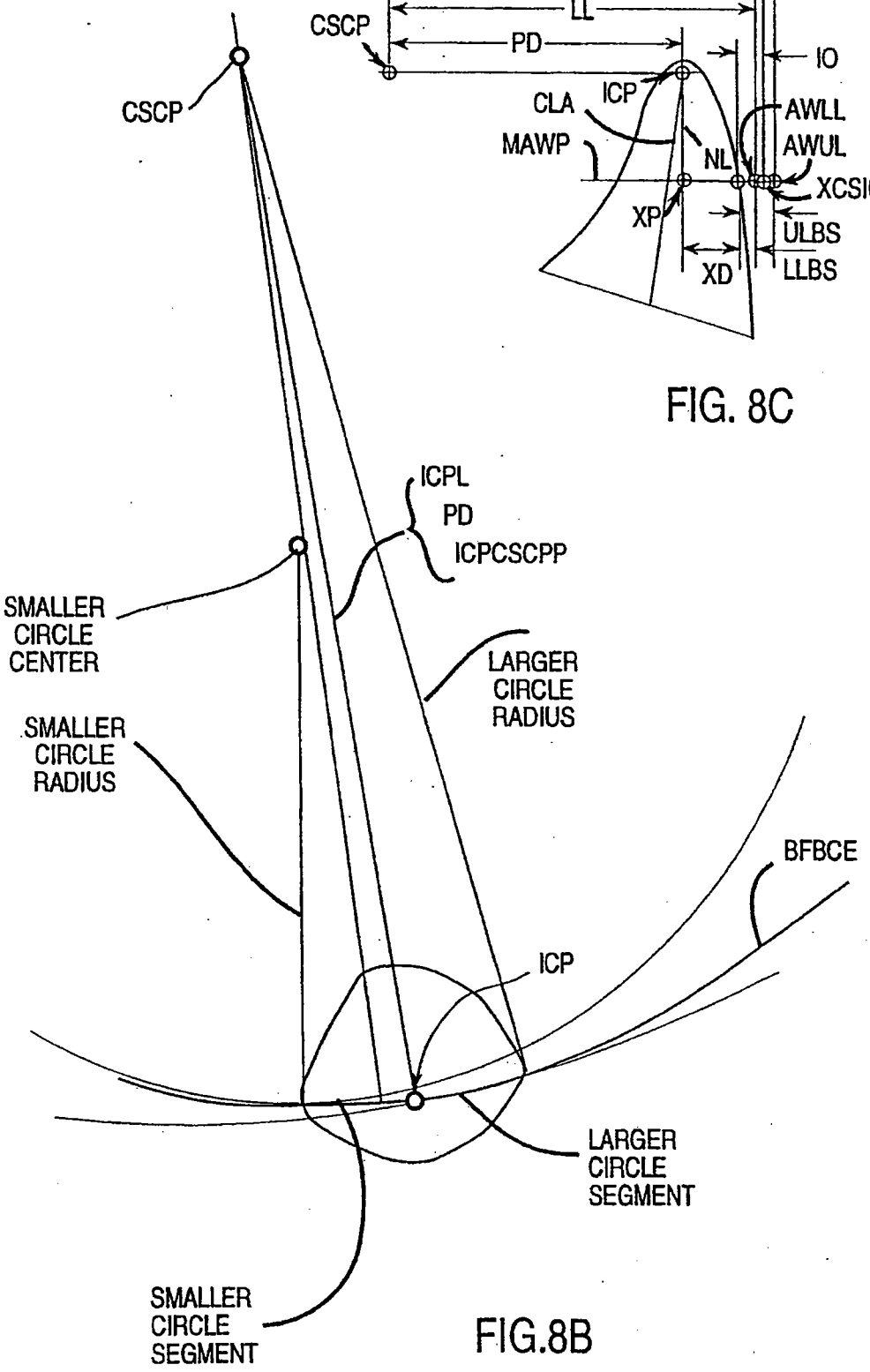

CSCP
ICPL
PD
ICPCSCPP
SMALLER CIRCLE CENTER
LARGER CIRCLE RADIUS
SMALLER CIRCLE RADIUS
BFBCE
ICP
LARGER CIRCLE SEGMENT
SMALLER CIRCLE SEGMENT

FIG.8B

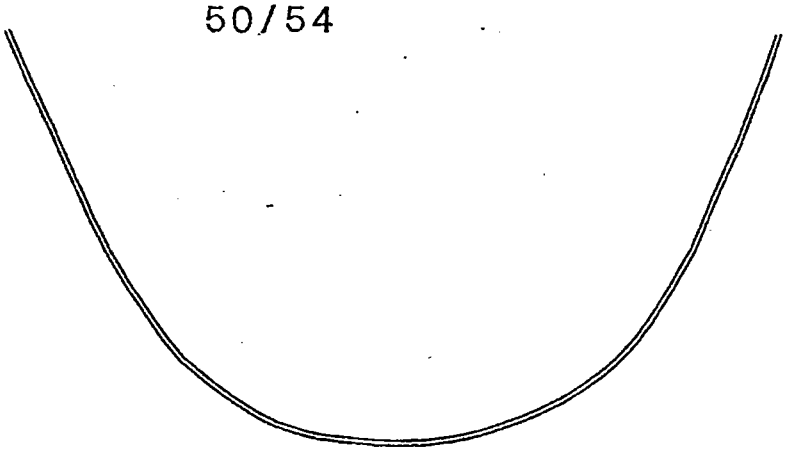


FIG. 8D

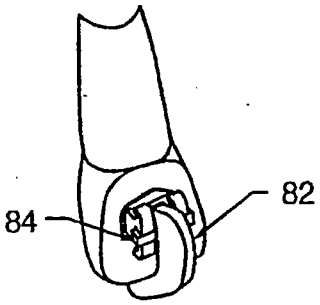


FIG. 8E

FIG. 8F

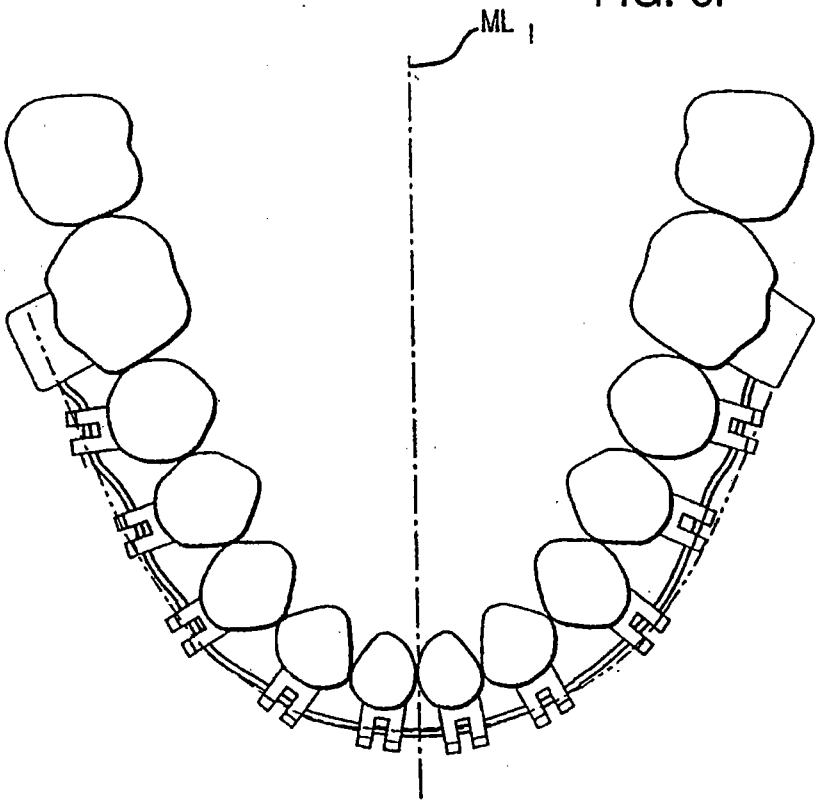
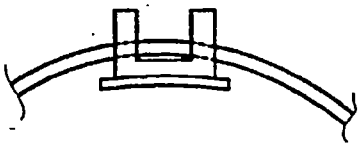


FIG. 8I



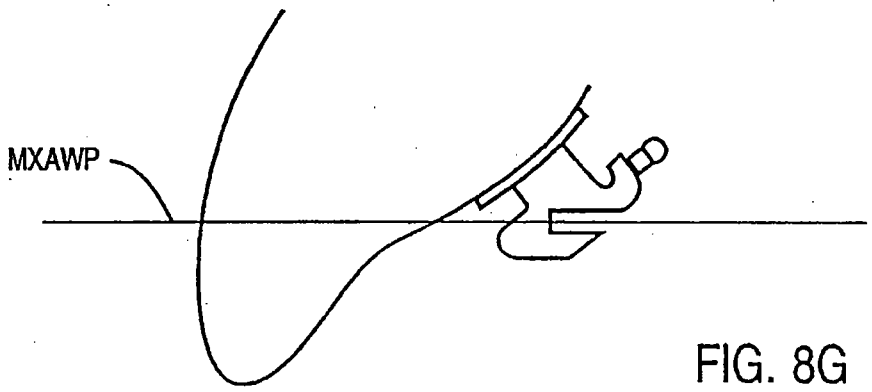


FIG. 8G

FIG. 8H

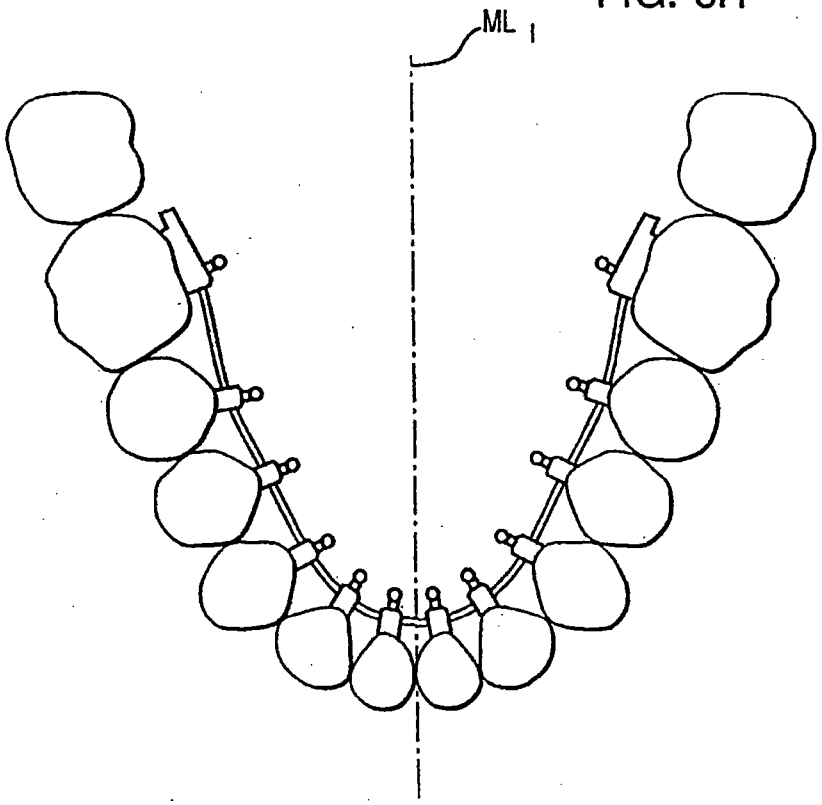


FIG. 9

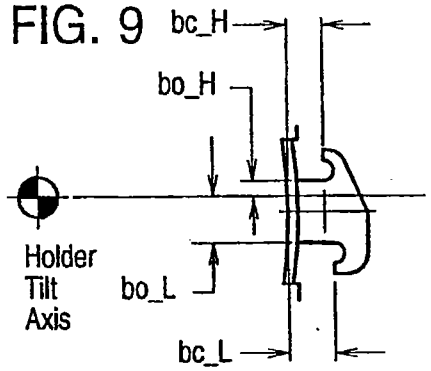


FIG. 9A

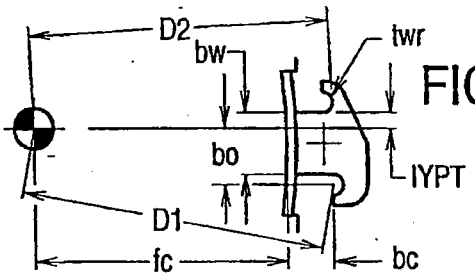


FIG. 9B

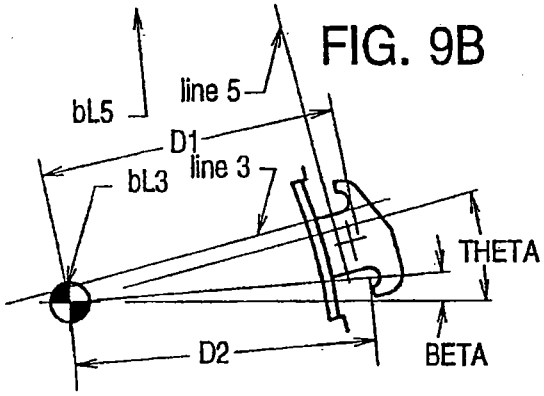


FIG. 9C

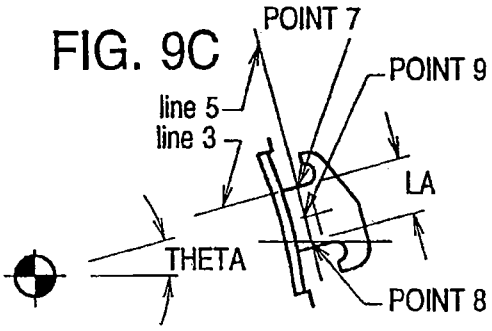


FIG. 9D

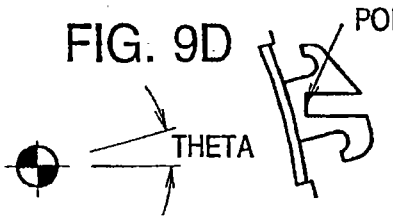


FIG. 9E

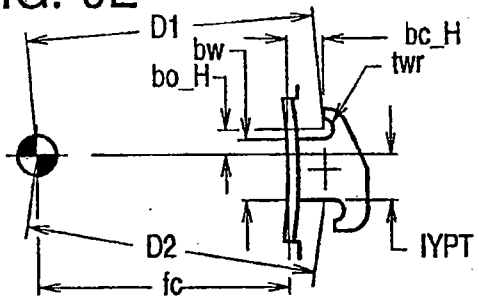
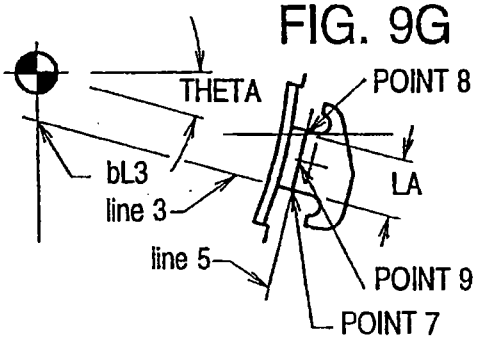


FIG. 9G



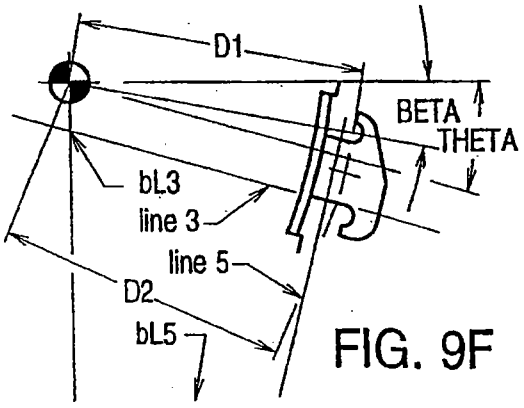
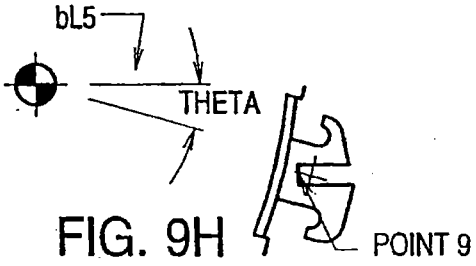


FIG. 9F

FIG. 9H



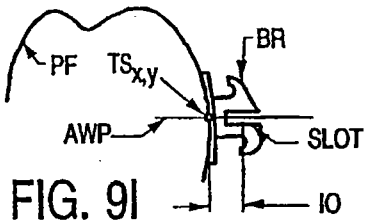


FIG. 9I

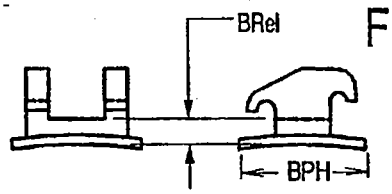


FIG. 9J

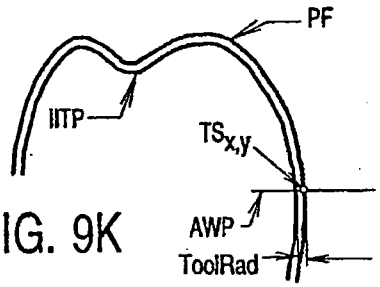


FIG. 9K

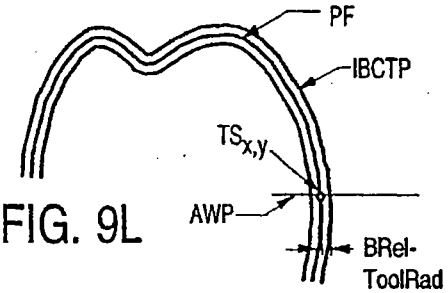


FIG. 9L

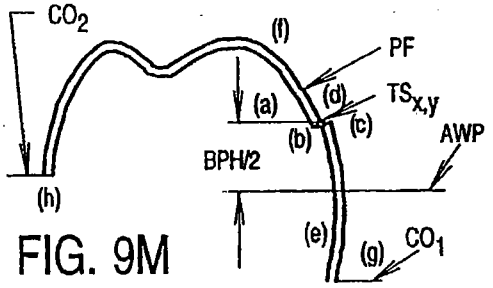


FIG. 9M

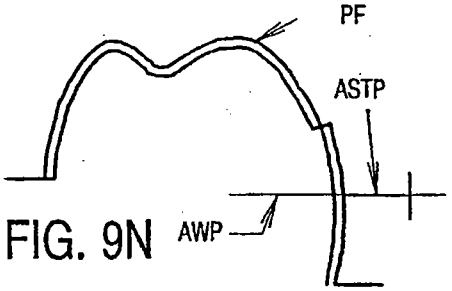


FIG. 9N

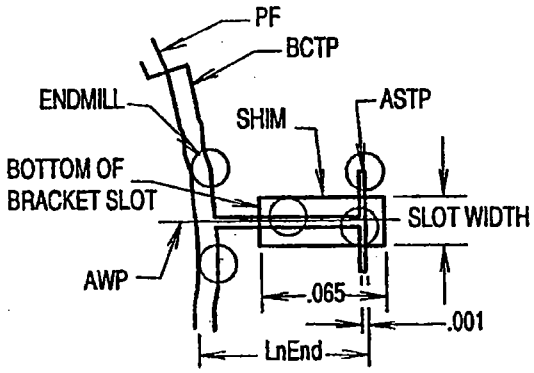
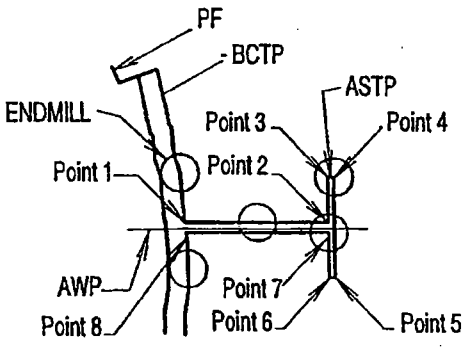


FIG. 9O

FIG. 9P



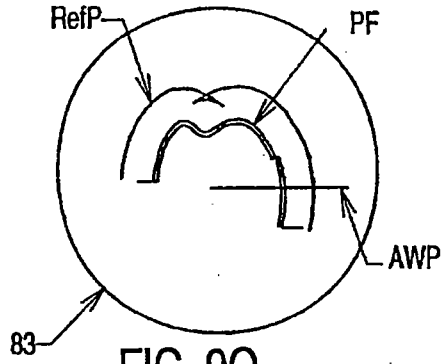


FIG. 9Q

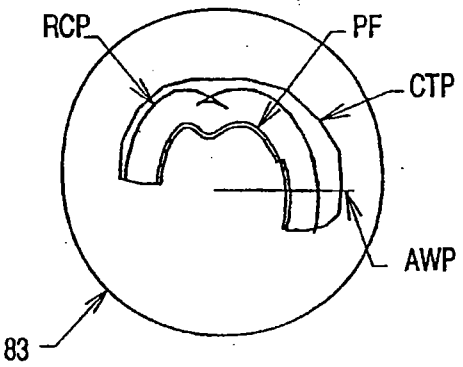


FIG. 9R

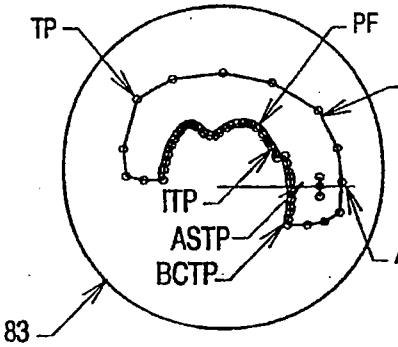


FIG. 9S

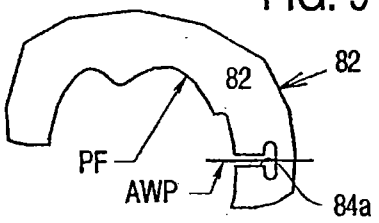


FIG. 9T

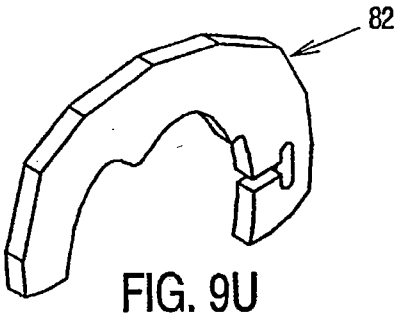


FIG. 9U

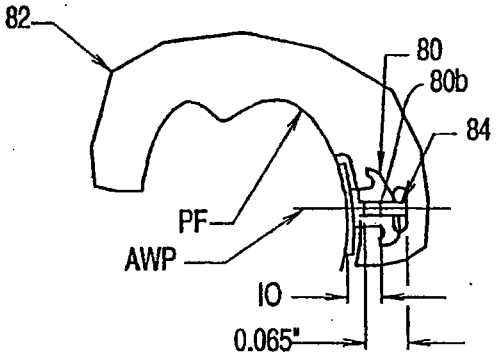


FIG. 9W

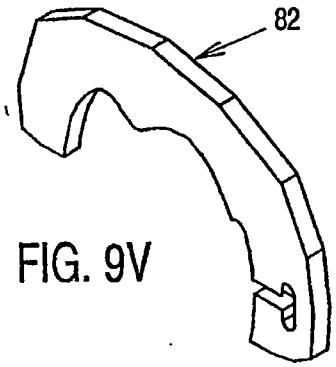


FIG. 9V

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/US 93/10858

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 A61C7/00 A61C13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 502 227 (ANDREIKO) 9 September 1992 see the whole document	1,2,6,9, 11,18, 23,29, 30,33
A	WO,A,90 08512 (DOLPHIN IMAGING SYSTEMS) 9 August 1990 see the whole document	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 February 1994	04. 03. 94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Vanrunxt, J

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter vnal Application No
PCT/US 93/10858

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0502227	09-09-92	NONE		
WO-A-9008512	09-08-90	US-A-	5011405	30-04-91
		AU-A-	5097090	24-08-90

ClearCorrect Exhibit 1010, Page 298 of 1447

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : A61C 7/00 — A1

(11) International Publication Number: **WO 98/58596**

(43) International Publication Date: 30 December 1998 (30.12.98)

(21) International Application Number: PCT/US98/12861

(22) International Filing Date: 19 June 1998 (19.06.98)

(30) Priority Data:

60/050,342	20 June 1997 (20.06.97)	US
08/947,080	8 October 1997 (08.10.97)	US

(63) Related by Continuation (CON) or Continuation-in-Part (CIP) to Earlier Applications

US	08/947,080 (CIP)
Filed on	8 October 1997 (08.10.97)
US	60/050,342 (CIP)
Filed on	20 June 1997 (20.06.97)

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(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published

With international search report.

Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD AND SYSTEM FOR INCREMENTALLY MOVING TEETH

(57) Abstract

A system for repositioning teeth comprises a plurality of individual appliances. The appliances are configured to be placed successively on the patient's teeth and to incrementally reposition the teeth from an initial tooth arrangement, through a plurality of intermediate tooth arrangements, and to a final tooth arrangement. The system of appliances is usually configured at the outset of treatment so that the patient may progress through treatment without the need to have the treating professional perform each successive step in the procedure.

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METHOD AND SYSTEM FOR INCREMENTALLY MOVING TEETH

The present application is a continuation-in-part of U.S. Patent application No. 08/947,080; filed on October 8, 1997, which claims priority from provisional Application No. 60/050,342; filed on June 20, 1997, the full disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is related generally to the field of orthodontics. More particularly, the present invention is related to a method and system for incrementally moving teeth from an initial tooth arrangement to a final tooth arrangement.

Repositioning teeth for aesthetic or other reasons is accomplished conventionally by wearing what are commonly referred to as "braces." Braces comprise a variety of appliances such as brackets, archwires, ligatures, and O-rings. Attaching the appliances to a patient's teeth is a tedious and time consuming enterprise requiring many meetings with the treating orthodontist. Consequently, conventional orthodontic treatment limits an orthodontist's patient capacity and makes orthodontic treatment quite expensive.

Before fastening braces to a patient's teeth, at least one appointment is typically scheduled with the orthodontist, dentist, and/or X-ray laboratory so that X-rays and photographs of the patient's teeth and jaw structure can be taken. Also during this preliminary meeting, or possibly at a later meeting, an alginate mold of the patient's teeth is typically made. This mold provides a model of the patient's teeth that the orthodontist uses in conjunction with the X-rays and photographs to formulate a treatment strategy. The orthodontist then typically schedules one or more appointments during which braces will be attached to the patient's teeth.

At the meeting during which braces are first attached, the teeth surfaces are initially treated with a weak acid. The acid optimizes

the adhesion properties of the teeth surfaces for brackets and bands that are to be bonded to them. The brackets and bands serve as anchors for other appliances to be added later. After the acid step, the brackets and bands are cemented to the patient's teeth using a suitable bonding material. No force-inducing appliances are added until the cement is set. For this reason, it is common for the orthodontist to schedule a later appointment to ensure that the brackets and bands are well bonded to the teeth.

The primary force-inducing appliance in a conventional set of braces is the archwire. The archwire is resilient and is attached to the brackets by way of slots in the brackets. The archwire links the brackets together and exerts forces on them to move the teeth over time. Twisted wires or elastomeric O-rings are commonly used to reinforce attachment of the archwire to the brackets. Attachment of the archwire to the brackets is known in the art of orthodontia as "ligation" and wires used in this procedure are called "ligatures." The elastomeric O-rings are called "plastics."

After the archwire is in place, periodic meetings with the orthodontist are required, during which the patient's braces will be adjusted by installing a different archwire having different force-inducing properties or by replacing or tightening existing ligatures. Typically, these meetings are scheduled every three to six weeks.

As the above illustrates, the use of conventional braces is a tedious and time consuming process and requires many visits to the orthodontist's office. Moreover, from the patient's perspective, the use of braces is unsightly, uncomfortable, presents a risk of infection, and makes brushing, flossing, and other dental hygiene procedures difficult.

For these reasons, it would be desirable to provide alternative methods and systems for repositioning teeth. Such methods and systems should be economical, and in particular should reduce the amount of time required by the orthodontist in planning and overseeing each individual patient. The methods and systems should also be more acceptable to the patient, in particular being less visible, less uncomfortable, less prone to infection, and more compatible with daily dental hygiene. At least some of these objectives will be met by the methods and systems of the present invention described hereinafter.

2. Description of the Background Art

Tooth positioners for finishing orthodontic treatment are described by Kesling in the *Am. J. Orthod. Oral. Surg. 31*:297-304 (1945) and *32*:285-293 (1946). The use of silicone positioners for the comprehensive orthodontic realignment of a patient's teeth is described in Warunek et al. (1989) *J. Clin. Orthod. 23*:694-700. Clear plastic retainers for finishing and maintaining tooth positions are commercially available from Raintree Essix, Inc., New Orleans, Louisiana 70125, and Tru-Tain Plastics, Rochester, Minnesota 55902. The manufacture of orthodontic positioners is described in U.S. Patent Nos. 5,186,623; 5,059,118; 5,055,039; 5,035,613; 4,856,991; 4,798,534; and 4,755,139.

Other publications describing the fabrication and use of dental positioners include Kleemann and Janssen (1996) *J. Clin. Orthodon. 30*:673-680; Cureton (1996) *J. Clin. Orthodon. 30*:390-395; Chiappone (1980) *J. Clin. Orthodon. 14*:121-133; Shilliday (1971) *Am. J. Orthodontics 59*:596-599; Wells (1970) *Am. J. Orthodontics 58*:351-366; and Cottingham (1969) *Am. J. Orthodontics 55*:23-31.

Kuroda et al. (1996) *Am. J. Orthodontics 110*:365-369 describes a method for laser scanning a plaster dental cast to produce a digital image of the cast. See also U.S. Patent No. 5,605,459.

U.S. Patent Nos. 5,533,895; 5,474,448; 5,454,717; 5,447,432; 5,431,562; 5,395,238; 5,368,478; and 5,139,419, assigned to Ormco Corporation, describe methods for manipulating digital images of teeth for designing orthodontic appliances.

U.S. Patent No. 5,011,405 describes a method for digitally imaging a tooth and determining optimum bracket positioning for orthodontic treatment. Laser scanning of a molded tooth to produce a three-dimensional model is described in U.S. Patent No. 5,338,198. U.S. Patent NO. 5,452,219 describes a method for laser scanning a tooth model and milling a tooth mold. Digital computer manipulation of tooth contours is described in U.S. Patent Nos. 5,607,305 and 5,587,912. Computerized digital imaging of the jaw is described in U.S. Patent Nos. 5,342,202 and 5,340,309. Other patents of interest include U.S. Patent Nos. 5,549,476; 5,382,164; 5,273,429; 4,936,862; 3,860,803; 3,660,900; 5,645,421; 5,055,039; 4,798,534; 4,856,991; 5,035,613; 5,059,118; 5,186,623; and 4,755,139.

SUMMARY OF THE INVENTION

The present invention provides improved methods and systems for repositioning teeth from an initial tooth arrangement to a final tooth arrangement. Repositioning is accomplished with a system comprising a series of appliances configured to receive the teeth in a cavity and incrementally reposition individual teeth in a series of at least three successive steps, usually including at least four successive steps, often including at least ten steps, sometimes including at least twenty-five steps, and occasionally including forty or more steps. Most often, the methods and systems will reposition teeth in from ten to twenty-five successive steps, although complex cases involving many of the patient's teeth may take forty or more steps. The successive use of a number of such appliances permits each appliance to be configured to move individual teeth in small increments, typically less than 2 mm, preferably less than 1 mm, and more preferably less than 0.5 mm. These limits refer to the maximum linear translation of any point on a tooth as a result of using a single appliance. The movements provided by successive appliances, of course, will usually not be the same for any particular tooth. Thus, one point on a tooth may be moved by a particular distance as a result of the use of one appliance and thereafter moved by a different distance and/or in a different direction by a later appliance.

The individual appliances will preferably comprise a polymeric shell having the teeth-receiving cavity formed therein, typically by molding as described below. Each individual appliance will be configured so that its tooth-receiving cavity has a geometry corresponding to an intermediate or end tooth arrangement intended for that appliance. That is, when an appliance is first worn by the patient, certain of the teeth will be misaligned relative to an undeformed geometry of the appliance cavity. The appliance, however, is sufficiently resilient to accommodate or conform to the misaligned teeth, and will apply sufficient resilient force against such misaligned teeth in order to reposition the teeth to the intermediate or end arrangement desired for that treatment step.

Systems according to the present invention will include at least a first appliance having a geometry selected to reposition a patient's teeth from the initial tooth arrangement to a first intermediate arrangement where individual teeth will be incrementally repositioned. The system will further comprise at least one intermediate appliance having a geometry selective to progressively reposition teeth from the

first intermediate arrangement to one or more successive intermediate arrangements. The system will still further comprise a final appliance having a geometry selected to progressively reposition teeth from the last intermediate arrangement to the desired final tooth arrangement. In some cases, it will be desirable to form the final appliance or several appliances to "over correct" the final tooth position, as discussed in more detail below.

As will be described in more detail below in connection with the methods of the present invention, the systems may be planned and all individual appliances fabricated at the outset of treatment, and the appliances may thus be provided to the patient as a single package or system. The order in which the appliances are to be used will be clearly marked, (e.g. by sequential numbering) so that the patient can place the appliances over his or her teeth at a frequency prescribed by the orthodontist or other treating professional. Unlike braces, the patient need not visit the treating professional every time an adjustment in the treatment is made. While the patients will usually want to visit their treating professionals periodically to assure that treatment is going according to the original plan, eliminating the need to visit the treating professional each time an adjustment is to be made allows the treatment to be carried out in many more, but smaller, successive steps while still reducing the time spent by the treating professional with the individual patient. Moreover, the ability to use polymeric shell appliances which are more comfortable, less visible, and removable by the patient, greatly improves patient compliance, comfort, and satisfaction.

According to a method of the present invention, a patient's teeth are repositioned from an initial tooth arrangement to a final tooth arrangement by placing a series of incremental position adjustment appliances in the patient's mouth. Conveniently, the appliances are not affixed and the patient may place and replace the appliances at any time during the procedure. The first appliance of the series will have a geometry selected to reposition the teeth from the initial tooth arrangement to a first intermediate arrangement. After the first intermediate arrangement is approached or achieved, one or more additional (intermediate) appliances will be successively placed on the teeth, where such additional appliances have geometries selected to progressively reposition teeth from the first intermediate arrangement through successive intermediate arrangement(s). The treatment will be finished by

placing a final appliance in the patient's mouth, where the final appliance has a geometry selected to progressively reposition teeth from the last intermediate arrangement to the final tooth arrangement. The final appliance or several appliances in the series may have a geometry or geometries selected to over correct the tooth arrangement, i.e. have a geometry which would (if fully achieved) move individual teeth beyond the tooth arrangement which has been selected as the "final." Such over correction may be desirable in order to offset potential relapse after the repositioning method has been terminated, i.e. to permit some movement of individual teeth back toward their pre-corrected positions. Over correction may also be beneficial to speed the rate of correction, i.e. by having an appliance with a geometry that is positioned beyond a desired intermediate or final position, the individual teeth will be shifted toward the position at a greater rate. In such cases, treatment can be terminated before the teeth reach the positions defined by the final appliance or appliances. The method will usually comprise placing at least two additional appliances, often comprising placing at least ten additional appliances, sometimes placing at least twenty-five additional appliances, and occasionally placing at least forty or more additional appliances. Successive appliances will be replaced when the teeth either approach (within a preselected tolerance) or have reached the target end arrangement for that stage of treatment, typically being replaced at an interval in the range from 2 days to 20 days, usually at an interval in the range from 5 days to 10 days.

Often, it may be desirable to replace the appliances at a time before the "end" tooth arrangement of that treatment stage is actually achieved. It will be appreciated that as the teeth are gradually repositioned and approach the geometry defined by a particular appliance, the repositioning force on the individual teeth will diminish greatly. Thus, it may be possible to reduce the overall treatment time by replacing an earlier appliance with the successive appliance at a time when the teeth have been only partially repositioned by the earlier appliance. Thus, the FDDS can actually represent an over correction of the final tooth position. This both speeds the treatment and can offset patient relapse.

In general, the transition to the next appliance can be based on a number of factors. Most simply, the appliances can be replaced on a predetermined schedule or at a fixed time interval (i.e. number of days

for each appliance) determined at the outset based on an expected or typical patient response. Alternatively, actual patient response can be taken into account, e.g. a patient can advance to the next appliance when that patient no longer perceives pressure on their teeth from a current appliance, i.e. the appliance they have been wearing fits easily over the patient's teeth and the patient experiences little or no pressure or discomfort on his or her teeth. In some cases, for patients whose teeth are responding very quickly, it may be possible for a treating professional to decide to skip one or more intermediate appliances, i.e. reduce the total number of appliances being used below the number determined at the outset. In this way, the overall treatment time for a particular patient can be reduced.

In another aspect, methods of the present invention comprise repositioning teeth using appliances comprising polymeric shells having cavities shaped to receive and resiliently reposition teeth to produce a final tooth arrangement. The present invention provides improvements to such methods which comprise determining at the outset of treatment geometries for at least three of the appliances which are to be worn successively by a patient to reposition teeth from an initial tooth arrangement to the final tooth arrangement. Preferably, at least four geometries will be determined in the outset, often at least ten geometries, frequently at least twenty-five geometries, and sometimes forty or more geometries. Usually, the tooth positions defined by the cavities in each successive geometry differ from those defined by the prior geometry by no more than 2 mm, preferably no more than 1 mm, and often no more than 0.5 mm, as defined above.

In yet another aspect, methods are provided for producing a digital data set representing a final tooth arrangement. The methods comprise providing an initial data set representing an initial tooth arrangement, and presenting a visual image based on the initial data set. The visual image is then manipulated to reposition individual teeth in the visual image. A final digital data set is then produced which represents the final tooth arrangement with repositioned teeth as observed in the visual image. Conveniently, the initial digital data set may be provided by conventional techniques, including digitizing X-ray images, images produced by computer-aided tomography (CAT scans), images produced by magnetic resonance imaging (MRI), and the like. Preferably, the images will be three-dimensional images and digitization may be accomplished

using conventional technology. Usually, the initial digital data set is provided by producing a plaster cast of the patient's teeth (prior to treatment) by conventional techniques. The plaster cast so produced may then be scanned using laser or other scanning equipment to produce a high resolution digital representation of the plaster cast of the patient's teeth. Use of the plaster cast is preferred since it does not expose the patient to X-rays or subject the patient to the inconvenience of an MRI scan.

In a preferred embodiment, a wax bite is also obtained from the patient using standard methods. The wax bite allows plaster casts of a patient's upper and lower dentition to be placed relative to one another in the centric occlusal position. The pair of casts are then scanned to provide information on the relative position of the jaw in this position. This information is then incorporated into the IDDS for both arches.

Once the digital data set is acquired, an image can be presented and manipulated on a suitable computer system equipped with computer-aided design software, as described in greater detail below. The image manipulation will usually comprise defining boundaries about at least some of the individual teeth, and causing the images of the teeth to be moved relative to the jaw and other teeth by manipulation of the image via the computer. Methods are also provided for detecting cusp information for the teeth. The image manipulation can be done entirely subjectively, i.e. the user may simply reposition teeth in an aesthetically and/or therapeutically desired manner based on observation of the image alone. Alternatively, the computer system could be provided with rules and algorithms which assist the user in repositioning the teeth. In some instances, it will be possible to provide rules and algorithms which reposition the teeth in a fully automatic manner, i.e. without user intervention. Once the individual teeth have been repositioned, a final digital data set representing the desired final tooth arrangement will be generated and stored.

A preferred method for determining the final tooth arrangement is for the treating professional to define the final tooth positions, e.g. by writing a prescription. The use of prescriptions for defining the desired outcomes of orthodontic procedures is well known in the art. When a prescription or other final designation is provided, the image can then be manipulated to match the prescription. In some cases, it would be possible to provide software which could interpret the prescription in

order to generate the final image and thus the digital data set representing the final tooth arrangement.

In yet another aspect, methods according to the present invention are provided for producing a plurality of digital data sets representing a series of discrete tooth arrangements progressing from an initial tooth arrangement to a final tooth arrangement. Such methods comprise providing a digital data set representing an initial tooth arrangement (which may be accomplished according to any of the techniques set forth above). A digital data set representing a final tooth arrangement is also provided. Such final digital data set may be determined by the methods described previously. The plurality of successive digital data sets are then produced based on the initial digital data set and the final digital data set. Usually, the successive digital data sets are produced by determining positional differences between selected individual teeth in the initial data set and in the final data set and interpolating said differences. Such interpolation may be performed over as many discrete stages as may be desired, usually at least three, often at least four, more often at least ten, sometimes at least twenty-five, and occasionally forty or more. Many times, the interpolation will be linear interpolation for some or all of the positional differences. Alternatively, the interpolation may be non-linear. In a preferred embodiment, non-linear interpolation is computed automatically by the computer using path scheduling and collision detection techniques to avoid interferences between individual teeth. The positional differences will correspond to tooth movements where the maximum linear movement of any point on a tooth is 2 mm or less, usually being 1 mm or less, and often being 0.5 mm or less.

Often, the user will specify certain target intermediate tooth arrangements, referred to as "key frames," which are incorporated directly into the intermediate digital data sets. The methods of the present invention then determine successive digital data sets between the key frames in the manner described above, e.g. by linear or non-linear interpolation between the key frames. The key frames may be determined by a user, e.g. the individual manipulating a visual image at the computer used for generating the digital data sets, or alternatively may be provided by the treating professional as a prescription in the same manner as the prescription for the final tooth arrangement.

In still another aspect, methods according to the present invention provide for fabricating a plurality of dental incremental position adjustment appliances. Said methods comprise providing an initial digital data set, a final digital data set, and producing a plurality of successive digital data sets representing the target successive tooth arrangements, generally as just described. The dental appliances are then fabricated based on at least some of the digital data sets representing the successive tooth arrangements. Preferably, the fabricating step comprises controlling a fabrication machine based on the successive digital data sets to produce successive positive models of the desired tooth arrangements. The dental appliances are then produced as negatives of the positive models using conventional positive pressure or vacuum fabrication techniques. The fabrication machine may comprise a stereolithography or other similar machine which relies on selectively hardening a volume of non-hardened polymeric resin by scanning a laser to selectively harden the resin in a shape based on the digital data set. Other fabrication machines which could be utilized in the methods of the present invention include tooling machines and wax deposition machines.

In still another aspect, methods of the present invention for fabricating a dental appliance comprise providing a digital data set representing a modified tooth arrangement for a patient. A fabrication machine is then used to produce a positive model of the modified tooth arrangement based on the digital data set. The dental appliance is then produced as a negative of the positive model. The fabrication machine may be a stereolithography or other machine as described above, and the positive model is produced by conventional pressure or vacuum molding techniques.

In a still further aspect, methods for fabricating a dental appliance according to the present invention comprise providing a first digital data set representing a modified tooth arrangement for a patient. A second digital data set is then produced from the first digital data set, where the second data set represents a negative model of the modified tooth arrangement. The fabrication machine is then controlled based on the second digital data set to produce the dental appliance. The fabrication machine will usually rely on selectively hardening a non-hardened resin to produce the appliance. The appliance typically comprises a polymeric shell having a cavity shape to receive and

resiliently reposition teeth from an initial tooth arrangement to the modified tooth arrangement.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A illustrates a patient's jaw and provides a general indication of how teeth may be moved by the methods and apparatus of the present invention.

Fig. 1B illustrates a single tooth from Fig. 1A and defines how tooth movement distances are determined.

Fig. 1C illustrates the jaw of Fig. 1A together with an incremental position adjustment appliance which has been configured according to the methods of the present invention.

Fig. 2 is a block diagram illustrating the steps of the present invention for producing a system of incremental position adjustment appliances.

Fig. 3 is a block diagram setting forth the steps for manipulating an initial digital data set representing an initial tooth arrangement to produce a final digital data set corresponding to a desired final tooth arrangement.

Fig. 4A is a flow chart illustrating an eraser tool for the methods herein.

Fig. 4B illustrates the volume of space which is being erased by the program of Fig. 4A.

Fig. 5 is a flow chart illustrating a program for matching high-resolution and low-resolution components in the manipulation of data sets of Fig. 3.

Fig. 6A is a flow chart illustrating a program for performing the "detection" stage of the cusp detection algorithm.

Fig. 6B is a flow chart illustrating a program for performing the "rejection" stage of the cusp detection algorithm.

Fig. 7 illustrates the method for generating multiple intermediate digital data sets which are used for producing the adjustment appliances of the present invention.

Fig. 8A is a flow chart illustrating the steps performed by the path scheduling algorithm.

Fig. 8B is a flow chart illustrating the steps for performing the "visibility" function according to one embodiment of the present invention.

Fig. 8C is a flow chart illustrating the steps for performing the "children" function according to one embodiment of the present invention.

Fig. 8D is a flow chart illustrating the steps for performing path scheduling step 128 of Fig. 8A.

Fig. 9A is a flow chart illustrating the steps for performing recursive collision testing during collision detection.

Fig. 9B is a flow chart illustrating node splitting performed during collision detection according to an embodiment of the present invention.

Fig. 9C is a flow chart illustrating steps for providing additional motion information to the collision detection process.

Fig. 10 illustrates alternative processes for producing a plurality of appliances according to the methods of the present invention utilizing digital data sets representing the intermediate and final appliance designs.

Fig. 11 is a simplified block diagram of a data processing system incorporating an embodiment of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

According to the present invention, systems and methods are provided for incrementally moving teeth using a plurality of discrete appliances, where each appliance successively moves one or more of the patient's teeth by relatively small amounts. The tooth movements will be those normally associated with orthodontic treatment, including translation in all three orthogonal directions relative to a vertical centerline, rotation of the tooth centerline in the two orthodontic directions ("root angulation" and "torque"), as well as rotation about the centerline.

Referring now to Fig. 1A, a representative jaw 100 includes sixteen teeth 102. The present invention is intended to move at least some of these teeth from an initial tooth arrangement to a final tooth arrangement. To understand how the teeth may be moved, an arbitrary centerline (CL) is drawn through one of the teeth 102. With reference to this centerline (CL), the teeth may be moved in the orthogonal directions represented by axes 104, 106, and 108 (where 104 is the centerline). The centerline may be rotated about the axis 108 (root angulation) and 104 (torque) as indicated by arrows 110 and 112, respectively. Additionally,

the tooth may be rotated about the centerline, as represented by arrow 114. Thus, all possible free-form motions of the tooth can be performed. Referring now to Fig. 1B, the magnitude of any tooth movement achieved by the methods and devices of the present invention will be defined in terms of the maximum linear translation of any point P on a tooth 102. Each point P_i will undergo a cumulative translation as that tooth is moved in any of the orthogonal or rotational directions defined in Fig. 1A. That is, while the point will usually follow a non-linear path, there will be a linear distance between any point in the tooth when determined at any two times during the treatment. Thus, an arbitrary point P_1 may in fact undergo a true side-to-side translation as indicated by arrow d_1, while a second arbitrary point P_2 may travel along an arcuate path, resulting in a final translation d_2. Many aspects of the present invention are defined in terms of the maximum permissible movement of a point P_i induced by the methods in any particular tooth. Such maximum tooth movement, in turn, is defined as the maximum linear translation of that point P_i on the tooth which undergoes the maximum movement for that tooth in any treatment step.

Referring now to Fig. 1C, systems according to the present invention will comprise a plurality of incremental position adjustment appliances. The appliances are intended to effect incremental repositioning of individual teeth in the jaw as described generally above. In a broadest sense, the methods of the present invention can employ any of the known positioners, retainers, or other removable appliances which are known for finishing and maintaining teeth positions in connection with conventional orthodontic treatment. The systems of the present invention, in contrast with prior apparatus and systems, will provide a plurality of such appliances intended to be worn by a patient successively in order to achieve the gradual tooth repositioning as described herein. A preferred appliance 100 will comprise a polymeric shell having a cavity shaped to receive and resiliently reposition teeth from one tooth arrangement to a successive tooth arrangement. The polymeric shell will preferably, but not necessarily, fit over all teeth present in the upper or lower jaw. Often, only certain one(s) of the teeth will be repositioned while others of the teeth will provide a base or anchor region for holding the repositioning appliance in place as it applies the resilient repositioning force against the tooth or teeth to be repositioned. In complex cases, however, many or most of the teeth will be repositioned at some point during the treatment. In such cases, the teeth which are moved can also

serve as a base or anchor region for holding the repositioning appliance. Additionally, the gums and/or the palette can serve as an anchor region, thus allowing all or nearly all of the teeth to be repositioned simultaneously.

The polymeric appliance 100 of Fig. 1C is preferably formed from a thin sheet of a suitable elastomeric polymeric, such as Tru-Tain 0.03 in. thermal forming dental material, Tru-Tain Plastics, Rochester, Minnesota 55902. Usually, no wires or other means will be provided for holding the appliance in place over the teeth. In some cases, however, it will be desirable or necessary to provide individual anchors on teeth with corresponding receptacles or apertures in the appliance 100 so that the appliance can apply an upward force on the tooth which would not be possible in the absence of such an anchor. Specific methods for producing the appliances 100 are described hereinafter.

Referring now to Fig. 2, the overall method of the present invention for producing the incremental position adjustment appliances for subsequent use by a patient to reposition the patient's teeth will be described. As a first step, a digital data set representing an initial tooth arrangement is obtained, referred to hereinafter as the IDDS. The IDDS may be obtained in a variety of ways. For example, the patient's teeth may be scanned or imaged using well known technology, such as X-rays, three-dimensional X-rays, computer-aided tomographic images or data sets, magnetic resonance images, etc. Methods for digitizing such conventional images to produce data sets useful in the present invention are well known and described in the patent and medical literature. Usually, however, the present invention will rely on first obtaining a plaster cast of the patient's teeth by well known techniques, such as those described in Graber, *Orthodontics: Principle and Practice*, Second Edition, Saunders, Philadelphia, 1969, pp. 401-415. After the tooth casting is obtained, it can be digitally scanned using a conventional laser scanner or other range acquisition system to produce the IDDS. The data set produced by the range acquisition system may, of course, be converted to other formats to be compatible with the software which is used for manipulating images within the data set, as described in more detail below. General techniques for producing plaster casts of teeth and generating digital models using laser scanning techniques are described, for example, in U.S. Patent No. 5,605,459, the full disclosure of which is incorporated herein by reference.

There are a variety of range acquisition systems, generally categorized by whether the process of acquisition requires contact with the three dimensional object. A contact-type range acquisition system utilizes a probe, having multiple degrees of translational and/or rotational freedom. By recording the physical displacement of the probe as it is drawn across the sample surface, a computer-readable representation of the sample object is made. A non-contact-type range acquisition device can be either a reflective-type or transmissive-type system. There are a variety of reflective systems in use. Some of these reflective systems utilize non-optical incident energy sources such as microwave radar or sonar. Others utilize optical energy. Those non-contact-type systems working by reflected optical energy further contain special instrumentation configured to permit certain measuring techniques to be performed (e.g., imaging radar, triangulation and interferometry).

A preferred range acquisition system is an optical, reflective, non-contact-type scanner. Non-contact-type scanners are preferred because they are inherently nondestructive (i.e., do not damage the sample object), are generally characterized by a higher capture resolution and scan a sample in a relatively short period of time. One such scanner is the Cyberware Model 15 manufactured by Cyberware, Inc., Monterey, California.

Either non-contact-type or contact-type scanners may also include a color camera, that when synchronized with the scanning capabilities, provides a means for capturing, in digital format, a color representation of the sample object. The importance of this further ability to capture not just the shape of the sample object but also its color is discussed below.

In a preferred embodiment, a wax bite is also obtained from a patient. The wax bite enables scanning of the relative positions of the upper and lower dentition in centric occlusion. This is usually accomplished by first placing the lower cast in front of the scanner, with the teeth facing upwards, then placing the wax bite on top of the lower cast, and finally by placing the upper cast on top of the lower cast, with the teeth downwards, resting on the wax bite. A cylindrical scan is then acquired for the lower and upper casts in their relative positions. The scanned data provides a digital model of medium resolution representing an object which is the combination of the patient's arches positioned in the same relative configuration as in the mouth.

The digital model acts as a template guiding the placement of the two individual digital models (one per arch). More precisely, using software, for example the CyberWare alignment software, each digital arch is in turn aligned to the pair scan. The individual models are then positioned relative to each other corresponding to the arches in the patient's mouth.

The methods of the present invention will rely on manipulating the IDDS at a computer or workstation having a suitable graphical user interface (GUI) and software appropriate for viewing and modifying the images. Specific aspects of the software will be described in detail hereinafter. While the methods will rely on computer manipulation of digital data, the systems of the present invention comprising multiple dental appliances having incrementally differing geometries may be produced by non-computer-aided techniques. For example, plaster casts obtained as described above may be cut using knives, saws, or other cutting tools in order to permit repositioning of individual teeth within the casting. The disconnected teeth may then be held in place by soft wax or other malleable material, and a plurality of intermediate tooth arrangements can then be prepared using such a modified plaster casting of the patient's teeth. The different arrangements can be used to prepare sets of multiple appliances, generally as described below, using pressure and vacuum molding techniques. While such manual creation of the appliance systems of the present invention will generally be much less preferred, systems so produced will come within the scope of the present invention.

Referring again to Fig. 2, after the IDDS has been obtained, the digital information will be introduced to the computer or other workstation for manipulation. In the preferred approach, individual teeth and other components will be "cut" to permit their individual repositioning or removal from the digital data. After thus "freeing" the components, the user will often follow a prescription or other written specification provided by the treating professional. Alternatively, the user may reposition them based on the visual appearance or using rules and algorithms programmed into the computer. Once the user is satisfied with the final arrangement, the final tooth arrangement is incorporated into a final digital data set (FDDS).

Based on both the IDDS and the FDDS, a plurality of intermediate digital data sets (INTDDS's) are generated to correspond to

Fig. 3 illustrates a representative technique for manipulating the IDDS to produce the FDDS on the computer. Usually, the data from the digital scanner will be in a high resolution form. In order to reduce the computer time necessary to generate images, a parallel set of digital data set representing the IDDS at a lower resolution will be created. The user will manipulate the lower resolution images while the computer will update the high resolution data set as necessary. The user can also view/manipulate the high resolution model if the extra detail provided in that model is useful. The IDDS will also be converted into a quad edge data structure if not already present in that form. A quad edge data structure is a standard topological data structure defined in *Primitives for the Manipulation of General Subdivisions and the Computation of Voronoi Diagrams*, ACM Transactions of Graphics, Vol. 4, No. 2, April 1985, pp. 74-123. Other topological data structures, such as the winged-edge data structure, could also be used.

As an initial step, while viewing the three-dimensional image of the patient's jaw, including the teeth, gingivae, and other oral tissue, the user will usually delete structure which is unnecessary for image manipulation and/or final production of an appliance. These unwanted sections of the model may be removed using an eraser tool to perform a solid modeling subtraction. The tool is represented by a graphic box. The volume to be erased (the dimensions, position, and orientation of the box) are set by the user employing the GUI. Typically, unwanted sections would include extraneous gum area and the base of the originally scanned cast. Another application for this tool is to stimulate the extraction of teeth and the "shaving down" of tooth surfaces. This is necessary when additional space is needed in the jaw for the final positioning of a tooth to be moved. The treating professional may choose to determine which teeth will be shaved and/or which teeth will be extracted. Shaving allows the patient to maintain their teeth when only a small amount of space is needed. Typically, extraction and shaving, of course, will be utilized in the treatment planning only when the actual patient teeth are to be extracted and/or shaved prior to initiating repositioning according to the methods of the present invention.

Removing unwanted and/or unnecessary sections of the model increases data processing speed and enhances the visual display. Unnecessary sections include those not needed for creation of the tooth

repositioning appliance. The removal of these unwanted sections reduces the complexity and size of the digital data set, thus accelerating manipulations of the data set and other operations.

After the user positions and sizes the eraser tool and instructs the software to erase the unwanted section, all triangles within the box set by the user will be removed and the border triangles are modified to leave a smooth, linear border. The software deletes all of the triangles within the box and clips all triangles which cross the border of the box. This requires generating new vertices on the border of the box. The holes created in the model at the faces of the box are re-triangulated and closed using the newly created vertices.

The saw tool is used to define the individual teeth (or possibly groups of teeth) to be moved. The tool separates the scanned image into individual graphic components enabling the software to move the tooth or other component images independent of remaining portions of the model. In one embodiment, the saw tool defines a path for cutting the graphic image by using two cubic B-spline curves lying in space, possibly constrained to parallel planes, either open or closed. A set of lines connects the two curves and shows the user the general cutting path. The user may edit the control points on the cubic B-splines, the thickness of the saw cut, and the number of erasers used, as described below.

In an alternate preferred embodiment, the teeth are separated by using the saw as a "coring" device, cutting the tooth from above with vertical saw cuts. The crown of the tooth, as well as the gingivae tissue immediately below the crown are separated from the rest of the geometry, and treated as an individual unit, referred to as a tooth. When this model is moved, the gingivae tissue moves relative to the crown, creating a first order approximation of the way that the gingivae will reform within a patient's mouth.

Each tooth may also be separated from the original trimmed model. Additionally, a base may be created from the original trimmed model by cutting off the crowns of the teeth. The resulting model is used as a base for moving the teeth. This facilitates the eventual manufacture of a physical mold from the geometric model, as described below.

Thickness: When a cut is used to separate a tooth, the user will usually want the cut to be as thin as possible. However, the user may want to make a thicker cut, for example, when shaving down surrounding

teeth, as described above. Graphically, the cut appears as a curve bounded by the thickness of the cut on one side of the curve.

Number of Erasers: A cut is comprised of multiple eraser boxes arranged next to each other as a piecewise linear approximation of the Saw Tool's curve path. The user chooses the number of erasers, which determines the sophistication of the curve created - the greater the number of segments, the more accurately the cutting will follow the curve. The number of erasers is shown graphically by the number of parallel lines connecting the two cubic B-spline curves. Once a saw cut has been completely specified the user applies the cut to the model. The cut is performed as a sequence of erasings. A preferred algorithm is set forth in Fig. 4A. Fig. 4B shows a single erasing iteration of the cut as described in the algorithm for a open ended B-spline curve. For a vertical cut, the curves are closed with $P_A[O]$ and $P_A[S]$ the same point and $P_B[O]$ and $P_B[S]$ being the same point.

In one embodiment, the software may automatically partition the saw tool into a set of erasers based upon a smoothness measure input by the user. The saw is adaptively subdivided until an error metric measures the deviation from the ideal representation to the approximate representation to be less than a threshold specified by the smoothness setting. The preferred error metric used compares the linear length of the subdivided curve to the arclength of the ideal spline curve. When the difference is greater than a threshold computed from the smoothness setting, a subdivision point is added along the spline curve.

A preview feature may also be provided in the software. The preview feature visually displays a saw cut as the two surfaces that represent opposed sides of the cut. This allows the user to consider the final cut before applying it to the model data set.

After the user has completed all desired cutting operations with the saw tool, multiple graphic solids exist. However, at this point, the software has not determined which triangles of the quad edge data structure belong to which components. The software chooses a random starting point in the data structure and traverses the data structure using adjacency information to find all of the triangles that are attached to each other, identifying an individual component. This process is repeated starting with the triangle whose component is not yet determined. Once the entire data structure is traversed, all components have been identified.

To the user, all changes made to the high resolution model appear to occur simultaneously in the low resolution model, and vice versa. However, there is not a one-to-one correlation between the different resolution models. Therefore, the computer "matches" the high resolution and low resolution components as best as it can subject to defined limits. The algorithm is described in Fig. 5.

Cusp detection: In a preferred embodiment, the software provides the ability to detect cusps for a tooth. Cusps are pointed projections on the chewing surface of a tooth. Cusp detection can be performed either before or after the cutting phase has been performed. The algorithm used for cusp detection is composed of two stages: (1) "detection" stage, during which a set of points on the tooth are determined as candidates for cusp locations; and (2) "rejection" stage, during which candidates from the set of points are rejected if they do not satisfy a set of criteria associated with cusps.

A preferred algorithm for the "detection" stage is set forth in Fig. 6A. In the detection stage, a possible cusp is viewed as an "island" on the surface of the tooth, with the candidate cusp at the highest point on the island. "Highest" is measured with respect to the coordinate system of the model, but could just as easily be measured with respect to the local coordinate system of each tooth if detection is performed after the cutting phase of treatment.

The set of all possible cusps is determined by looking for all local maxima on the tooth model that are within a specified distance of the top of the bounding box of the model. First, the highest point on the model is designated as the first candidate cusp. A plane is passed through this point, perpendicular to the direction along which the height of a point is measured. The plane is then lowered by a small predetermined distance along the Z axis. Next, all vertices connected to the tooth and which are above the plane and on some connected component are associated with the candidate cusp as cusps. This step is also referred to as the "flood fill" step. From each candidate cusp point, outward "flooding" is performed, marking each vertex on the model visited in this matter as "part of" the corresponding candidate cusp. After the flood fill step is complete, every vertex on the model is examined. Any vertex that is above the plane and has not been visited by one of the flood fills is added to the list of candidate cusps. These steps are repeated until the plane is traveled a specified distance.

While this iterative approach can be more time consuming than a local maximum search, the approach described above leads to a shorter list of candidate cusps. Since the plane is lowered a finite distance at each step, very small local maxima that can occur due to noisy data are skipped over.

After the "detection" stage, the cusp detection algorithm proceeds with the "rejection" stage. A preferred algorithm for the "rejection" stage is set forth in Fig. 6B. In this stage, the local geometries around each of cusp candidates are analyzed to determine if they possess "non-cusp-like features." Cusp candidates that exhibit "non-cusp-like features" are removed from the list of cusp candidates.

Various criteria may be used to identify "non-cusp-like features." According to one test, the local curvature of the surface around the cusp candidate is used to determine whether the candidate possesses non-cusp-like features. As depicted in Fig. 6B, the local curvature of the surface around the cusp candidate is approximated, and then analyzed to determine if it is too large (very pointy surface) or too small (very flat surface), in which case the candidate is removed from the list of cusp candidates. Conservative values are used for the minimum and maximum curvatures values to ensure that genuine cusps are not rejected by mistake.

According to an alternate test, a measure of smoothness is computed based on the average normal in an area around the candidate cusp. If the average normal deviates from the normal at the cusp by more than a specified amount, the candidate cusp is rejected. In a preferred embodiment, the deviation of a normal vector N from the cusp normal CN is approximated by the formula:

1 - Abs(N*CN),

which is zero at no deviation, and 1 when N and CN are perpendicular.

Once the teeth have been separated, the FDDS can be created from the IDDS. The FDDS is created by following the orthodontists prescription, moving the teeth into their final prescription. In one embodiment, the prescription is entered into a computer, which algorithmically computes the final position of the teeth. In alternate embodiments, a user may move the teeth into their final positions by independently manipulating one or more teeth while satisfying the constraints of the prescription. It should be appreciated that various

combinations of the above described techniques may also be used to arrive at the final teeth position.

The preferred method for creating the FDDS involves moving the teeth in a specified sequence. First, the centers of each of the teeth are aligned to a standard arch. Then, the teeth are rotated until their roots are in the proper vertical position. Next, the teeth are rotated around their vertical axis into the proper orientation. The teeth are then observed from the side, and translated vertically into their proper vertical position. Finally, the two arches are placed together, and the teeth moved slightly to ensure that the upper and lower arches properly mesh together. The meshing of the upper and lower arches together is visualized using the collision detection algorithm to highlight the contacting points of the teeth in red.

After the teeth and other components have been placed or removed so that the final tooth arrangement has been produced, it is necessary to generate a treatment plan, as illustrated in Fig. 7. The treatment plan will ultimately produce the series of INTDDS's and FDDS as described previously. To produce these data sets, it is necessary to define or map the movement of selected individual teeth from the initial position to the final position over a series of successive steps. In addition, it may be necessary to add other features to the data sets in order to produce desired features in the treatment appliances. For example, it may be desirable to add wax patches to the image in order to define cavities or recesses for particular purposes. For example, it may be desirable to maintain a space between the appliance and particular regions of the teeth or jaw in order to reduce soreness of the gums, avoid periodontal problems, allow for a cap, and the like. Additionally, it will often be necessary to provide a receptacle or aperture intended to accommodate an anchor which is to be placed on a tooth in order to permit the tooth to be manipulated in a manner that requires the anchor, e.g. lifted relative to the jaw.

Some methods for manufacturing the tooth repositioning appliances require that the separate, repositioned teeth and other components be unified into a single continuous structure in order to permit manufacturing. In these instances, "wax patches" are used to attach otherwise disconnected components of the INTDDS's. These patches are added to the data set underneath the teeth and above the gum so that they do not effect the geometry of the tooth repositioning appliances.

The application software provides for a variety of wax patches to be added to the model, including boxes and spheres with adjustable dimensions. The wax patches that are added are treated by the software as additional pieces of geometry, identical to all other geometries. Thus, the wax patches can be repositioned during the treatment path as well as the teeth and other components. The preferred method of separating the teeth using vertical coring, as described above, removes the need for most of these "wax patches".

In the manufacturing process, which relies on generation of positive models to produce the repositioning appliance, adding a wax patch to the graphic model will generate a positive mold that has the same added wax patch geometry. Because the mold is a positive of the teeth and the appliance is a negative of the teeth, when the appliance is formed over the mold, the appliance will also form around the wax patch that has been added to the mold. When placed in the patient's mouth, the appliance will thus allow for a space between the inner cavity surface of the appliance and the patient's teeth or gums. Additionally, the wax patch may be used to form a recess or aperture within the appliance which engages an anchor placed on the teeth in order to move the tooth in directions which could not otherwise be accomplished.

In addition to such wax patches, an individual component, usually a tooth, can be scaled to a smaller or larger size which will result in a manufactured appliance having a tighter or looser fit, respectively.

Treatment planning is extremely flexible in defining the movement of teeth and other components. The user may change the number of treatment stages, as well as individually control the path and speed of components.

Number of Treatment Stages: The user can change the number of desired treatment stages from the initial to the target states of the teeth. Any component that is not moved is assumed to remain stationary, and thus its final position is assumed to be the same as the initial position (likewise for all intermediate positions, unless one or more key frames are defined for that component).

Key frames: The user may also specify "key frames" by selecting an intermediate state and making changes to component position(s). Unless instructed otherwise, the software automatically linearly interpolates between all user-specified positions (including the

initial position, all key frame positions, and the target position). For example, if only a final position is defined for a particular component, each subsequent stage after the initial stage will simply show the component an equal linear distance and rotation (specified by a quaternion) closer to the final position. If the user specifies two key frames for that component, it will "move" linearly from the initial position through different stages to the position defined by the first key frame. It will then move, possibly in a different direction, linearly to the position defined by the second key frame. Finally, it will move, possibly in yet a different direction, linearly to the target position.

The user can also specify non-linear interpolation between the key frames. A spline curve is used to specify the interpolating function in a conventional manner.

These operations may be done independently to each component, so that a key frame for one component will not affect another component, unless the other component is also moved by the user in that key frame. One component may accelerate along a curve between stages 3 and 8, while another moves linearly from stage 1 to 5, and then changes direction suddenly and slows down along a linear path to stage 10. This flexibility allows a great deal of freedom in planning a patient's treatment.

In one embodiment, the software automatically determines the treatment path, based upon the IDDS and the FDDS. This is usually accomplished using a path scheduling algorithm which determines the rate at which each component, i.e. a tooth, moves along a straight path from the initial position to the final position. The path scheduling algorithm used by the present invention determines the treatment path while avoiding "round-tripping" which is the term used by orthodontists referring to moving a tooth along a distance greater than absolutely necessary to straighten the teeth. Such motion is highly undesirable, and has potential negative side effects on the patient. In order to avoid "round-tripping", the path scheduling algorithm schedules or stages the movements of all the teeth by constraining them to the shortest straight-line path between the initial and final position, while avoiding all interferences between separate teeth.

The path scheduling algorithm utilizes a randomized search technique to find an unobstructed path through a configuration space which describes possible treatment plans. A preferred embodiment of the algorithm for scheduling motion between two user defined global keyframes

is described below. Scheduling over a time interval which includes intermediate keyframes is accomplished by dividing the time interval into subintervals which do not include intermediate keyframes, scheduling each of these intervals independently, and then concatenating the resulting schedules.

Flow chart 120 in Fig. 8A depicts a simplified path scheduling algorithm according to one embodiment of the present invention. As shown in Fig. 8A, first step 122 involves construction of the "configuration space" description. A "configuration," in this context, refers to a given set of positions of all the teeth being considered for movement. Each of these positions may be described in multiple ways. In a preferred embodiment of the present invention, the positions are described by one affine transformation to specify change in location and one rotational transformation to specify the change in orientation of a tooth from its initial position to its final position. The intermediate positions of each tooth are described by a pair of numbers which specify how far to interpolate the location and orientation between the two endpoints. A "configuration" thus consists of two numbers for each tooth being moved, and the "configuration space" refers to the space of all such number pairs. Thus, the configuration space is a Cartesian space, any location in which can be interpreted as specifying the positions of all teeth.

The affine transformation describing the movement of each tooth from its starting position to its ending position is decomposed into translational and rotational components; these transformations are independently interpolated with scalar parameters which are considered two dimensions of the configuration space. The entire configuration space thus consists of two dimensions per moved tooth, all of which are treated equivalently during the subsequent search.

The configuration space is made of "free space" and "obstructed space." "Free" configurations are those which represent valid, physically realizable positions of teeth, while "obstructed" configurations are those which do not. To determine whether a configuration is free or obstructed, a model is created for the positions of the teeth which the configuration describes. A collision detection algorithm is then applied to determine if any of the geometries describing the tooth surfaces intersect. If there are no obstructions, the space is considered free; otherwise it is obstructed. The collision detect algorithm is discussed below in more detail.

At step 124, a "visibility" function $V(s_i, s_2)$ is defined which takes two vectors in the configuration space, "s_1" and "s_2", as input and returns a true or false boolean value. The visibility function returns a true value if and only if a straight line path connecting s_1 and s_2 passes entirely through a free and unobstructed region of the configuration space. A preferred algorithm for the visibility function is set forth in Fig. 8B. The visibility function is approximately computed by testing the teeth model for interferences at discretely sampled points along the line s_1-s_2. Techniques, such as early termination on failure or choosing the order of sample points by recursively subdividing the interval to be tested, may be used to increase the efficiency of the visibility function.

At step 126 of Fig. 8A, a "children" function C(s) is defined whose input parameter, "s", is a vector in the configuration space and which returns a set of vectors, "s_c" in the configuration space. Fig. 8C depicts a simplified flow chart illustrating the steps followed for computing children function C(s). Each vector within set s_c satisfies the property that $V(s, s_c)$ is true and that each of its components are greater than or equal to the corresponding component of "s." This implies that any state represented by such a vector is reachable from "s" without encountering any interferences and without performing any motion which is not in the direction prescribed by treatment. Each vector of set "s_c" is created by perturbing each component of "s" by some random, positive amount. The visibility function $V(s, s_c)$ is then computed and "s" added to the set "s_c" if the visibility function returns a true boolean value. Additionally, for each such vector generated, a pointer to its parent "s" is recorded for later use.

After the configuration space has been defined, at step 128, path scheduling is performed between an initial state "s_{init}" and a final state "s_{final}". Fig. 8D depicts a preferred flow chart for performing step 128 depicted in Fig. 8A. As illustrated in Fig. 8D, at step 128a, a set of states "W" is defined to initially contain only the initial state s_{init}. Next, at step 128b, the visibility function is invoked to determine if $V(s, s_{final})$ is true for at least one state s_i in W. If the visibility function returns a false boolean value, at step 128c, the set of states "W" is replaced with the union of $C(s_i)$ for all s_i in W. Steps 128b and 128c are repeated until $V(s_i, s_{final})$ returns a true boolean value for any s_i belonging to W.

At step 128d, for each s_i for which $V(s_i, s_{final})$ is true, an unobstructed path P_i is constructed from s_i to s_{init} by following the parent pointers back to s_{init}. At step 128e, the path from s_{init} to s_{final} is then constructed by concatenating the paths P_i with the final step from s_i to s_{final}. If there are multiple paths from s_{init} to s_{final}, the total length of each path is computed at step 128f. Finally, at step 128g, the path with the shortest length is then chosen as the final path. The length of the chosen path corresponds to the total time and stages required for a treatment plan.

The resulting final path consists of a series of vectors, each of which represents a group of values of the interpolation parameters of the translational and rotational components of the transformations of the moving teeth. Taken together, these constitute a schedule of tooth movement which avoids tooth-to-tooth interferences.

Collision detect algorithm: The collision or interference detection algorithm employed by the present invention is based on the algorithm described in SIGGRAPH article, Stefan Gottschalk et al. (1996): *"OBBTree: A Hierarchical Structure for Rapid Interference Detection."* The contents of the SIGGRAPH article are herein incorporated by reference.

The algorithm is centered around a recursive subdivision of the space occupied by an object, which is organized in a binary-tree like fashion. Triangles are used to represent the teeth in the DDS. Each node of the tree is referred to as an oriented bounding box (OBB) and contains a subset of triangles appearing in the node's parent. The children of a parent node contain between them all of the triangle data stored in the parent node.

The bounding box of a node is oriented so it tightly fits around all of the triangles in that node. Leaf nodes in the tree ideally contain a single triangle, but can possibly contain more than one triangle. Detecting collisions between two objects involves determining if the OBB trees of the objects intersect. Fig. 9A sets forth a flow chart depicting a simplified version of a recursive collision test to check if a node "N1" from a first object intersects with node "N2" of a second object. If the OBBs of the root nodes of the trees overlap, the root's children are checked for overlap. The algorithm proceeds in a recursive fashion until the leaf nodes are reached. At this point, a robust triangle intersection routine is used to determine if the triangles at the leaves are involved in a collision.

The present invention provides several enhancements to the collision detection algorithm described in the SIGGRAPH article. In one embodiment, the present invention provides a unique method of building OBB trees in a lazy fashion to save memory and time. This approach stems from the observation that there are parts of the model which will never be involved in a collision, and consequently the OBB tree for such parts of the model need not be computed. The OBB trees are expanded by splitting the internal nodes of the tree as necessary during the recursive collision determination algorithm, as depicted in Fig. 9B.

In another embodiment of the present invention, the triangles in the model which are not required for collision data may also be specifically excluded from consideration when building an OBB tree. As depicted in Fig. 9C, additional information is provided to the collision algorithm to specify objects in motion. Motion may be viewed at two levels. Objects may be conceptualized as "moving" in a global sense, or they may be conceptualized as "moving" relative to other objects. The additional information improves the time taken for the collision detection by avoiding recomputation of collision information between objects which are at rest relative to each other since the state of the collision between such objects does not change.

The software of the present invention may also incorporate and the user may at any point use a "movie" feature to automatically animate the movement from initial to target states. This is helpful for visualizing overall component movement throughout the treatment process.

Above it was described that the preferred user interface for component identification is a three dimensional interactive GUI. A three-dimensional GUI is also preferred for component manipulation. Such an interface provides the treating professional or user with instant and visual interaction with the digital model components. It is preferred over interfaces that permit only simple low-level commands for directing the computer to manipulate a particular segment. In other words, a GUI adapted for manipulation is preferred over an interface that accepts directives, for example, only of the sort: "translate this component by 0.1 mm to the right." Such low-level commands are useful for fine-tuning, but, if they were the sole interface, the processes of component manipulation would become a tiresome and time-consuming interaction.

Before or during the manipulation process, one or more tooth components may be augmented with template models of tooth roots.

Manipulation of a tooth model augmented with a root template is useful, for example, in situations where impacting of teeth below the gumline is a concern. These template models could, for example, comprise a digitized representation of the patient's teeth x-rays.

The software also allows for adding annotations to the datasets which can comprise text and/or the sequence number of the apparatus. The annotation is added as recessed text (i.e. it is 3-D geometry), so that it will appear on the printed positive model. If the annotation can be placed on a part of the mouth that will be covered by a repositioning appliance, but is unimportant for the tooth motion, the annotation may appear on the delivered repositioning appliance(s).

The above-described component identification and component manipulation software is designed to operate at a sophistication commensurate with the operator's training level. For example, the component manipulation software can assist a computer operator, lacking orthodontic training, by providing feedback regarding permissible and forbidden manipulations of the teeth. On the other hand, an orthodontist, having greater skill in intraoral physiology and teeth-moving dynamics, can simply use the component identification and manipulation software as a tool and disable or otherwise ignore the advice.

Once the intermediate and final data sets have been created, the appliances may be fabricated as illustrated in Fig. 10. Preferably, fabrication methods will employ a rapid prototyping device 200 such as a stereolithography machine. A particularly suitable rapid prototyping machine is Model SLA-250/50 available from 3D System, Valencia, California. The rapid prototyping machine 200 will selectively harden a liquid or other non-hardened resin into a three-dimensional structure which can be separated from the remaining non-hardened resin, washed, and used either directly as the appliance or indirectly as a mold for producing the appliance. The prototyping machine 200 will receive the individual digital data sets and produce one structure corresponding to each of the desired appliances. Generally, because the rapid prototyping machine 200 may utilize a resin having non-optimum mechanical properties and which may not be generally acceptable for patient use, it will be preferred to use the prototyping machine to produce molds which are, in effect, positive tooth models of each successive stage of the treatment. After the positive models are prepared, a conventional pressure or vacuum molding machine may be used to produce the appliances from a more suitable

material, such as 0.03 inch thermal forming dental material, available from Tru-Tain Plastics, Rochester, Minnesota 55902. Suitable pressure molding equipment is available under the tradename BIOSTAR from Great Lakes Orthodontics, Ltd., Tonawanda, New York 14150. The molding machine 250 produces each of the appliances directly from the positive tooth model and the desired material. Suitable vacuum molding machines are available from Raintree Essix, Inc.

After production, the plurality of appliances which comprise the system of the present invention are preferably supplied to the treating professional all at one time. The appliances will be marked in some manner, typically by sequential numbering directly on the appliances or on tags, pouches, or other items which are affixed to or which enclose each appliance, to indicate their order of use. Optionally, written instructions may accompany the system which set forth that the patient is to wear the individual appliances in the order marked on the appliances or elsewhere in the packaging. Use of the appliances in such a manner will reposition the patient's teeth progressively toward the final tooth arrangement.

Fig. 11 is a simplified block diagram of a data processing system 300 embodying the present invention. Data processing system 300 typically includes at least one processor 302 which communicates with a number of peripheral devices via bus subsystem 304. These peripheral devices typically include a storage subsystem 306 (memory subsystem 308 and file storage subsystem 314), a set of user interface input and output devices 318, and an interface to outside networks 316, including the public switched telephone network. This interface is shown schematically as "Modems and Network Interface" block 316, and is coupled to corresponding interface devices in other data processing systems via communication network interface 324. Data processing system 300 could be a terminal or a low-end personal computer or a high-end personal computer, workstation or mainframe.

The user interface input devices typically include a keyboard and may further include a pointing device and a scanner. The pointing device may be an indirect pointing device such as a mouse, trackball, touchpad, or graphics tablet, or a direct pointing device such as a touchscreen incorporated into the display. Other types of user interface input devices, such as voice recognition systems, are also possible.

User interface output devices typically include a printer and a display subsystem, which includes a display controller and a display device coupled to the controller. The display device may be a cathode ray tube (CRT), a flat-panel device such as a liquid crystal display (LCD), or a projection device. The display subsystem may also provide non-visual display such as audio output.

Storage subsystem 306 maintains the basic programming and data constructs that provide the functionality of the present invention. The software modules discussed above are typically stored in storage subsystem 306. Storage subsystem 306 typically comprises memory subsystem 308 and file storage subsystem 314.

Memory subsystem 308 typically includes a number of memories including a main random access memory (RAM) 310 for storage of instructions and data during program execution and a read only memory (ROM) 312 in which fixed instructions are stored. In the case of Macintosh-compatible personal computers the ROM would include portions of the operating system; in the case of IBM-compatible personal computers, this would include the BIOS (basic input/output system).

File storage subsystem 314 provides persistent (non-volatile) storage for program and data files, and typically includes at least one hard disk drive and at least one floppy disk drive (with associated removable media). There may also be other devices such as a CD-ROM drive and optical drives (all with their associated removable media). Additionally, the system may include drives of the type with removable media cartridges. The removable media cartridges may, for example be hard disk cartridges, such as those marketed by Syquest and others, and flexible disk cartridges, such as those marketed by Iomega. One or more of the drives may be located at a remote location, such as in a server on a local area network or at a site on the Internet's World Wide Web.

In this context, the term "bus subsystem" is used generically so as to include any mechanism for letting the various components and subsystems communicate with each other as intended. With the exception of the input devices and the display, the other components need not be at the same physical location. Thus, for example, portions of the file storage system could be connected via various local-area or wide-area network media, including telephone lines. Similarly, the input devices and display need not be at the same location as the processor, although it is

display need not be at the same location as the processor, although it is anticipated that the present invention will most often be implemented in the context of PCs and workstations.

Bus subsystem 304 is shown schematically as a single bus, but a typical system has a number of buses such as a local bus and one or more expansion buses (e.g., ADB, SCSI, ISA, EISA, MCA, NuBus, or PCI), as well as serial and parallel ports. Network connections are usually established through a device such as a network adapter on one of these expansion buses or a modem on a serial port. The client computer may be a desktop system or a portable system.

Scanner 320 is responsible for scanning casts of the patient's teeth obtained either from the patient or from an orthodontist and providing the scanned digital data set information to data processing system 300 for further processing. In a distributed environment, scanner 320 may be located at a remote location and communicate scanned digital data set information to data processing system 300 via network interface 324.

Fabrication machine 322 fabricates dental appliances based on intermediate and final data set information received from data processing system 300. In a distributed environment, fabrication machine 322 may be located at a remote location and receive data set information from data processing system 300 via network interface 324.

While the above is a complete description of the preferred embodiments of the invention, various alternatives, modifications, and equivalents may be used. Therefore, the above description should not be taken as limiting the scope of the invention which is defined by the appended claims.

WHAT IS CLAIMED IS:

1. A system for repositioning teeth from an initial tooth arrangement to a final tooth arrangement, said system comprising a plurality of dental incremental position adjustment appliances including:

a first appliance having a geometry selected to reposition the teeth from the initial tooth arrangement to a first intermediate arrangement;

one or more intermediate appliances having geometries selected to progressively reposition the teeth from the first intermediate arrangement to successive intermediate arrangements; and

a final appliance having a geometry selected to progressively reposition the teeth from the last intermediate arrangement to the final tooth arrangement.

2. A system as in claim 1, wherein the appliances comprise polymeric shells having cavities shaped to receive and resiliently reposition teeth from one arrangement to a successive arrangement.

3. A system as in claim 2, wherein the tooth positions defined by the cavities in each successive appliance differ from those defined by the prior appliance by no more than 2 mm.

4. A system as in claim 1, comprising at least two intermediate appliances.

5. A system as in claim 4, comprising at least ten intermediate appliances.

6. A system as in claim 5, comprising at least twenty-five intermediate appliances.

7. A method for repositioning teeth from an initial tooth arrangement to a final tooth arrangement, said method comprising:

placing a first incremental position adjustment appliance in a patient's mouth, wherein the first appliance has a geometry selected to reposition the teeth from the initial tooth arrangement to a first intermediate arrangement;

successively replacing one or more additional appliances, wherein the additional appliances have geometries selected to progressively reposition the teeth from the first intermediate arrangement to successive intermediate arrangements; and

placing a final appliance into the patient's mouth, wherein the final appliance has a geometry selected to progressively reposition the teeth from the last intermediate arrangement to the final tooth arrangement.

8. A method as in claim 7, wherein the appliances comprise polymeric shells having cavities shaped to receive and resiliently reposition teeth from one arrangement to a successive arrangement.

9. A method as in claim 8, where the tooth positions defined by the cavities in each successive appliance differ from those defined by the prior appliance by no more than 2 mm.

10. A method as in claim 7, wherein the successively placing step comprises placing at least two additional appliances prior to placing the final appliance.

11. A method as in claim 10, wherein the successively placing step comprises placing at least ten additional appliances.

12. A method as in claim 11, wherein the successively placing step comprises placing at least twenty-five additional appliances.

13. A method as in claim 7, wherein the appliances are successively replaced at an interval in the range from 2 days to 20 days.

14. An improved method for repositioning teeth using appliances comprising polymeric shells having cavities shaped to receive and resiliently reposition teeth to produce a final tooth arrangement, wherein the improvement comprises determining at the outset of treatment geometries for at least three appliances which are to be worn successively by a patient to reposition teeth from an initial tooth arrangement to the final tooth arrangement.

15. An improved method as in claim 14, wherein at least four geometries determined at the outset.

16. An improved method as in claim 15, wherein at least ten geometries are determined at the outset.

17. An improved method as in claim 16, wherein at least twenty-five geometries are determined at the outset.

18. An improved method as in claim 14, wherein the tooth positions defined by the cavities in each successive geometry differ from those defined by the geometry by no more than 2 mm.

19. A method for producing a digital data set representing a final tooth arrangement, said method comprising:

providing an initial digital data set representing an initial tooth arrangement;

presenting a visual image based on the initial data set;

manipulating the visual image to reposition individual teeth in the visual image; and

producing a final digital data set representing the final tooth arrangement with repositioned teeth as observed in the image.

20. A method as in claim 19, wherein the step of providing a digital data set representing an initial tooth arrangement comprises scanning a three-dimensional model of a patient's teeth.

21. A method as in claim 20, wherein the manipulating step comprises:

defining boundaries about at least some of the individual teeth; and

moving at least some of the tooth boundaries relative to the other teeth in an image based on the digital data set.

22. A method for producing a plurality of digital data sets representing a series of discrete tooth arrangements progressing from an initial to a final arrangement, said method comprising:

providing a digital data set representing an initial tooth arrangement;

providing a digital data set representing a final tooth arrangement;

producing a plurality of successive digital data sets based on the provided digital data sets, wherein said plurality of digital data sets represent a series of successive tooth arrangements progressing from the initial tooth arrangement to the final tooth arrangement.

23. A method as in claim 22, wherein the step of providing a digital data set representing an initial tooth arrangement comprises scanning a three-dimensional model of a patient's teeth.

24. A method as in claim 22, wherein the step of providing a digital data set representing a final tooth arrangement comprises:

defining boundaries about at least some of the individual teeth; and

moving at least some of the tooth boundaries relative to the other teeth in an image based on the digital data set to produce the final data set.

25. A method as in claim 22, wherein the step of producing a plurality of successive digital data sets comprises determining positional differences between the initial data set and the final data set and interpolating said differences.

26. A method as in claim 25, wherein the interpolating step comprises linear interpolation.

27. A method as in claim 25, wherein the interpolating step comprises non-linear interpolation.

28. A method as in claim 25, further comprising defining one or more key frames between the initial tooth arrangement and final tooth arrangement and interpolating between the key frames.

29. A method for fabricating a plurality of dental incremental position adjustment appliances, said method comprising:

providing a digital data set representing an initial tooth arrangement;

providing a digital data set representing a final tooth arrangement;

producing a plurality of successive digital data sets based on the provided digital data sets, wherein said plurality of digital data sets represent a series of successive tooth arrangements progressing from the initial tooth arrangement to the final tooth arrangement; and

fabricating appliances based on at least some of the produced digital data sets.

30. A method as in claim 29, wherein the step of providing a digital data set representing an initial tooth arrangement comprises scanning a three-dimensional model of a patient's teeth.

31. A method as in claim 29, wherein the step of providing a digital data set representing a final tooth arrangement comprises:

defining boundaries about at least some of the individual teeth; and

moving at least some of the tooth boundaries relative to the other teeth in an image based on the digital data set to produce the final data set.

32. A method as in claim 29, wherein the step of producing a plurality of successive digital data sets comprises determining positional differences between the initial data set and the final data set and interpolating said differences.

33. A method as in claim 32, wherein the interpolating step comprises linear interpolation.

34. A method as in claim 32, wherein the interpolating step comprises non-linear interpolation.

35. A method as in claim 32, further comprising defining one or more key frames between the initial tooth arrangement and final tooth arrangement and interpolating between the key frames.

36. A method as in claim 29, wherein the fabricating step comprises:

controlling a fabrication machine based on the successive digital data sets to produce successive positive models of the successive tooth arrangements; and

producing the dental appliance as a negative of the positive model.

37. A method as in claim 36, wherein the controlling step comprises:

providing a volume of non-hardened polymeric resin; and

scanning a laser to selectively harden the resin in a shape based on the digital data set to produce the positive model.

38. A method as in claim 36, wherein the producing step comprises modeling the appliance over the positive model.

39. A method for fabricating a dental appliance, said method comprising:

providing a digital data set representing a modified tooth arrangement for a patient;

controlling a fabrication machine based on the digital data set to produce a positive model of the modified tooth arrangement; and

producing the dental appliance as a negative of the positive model.

40. A method as in claim 39, wherein the controlling step comprises:

providing a volume of non-hardened polymeric resin;

scanning a laser to selectively harden the resin in a shape based on the digital data set to produce the positive model.

41. A method as in claim 39, wherein the producing step comprises molding the appliance over the positive model.

42. A method for fabricating a dental appliance, said method comprising:

providing a first digital data set representing a modified tooth arrangement for a patient;

producing a second digital data set from the first data set, wherein the second data set represents a negative model of the modified tooth arrangement; and

controlling a fabrication machine based on the second digital data set to produce the dental appliance.

43. A method as in claim 42, wherein the controlling step comprises selectively hardening a non-hardened resin to produce the appliance and separating the appliance from the remaining liquid resin.

44. A method as in claim 42, wherein the appliance comprises a polymeric shell having a cavity shaped to receive and resiliently reposition teeth from an initial tooth arrangement to the modified tooth arrangement.

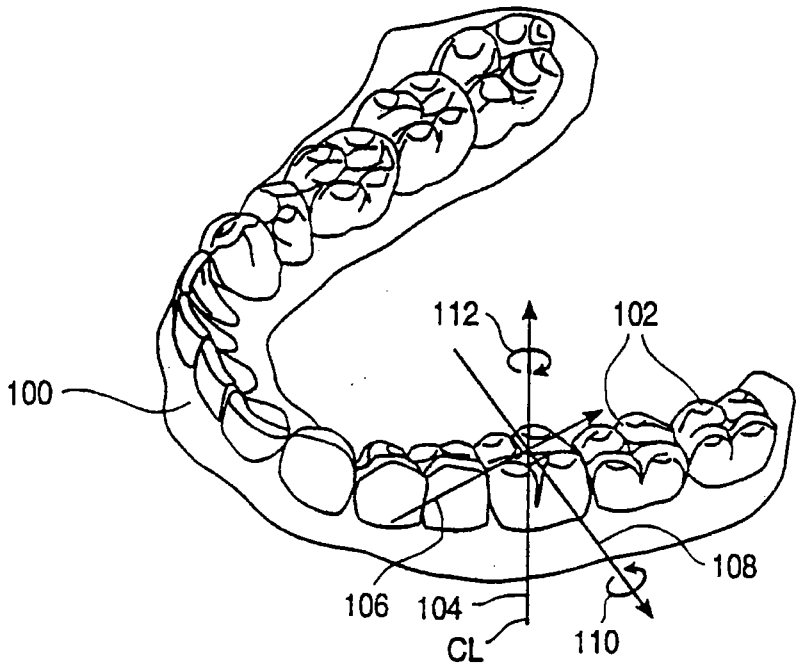


FIG. 1A

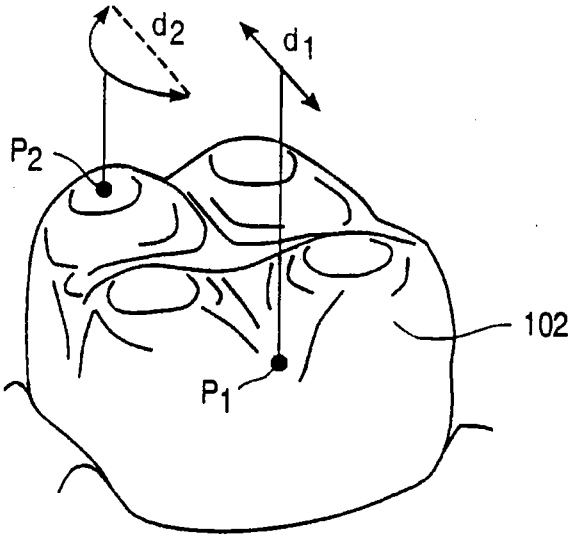


FIG. 1B

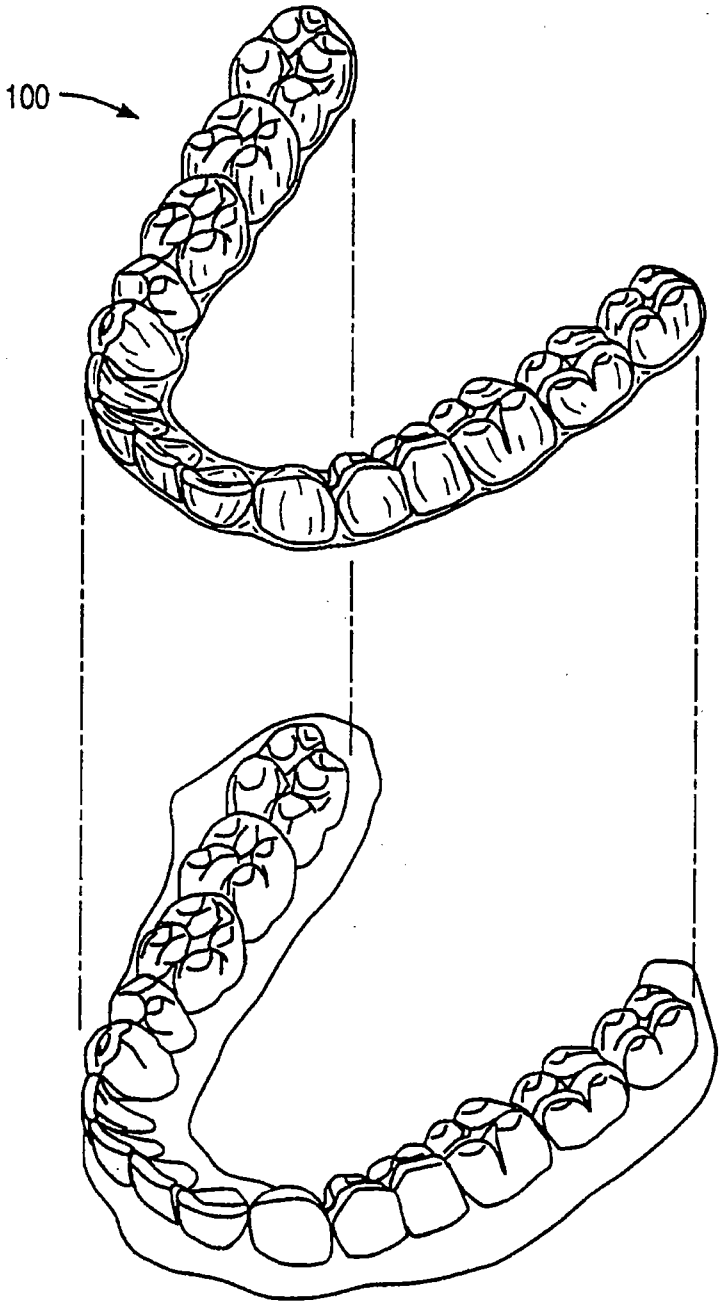


FIG. 1C

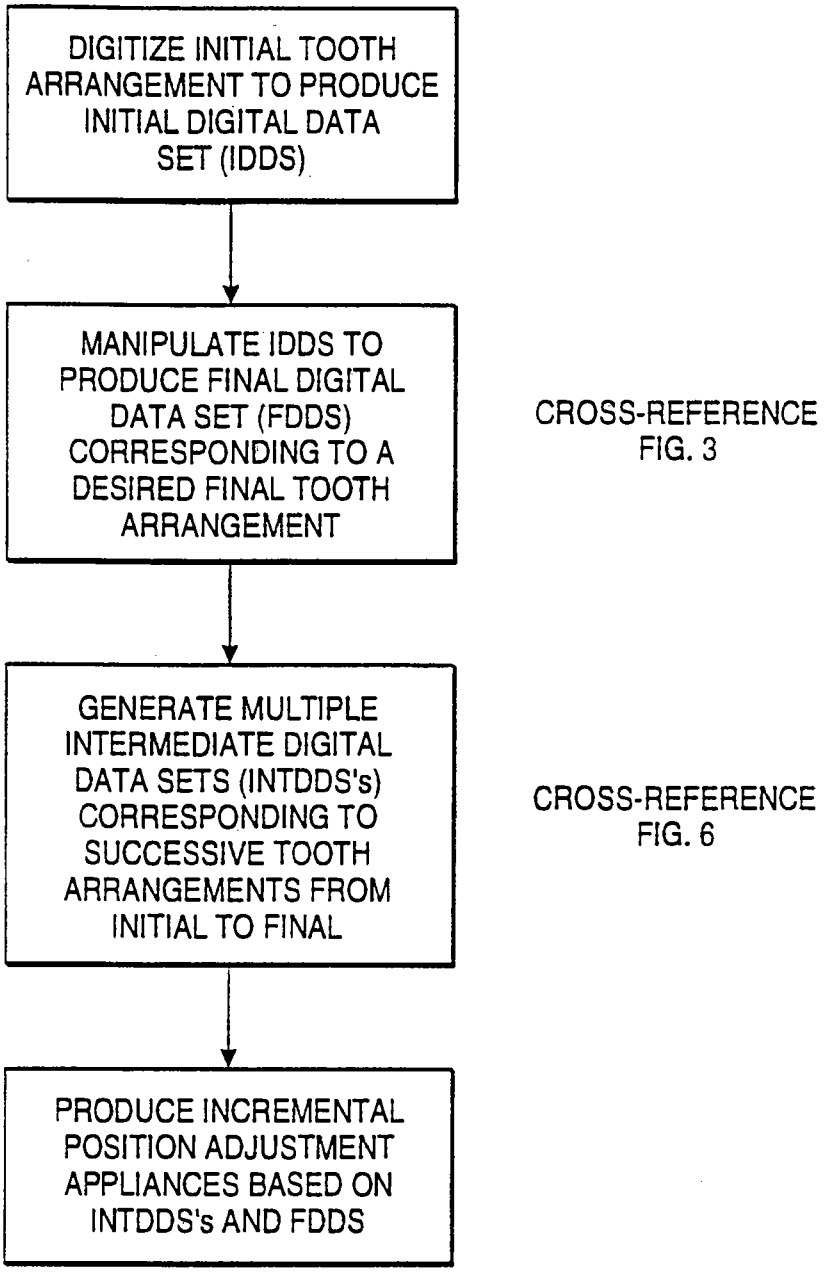

DIGITIZE INITIAL TOOTH ARRANGEMENT TO PRODUCE INITIAL DIGITAL DATA SET (IDDS)
MANIPULATE IDDS TO PRODUCE FINAL DIGITAL DATA SET (FDDS) CORRESPONDING TO A DESIRED FINAL TOOTH ARRANGEMENT
CROSS-REFERENCE FIG. 3
GENERATE MULTIPLE INTERMEDIATE DIGITAL DATA SETS (INTDDS's) CORRESPONDING TO SUCCESSIVE TOOTH ARRANGEMENTS FROM INITIAL TO FINAL
CROSS-REFERENCE FIG. 6
PRODUCE INCREMENTAL POSITION ADJUSTMENT APPLIANCES BASED ON INTDDS's AND FDDS

FIG. 2

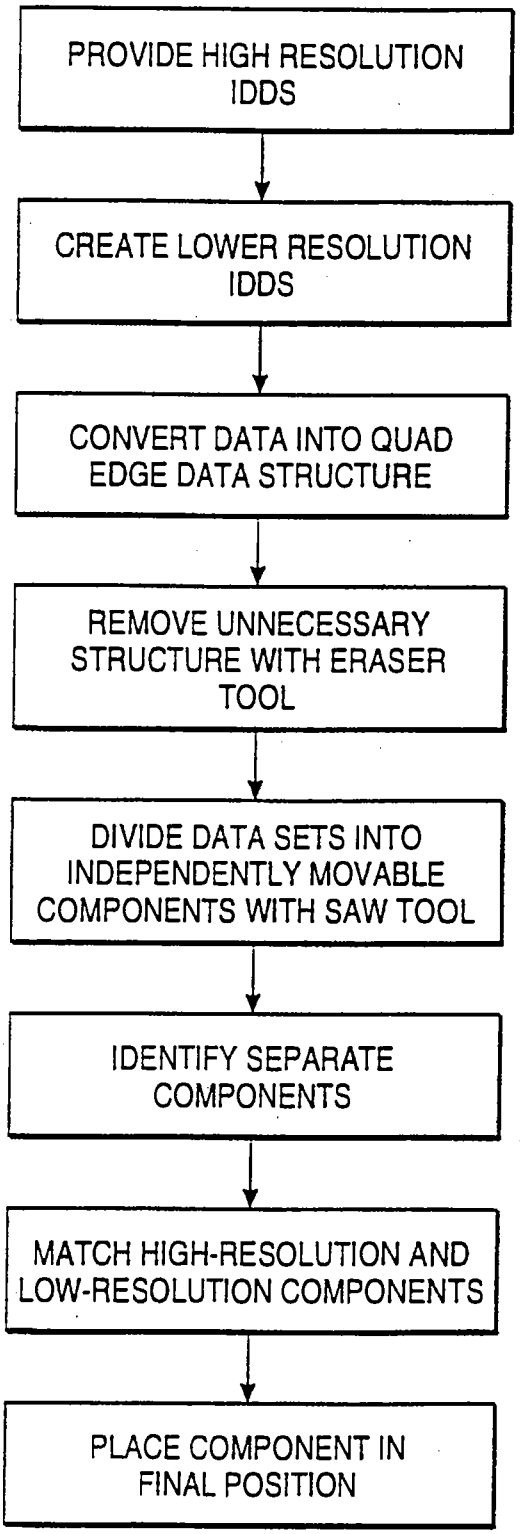

PROVIDE HIGH RESOLUTION IDDS
CREATE LOWER RESOLUTION IDDS
CONVERT DATA INTO QUAD EDGE DATA STRUCTURE
REMOVE UNNECESSARY STRUCTURE WITH ERASER TOOL
DIVIDE DATA SETS INTO INDEPENDENTLY MOVABLE COMPONENTS WITH SAW TOOL
CROSS-REFERENCE FIG. 4A
IDENTIFY SEPARATE COMPONENTS
MATCH HIGH-RESOLUTION AND LOW-RESOLUTION COMPONENTS
CROSS-REFERENCE FIG. 5
PLACE COMPONENT IN FINAL POSITION

FIG. 3

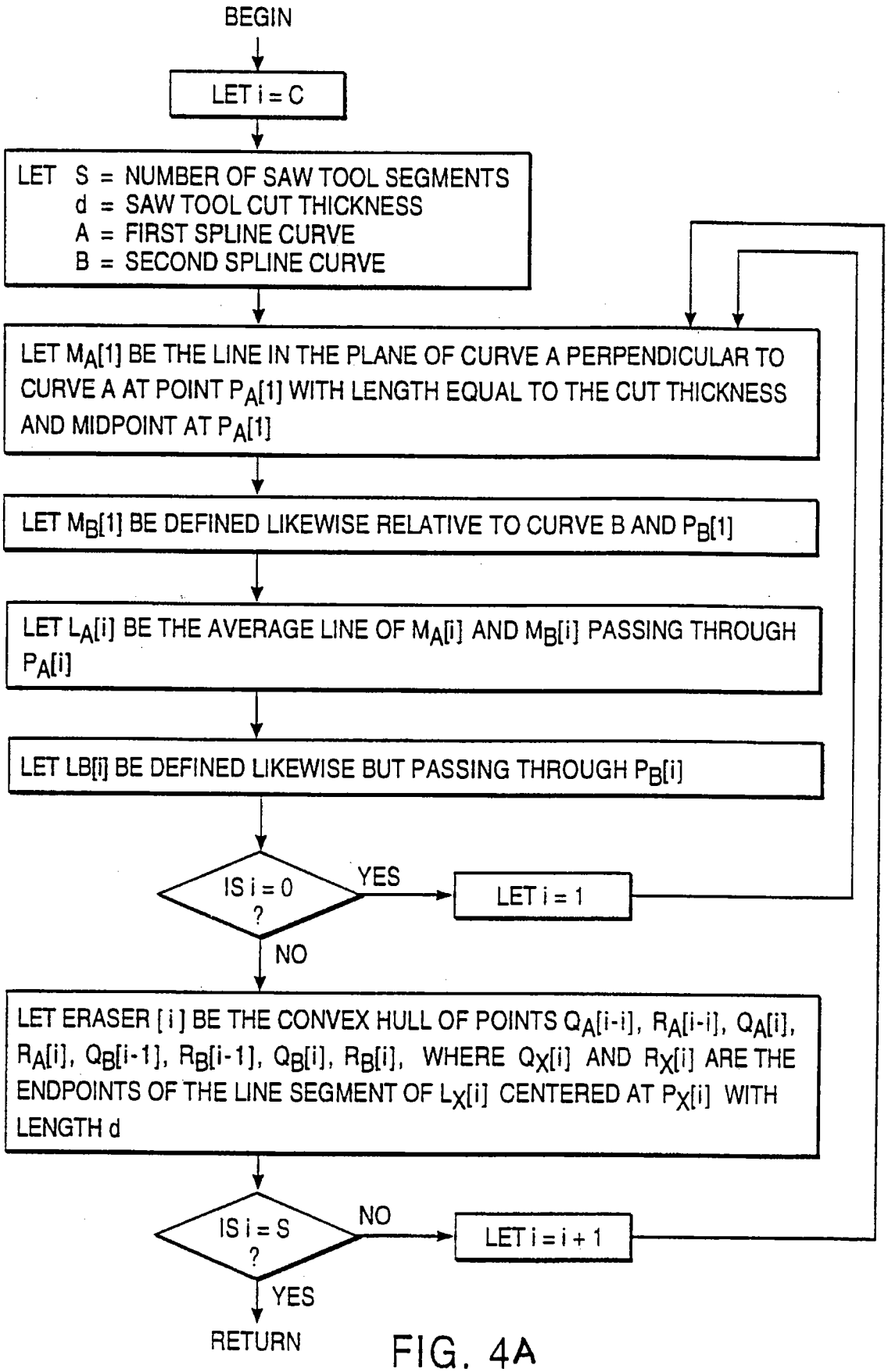

BEGIN
LET i = C
LET S = NUMBER OF SAW TOOL SEGMENTS
d = SAW TOOL CUT THICKNESS
A = FIRST SPLINE CURVE
B = SECOND SPLINE CURVE
LET $M_A[1]$ BE THE LINE IN THE PLANE OF CURVE A PERPENDICULAR TO CURVE A AT POINT $P_A[1]$ WITH LENGTH EQUAL TO THE CUT THICKNESS AND MIDPOINT AT $P_A[1]$
LET $M_B[1]$ BE DEFINED LIKEWISE RELATIVE TO CURVE B AND $P_B[1]$
LET $L_A[i]$ BE THE AVERAGE LINE OF $M_A[i]$ AND $M_B[i]$ PASSING THROUGH $P_A[i]$
LET LB[i] BE DEFINED LIKEWISE BUT PASSING THROUGH $P_B[i]$
IS i = 0 ?
YES
LET i = 1
NO
LET ERASER [i] BE THE CONVEX HULL OF POINTS $Q_A[i-i]$, $R_A[i-i]$, $Q_A[i]$, $R_A[i]$, $Q_B[i-1]$, $R_B[i-1]$, $Q_B[i]$, $R_B[i]$, WHERE $Q_X[i]$ AND $R_X[i]$ ARE THE ENDPOINTS OF THE LINE SEGMENT OF $L_X[i]$ CENTERED AT $P_X[i]$ WITH LENGTH d
IS i = S ?
NO
LET i = i + 1
YES
RETURN

FIG. 4A

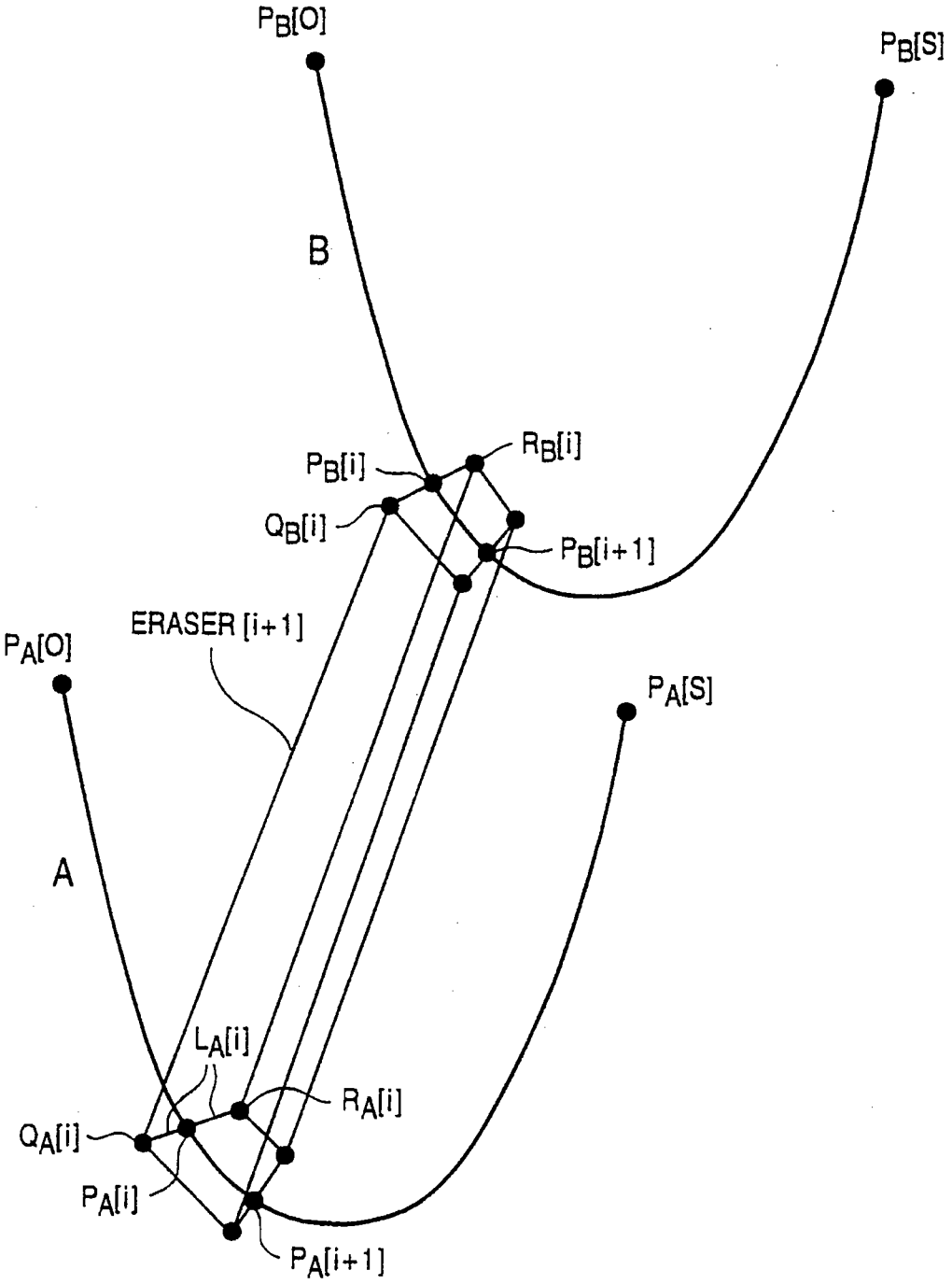

$P_B[O]$
$P_B[S]$
B
$P_B[i]$
$R_B[i]$
$Q_B[i]$
$P_B[i+1]$
ERASER [i+1]
$P_A[O]$
$P_A[S]$
A
$L_A[i]$
$R_A[i]$
$Q_A[i]$
$P_A[i]$
$P_A[i+1]$

FIG. 4B

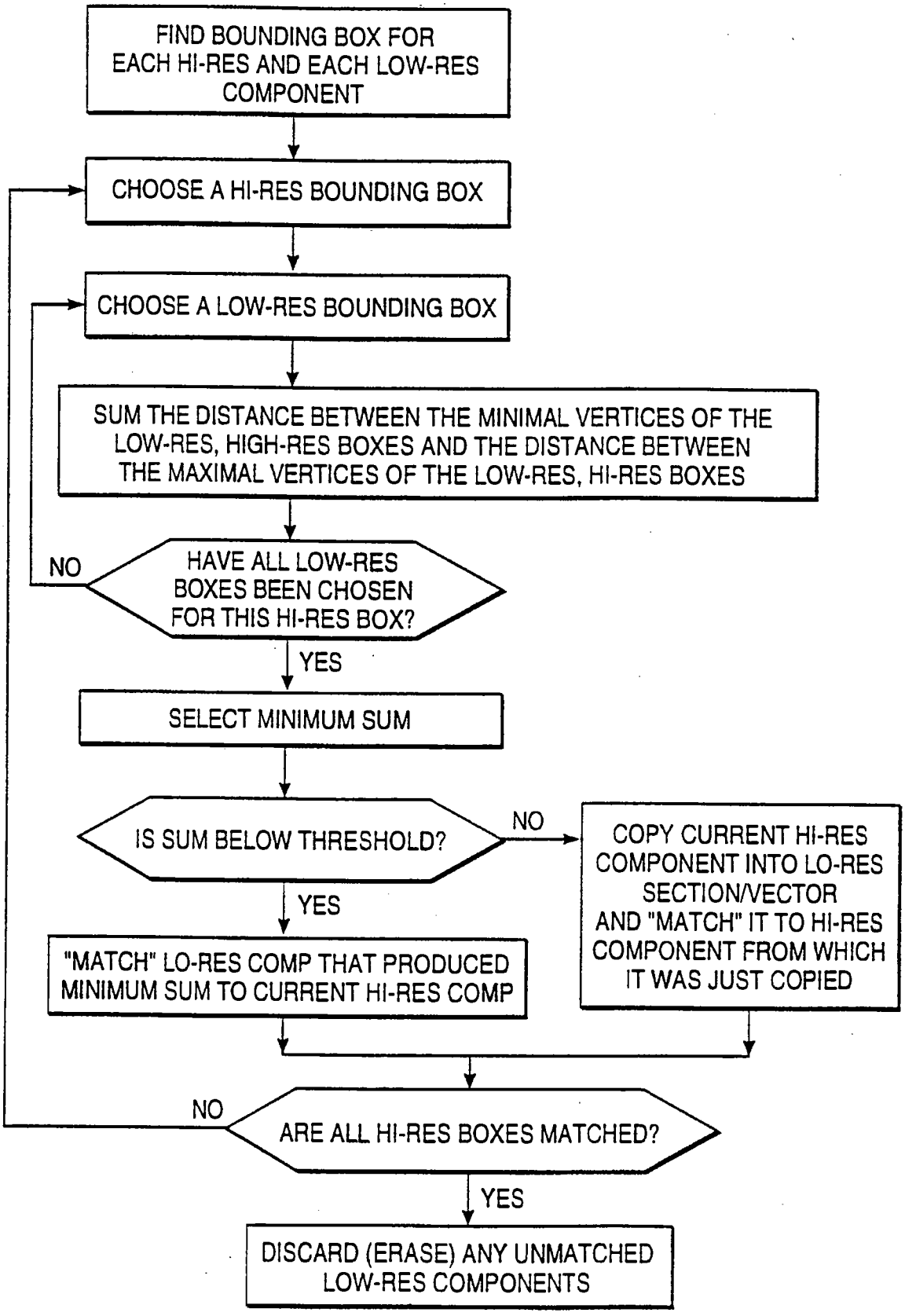

FIND BOUNDING BOX FOR EACH HI-RES AND EACH LOW-RES COMPONENT
CHOOSE A HI-RES BOUNDING BOX
CHOOSE A LOW-RES BOUNDING BOX
SUM THE DISTANCE BETWEEN THE MINIMAL VERTICES OF THE LOW-RES, HIGH-RES BOXES AND THE DISTANCE BETWEEN THE MAXIMAL VERTICES OF THE LOW-RES, HI-RES BOXES
NO
HAVE ALL LOW-RES BOXES BEEN CHOSEN FOR THIS HI-RES BOX?
YES
SELECT MINIMUM SUM
IS SUM BELOW THRESHOLD?
NO
COPY CURRENT HI-RES COMPONENT INTO LO-RES SECTION/VECTOR AND "MATCH" IT TO HI-RES COMPONENT FROM WHICH IT WAS JUST COPIED
YES
"MATCH" LO-RES COMP THAT PRODUCED MINIMUM SUM TO CURRENT HI-RES COMP
NO
ARE ALL HI-RES BOXES MATCHED?
YES
DISCARD (ERASE) ANY UNMATCHED LOW-RES COMPONENTS

FIG. 5

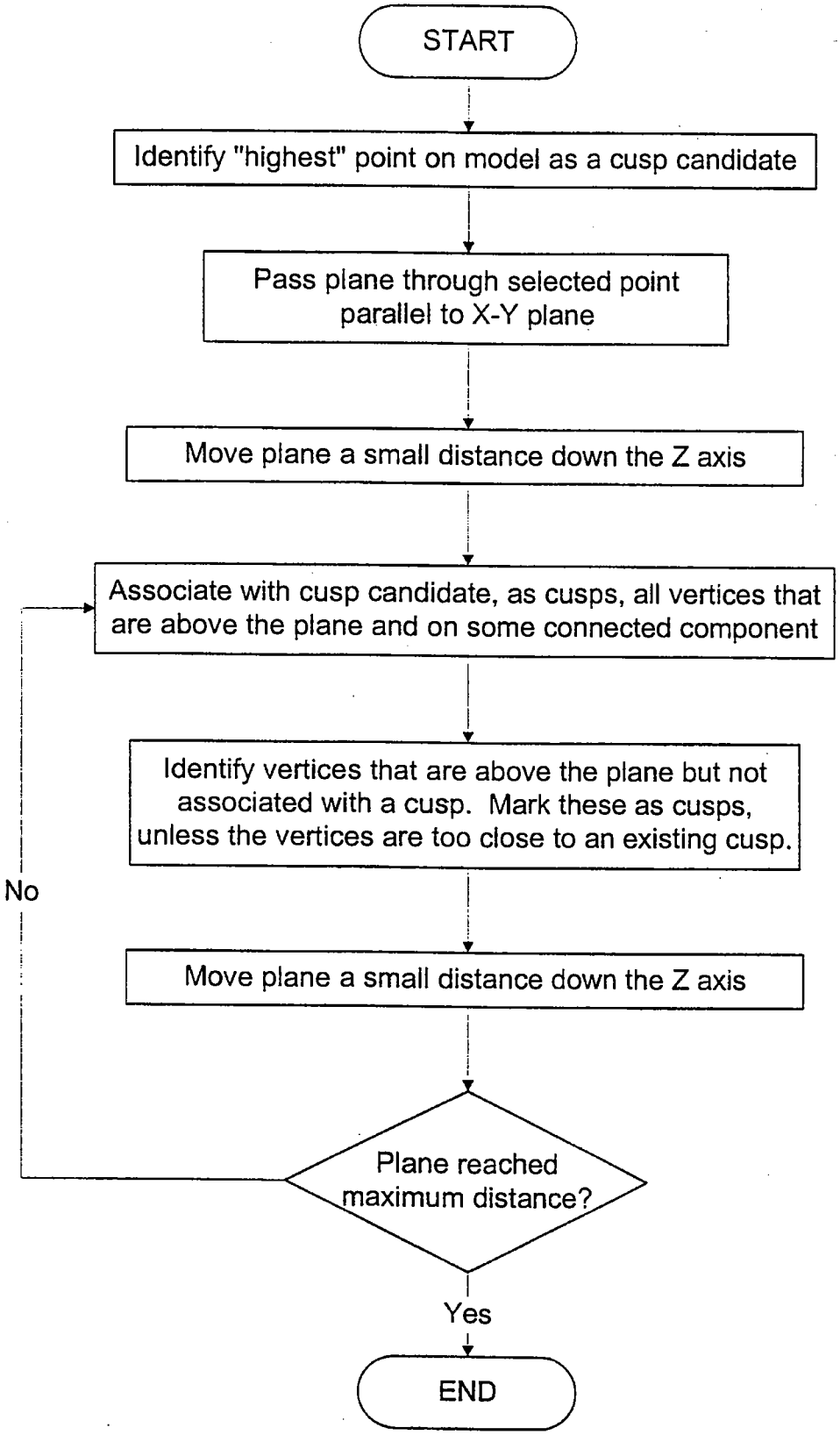

START
Identify "highest" point on model as a cusp candidate
Pass plane through selected point parallel to X-Y plane
Move plane a small distance down the Z axis
Associate with cusp candidate, as cusps, all vertices that are above the plane and on some connected component
Identify vertices that are above the plane but not associated with a cusp. Mark these as cusps, unless the vertices are too close to an existing cusp.
Move plane a small distance down the Z axis
Plane reached maximum distance?
No
Yes
END

FIG. 6A

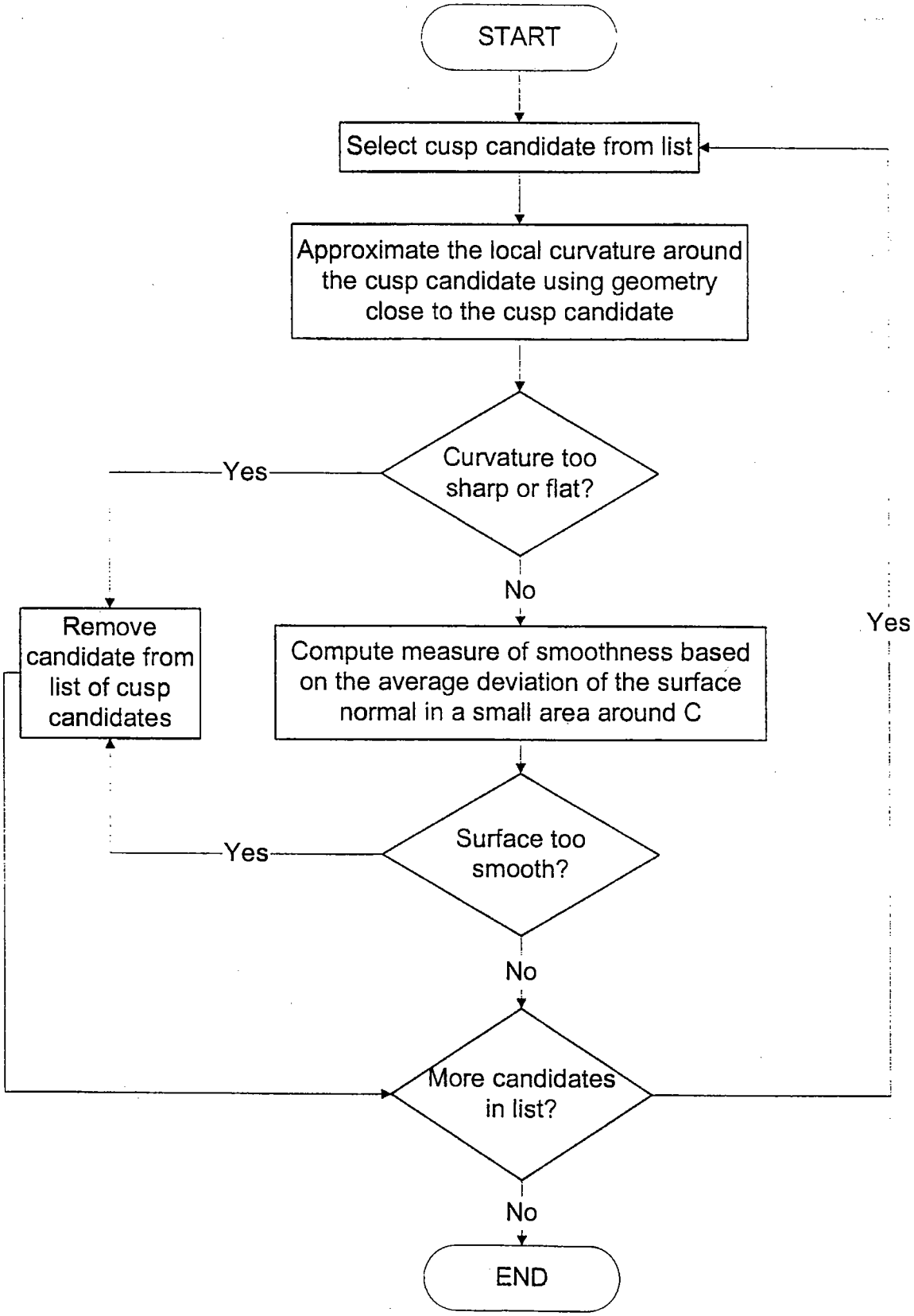

START
Select cusp candidate from list
Approximate the local curvature around the cusp candidate using geometry close to the cusp candidate
Curvature too sharp or flat?
Yes
No
Remove candidate from list of cusp candidates
Compute measure of smoothness based on the average deviation of the surface normal in a small area around C
Surface too smooth?
Yes
No
More candidates in list?
Yes
No
END

FIG. 6B

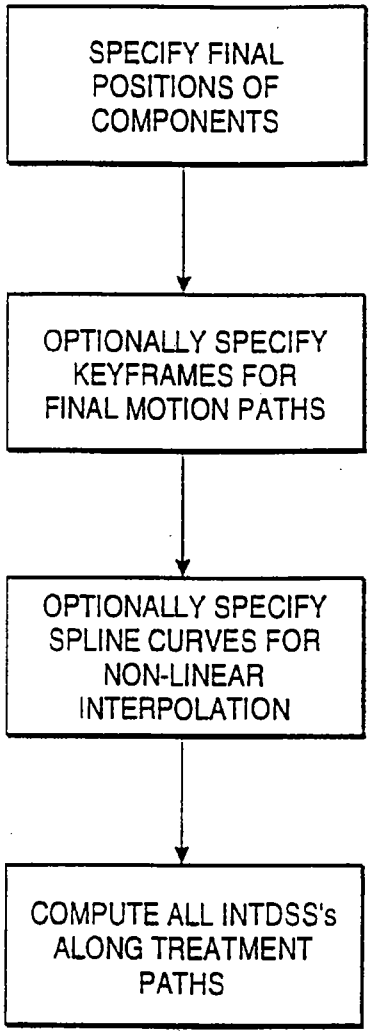

SPECIFY FINAL POSITIONS OF COMPONENTS
OPTIONALLY SPECIFY KEYFRAMES FOR FINAL MOTION PATHS
OPTIONALLY SPECIFY SPLINE CURVES FOR NON-LINEAR INTERPOLATION
COMPUTE ALL INTDSS's ALONG TREATMENT PATHS

FIG. 7

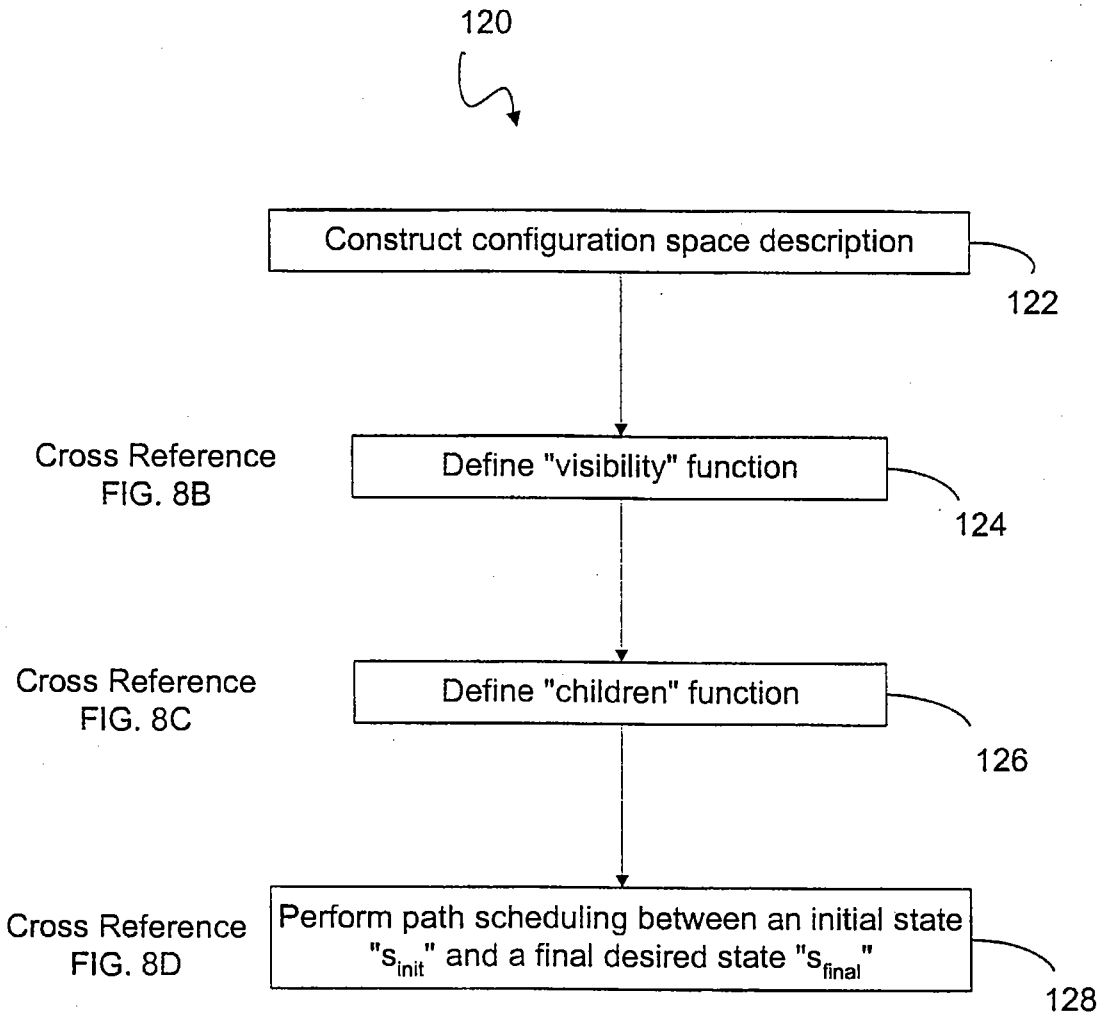

120
Construct configuration space description
122
Cross Reference
FIG. 8B
Define "visibility" function
124
Cross Reference
FIG. 8C
Define "children" function
126
Cross Reference
FIG. 8D
Perform path scheduling between an initial state "s_{init}" and a final desired state "s_{final}"
128

FIG. 8A

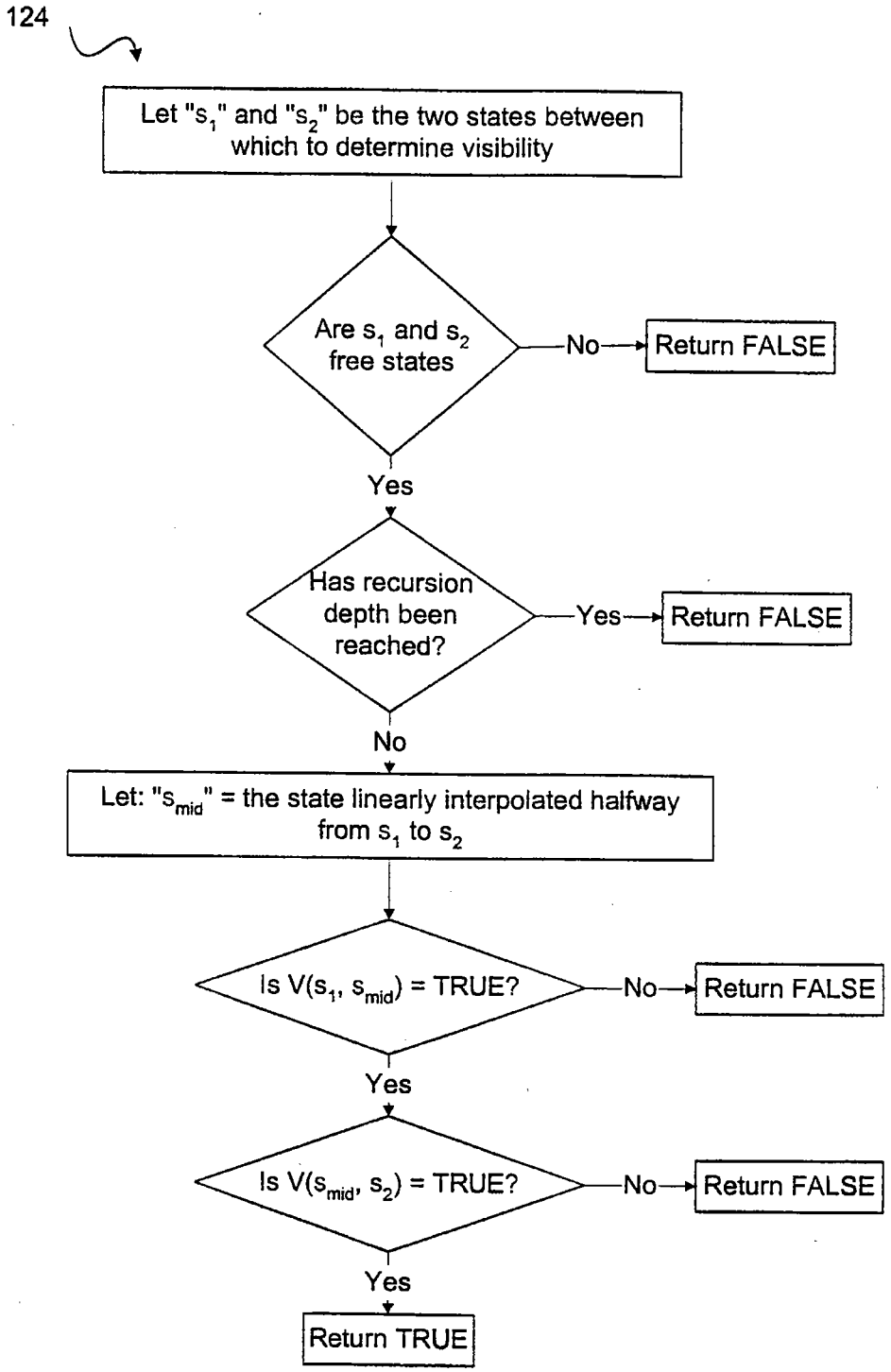

124
Let "s_1" and "s_2" be the two states between which to determine visibility
Are s_1 and s_2 free states
No
Return FALSE
Yes
Has recursion depth been reached?
Yes
Return FALSE
No
Let: "s_{mid}" = the state linearly interpolated halfway from s_1 to s_2
Is $V(s_1, s_{mid})$ = TRUE?
No
Return FALSE
Yes
Is $V(s_{mid}, s_2)$ = TRUE?
No
Return FALSE
Yes
Return TRUE

FIG. 8B

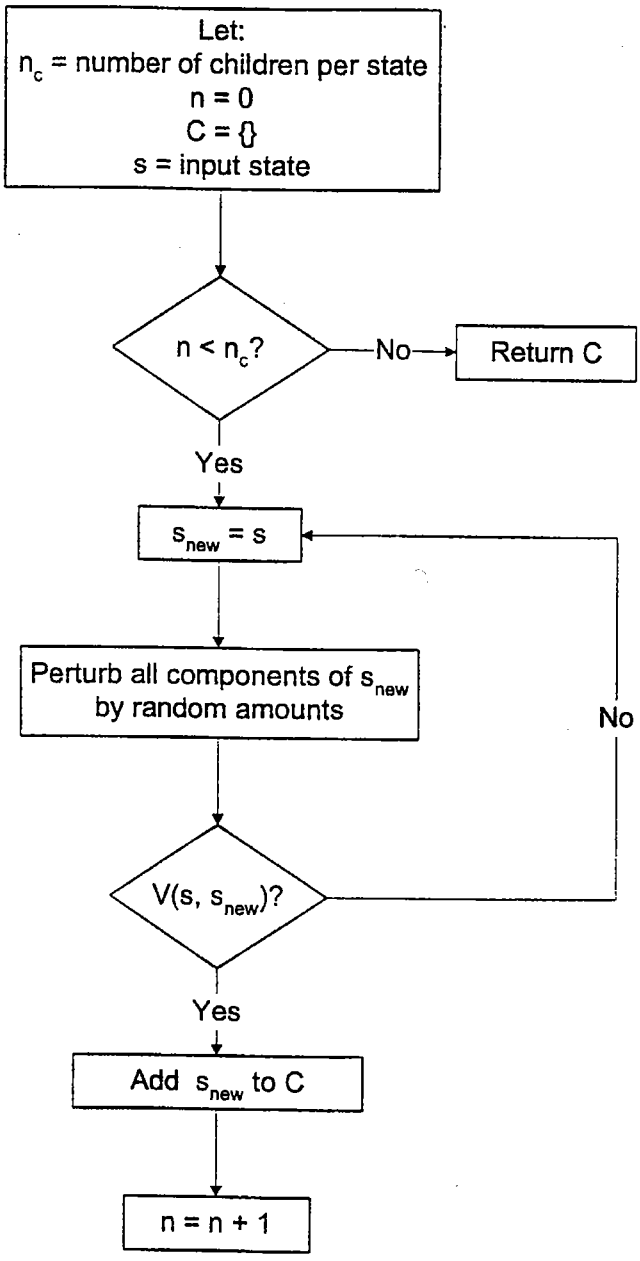

Let:
n_c = number of children per state
n = 0
C = {}
s = input state
n < n_c?
No
Return C
Yes
s_{new} = s
Perturb all components of s_{new} by random amounts
No
V(s, s_{new})?
Yes
Add s_{new} to C
n = n + 1

FIG. 8C

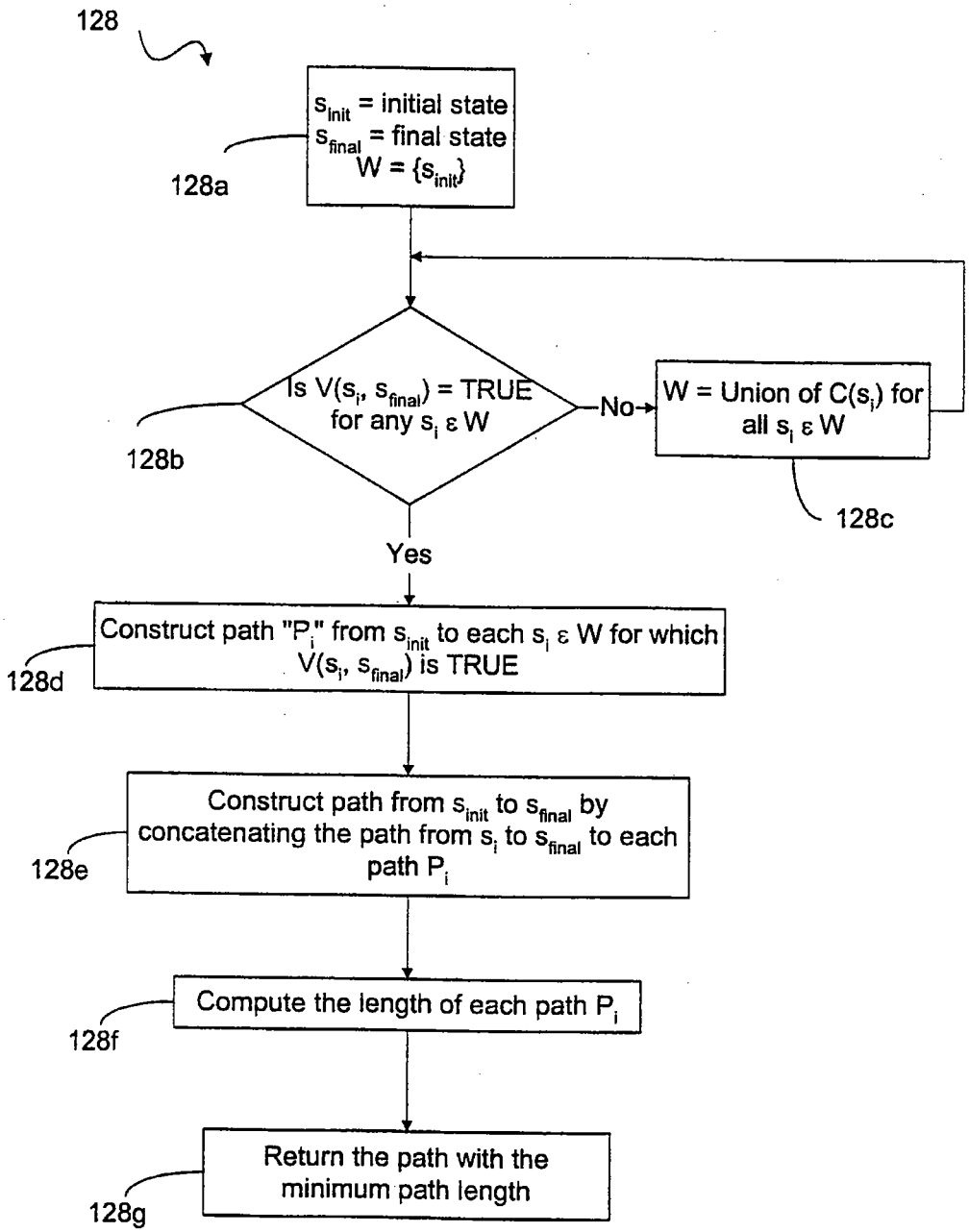

128
s_{init} = initial state
s_{final} = final state
W = {s_{init}}
128a
Is $V(s_i, s_{final})$ = TRUE for any $s_i \varepsilon W$
No
W = Union of $C(s_i)$ for all $s_i \varepsilon W$
128b
128c
Yes
Construct path "P_i" from s_{init} to each $s_i \varepsilon W$ for which $V(s_i, s_{final})$ is TRUE
128d
Construct path from s_{init} to s_{final} by concatenating the path from s_i to s_{final} to each path P_i
128e
Compute the length of each path P_i
128f
Return the path with the minimum path length
128g

FIG. 8D

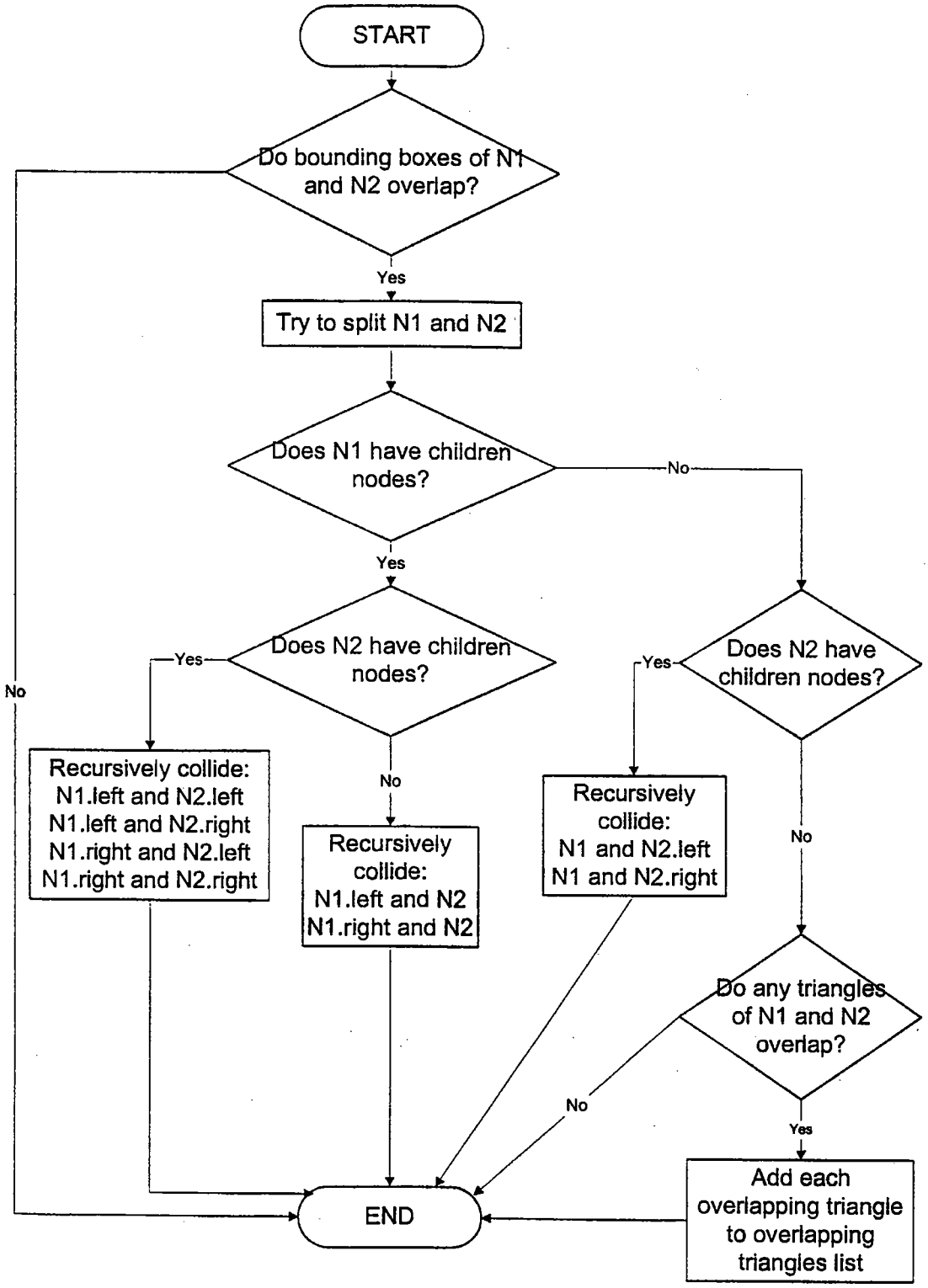

START
Do bounding boxes of N1 and N2 overlap?
Yes
No
Try to split N1 and N2
Does N1 have children nodes?
Yes
No
Does N2 have children nodes?
Yes
No
Recursively collide: N1.left and N2.left N1.left and N2.right N1.right and N2.left N1.right and N2.right
Recursively collide: N1.left and N2 N1.right and N2
Does N2 have children nodes?
Yes
No
Recursively collide: N1 and N2.left N1 and N2.right
Do any triangles of N1 and N2 overlap?
No
Yes
Add each overlapping triangle to overlapping triangles list
END

FIG. 9A

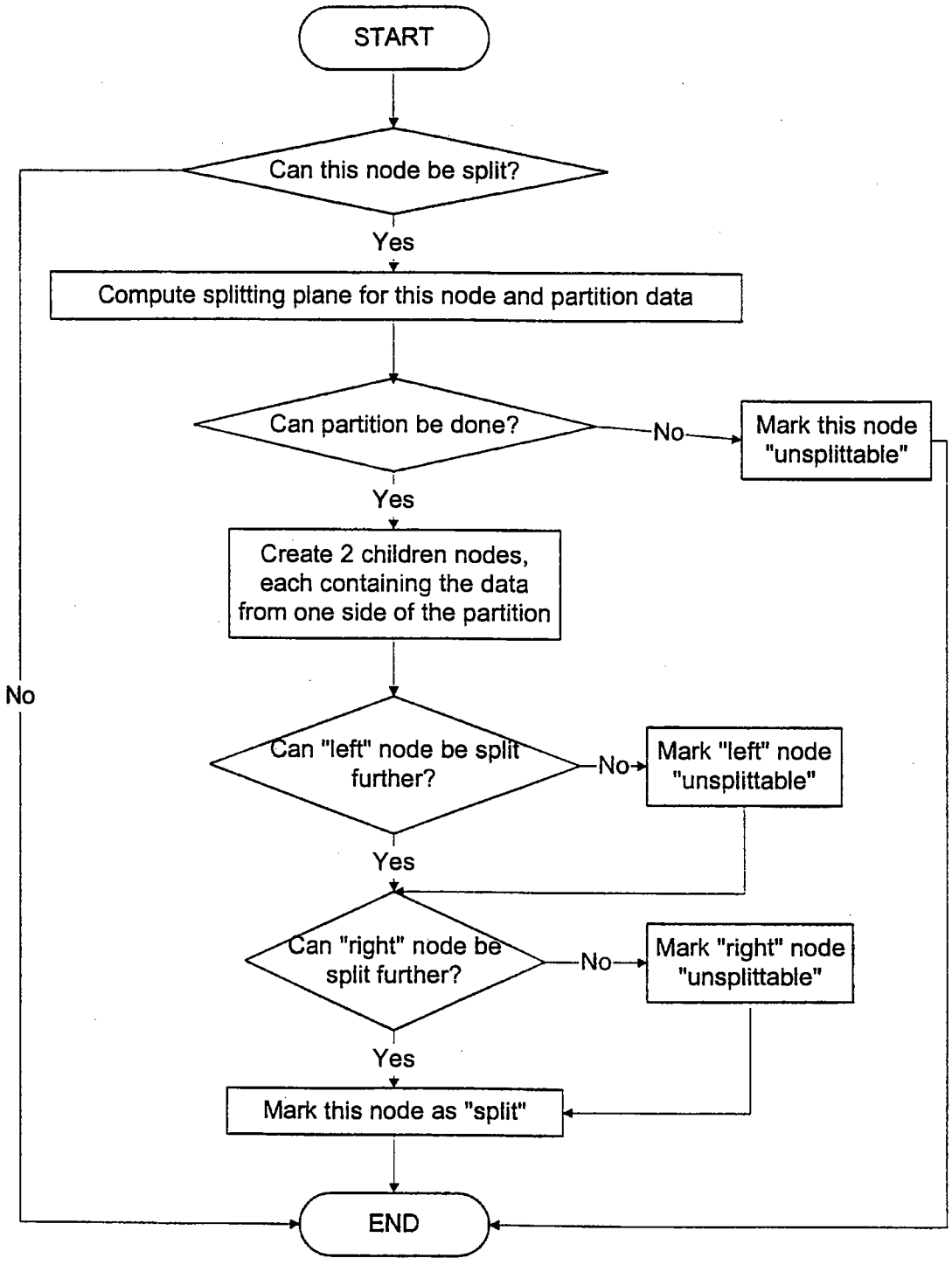

START
Can this node be split?
Yes
Compute splitting plane for this node and partition data
Can partition be done?
No
Mark this node "unsplittable"
Yes
Create 2 children nodes, each containing the data from one side of the partition
No
Can "left" node be split further?
No
Mark "left" node "unsplittable"
Yes
Can "right" node be split further?
No
Mark "right" node "unsplittable"
Yes
Mark this node as "split"
END

FIG. 9B

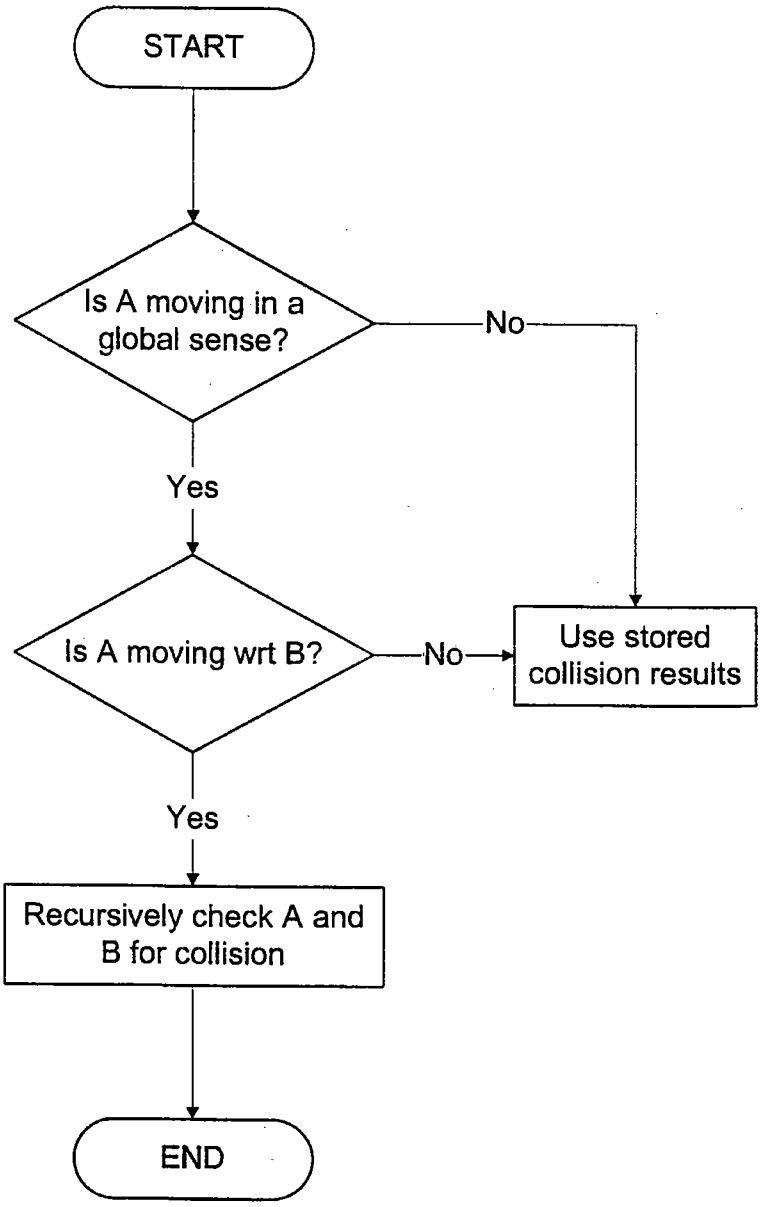

START
Is A moving in a global sense?
No
Yes
Is A moving wrt B?
No
Use stored collision results
Yes
Recursively check A and B for collision
END

FIG. 9C

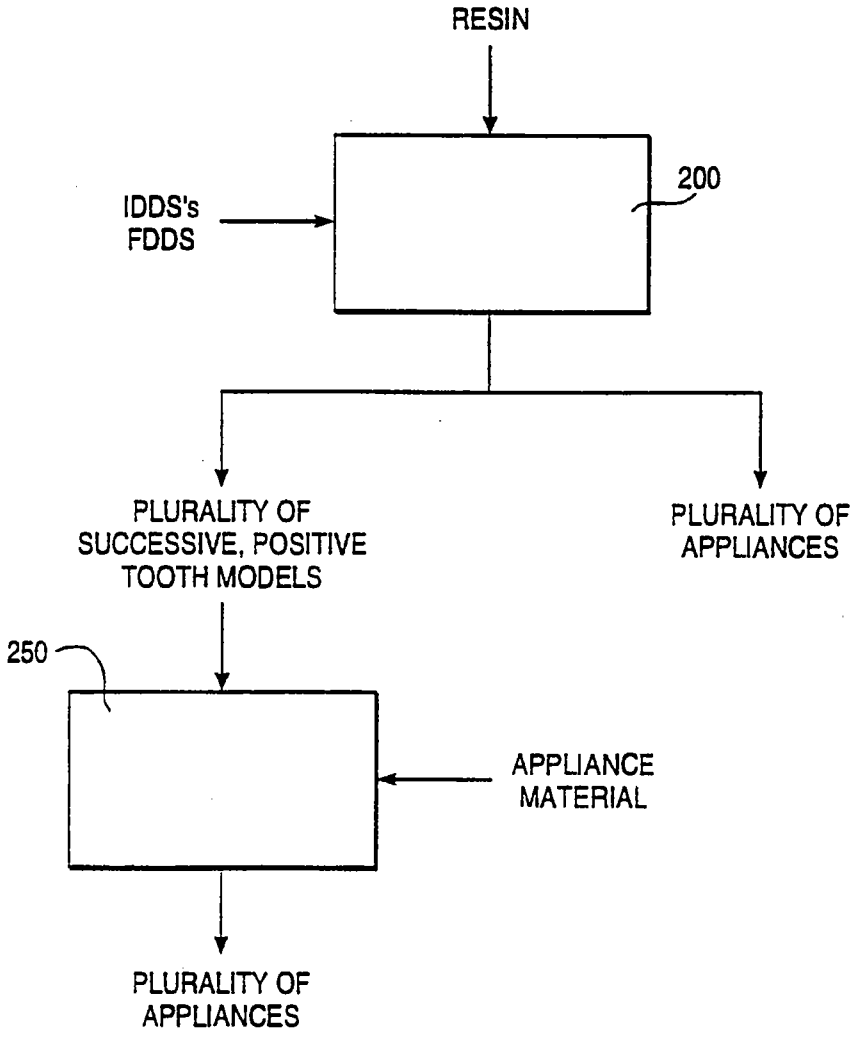

RESIN
200
IDDS's
FDDS
PLURALITY OF
SUCCESSIVE, POSITIVE
TOOTH MODELS
PLURALITY OF
APPLIANCES
250
APPLIANCE
MATERIAL
PLURALITY OF
APPLIANCES

FIG. 10

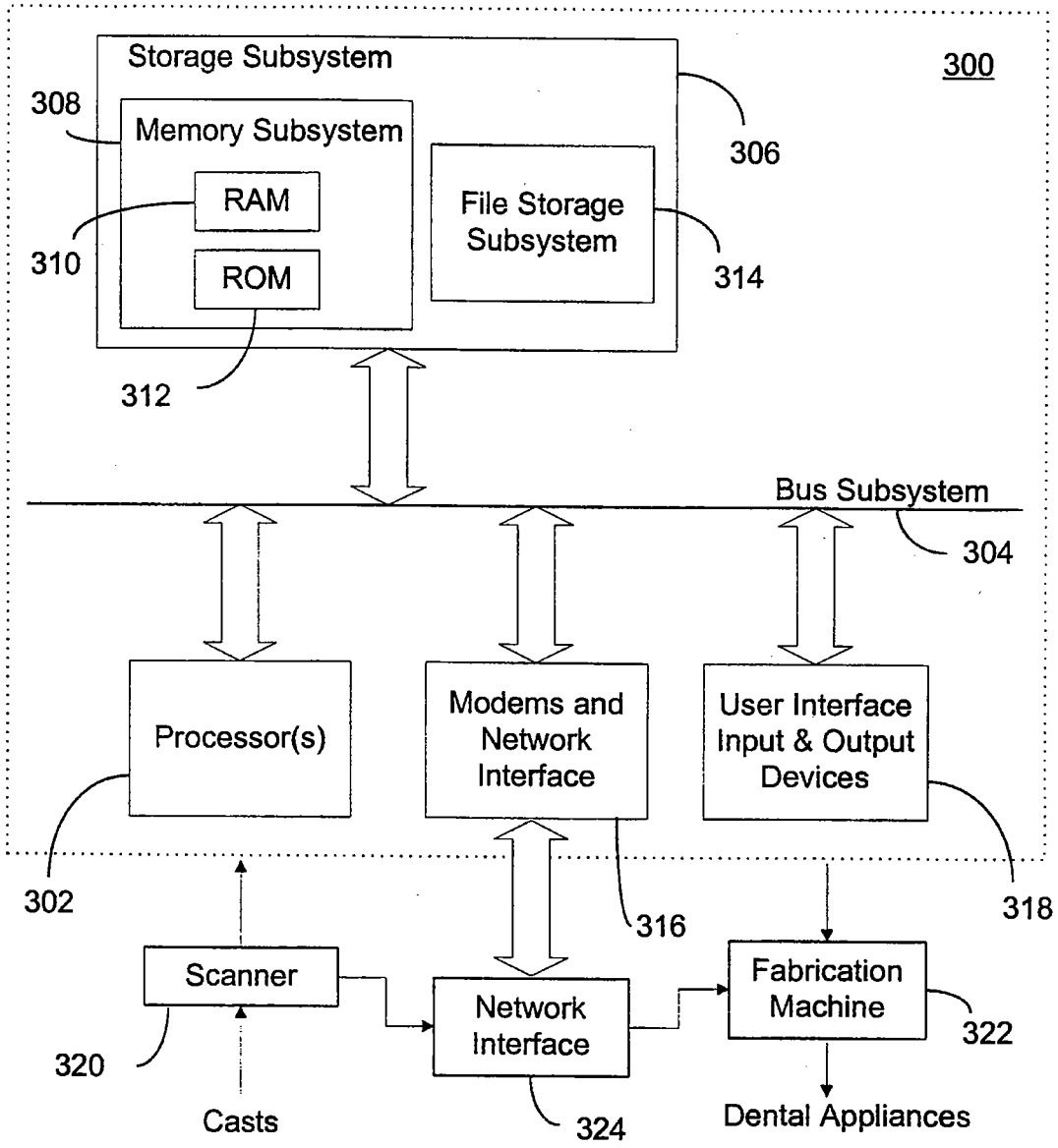

Storage Subsystem
300
308
Memory Subsystem
306
RAM
File Storage Subsystem
310
ROM
314
312
Bus Subsystem
304
Processor(s)
Modems and Network Interface
User Interface Input & Output Devices
302
316
318
Scanner
Network Interface
Fabrication Machine
322
320
Casts
324
Dental Appliances

FIG. 11

INTERNATIONAL SEARCH REPORT

Intern ıal Application No
PCT/US 98/12861

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61C7/00

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 94 10935 A (ORMCO) 26 May 1994 see the whole document ---	1,7,19, 22,29,42
A	FR 2 369 828 A (HITO SUYEHIRO) 2 June 1978 see the whole document ------	1,2,7,8, 14

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of theinternational search	Date of mailing of the international search report
13 October 1998	20/10/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Vanrunxt, J

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

...ormation on patent family members

Internat al Application No
PCT/US 98/12861

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9410935 A	26-05-1994	US 5368478 A	29-11-1994
		US 5447432 A	05-09-1995
		US 5454717 A	03-10-1995
		US 5431562 A	11-07-1995
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		US 4505673 A	19-03-1985

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1 550 777

PATENT SPECIFICATION

(11) 1 550 777

(21) Application No. 45346/77 (22) Filed 1 Nov. 1977
(31) Convention Application No. 51/132323
(32) Filed 5 Nov. 1976 in
(33) Japan (JP)
(44) Complete Specification published 22 Aug. 1979
(51) INT CL² A61C 7/00
(52) Index at acceptance
A5R DR



(54) ORTHODONTIC TREATING DEVICE AND METHOD OF MANUFACTURING SAME

(71) I, HITO SUYEHIRO, a Citizen of the United States of America, residing at 11205 Buckwood Lane, Rockville, Maryland, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Conventional orthodontic treatment is accomplished with metal bands provided with an attachment made to adapt to the teeth and is fixed to the teeth with cement, and metal wire is made to run through it to move the teeth. In this case, the correcting force (stress to move the teeth) primarily utilizes the elastic forces of the metal wire itself, and it is generally widely used as the orthodontic treating device.

However, in the orthodontic treatment using this multibanded technique with the bending of the metal wire in complicated shapes, it has been recognized that tremendous amounts of energy and skill as well as long periods of education are needed. Also, such treatment not only causes discomfort to the patient, but also other problems such as decayed or decalcified teeth or periodontal disease result from food particles adhering to the teeth during the orthodontic treatment, and, moreover, costs rise enormously.

The present invention has been conceived with a view to manufacturing an orthodontic treating device by which a malocclusion can be treated simply by utilizing the elastic force of silicone resins as a functional force instead of the metal wire presently being employed, and since it is easily detachable, it does not render any discomfort to the patient, making it possible to accomplish the orthodontic treatment when used at bedtime and waking hours as needed.

First, it is necessary to select an elastic high molecular material that satisfies sufficiently the special and severe conditions of intraoral treatment. The applicants have found that silicone resins are an elastic material suitable for orthodontic treatment bringing about the best results from the standpoint of science, engineering and clinical study. Namely, the material has been recognized to have scientific and engineering quality so that it does not deteriorate in its elasticity while in the mouth, has sufficient breaking stress, and does not deform for long periods of time due to force during treatment. Because of these important properties, the treating device of the present invention can be used to treat patients from the initial stages until completion of treatment.

Moreover, by changing the hardener portion of the silicone resins and catalysts and the blending thereof, hardness of the molded silicone resin can be changed freely. Forces can be provided from a light force to a strong force which is advantageous from the clinical standpoint. The device maintains a high degree of transparency without having any taste or odor, and is prepared from a composition which causes no harn to the human body. These properties cannot be found in other rubber materials.

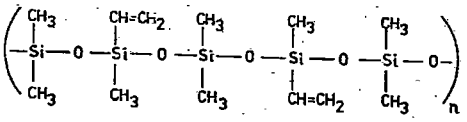
In addition to the silicone resin, polyurethane resins have somewhat similar qualities mentioned above, but silicone resins provide additional advantages such as shorter hardening processing time as compared with the polyurethane resin, and the manufacturing process can be accomplished simply, and therefore a remarkable difference is recognized between the two resins. In addition, where polyurethane resins are used to prepare similar devices, such resins break down in the patient's mouth and are not transparent. Therefore, such devices are only used during the final stages of treatment and cannot be used from the initial stage.

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Accordingly, the applicants have discovered that the treating device of the present invention made from silicone resins for the first time, provides a means of treating a patient from the beginning to completion. To date, this has only been possible through the known procedure of using metal bands.

According to the present invention there is provided a silicone resin orthodontic treating device for the complete treatment of malocclusion of a patient's teeth, said device having upper and lower negative impressions which duplicate the patient's upper and lower teeth and move the teeth to a desired position during treatment, wherein the silicone resin is obtained by curing a composition containing:

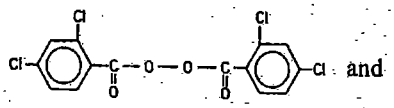
(a) a silicone resin comprising the following structural unit:



wherein n=100 to 2000, and

(b) a catalyst composition containing:

(1) a compound having the formula



and

(2) a silicone oil.

Also according to the present invention there is provided a method for complete treatment of malocclusion of a patient's teeth with the silicone resin orthodontic treating device of the present invention, said method comprising the steps of:

(a) opening the patient's mouth to expose the upper and lower jaws and teeth,

(b) fitting the device by finger pressure to force the device over the upper teeth,

(c) closing the lower jaw to force the device over the lower teeth,

(d) clenching the upper and lower teeth together for short periods of time to cause the device to place pressure against the teeth, relaxing the jaws to relieve the pressure and repeating the clenching and relaxing during the patient's waking hours,

(e) retaining the device over the patient's teeth during sleeping hours, and

(f) repeating steps (d) and (e) for a period of time sufficient to move the teeth to the desired position.

Also according to the present invention there is provided a method of manufacturing the silicone resin orthodontic treating device of the present invention, said method comprising the steps of:

(a) preparing plaster models of a patient's upper and lower jaw including the teeth showing malocclusion,

(b) determining the centric relationship between the patient's upper and lower teeth by taking a wax impression,

(c) taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face,

(d) placing the face-bow in an anatomical articulator,

(e) positioning the upper and lower models of step (a) in the anatomical articulator using the face-bow and wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator,

(f) removing the teeth from the models and re-aligning the teeth in wax to normal occlusion,

(g) duplicating the normal occlusion of the models with a duplicating material to form negative impressions,

(h) forming positive plaster models from the negative impressions,

(i) aligning the positive plaster models in the normal occlusion with a space of from 3 to 5 mm between the upper and lower incisor edge,

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(j) forming a heat-curable silicone resin composition as defined above to fit the aligned models of step (i) and curing the resin, and

(k) removing the resulting treating device.

The present invention will be further illustrated by way of example, with reference to the accompanying drawings in which:—

Fig. 1 is an occlusal view of an original model with malocclusion.

Fig. 2 is an elevation of several teeth separated from the model of Fig. 1.

Fig. 3 is an occlusal view of a model obtained by rearranging in wax the teeth from the original model to a normal occlusion.

Fig. 4 is an occlusal view of the complete orthodontic treating device.

Fig. 5 is a front elevation of the orthodontic treating device.

Fig. 6 is a cross sectional view taken along a line VI—VI in Fig. 5.

Fig. 7 is an end cross sectional view of the cross section taken along a line VII—VII in Fig. 4.

Fig. 8 is a comparison view showing before and after the orthodontic treatment and 8A shows before and 8B shows after the treatment.

Fig. 9 shows the first embodiment of the present invention, and 9A shows an end view of the condition where a split-cast (9) is separated, and 9B shows an end cross sectional view of the condition where the silicone resin is filled in the split-cast, and 9C shows an end cross sectional view of the condition where the separated portions of the split-cast are joined.

Fig. 10 shows a second embodiment of the present invention, and 10A shows a top view of an anatomical articulator, and 10B shows a side view of the condition where the wax plate material necessary to fix the upper and lower plaster models is melted and discharged, and 10C shows a side view of the condition where the silicone resin is pressure contacted on the surface of the working model to produce the orthodontic treating device, and 10D shows a cross sectional view taken along a line X—X of 10A.

A method of making the silicone resin orthodontic treating device of the present invention preferably comprises (a) preparing plaster models of a patient's upper and lower jaw including the teeth showing malocclusion, (b) determining the centric relationship between the patient's upper and lower teeth by taking a wax impression, (c) taking a face-bow transfer of the patient's upper teeth to establish the relationship of the upper jaw to the head and face, (d) placing the face-bow in an anatomical articulator, (e) positioning the upper and lower models of step (a) in the anatomical articulator using the face-bow and the wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator, (f) removing the teeth from the models and realigning the teeth in wax to normal occlusion, (g) duplicating the normal occlusion of the models with a duplicating material to form negative impressions, (h) forming positive plaster models from the negative impressions, (i) opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge, (j) placing wax in the space to obtain an impression of the upper and lower teeth in normal occlusion, (k) placing the teeth of the upper and lower plaster models of step (h) into the wax impression of step (j), (l) covering the resulting combination of step (k) with wax such that the wax will have substantially the same shape and thickness as the silicone resin treating device, (m) flasking the wax covered model combination step (l) in a split-cast, (n) subjecting the split-cast containing the wax covered model to heat sufficient to melt the wax and produce a void, (o) removing the wax, (p) filling the void with silicone resin and curing the resin, and (q) removing the silicone resin treating device.

A second method for producing the silicone resin orthodontic treating device of the present invention comprises substantially repeating steps (a)—(h) as set forth above including the additional steps of: (i) removing the wax models from the articulator and replacing them with the plaster models of step (h) while maintaining the same upper and lower jaw relationship, (j) opening the articulator to form a space of 3 to 5 mm between the upper and lower incisor edge, (k) forming heat-curable silicone resin around the upper and lower teeth and curing the resin and (l) removing the resulting treating device.

Although either of the above-identified procedures may be used to make the orthodontic treating device of the present invention, the first method is preferred, since it provides the means of using adequate pressure to force the silicone resin into every crevice surrounding the teeth and the resulting treating device provides an accurate duplication of the patient's teeth in normal occlusion.

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The device of the present invention may be utilized in a process employing the following steps:

(a) Preparing plaster models of the patient's upper and lower jaw including the teeth showing malocclusion.

An impression is taken of the patient's upper and lower teeth and surrounding tissue by using a duplicating material to obtain a negative impression. The duplicating material is removed from the teeth and a void is formed in the material. Plaster is poured into the void of the negative impression to obtain a positive plaster mold of the patient's upper and lower teeth.

(b) Determining the centric relationship between the patient's upper and lower teeth by taking a wax impression.

Wax is placed between the patient's upper and lower teeth to obtain an imprint of the bite to determine the centric relationship of the upper and lower teeth. This wax impression is used later in the process to properly align the upper and lower plaster models prepared in step (a).

(c) Taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face.

A face-bow is used to take a wax impression of the patient's upper teeth to reproduce the upper jaw relationship to the head and face. This step is critical to the process of the invention, since it provides the only means of accurately reproducing the ultimate relationship of the patient's upper and lower jaw and this procedure serves the basis for properly aligning the plaster models from which the orthodontic treating device is to be prepared. The device must have the same upper and lower jaw relationship as that of the patient such that, when the device is used, the relationship of the teeth will properly fit into the device to cause the teeth to move towards normal conclusion.

(d) Placing the face-bow in an anatomic articulator.

The face-bow with the wax impression of the patient's upper teeth is attached to an anatomical articulator to properly align the upper and lower plaster models.

(e) Positioning the upper and lower models of step (a) in the anatomic articulator using the face-bow and the wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator.

This procedure is accomplished by placing the teeth of the upper plaster model as prepared in step (a) into the wax impression of the face-bow which has been attached to the anatomical articulator. Plaster is placed on top of the upper model and forced against the top of the articulator and permitted to dry, thereby causing the upper model to be attached to the top of the articulator. Once the plaster has become dry, the face-bow is removed from the articulator. The upper model has now been placed into the articulator in the same relationship as the natural position of the patient's upper teeth and jaw.

The wax bite impression as prepared in step (b) is placed over the teeth of the upper model and luted or attached. The lower plaster model from step (a) is inserted into the lower portion of the wax impression which is attached to the upper model. Plaster is poured over the surface of the lower model and the articulator is closed and the plaster permitted to dry such that the lower model becomes attached to the articulator.

Up to this point in the process of the invention, the upper and lower plaster models have been attached to the articulator in the manner such that an exact reproduction of the patient's jaw and teeth relationship has been established.

(f) Removing the teeth from the models and re-aligning the teeth in wax to normal occlusion.

The plaster teeth are individually removed from the plaster model by means of a thin blade saw. Then, wax material is placed upon the base of the plaster models from which the individual teeth have been removed and the teeth are placed into the wax and arranged in normal occlusion. At this point, the upper and lower models have the teeth positioned in the manner such that the silicone resin orthodontic treating device to be made from the process of the invention will move the teeth to the position formed by the wax models.

(g) Duplicating the normal occlusion of the models with a duplicating material to form negative impressions.

A duplicating material is formed around the wax models to form negative impressions in normal occlusion. The material is removed from the models and the impression show voids of the teeth in normal occlusion.

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(h) Forming positive plaster models from the negative impression.

Plaster is poured into the voids of the negative impression to prepare positive plaster models which show the position of the patient's teeth after treatment with the orthodontic treating device made by the process of the invention.

(i) Opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge.

The articulator is opened such that a space is formed of from 3 to 5 mm, preferably 4 mm, between the upper and lower incisor edge. This space is necessary to properly form the orthodontic treating device in that the silicone resin will fill the space between the teeth and when the patient bites down on the resin during orthodontic treatment, the biting force and the resilience of the resin assist in moving the teeth.

(j) Placing wax in the space to obtain an impression of the upper and lower teeth in normal occlusion.

This step is necessary to obtain the proper relationship between the upper and lower teeth. This impression will be later used to replace the wax models with the plaster models of step (h) in the articulator.

(k) Placing the teeth of the upper and lower plaster models of step (h) into the wax impressions of step (j).

The plaster models in normal occlusion as prepared in step (h) are placed into the wax impression as obtained in step (j). The wax impression is employed to properly align the upper and lower plaster models. This combination or assembly is accomlished separately and outside of the articulator.

(l) Covering the resulting combination of step (k) with wax such that the wax will have substantially the same shape and thickness as the silicone resin treating device.

Wax is placed over the entire teeth surface areas and the portion representing the tissue of the upper and lower models which includes the wax material placed between the teeth in step (k). The wax material should have substantially the same shape and thickness as the silicone resin treating device which is to be prepared during the process as will hereinafter be explained.

(m) Flasking the wax covered model combination of step (l) in a split-cast.

The combination as prepared in step (l) is placed into the lower half of a split-cast and plaster is poured into the cast to cover the entire lower half of the combination model. The plaster is permitted to dry and harden and a separating medium is applied over the hardened plaster layer.

The split-cast is turned over and plaster is poured into the cast and the cast is closed such that the exposed upper portion of the combination is totally embedded into the soft plaster. Sufficient plaster should be used so that the plaster covers the entire surface of the combination model as evidenced by excess plaster flowing out of the cast. The cast is then clamped closed and the plaster permitted to dry.

(n) Subjecting the split-cast containing the wax covered model to heat sufficient to melt the wax and produce a void.

The entire split-cast containing the model as prepared in step (m) is heated such as by placing into boiling water for a time sufficient to melt the wax.

(o) Removing the wax

The split-cast is opened and the melted wax is removed leaving a void around the teeth and tissue of the plaster model including the space between the upper and lower teeth.

(p) Filling the void with heat-curable silicone resin and curing the resin.

A soft silicone resin material is placed into the void in amounts sufficient to completely fill the void. The cast is closed tightly such that the resin material will fill every space and crevice completely and excess material will flow out of the void. The split-cast is then subjected to heat such as boiling water for a period of about 40 minutes to cure the silicone resin material.

(q) Removing the silicone resin treating device.

The split-cast is removed, cooled, opened and the resulting silicone resin orthodontic treating device is removed.

As a final step, the resulting treating device may be coated with a silicone resin solution containing two different silicone resins, including a catalyst, to provide a clear, invisible smooth surface. The two resins are mixed in a ratio of about 10 to 1. The procedure discussed above is the preferred method, since the treating device is made as a result of using a split-cast to force the silicone resin into each space and crevice of the void in the plaster model.

In a second embodiment of the invention, a similar process is employed,

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except that only steps (a) through (h) of the former process are repeated. The second embodiment is accomplished by the following steps:

(a) Preparing plaster models of the patient's upper and lower jaw including the teeth showing malocclusion.

An impression is taken of the patient's upper and lower teeth and surrounding tissue by using a duplicating material to obtain a negative impression. The duplicating material is removed from the teeth and a void is formed in the material. Plaster is poured into the void of the negative impression to obtain a positive plaster mold of the patient's upper and lower teeth.

(b) Determining the centric relationship between the patient's upper and lower teeth by taking a wax impression.

Wax is placed between the patient's upper and lower teeth to obtain an imprint of the bite to determine the centric relationship of the upper and lower teeth. This wax impression is used later in the process to properly align the upper and lower plaster molds prepared in step (a).

(c) Taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face.

A face-bow is used to take a wax impression of the patient's upper teeth to reproduce the upper jaw relationship to the head and face. This step is critical to the process of the invention, since it provides the only means of accurately reproducing the ultimate relationship of the patient's upper and lower jaw and this procedure serves the basis for properly aligning the plaster models from which the orthodontic treating device is to be prepared. The device must have the same upper and lower jaw relationship as that of the patient such that, when the device is used, the relationship of the teeth will properly fit into the device to cause the teeth to move towards normal conclusion.

(d) Placing the face-bow in an anatomic articulator.

The face-bow with the wax impression of the patient's upper teeth is attached to an anatomical articulator to properly align the upper and lower plaster models.

(e) Positioning the upper and lower models of step (a) in the anatomic articulator using the face-bow and the wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator.

This procedure is accomplished by placing the teeth of the upper plaster model as prepared in step (a) into the wax impression of the face-bow which has been attached to the anatomical articulator. Plaster is placed on top of the upper model and forced against the top of the articulator and permitted to dry, thereby, causing the upper model to be attached to the top of the articulator. Once the plaster has become dry, the face-bow is removed from the articulator. The upper model has now been placed into the articulator in the same relationship as the natural position of the patient's upper teeth and jaw.

The wax bite impression as prepared in step (b) is placed over the teeth of the upper model and luted or attached. The lower plaster model from step (a) is inserted into the lower portion of the wax impression which is attached to the upper model. Plaster is poured over the surface of the lower model and the articulator is closed and the plaster permitted to dry such that the lower model becomes attached to the articulator.

Up to this point in the process of the invention, the upper and lower plaster models have been attached to the articulator in the manner such that an exact reproduction of the patient's jaw and teeth relationship has been established.

(f) Removing the teeth from the models and re-aligning the teeth in wax to normal occlusion.

The plaster teeth are individually removed from the plaster model by means of a thin blade saw. Then, wax material is placed upon the base of the plaster models from the individual teeth have been removed and the teeth are placed into the wax and arranged in normal occlusion. At this point, the upper and lower models have the teeth positioned in the manner such that the silicone resin orthodontic treating device to be made from the process of the invention will move the teeth to the position formed by the wax models.

(g) Duplicating the normal occlusion of the models with a duplicating material to form negative impressions.

A duplicating material is formed around the wax models to form negative impressions in normal occlusion. The material is removed from the models and the impressions show voids of the teeth in normal occlusion.

(h) Forming positive plaster models from the negative impression.

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Plaster is poured into the voids of the negative impression to prepare positive plaster models which show the position of the patient's teeth after treatment with the orthodontic treating device made by the process of the invention.

(i) Removing the wax models from the articulator and replacing them with the plaster models of step (h) while maintaining the same upper and lower jaw relationship.

The duplicated plaster models as prepared in step (h) are mounted on the articulator in accordance with the following steps:

(1) The upper wax model is removed from the articulator and the upper plaster model is positioned and placed onto the lower wax model such that the plaster model maintains exactly the same relationship to the lower wax model as the upper wax model which has been removed. At this point, the upper model is made of plaster and the lower model has the teeth positioned in wax.

(2) Plaster is poured on the top of the plaster upper model and the articulator closed such that, when the plaster dries, the upper plaster model is attached to the articulator.

(3) The lower wax model is removed from the articulator and replaced with the lower plaster model of step (h) by placing and positioning the lower plaster model in alignment with the upper model now attached to the articulator in the manner as described above. Plaster is then poured over the surface of the lower plaster model, the articulator closed and upon drying of the plaster, the lower model becomes attached to the articulator.

(j) Opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge.

Again, this space is necessary to properly form the silicone resin treating device as previously discussed in step (i) of the first procedure.

(k) Forming heat-curable silicone resin around the upper and lower teeth and curing the resin.

Soft silicone resin is pressed by hand over the entire surface areas of the teeth, front and back, and between the upper and lower teeth to fill the space created in the previous step. The resin is shaped to the final form of the treating device by trimming any excess material. The entire assembly is then subjected to heat such as placing in the boiling water for about 40 minutes to cure the resin. It is to be understood that in either procedure of the present invention, the resin may be cured by heating to a temperture of 100° to 130°C by means of, for example, boiling water or hot air.

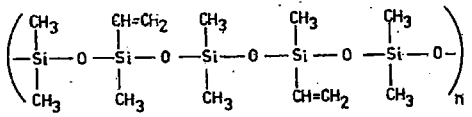
(l) Removing the resulting treating device.

After curing of the resin, the entire assembly of the plaster model having applied thereto the silicone resin material is cooled, the articulator opened and the resulting treating device removed from the plaster cast.

The device may then be coated with the two-component silicone resin solution as described above to provide a final product having a smooth finish.

The silicone resin materials employed in the present invention are prepared from a composition containing (a) a silicone resin base material and (b) a catalyst including a silicone oil. The silicone resin materials employed comprise the following structural unit.

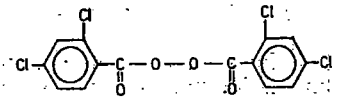
(a)



wherein n=100 to 2000.

The catalyst employed in the silicone resin composition comprises a compound represented by the formula:

(b)



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The catalyst composition includes a silicone oil. The catalyst composition preferably contains from 40 to 50% by weight of the catalyst and from 50 to 60% by weight of the oil. The ratio of the silicone resin material to the catalyst composition may be about 100g of (a) to from 1 to 2g of (b), respectively.

The silicone resin composition may be prepared by mixing together (a) and (b) in a mixer for a time sufficient to obtain a complete physical blend of the materials. The resulting composition may then be stored in a cool area such as a refrigerator.

The properties of the preferred silicone resin materials to be employed in the present invention are as follows:

1) Hardness (JIS)	40 to 60
2) Tensile strength	85 to 130 kg/cm²
3) Strain	400 to 560%
4) Molecular weight	6×10^5 (base silicone)
5) 200% modulus	35 to 45 kg/cm²

Fig. 1 shows the original plaster model after taking an impression of the malocclusion of a patient to be treated including teeth 1 also made of plaster.

Fig. 2 shows the respective teeth removed from the original model of Fig. 1, and Fig. 3 shows the condition where the teeth are rearranged into the normal occlusion using wax 2 employed for mounting and fixing the teeth. Fig. 4 shows the complete orthodontic treating device using silicone resin 14 as blank material, and Fig. 5 shows the device having ventilation holes 3 for respiration and the teeth shown by dotted lines are negative impressions of the teeth which are rearranged to the normal occlusion. The malaligned teeth of the patient to be treated are inserted into the device having the negative impressions by the patient closing his jaws together. When the silicone resin device is deformed by the teeth, the restoring force of the resin is generated and the correcting force causes the teeth to shift to the normal occlusion of the device.

Fig. 6 is a cross sectional view taken along a line VI—VI of the preceding drawing, and Fig. 7 is an end sectional view taken along a line VII—VII of Fig. 4 showing a concave mold 4 of the device for insertion of a molar of the upper jaw, and a concave mold 5 for a molar of the lower jaw. Fig. 8 is a comparison drawing shown the conditions before and after the orthodontic treatment with the device of the invention, and 8A shows before the orthodontic treatment and 8B shows after the orthodontic treatment and also showing an anterior tooth 6 of the upper jaw, and an anterior tooth 7 of the lower jaw. Fig. 8A shows gaps on the lip side of the upper anterior tooth and on the tongue side of the lower anterior tooth. Fig. 8B does not show the gap due to the movement of the tooth with the orthodontic force generated from the restoring force of the resin during the treatment.

Fig. 9 shows the first embodiment of the present invention, and 9A shows the condition where the split-cast 9 is separated and contains the plaster models with the teeth in normal occlusion embedded in plaster 12, and 9B shows the condition where the silicone resin 8 is filled or poured into the lower half portion of the split-cast, and 9C shows the condition where the separated split-cast are joined and the silicone resin 8 completely surrounds the teeth, and 10 denotes a correcting member for the split-cast.

Fig. 10 shows the second embodiment of the present invention, and 10A is a top view of the anatomical articulator 11, and 10B is the side view thereof, showing the condition where the wax plate is melted and discharged, and in this conditional position, the silicone resin is pressure contacted and molded over the plaster models to form the orthodontic treating device. The drawing 10C is a side view of the orthodontic treating device formed with the silicone resin, and then this device is cured by hot water or hot air, a final product is formed. Fig. 10D is a cross sectional view taken along a line X—X of the 10A. The number 12 denotes a working model, and number 14 denotes the orthodontic treating device.

The silicone resin treating device as prepared above has negative impressions or voids which duplicate the patient's teeth and move the teeth to a desired position such as normal occlusion during treatment. Complete orthodontic treating is accomplished by (a) opening the patient's mouth to expose the upper and lower jaws and teeth, (b) fitting the device by using finger pressure to force the device over the upper teeth, and (c) closing the lower jaw to force the device over the lower teeth. The actual movement of the teeth is accomplished by (d) forcing or clenching the upper and lower teeth together for short periods of time, preferably from about 10 to 20 seconds to cause the device to place pressure or force against

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the teeth, relaxing the jaws to relieve the pressure and repeating the clenching and relaxing during the patient's waking hours, (e) retaining the device over the patient's teeth during sleeping hours, and (f) repeating steps (d) and (e) for a period of time sufficient to move the teeth to the desired position.

It is to be understood that where the malocclusion is severe such that the teeth must be moved considerable distances, it may be necessary to use several treating devices of the invention such that the teeth may be moved short distances with each treatment in accordance with the above treatment procedures. Furthermore, where several devices are necessary for treatment, each device can be prepared in accordance with the above-described procedures.

The orthodontic treating device obtained according to the present invention produces a normal occlusion on the basis of the rearranged teeth of the patient. As the teeth are gradually corrected after placing it in the mouth, it renders no undue stress to the teeth or the periodontal structure, causing the correcting force of the device to work and, as a result, the orthodontic treatment is accomplished.

Because of its properties, the orthodontic treating device molded from silicone resin cannot be permanently deformed and is free from changes due to stress. Its hardness can be changed freely and it can be made transparent without taste and odor, whereby it has advantageous points that is provides not only an excellent orthodontic treatment but also ease of use on the part of the patient.

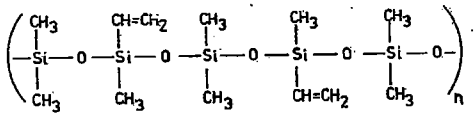
Particularly, the present invention is advantageous in comparison with known polyurethane resins, since the time for polymerizing the polyurethane is about 20 minutes and therefore the present invention shortens the manufacturing time tremendously. Also, the polyurethane resin produces foam of carbonic acid gas in large quantities when reacted with the water in the plaster and, therefore, the working model has to be manufactured by using special resins, and it has the drawback of producing deformation due to the great shrinkage resulting from heat curing the resin. Therefore, in the case of using silicone resin of the present invention, plaster can be used to make the working model and absolutely no deformation occurs, and as a result, the orthodontic treating device can be produced with improved accuracy.

Furthermore, in using polyurethane resins, handling of the undiluted liquid is attended with danger, and also defoaming during the stirring process with a vacuum pump is needed to prevent the foaming of the polyurethane. Also, a high pressure compressor and an autoclave must be used, and moreover, in the molding, a large size grinder is required, so there are complicated operation processes and inconveniences of using special machines. On the contrary, the present invention is extremely safe, since it employs the silicone resin, eliminating the defoaming during the stirring process and polishing and finishing procedures, and, accordingly, it has many excellent effects.

WHAT I CLAIM IS:—

1. A silicone resin orthodontic treating device for the complete treatment of malocclusion of a patient's teeth, said device having upper and lower negative impressions which duplicate the patient's upper and lower teeth and move the teeth to a desired position during treatment, wherein the silicone resin is obtained by curing a composition containing:

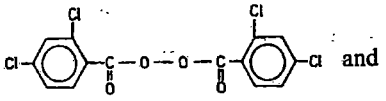
(a) a silicone resin comprising the following structural unit



wherein n=100 to 2000, and

(b) a catalyst composition containing

(1) a compound having the formula



and

(2) a silicone oil.

2. A method for complete treatment of malocclusion of a patient's teeth with

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the silicone resin orthodontic treating device of Claim 1, said method comprising the steps of:

(a) opening the patient's mouth to expose the upper and lower jaws and teeth,
(b) fitting the device by finger pressure to force the device over the upper teeth,
(c) closing the lower jaw to force the device over the lower teeth,
(d) clenching the upper and lower teeth together for short periods of time to cause the device to place pressure against the teeth, relaxing the jaws to relieve the pressure and repeating the clenching and relaxing during the patient's waking hours.
(e) retaining the device over the patient's teeth during sleeping hours, and
(f) repeating steps (d) and (e) for a period of time sufficient to move the teeth on the desired position.

3. A method of manufacturing the silicone resin orthodontic treating device of Claim 1, said method comprising the steps of:

(a) preparing plaster models of a patient's upper and lower jaw including the teeth showing malocclusion,
(b) determining the centric relationship between the patient's upper and lower teeth by taking a wax impression,
(c) taking a face-bow transfer of the patient's upper teeth to establish and reproduce the relationship of the upper jaw to the head and face,
(d) placing the face-bow in an anatomical articulator,
(e) positioning the upper and lower models of step (a) in the anatomical articulator using the face-bow and wax bite of step (b) to reproduce the patient's upper and lower jaw relationship and fixing the models in plaster such that the models are attached to the articulator,
(f) removing the teeth from the models and re-aligning the teeth in wax to normal occlusion,
(g) duplicating the normal occlusion of the models with a duplicating material to form negative impressions,
(h) forming positive plater models from the negative impressions,
(i) aligning the positive plaster models in the normal occlusion with a space of from 3 to 5 mm between the upper and lower incisor edge,
(j) forming a heat-curable silicone resin composition as defined in claim 1 to fit the aligned models of step (i) and curing the resin, and
(k) removing the resulting treating device.

4. A method as claimed in Claim 3, wherein said aligning step (i) includes removing the wax models from the articulator and replacing them with the plaster models of step (h) while maintaining the same upper and lower jaw relationship, and opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge, and wherein said forming step (j) includes forming heat-curable silicone resin around the upper and lower plaster models.

5. A method as claimed in Claim 3, wherein said aligning step (i) includes the steps of:

(l) opening the articulator to form a space of from 3 to 5 mm between the upper and lower incisor edge,
(m) placing wax in the space to obtain an impression of the upper and lower teeth in normal occlusion, and
(n) placing the teeth of the upper and lower plaster models of step (h) into the wax impression of step (m), and wherein said forming step (j) includes the steps of:
(o) covering the resulting combination of step (n) with wax such that the wax will have substantially the same shape and thickness as the desired silicone resin treating device.
(p) flasking the wax covered model combination of step (o) in a split-cast,
(q) subjecting the split-cast containing the wax covered model to heat sufficient to melt the wax and produce a void,
(r) removing the wax, and
(s) filling the void with a heat-curable silicone resin composition as defined in claim 1 and curing the resin.

6. A method as claimed in Claim 3, 4 or 5, wherein the resin is cured at a temperature of from 100°C to 130°C.

7. A silicone resin orthodontic treating device for the complete treatment of

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malocclusion of a patient's teeth, substantially as hereinbefore described with reference to and illustrated in the accompanying drawings.

8. A method for the complete treatment of malocclusion of a patient's teeth, as claimed in claim 2, substantially as hereinbefore described.

9. A method of manufacturing a silicone resin orthodontic treating device as claimed in any one of claims 3, 4, 5 or 6, substantially as hereinbefore described.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1979
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

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1550777 COMPLETE SPECIFICATION
4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 1

FIG. 1

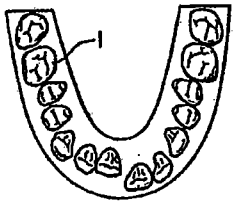


FIG. 2

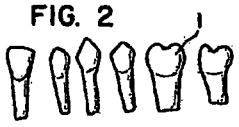


FIG. 3

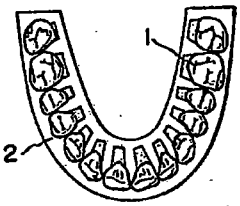


FIG. 4

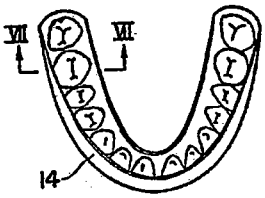


FIG. 5

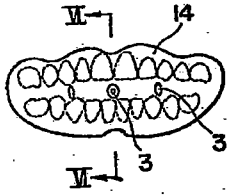


FIG. 6

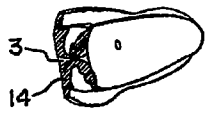


FIG. 7



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FIG. 8A

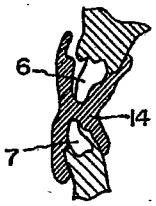


FIG. 8B

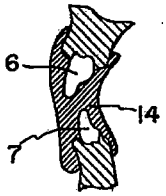


FIG. 9A

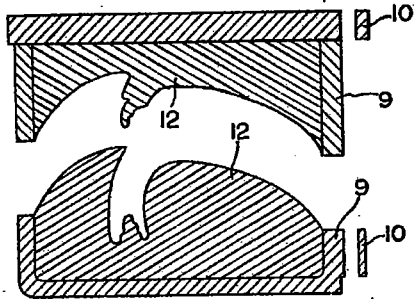


FIG. 9B

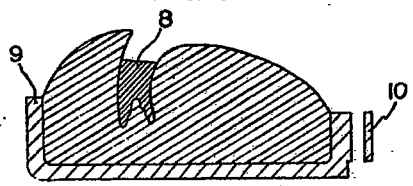


FIG. 9c

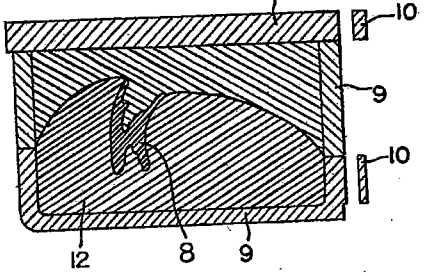


FIG. 10A

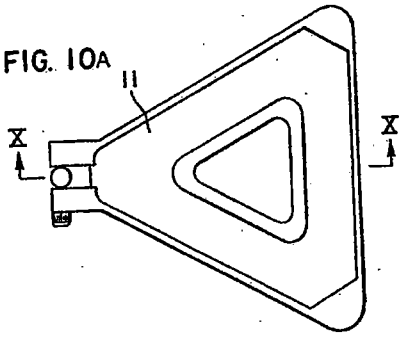


FIG. 10B

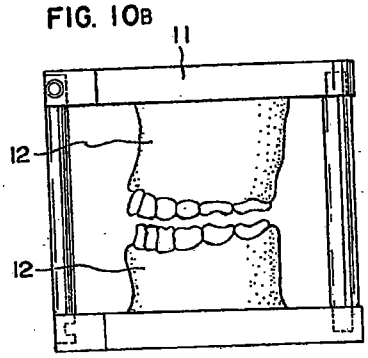


FIG. 10C

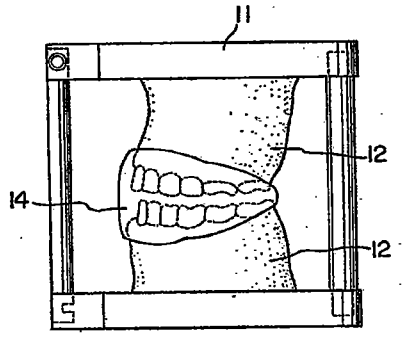
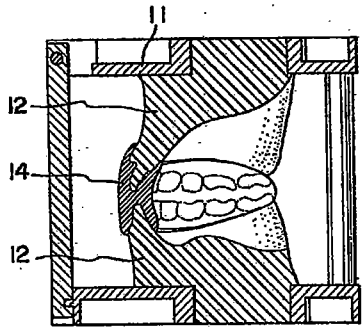


FIG. 10D



CUSTOM ORTHODONTIC APPLIANCE FORMING METHOD AND APPARATUS

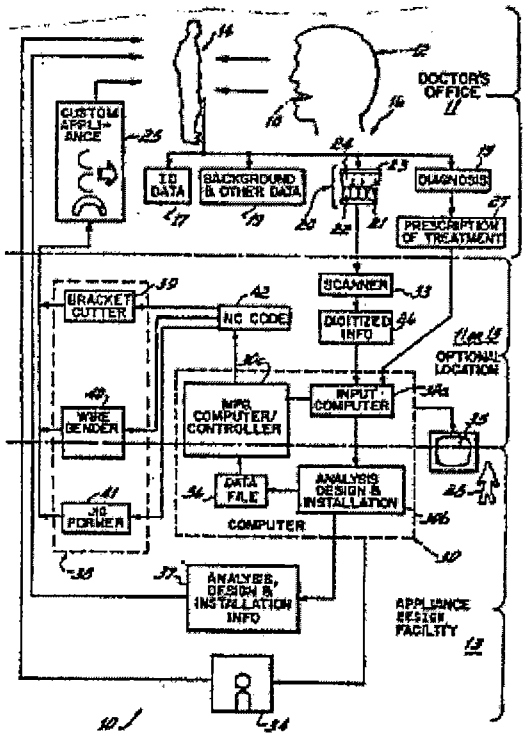
Patent number: DE69327661T
Publication date: 2000-07-20
Inventor: ANDREIKO A (US); PAYNE A (US)
Applicant: ORMCO CORP (US)
Classification:
- international: A61C7/00; A61C13/00
- european: A61C7/00; A61C7/14P; A61C7/20
Application number: DE19936027661T 19931109
Priority number(s): US19920973844 19921109; US19920973947 19921109; US19920973965 19921109; US19920973973 19921109; WO1993US10858 19931109

Also published as:
WO9410935 (A1)
EP0667753 (A1)
EP0667753 (B1)

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Abstract not available for DE69327661T
Abstract of corresponding document: **WO9410935**

A system (10) and method by which an orthodontic appliance (25) is automatically designed and manufactured from digital lower jaw and tooth shape data (26) of a patient (14) provides for scanning, preferably from a model (20) of the patient's mouth, to produce two or three dimensional images, and digitizing contours and selected point on the patient's teeth and jaw. From the scanned individual patient data, a computer (30) constructs archforms and calculates finish tooth positions, then designs an appliance (25), preferably including archwires and brackets, to move the teeth to the calculated positions. Lower teeth are positioned at the gums on an arch defined by the lower jaw bone and modified to best fit the tooth tips on a smooth curve. Then upper archforms are derived from the lower archform. Crown long axes of the teeth are derived and optimally inclined in the treatment which places all lower teeth but the cuspids in a plane and fits the occluding teeth to them. Overlaps for the upper incisors and cuspid rise are calculated. Brackets each have a base and an archwire support in which an archwire slot is to be cut to a custom inclination, depth, location and curvature, in a blank clamped to an inclinable holder, using a blade of a cutting machine (39). The holder and blade are moved by commands from a computer (30c). An archwire is automatically formed by a wire bender (40) into an optimize smooth arcuate shape and optimal low profile bracket design. Arch equations preferably start with a cubic spline equation and are converted to the form of a series of circle segments for machine control



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instructions for a numerically forming equipment. Placement jigs, simultaneously designed and automatically made with numerically controlled machinery (41) for positioning and orienting the appliance at connection points on the teeth, each have a surface custom shaped to the contour of a tooth. The machines (38-41) for making the brackets, wires and jigs are driven by commands derived from digitized tooth and jaw shape data and from digital representations of the tooth finish positions and appliance design.

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(19) BUNDESREPUBLIK DEUTSCHLAND

DEUTSCHES PATENT- UND MARKENAMT

(12) Übersetzung der europäischen Patentschrift

(97) EP 0 667 753 B1

(10) DE 693 27 661 T 2

(51) Int. Cl.[7]: A 61 C 7/00
A 61 C 13/00

(21) Deutsches Aktenzeichen: 693 27 661.4
(86) PCT-Aktenzeichen: PCT/US93/10858
(96) Europäisches Aktenzeichen: 94 901 388.2
(87) PCT-Veröffentlichungs-Nr.: WO 94/10935
(86) PCT-Anmeldetag: 9. 11. 1993
(87) Veröffentlichungstag der PCT-Anmeldung: 26. 5. 1994
(97) Erstveröffentlichung durch das EPA: 23. 8. 1995
(97) Veröffentlichungstag der Patenterteilung beim EPA: 19. 1. 2000
(47) Veröffentlichungstag im Patentblatt: 20. 7. 2000

(30) Unionspriorität:

973844	09. 11. 1992	US
973947	09. 11. 1992	US
973965	09. 11. 1992	US
973973	09. 11. 1992	US

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DE, FR

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(54) VERFAHREN UND VORRICHTUNG ZUM HERSTELLEN VON INDIVIDUELL ANGEPASSTENORTHODONTISCHEN EINRICHTUNGEN

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94901388.2-2310 B 31-03-00

VERFAHREN UND FERTIGUNGSKOMPLEX ZUR HERSTELLUNG VON INDIVIDUELLEN KIEFERORTHOPÄDISCHEN APPARATEN

Die vorliegende Erfindung betrifft die Konstruktion, die Herstellung sowie den Einsatz von kieferorthopädischen Apparaten zur Ausrichtung von Zähnen und insbesondere die automatisierte Konstruktion, Herstellung und die Anwendung von individuellen kieferorthopädischen Apparaten unter Berücksichtigung der individuellen Anatomie der Patienten sowie die Diagnose der Patienten zu diesem Zweck und deren Behandlung damit.

Das grundlegende Ziel der kieferorthopädischen Behandlung von Patienten besteht darin, die Zähne eines Patienten in seinem Mund auszurichten oder an Positionen zu bewegen, an denen sie optimal zusammenwirken und relative Stellungen und Ausrichtungen einnehmen, die sie als ein Paar einander gegenüberstehender und zusammenarbeitender ebener oder nahezu ebener glatter Bögen definieren. Die Zähne der beiden Bögen, der maxillare Zahnbogen des Oberkiefers sowie der mandibulare Zahnbogen des Unterkiefers, berühren, wenn sie sich in einer optimalen oder idealen Position befinden, die Zähne des gegenüberliegenden Bogens entlang einer Fläche, die normalerweise eben oder leicht nach oben gewölbt ist und im allgemeinen als Okklusionsebene bezeichnet wird.

Die Behandlung, denen Patienten unterzogen werden, bei denen eine zu große Abweichung von den idealen Zahnstellungen diagnostiziert wurde und eine kieferorthopädische Korrektur erforderlich ist, umfaßt eine anfängliche oder Grundbehandlung, um die ernsthafteren Schäden der Zahnpositionierung zu beseitigen, worauf sich eine Feinbehandlung anschließt, die die Zähne so nahe wie möglich an oder praktisch in ihre idealen Positionen bringen soll. Die Grundbehandlung umfaßt für gewöhnlich die Bewegung bestimmter Zähne mittels eines von mehreren anerkannten Verfahrens durch einen Kieferorthopäden, zuweilen auch Verfahren wie die Extraktion bestimmter Zähne oder eine Operation am Kiefer des Patienten durch einen Kieferchirurgen.

Bei der Feinbehandlung bringt der Kieferorthopäde einen Apparat oder Klammern an den Zähnen des Patienten an, durch die kontinuierliche Kräfte auf die Zähne des Patienten ausgeübt werden sollen, um diese schrittweise in ihre idealen Positionen zu zwingen. Die Anwendung einer Apparatur bedeutet im allgemeinen das Anbringen von Brackets an den Zähnen, entweder mittels eines Haftmittels an den Zähnen oder durch Befestigung mit Bändern um die Zähne. Die Brackets sind für gewöhnlich mit einem Schlitz versehen, durch den ein Bogendraht gezogen ist. Ein Bogendraht ist für die oberen Zähne vorgesehen und einer für die unteren. Typischerweise haben die Schlitze in den Brackets einen rechteckigen Querschnitt, und der Bogendraht hat einen rechteckigen Querschnitt. Der in den Schlitzen untergebrachte Bogendraht verbindet die Zähne mittels der Brackets und übt Kräfte auf die Zähne aus, um sie in die vom Kieferorthopäden vorgesehene Endposition zu bewegen oder zu drehen.

Bei Konstruktion und Anwendung von kieferorthopädischen Apparaten hat sich gezeigt, daß bei einem optimal konstruierten und eingesetzten kieferorthopädischen Apparat die Schlitze der

Brackets so angeordnet sind, daß sie zunächst einen vorgeformten Bogendraht aufnehmen, der sich elastisch verformt, so daß er korrigierende Kräfte auf die Zähne ausübt, um sie in ihre Endpositionen zu zwingen. Befinden sie sich in ihren Endpositionen, wird der Bogendraht eines optimal konstruierten Apparats nicht länger elastisch verformt, so daß er keine Kräfte mehr auf die Zähne ausübt. Unterschiedliche Probleme haben bei der bisherigen Technik die Erreichung dieses Ziels verhindert.

Ein Problem der bisherigen Technik bestand darin, daß die gängigen kieferorthopädischen Erzeugnisse für eine durchschnittliche Anatomie konstruiert und hergestellt wurden. Demzufolge stehen die Kieferorthopäden vor der Notwendigkeit, Apparate auszuwählen, von denen sie meinen, daß die Brackets und Bogendrähte eine Gestalt aufweisen, die der vom Patienten benötigten am nächsten kommt, und diese für die Behandlung des Patienten zu modifizieren. Einige dieser Modifikationen können vorgenommen werden, wenn der Apparat erstmals eingesetzt wird, doch macht sich fast unvermeidlich eine Modifikation während des Behandlungsablaufes des Patienten erforderlich. Diese Modifikation kann in einem Austausch von Brackets bestehen, erfordert jedoch meistens ein wiederholtes Biegen und Neuformen des Bogendrahtes im Verlauf der Behandlung. Dadurch ist die Behandlung des Patienten zu einem System manuellen Feedbacks geworden, bei dem der Kieferorthopäde den Fortschritt der Behandlung des Patienten beobachtet und dann den Apparat neu einrichtet, üblicherweise, indem er die Bogendrähte biegt, um die Kräfte zu korrigieren, die auf die Zähne ausgeübt werden, um sie in ihre Endpositionen zu bringen, die dann jedoch auf keinen Fall ideal sind. Als Folge muß sich der Patient möglicherweise einer langwierigeren Behandlung unterziehen, als sie nötig gewesen wäre, wenn der Apparat von Anfang an mit der optimalen Form angefertigt worden wäre. Zusätzlich kann die Zeit, die der Kieferorthopäde zur Durchführung der Behandlung benötigt, um ein Mehrfaches länger sein als in dem Fall, wenn keine Modifikation des Apparats erforderlich wäre. Aus diesem Grunde kann der Kieferorthopäde weniger Patienten behandeln, und die Kosten der Behandlung für den Patienten oder den Kieferorthopäden steigen.

Die Lage der Apparatfixierpunkte an den Zähnen stellte ebenfalls bei den bisherigen Verfahren eine Schwierigkeit dar. Normalerweise werden Brackets an den Zähnen angebracht und dann durch die Bogendrähte miteinander verbunden. Dies erfolgt, wenn sich die Zähne in der Stellung mit mangelhafter Okklusion befinden, wobei der Kieferorthopäde nur eine geistige Vorstellung hat, wo die Endpositionen der Zähne sein werden und wo die Brackets angebracht werden müssen, um die Zähne in diese Endpositionen zu bringen. Um einen wirkungsvolleren Einsatz des Apparats zu erzielen und um das Reinigen der Zähne zu erleichtern, zieht der Kieferorthopäde es vor, die Brackets und Bogendrähte von der Gingiva entfernt zu positionieren. Befinden sie sich jedoch zu dicht an den Zahnspitzen, kommt es möglicherweise zu Störungen mit den Zähnen des gegenüberliegenden Bogens, wenn sich die Zähne ihren Endpositionen nähern.

Ein weiteres Problem der bisherigen Verfahren, das die Auswahl oder Konstruktion eines idealen kieferorthopädischen Apparats für den Patienten erschwert hat, liegt in der Schwierigkeit, einen Ausdruck für die ideale Endposition der Zähne zu finden. Normalerweise fertigen Kieferorthopäden Modelle vom Mund des Patienten an, und anhand dieser Modelle und mit der Hilfe von Röntgenaufnahmen legen sie eine Behandlung fest, um die Zähne zu den Zahnendpositionen zu

bewegen. Dieser Vorgang ist zeitraubend und bietet eine Quelle für Fehler und Ungenauigkeiten. Ausgehend von Messungen und der Beurteilung durch den Kieferorthopäden werden Komponenten des Apparats ausgewählt, um die vorgeschriebene Behandlung durchzuführen. In der Praxis handelt es sich bei der Behandlung der Patienten mehr um eine Kunst als um eine Wissenschaft, wobei sich die Ergebnisse zwischen dürftig und ausgezeichnet bewegen und starke Unterschiede aufweisen.

Einige Kieferorthopäden haben die Notwendigkeit von individuell angefertigten kieferorthopädischen Apparaten und der Anwendung automatischer Konstruktionsverfahren erkannt, während andere angesichts des Mangels an Verfahren zur Herstellung praktischer individueller Apparate und automatisierter Systeme zur Konstruktion der Apparate dafür plädieren, an Standardkomponenten und manuellen Verfahren festzuhalten.

E-P-A 0502227 beschreibt ein Verfahren zur Herstellung einer kieferorthopädischen Klammer, bei dem ein Modell der Zähne des Patienten eingesetzt wird, um deren Konturen zu bestimmen, und aufgrund dieses Modells sowie der vom Kieferorthopäden festgelegten gewünschten Zahnpositionen wird eine geeignete Bracketgeometrie erstellt. Bei ihrer Festlegung werden mesiodistale Profile der Zähne verwendet, bei denen es sich um zweidimensionale Darstellungen einzelner Zahnformen handelt, wobei diese Profile mit der Position des Bogendrahts korreliert werden. Die Geometrie wird so berechnet, daß der Bogendraht, wenn er in die Brackets eingesetzt ist, in der vertikalen Ebene eine im wesentlichen lineare Konfiguration und in der horizontalen Ebene eine progressive Krümmung aufweist. Die errechnete Geometrie wird dann zur automatischen Herstellung der Brackets benutzt, die zusammen mit dem Bogendraht an den Kieferorthopäden zum Einsetzen geliefert werden.

WO90/08512 offenbart ebenfalls ein Verfahren zur Konstruktion eines kieferorthopädischen Apparats, das die Digitalisierung der Zahnform sowie die Berechnung der gewünschten Bracketgeometrie umfaßt. In diesem Fall wird die Endposition aufgrund der Anfangsposition in einem mathematischen Modell berechnet, das von einem CAD-System aus den digitalisierten Werten erstellt wird. Der Kieferorthopäde gibt eine Beschreibung der gewünschten Ergebnisse, und die physischen Gegebenheiten des Patienten werden berücksichtigt. Anschließend wird ein Standard-Bracket modifiziert, so daß die festgelegten notwendigen Zahnbewegungen ermöglicht werden. Da ein CAD-System eingesetzt wird, wäre es angebracht, wenn ein Operator die Endpositionen anhand des bildlich dargestellten Modells berechnet.

Die Entwicklung automatischer Konstruktionssysteme für individuelle Apparate ist auf unterschiedliche Schwierigkeiten gestoßen. Dazu zählte die Aufgabe, ein automatisiertes System zu entwickeln, das zuverlässige und effiziente Algorithmen zur Entscheidungsfindung sowie Verfahren zur automatischen Bestimmung der idealen Zahnendposition umfaßt. Ferner gehörte zu diesen Schwierigkeiten, eine solche Form eines Ausdrucks für die Apparatgeometrie zu finden, die in effektiver Weise mit einer automatisierten Apparatfertigungsanlage gewonnen werden kann. Außerdem hat die bisherige Technik keine Möglichkeit erbracht, entsprechend der Apparatkonstruktion einen Apparat präzise den individuellen Gegebenheiten angepaßt herzustellen. Ein zusätzliches Problem bei der automatisierten Konstruktion und Herstellung kieferorthopädischer Apparate liegt in der Schwierigkeit, ein Individualkonstruktionssystem zu entwickeln, das die fachlich anerkannten Parameter und Kriterien berücksichtigt, die sich über viele Jahre hinweg aus dem

Wissen und der Erfahrung der praktizierenden und klinischen Kieferorthopäden entwickelt haben und auf denen Diagnose und Behandlung beruhen.

Demzufolge besteht bei der Kieferorthopädie ein immenser Bedarf an einem praktischen, zuverlässigen und effizienten System zur automatisierten Konstruktion und Herstellung individueller Apparate sowie an der Bereitstellung von individuellen Apparaten und deren Behandlung damit.

Ein vorrangiges Ziel der vorliegenden Erfindung liegt darin, ein praktisches, zuverlässiges und effizientes System zur automatisierten Konstruktion und Herstellung individueller Apparate anzubieten sowie individuelle Apparate zur Verfügung zu stellen und die Behandlung von Patienten damit zu ermöglichen.

Ein besonderes Ziel der vorliegenden Erfindung besteht darin, ein automatisiertes System zur Konstruktion und Herstellung individueller kieferorthopädischer Apparate anzubieten, das sich einfach und zuverlässig von praktizierenden Kieferorthopäden anwenden läßt und das Fähigkeiten, Wissen und Erfahrungen nutzt, über die der Kieferorthopäde verfügt. Ein weiteres Ziel der vorliegenden Erfindung ist, die Genauigkeit der Behandlung durch den Kieferorthopäden zu erhöhen, eine effektivere Ausnutzung der Zeit des Kieferorthopäden zu ermöglichen, Fehlerquellen und Vermutungen aus der Behandlung der Patienten durch den Kieferorthopäden zu verbannen, so daß die zahlreichen Routineschritte bei Diagnose, Verordnung und Durchführung der kieferorthopädischen Behandlung sowie bei der Konstruktion und Anfertigung von kieferorthopädischen Apparaten in effizienter und zuverlässiger Weise bei häufiger Wiederholbarkeit automatisch ausgeführt werden können.

Ein weiteres Ziel der vorliegenden Erfindung besteht darin, die Verfahren der Kieferorthopäden zu verbessern, indem den Praktikern geholfen wird, eine optimale Feinbehandlung der Patienten zu erzielen sowie die Endposition der Zähne des Patienten genauer zu bestimmen und präziser zu erlangen. Eine zusätzliche Zielsetzung der vorliegenden Erfindung ist die Zusammenstellung von Daten einzelner Patienten für die Analyse der Daten, um die kieferorthopädische Praxis weiterzuentwickeln.

Wiederum ein weiteres Ziel der vorliegenden Erfindung liegt darin, die Aufgaben bei der Konstruktion und Herstellung individueller Apparate zwischen Kieferorthopäde und Apparatfertigungsstätte bestmöglich aufzuteilen, und zwar in Übereinstimmung mit der Größe der Praxis und anderen Besonderheiten der Arbeit der einzelnen Praktiker.

Ein Verfahren zur Herstellung eines individuellen kieferorthopädischen Apparats für die Bewegung der Zähne eines Patienten in gewünschte Endpositionen im Mund des Patienten umfaßt erfindungsgemäß folgende Schritte: Vermessen der anatomischen Formen im Mund des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den anatomischen Formen, einschließlich der die Formen der einzelnen Zähne des Patienten darstellenden dreidimensionalen Zahnformdaten; Ableiten einer idealen Zahnbogenform durch Verarbeiten der digitalisierten Daten zu den anatomischen Formen mit Hilfe eines Computers, der für die Erstellung eines zumindest teilweise von den digitalisierten Daten zu den anatomischen Formen abhängigen digitalisierten mathematischen Bogenform-Modells programmiert ist; Ableiten der Zahnendpositionen aus den digitalisierten Daten zu den anatomischen Formen sowie des digitalisierten mathematischen Bogenform-Modells mit Hilfe des

Computers zur mesiodistalen Anordnung der Zähne auf dem abgeleiteten idealen Zahnbogen und zur Bewegung der Zähne auf dem abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; Konstruktion eines individuellen kieferorthopädischen Apparats anhand der digitalisierten dreidimensionalen Zahnformdaten, der vorgegebenen Apparatfixierpunkte und der abgeleiteten Zahnendpositionen mit Hilfe des Computers, so daß der individuelle kieferorthopädische Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihren entsprechenden Fixierpunkten und den Zähnen in den abgeleiteten Zahnendpositionen besteht; Erzeugen maschinenlesbarer Steuersignale, die mit den Ergebnissen des Apparatkonstruktionsschritts korrelierende geometrische Informationen enthalten; und automatisches Fertigen eines individuellen kieferorthopädischen Apparats mit Hilfe einer Fertigungsanlage, die mittels maschinenlesbarer Steuersignale steuerbar ist und den Apparat entsprechend den in den Steuersignalen enthaltenen geometrischen Informationen formt, so daß der individuelle kieferorthopädische Apparat mit der zuvor konstruierten Konfiguration entsteht.

Eine erfindungsgemäße Fertigungsanlage für individuelle kieferorthopädische Apparate umfaßt Mittel zur Vermessung der anatomischen Formen im Mund des Patienten und zur darauf aufbauenden Erzeugung von digitalisierten anatomischen Formdaten, einschließlich dreidimensionaler Zahnformdaten, die die Formen einzelner Zähne des Patienten darstellen; einen digitalen Computer, der ein Programm zur Ableitung einer idealen Zahnbogenform aus den digitalisierten Daten mittels eines speziell programmierten digitalen Computers enthält, so daß ein digitalisiertes Bogenform-Modell erzeugt wird, das zumindest teilweise von den digitalisierten anatomischen Formdaten abhängig ist; Mittel zur computergestützten Ableitung von Zahnendpositionen aus den digitalisierten anatomischen Daten und der abgeleiteten digitalisierten idealen Bogenform zur mesiodistalen Anordnung der Zähne auf dem abgeleiteten idealen Zahnbogen und zur Bewegung und Ausrichtung der Zähne auf dem abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; ausgehend von den digitalisierten Zahnformdaten Konstruktion des vorgegebenen Apparatfixierpunkts und der abgeleiteten Zahnendpositionen und einer solchen Apparatkonfiguration, daß der dementsprechend gefertigte individuelle Apparat so ausgelegt ist, daß eine Verbindung zwischen den Zähnen an ihren entsprechenden Fixierpunkten und den Zähnen in den abgeleiteten Zahnendpositionen besteht; Erzeugung eines Maschinencodes, der die mit der vorgegebenen Apparatkonfiguration korrelierenden geometrischen Informationen enthält; sowie eine Fertigungsanlage zur automatischen Herstellung von individuellen kieferorthopädischen Apparaten in Übereinstimmung mit dem Maschinencode, so daß der Apparat entsprechend der geometrischen Informationen so geformt wird, daß der Apparat mit der vorgegebenen Apparatkonfiguration entsteht.

System und Verfahren weichen von traditioneller Konstruktion und Herstellung dadurch ab, daß sie kieferorthopädische Apparate nach der Anatomie des einzelnen Patienten entwerfen. Außerdem sind im Unterschied zu herkömmlichen kieferorthopädischen Erzeugnissen, die gemäß einer Durchschnittsanatomie konstruiert und hergestellt werden, die erfindungsgemäßen

kieferorthopädischen Erzeugnisse sowie die Verfahren ihrer Herstellung und Anwendung auf die individuelle Anatomie des Patienten zugeschnitten.

Diese und andere Ziele und Vorteile der vorliegenden Erfindung werden anhand der folgenden ausführlichen Beschreibung der Zeichnungen weiter ersichtlich:

Fig. 1-1F sind Schemata zur Veranschaulichung der bevorzugten Ausführungen des erfindungsgemäßen Systems, wobei:

Fig. 1 ein Blockdiagramm ist, das eine bevorzugte Ausführung eines automatisierten Systems zur Konstruktion und Herstellung individueller kieferorthopädischer Apparate für die damit vorgenommene Behandlung von Patienten entsprechend den erfindungsgemäßen Prinzipien veranschaulicht.

Fig. 1A eine Aufrißdarstellung einer Ausführung zur Erzeugung von Bildern für die Darstellung an Sichtgeräten der Dateneingabeeinheit einer Ausführung des Scanners des Systems von Fig. 1 zeigt.

Fig. 1B eine Aufrißdarstellung einer Laserscanner-Version einer Ausführung des Scanners des Systems von Fig. 1 für die Erzeugung dreidimensionaler Bilder ist.

Fig. 1C eine Aufrißdarstellung einer mechanischen Scanner-Version mit Zahnprofilabtaster einer Einheit zur zweidimensionalen Bilderzeugung einer Ausführung des Scanners des Systems von Fig. 1 ist.

Fig. 1D eine isometrische Darstellung einer Ausführung einer Bracketfräsvorrichtung des Systems von Fig. 1 ist.

Fig. 1E eine isometrische Darstellung einer Ausführung einer Drahtformvorrichtung des Systems von Fig. 1 ist.

Fig. 1F eine isometrische Darstellung einer Bracketeinsetzhalter-Fertigungsvorrichtung des Systems von Fig. 1.

Fig. 2-2D sind Flußdiagramme der bevorzugten Verfahren zur Ausführung der vorliegenden Erfindung, wobei:

Fig. 2 ein Flußdiagramm einer bevorzugten Ausführung des mit Hilfe des Systems von Fig. 1 durchgeführten erfindungsgemäßen Prozesses ist.

Fig. 2A ein ausführlicheres Flußdiagramm ist, das die Schritte der Eingabeprozedur der automatisierten Zahnpositionierung sowie Apparatkonstruktion und -herstellung gemäß dem Prozeß von Fig. 2 zeigt.

Fig. 2B ein ausführlicheres Flußdiagramm ist, das die Schritte der Analyse- und Zahnendpositionsberechnungsprozedur der automatisierten Zahnpositionierung sowie Apparatkonstruktion- und -herstellung gemäß dem Prozeß von Fig. 2 zeigt.

Fig. 2C ein ausführlicheres Flußdiagramm ist, das die Schritte der Apparatekonstruktionsprozedur für individuelle Apparate der automatisierten Apparatkonstruktion und -herstellung gemäß dem Prozeß von Fig. 2 zeigt.

Fig. 2D ein ausführlicheres Flußdiagramm ist, das die Schritte des Herstellungsprozedur für individuelle Apparate der automatisierten Zahnpositionierung sowie Apparatkonstruktion und -herstellung gemäß dem Prozeß von Fig. 2 zeigt.

Fig. 3-3C sind Darstellungen bei der Eingabe erzeugter Computerbilder, wobei:

Fig. 3 ein Beispiel für eine Bildschirmdarstellung ist, die von dem Scanner des Systems von Fig. 1 erzeugt wurde und eine vom Scanner des in Fig. 1A gezeigten Typs erstellte Draufsicht eines Unterkiefermodells zeigt.

Fig. 3A ein Beispiel für den Ausschnitt eines dreidimensionalen digitalen Bildes ist, und zwar perspektivisch dargestellt und von dem Scanner des in Fig. 2B gezeigten Typs erzeugt.

Fig. 3B eine Fig. 3A ähnliche Darstellung eines anderen Bereichs des vom Scanner von Fig. 1B erzeugten dreidimensionalen digitalen Bildes ist.

Fig. 3C ein Beispiel für eine Reihe von vertikalen Zahnprofilansichten ist, die von dem Scanner von Fig. 1C erzeugt wurden.

Fig. 4-4E sind Draufsichten von Zähnen des Patienten auf Zahnpositionierungsbogenformen in unterschiedlichen Stadien der Zahnpositionsberechnung von Fig. 2B, wobei:

Fig. 4 ein geometrisches Schema ist, das das Dateneingabebild als horizontale Draufsicht veranschaulicht und schematisch die Bildschirmdarstellung von Fig. 3 in seiner Verwendung als Modell zeigt, und zwar mit eingezeichneten Variablen, die für die Digitalisierung der Daten aus der Unterkiefer-Bildschirmdarstellung relevant sind.

Fig. 4A ein Fig. 4 ähnliches geometrisches Schema ist, und zwar für die Oberkieferzähne.

Fig. 4B ein geometrisches Schema ist, das horizontale Unterkieferbogenformen darstellt, die mittels der Analyseprozedur von Fig. 2B errechnet wurden.

Fig. 4C ein geometrisches Schema ist, das horizontale Oberkieferbogenformen darstellt, die mittels der Analyseprozedur von Fig. 2B errechnet wurden.

Fig. 4D eine horizontale Draufsicht ist, die die Oberkieferzähne in ihrer Endposition zeigt.

Fig. 4E eine horizontale Draufsicht ist, die die Unterkieferzähne in ihrer Endposition zeigt, wobei der individuelle Apparat eingesetzt wurde.

Fig. 5-5P sind mathematische Referenz-Berechnungs-Schemata, und zwar in Verbindung mit der Spline-Kreis-Umwandlungs- und der Zahnpositionierungsroutine, wobei:

Fig. 5 eine horizontale Draufsicht ist, die die Positionierung eines Zahns auf einer in Kreissegmentform beschriebenen Bogenformgleichung zeigt.

Fig. 5A-5J ausführliche Schemata der Spline-Kreis-Umwandlung und der Zahnpositionierungs-Subroutinen sind.

Fig. 5K-5P ausführliche Schemata der Zahnpositionierungs-Subroutinen sind.

Fig. 6-6I sind Schemata von Zahnprofilen, welche Meßpunktbestimmung, Zahnneigung und vertikale Positionierung zeigen, wobei:

Fig. 6 ein isometrisches Bild einer dreidimensionalen Computerdarstellung eines Backenzahns, ähnlich Fig. 3A, die die Lage der alternativen vertikalen labial-lingualen Profilebenen und Zahnprofile zeigt.

Fig. 6A eine mathematische Zahnprofildarstellung ist, wie sie auf dem Computerbildschirm des Systems von Fig. 1 erscheint und einen Unterkieferbackenzahn sowie ausgewählte Meßpunktparameter zeigt.

Fig. 6B eine mathematische Zahnprofildarstellung ist, ähnlich Fig. 6A, die einen Eckzahn oder

Schneidezahn des Unterkiefers sowie ausgewählte Meßpunktparameter zeigt.

Fig. 6C eine mathematische Zahnprofildarstellung ist, ähnlich Fig. 6A, die einen Backenzahn oder Prämolar des Oberkiefers sowie ausgewählte Meßpunktparameter zeigt.

Fig. 6D eine mathematische Zahnprofildarstellung ist, ähnlich Fig. 6A, die einen Eckzahn oder Schneidezahn des Oberkiefers sowie dafür relevante ausgewählte Meßpunktparameter zeigt.

Fig. 6E das Schema einer Reihe von mathematischen Zahnprofildarstellungen aller Zähne, winklig angeordnet, mit darauf verzeichneten Meßpunktparametern, ähnlich Fig. 3C, ist.

Fig. 6F das Schema einer Reihe von mathematischen Zahnprofildarstellungen, ähnlich einem Ausschnitt von Fig. 6E, und zwar der Unterkieferzähne mit darauf verzeichneten praktischen horizontalen Positionierungsebenen, zeigt.

Fig. 6G eine mathematische Zahnprofildarstellung ist, ähnlich Fig. 6A, und zwar eines hinteren Unterkieferzahns mit darauf verzeichneten relevanten Dimensionsvariablen für die Positionierung des Zahns.

Fig. 6H eine mathematische Zahnprofildarstellung ist, ähnlich Fig. 6B, und zwar eines vorderen Unterkieferzahns mit darauf verzeichneten relevanten Dimensionsvariablen für die Positionierung des Zahns.

Fig. 6I eine mathematische Zahnprofildarstellung ist, ähnlich Fig. 6H, und zwar des größten Unterkieferzahns.

Fig. 7-7D sind Referenz-Schemata in Verbindung mit der Berechnung der Zahnendposition, wobei:

Fig. 7 eine Aufrißdarstellung der Beziehung zwischen den Kiefern eines Patienten zur Veranschaulichung der Okklusionsberechnung bei Eckzahnanhebung ist.

Fig. 7A ein vergrößerter Ausschnitt von Fig. 7 ist.

Fig. 7B eine mathematische Darstellung als Draufsicht ist, die bestimmte mathematische Erscheinungen bei der Zahnpositionierung auf dem versetzten Unterkieferbogen veranschaulicht.

Fig. 7C eine perspektivische Darstellung ist, die die Beziehung zwischen dem vertikalen Zahnprofilebenen und den relevanten horizontalen Bogenebenen im Verlauf der Berechnung der Zahnendpositionen veranschaulicht.

Fig. 7D eine Reihe ähnlicher Aufrißprofile von Unterkiefer- und Oberkieferzähnen ist, die die Okklusions- und Übergreifbeziehungen während der Berechnung der Zahnendposition zeigen.

Fig. 8-8H sind Referenz-Schemata in Verbindung mit der Apparatekonstruktionsprozedur für individuelle Apparate, wobei:

Fig. 8 ein Schema ist, ähnlich Fig. 7D, das die Konstruktion von Bogendrahtebene und Bracketschlitz an positionierten Zähnen zeigt.

Fig. 8A eine Aufrißdarstellung ist, die die Konfiguration von Bracket und Schlitz in Verbindung mit dem Schema von Fig. 8 veranschaulicht.

Fig. 8B eine Draufsicht ist, die die Beziehung zwischen eine Zahn und einer Bogenform anhand der Positionierungsroutine zeigt.

Fig. 8C eine Zahnprofildarstellung ist, die die Berechnung der inneren und äußeren Abmessungen des Schlitzes zeigt.

Fig. 8D eine perspektivische Darstellung ist, die die Positionierung eines individuellen Brackets an einem Zahn mit Hilfe eines individuellen Einsetzhalters zeigt.

Fig. 8E eine Draufsicht eines individuellen Bogendrahts für den Apparat, der zur Bewegung der Unterkieferzähne in die Endpositionen, die in Fig. 4E dargestellt sind, notwendig ist.

Fig. 8F eine Draufsicht ist, die den labial eingesetzten Apparat an den Zähnen des Patienten in ihrer Ausgangsposition zeigt.

Fig. 8G eine Draufsicht ist, ähnlich Fig. 8F, die einen lingualen Apparat zeigt, der an den Zähnen des Patienten eingesetzt ist.

Fig. 8H eine Aufrißdarstellung ist, die ein kieferorthopädisches linguales Bracket des Apparats von Fig. 8G zeigt.

Fig. 8I eine Draufsicht eines Brackets ist, das eine Grundschlitzkrümmung hat, die mit der eines darin gehaltenen Bogendrahts übereinstimmt.

Fig. 9-9W sind Schemata in bezug auf die Herstellungsschritte des Apparats, wobei:

Fig. 9-9H die Unterschritte der Erzeugung des Codes für das Bracketschlitzfräsen sowie den Schritt der Bracketherstellung betreffen.

Fig. 9I-9W die Unterschritte bei der Herstellung des Bracketeinsetzhalters betreffen.

Die Gesamtkonfiguration des Systems 10 wird schematisch in Fig. 1 dargestellt. Der Gesamtarbeitsablauf des bevorzugten erfindungsgemäßen Verfahrens wird im Flußdiagramm von Fig. 2 dargestellt, wobei die Untersuchung eines Patienten durch den Kieferorthopäden in dessen Praxis zur Gewinnung von Informationen durchgeführt wird, um die Gegebenheiten beim Patienten festzustellen, die geeignete Behandlung zu verordnen und die Art des kieferorthopädischen Apparats zu spezifizieren, um die Behandlung auszuführen. Die Informationen werden an eine entfernt gelegene für die Konstruktion und Herstellung von Apparaten zuständige Fertigungsstätte weitergeleitet, wo die Konstruktion eines individuellen Apparats für den Einsatz zur Behandlung erfolgt, und zwar mit Hilfe einer Computeranalyse. Die Apparatkonstruktion wird dann zusammen mit den Informationen, die der Kieferorthopäde braucht, um den Apparat beim Patienten einzusetzen, an den Kieferorthopäden zurückgesandt, der den Apparat einsetzt und die Behandlung durchführt, und zwar in Übereinstimmung mit den Instruktionen des Apparateherstellers und seinen eigenen Fachkenntnissen.

SYSTEMKONFIGURATION

In dem in Fig. 1 gezeigten System-Schema wird das System 10 zur Herstellung kieferorthopädischer Apparate und zur Behandlung von Patienten dargestellt. Die Systemkomponenten sind zwischen zwei Orten verteilt, einer Arztpraxis 11 und einer für die Konstruktion und Herstellung von Apparaten zuständigen Fertigungsstätte 13. In der Arztpraxis 11 wird ein Patient 12, der eine kieferorthopädische Behandlung benötigt, von einem Kieferorthopäden 14 untersucht, der eine Diagnose 15 anhand der Gegebenheiten beim Patienten stellt und, falls notwendig, die erforderliche Behandlung festlegt. Die Untersuchung basiert auf den traditionellen Fähigkeiten, dem Wissen und den Fachkenntnissen des Kieferorthopäden 14, und ihr Ergebnis ist die Erstellung von ausführlichen Unterlagen 16 über die Anatomie und die Gegebenheiten des Mundes 18 des Patienten, über die vorgeschlagene Behandlung und von weiteren Informationen, die zur Anfertigung eines

kieferorthopädischen Apparats erforderlich sind.

Die vom Kieferorthopäden erstellten Unterlagen 16 umfassen ein physisches Modell 20 von einem Abdruck des Mundes 18 des Patienten, welches aus einem Mandibularmodell 21 des Unterkiefers des Patienten oder Unterkieferknochens 22 sowie einem Maxillarmodell 23 des Oberkiefers des Patienten oder Oberkieferknochens 24 besteht. Die Unterlagen 16 enthalten ebenfalls die Verordnung 27, in der der Kieferorthopäde eine dem Patienten zu erteilende Behandlung sowie ein durch die Behandlung zu erzielendes Ergebnis darlegt. Die Verordnung 27 kann außerdem eine Spezifikation der in die Behandlung einzubeziehenden Verfahren sowie eine Benennung eines einzusetzenden kieferorthopädischen Apparats umfassen. Die Unterlagen 16 sollten weiterhin Informationen zur Identifikation 17 und zur Patientengeschichte 19 enthalten.

Bei der dargestellten erfindungsgemäßen Ausführung werden die Unterlagen 16 an die Fertigungsstätte 13 zur Apparatherstellung weitergeleitet, wo die Zahnendposition berechnet und ein individueller Apparat 25 konstruiert und hergestellt wird. In der Fertigungsstätte 13 arbeiten ein oder mehrere ausgebildete Operatoren 28. Bei einigen Ausführungen wird das physische Modell 20 selbst mit den Informationen 16 an die Fertigungsstätte 13 übermittelt. In diesen Fällen besteht die vorrangige Aufgabe der Operatoren 28 darin, die Eingabe digitaler Informationen aus den Unterlagen 16 in einen Computer 30a zu gewährleisten. Eine weitere Aufgabe ist, denselben oder einen anderen Computer 30b zu bedienen, um den individuellen Apparat 25 zu konstruieren, und eine NC-Anlage 38 zu bedienen, die von demselben oder einem anderen Computer 30c gesteuert wird, um den Apparat 25 herzustellen. Wenn Eingabe, Konstruktion und Herstellung in der Fertigungsstätte 13 erfolgen, können diese Arbeiten, die sonst mit Hilfe der Computer 30a, 30b und 30c ausgeführt werden, an einem einzigen Computer 30 erledigt werden.

Bei anderen Ausführungen erstellt der Kieferorthopäde 14 die digitalisierten Daten vom Modell 20, in welchem Fall sich der Eingabecomputer 30 in der Praxis 11 des Kieferorthopäden befindet. Bei diesen Ausführungen werden die digitalisierten Informationen 26 anstelle des physischen Modells 20 an die Fertigungsstätte 13 übermittelt. Der Computer für die Analyse und die Apparatkonstruktion befindet sich trotzdem in der Fertigungsstätte 13.

Die Eingabe der Informationen in den Eingabecomputer 30 umfaßt eine Digitalisierung der Informationen 16, um die digitalisierten anatomischen Informationen 26 in maschinenlesbarer Form für die Analyse durch den Analysecomputer 30b zu erzeugen. Der Eingabecomputer 30 ist mit diesem durch einen Scanner 33 verbunden, der bei den alternativen erfindungsgemäßen Ausführungen eine Ausstattung enthält, die mit einer oder mehreren Kameras, mechanischen Abtastern, Laserscannern, Ultraschallscannern, Moiré-Bildscannern oder anderen Geräten der Bilderzeugung oder mit Vermessungshardware arbeitet, die allein oder in Kombination mit weiteren derartigen Komponenten anatomische geometrische Informationen erzeugen, die Zähne und Kiefer des Patienten beschreiben. Die Bilder können dreidimensional oder entlang einer Mehrzahl von Ebenen oder anderen Flächen aufgenommen sein, die schließlich so kombiniert werden können, daß dreidimensionale Informationen erzeugt werden.

Die kombinierten Informationen vom Scanner 33 der dargestellten Ausführung bieten eine Grundlage für eine dreidimensionale Analyse der Zähne des Patienten und für die Berechnung der

Zahnendposition. Aufgrund der Endpositionsberechnung und der Zahnanatomiedaten wird die automatische Konstruktion und Herstellung des individuellen kieferorthopädischen Apparats 25 durchgeführt. Bei der dargestellten Ausführung werden die Daten in einer Vielzahl von unterschiedlich ausgerichteten zweidimensionalen Ebenen im Computer 30 abgebildet, anschließend im Computer 30b berechnet und kombiniert, um eine dreidimensionale Lösung für die Probleme der Zahnpositionierung und Apparatherstellung zu erbringen.

Bei einer Konfiguration, in der der Scanner 33 mit einem separaten speziellen Eingabecomputer 30 verbunden ist, wie sie hier beschrieben wird, kann das funktionelle Äquivalent des Eingabecomputers 30 auch im Schaltungsaufbau innerhalb des Scanners 33 selbst enthalten sein.

Vorzugsweise werden beim digitalen Eingabeprozeß interaktive Verfahren eingesetzt, wobei ein Operator 28 ein Zeigegerät und einen Digitalisierer verwendet, um besonders geeignete kieferorthopädische Parameter von den grafischen Bildern auszuwählen, die von dem Scanner 33 auf einem Bildschirm 35 eines Monitors erzeugt werden, der mit dem Eingabecomputer 30 verbunden ist.

Bei Ausführungen, bei denen ein Teil der oder die gesamte Gewinnung der digitalisierten anatomischen Informationen 26 vom Modell 20, die auch unmittelbar vom Mund 18 des Patienten 12 erfolgen kann, vom Kieferorthopäden 14 in der kieferorthopädischen Praxis 11 vorgenommen wird, werden die Informationen 26 durch den Kieferorthopäden 14 als digitalisierte Daten erfaßt und anschließend als Teil der Informationen 16 an das Apparatkonstruktionszentrum 13 weitergeleitet. Die Übermittlung der Informationen 16 von der Praxis 11 des Kieferorthopäden zur Fertigungsstätte 13 erfolgt vorzugsweise mit Modem, kann aber auch mit jedem anderen verfügbaren Verfahren vorgenommen werden.

Ein Analyse- und Konstruktionscomputer 30b, der sich vorzugsweise in der Apparatkonstruktions- und Fertigungsstätte 13 befindet, stellt eine Archivdiskette 34 her, die formatiert und mit allen relevanten Informationen der Analyse sowie der Geschichte und über die verordnete Behandlung des Patienten 14 beschrieben wird.

Der Computer 30b in der Fertigungsstätte 13 berechnet auf der Grundlage der digitalisierten Informationen 26 die Endposition der Zähne des Patienten und die Konfiguration des Apparats 25, die erforderlich ist, um die Zähne des Patienten in diese Endposition zu bewegen. Anschließend werden die für den Patienten berechneten Informationen in einer Patientendatei 36 gespeichert. Aus den Berechnungen erzeugt der Computer 30c einen CNC-maschinenlesbaren Code 42 zur Steuerung der NC-Fertigungsanlage 38 für die Fertigung des Apparats 25. Die Computer 30b oder 30c erzeugen weiterhin ein Instruktionsdokument 37 mit Informationen, die den Kieferorthopäden 14 bei der Behandlung des Patienten 12 mit dem individuellen Apparat 25 unterstützen.

Die Fertigungsanlage 38 umfaßt eine Maschine 39 zum Fräsen oder Bearbeiten der Brackets, welche die individuellen Brackets für den Apparat 25 herstellt, indem sie Schlitze in berechneten Winkeln und in berechnete Tiefen bei schlitzlosen Standard-Brackets fräst. Die Maschine 39 kann außerdem oder alternativ die Oberflächen der Bracketbasis bearbeiten. Dadurch ergibt sich je nachdem, wie es bei verschiedenen Bracketwerkstoffen optimal erscheint, für die Bracketkonstruktion die Option, das Drehen des Zahns entweder mittels Bracketschlitz oder Bracketbasis vorzusehen.

Die Anlage 38 umfaßt weiterhin eine Maschine 40 zum Biegen oder Bearbeiten des

Apparatbogendrahts, die individuell geformte Bogendrähte für den Apparat 25 produziert, indem sie Draht aller unterschiedlichen verfügbaren Werkstoffe und Steifigkeiten zuführt und in die individuelle Bogendrahtform biegt. Die Anlage 38 kann weiterhin eine Maschine zur Formung von Patientenbehandlungskomponenten und Hardware beinhalten, um die Herstellung oder das Einsetzen des Apparats 25 zu unterstützen. Bei der dargestellten Ausführung gehört dazu eine Maschine 41 zur Herstellung von Bracketeinsetzhaltern, die jeden Zahnkronenabschnitt des Zahnprofils in einem Kunststoffrohling entsprechend jedem Zahnkronenabschnitt sowie einer zusätzlich zu berücksichtigenden Aussparung für das positionierte Bracket zur Gewährleistung des präzisen Einsetzens der individuellen Brackets in ihren berechneten Positionen an den Zähnen bearbeitet.

Die Apparatfertigungsanlagen 38 können direkt mit dem Analysecomputer 30b verbunden sein, oder eine oder mehrere können mit einem separaten Computer zur Steuerung der Fertigungsanlagen bzw. der Maschinensteuerungsvorrichtung 30c verbunden sein. Der Computer 30c kann sich in der Fertigungsstätte 13 befinden oder zusammen mit einer oder mehreren Apparatfertigungsanlagen 38, 40 oder 41 in der Praxis 11 des Kieferorthopäden stationiert sein. Bei einer bevorzugten erfindungsgemäßen Ausführung sind ein Herstellungscomputer 30c und die Bracketfräsvorrichtung 40 (muß eigtl. 39 sein) in der Praxis des Kieferorthopäden untergebracht, ebenso wie der Scanner 33 und der Eingabecomputer 30, der derselbe Computer wie der Herstellungscomputer 30c sein kann, während sich ein weiterer zentraler Herstellungscomputer 30c, bei dem es sich um den Analysecomputer 30b handeln kann, sowie die Drahtbiegevorrichtung 40 und die Vorrichtung 41 zur Bearbeitung des Bracketeinsetzhalters in der Fertigungsstätte 13 befinden. Die optimale Verteilung der Computer 30, 30b und 30c, des Scanners 33 und der Apparatfertigungsanlagen 38, 40 und 41 wird durch die Größe der Praxis sowie die bevorzugten Arbeitsweisen des Kieferorthopäden bestimmt. Bei der dargestellten Ausführung handelt es sich bei den Computern 30-30c um IBM-PC-Klone mit Intel-Mikroprozessoren 80386 oder 80486, die jeweils mit mathematischen Koprozessoren 80387 oder 80487 ausgerüstet sind.

Bestimmte Komponenten des Systems 10 von Fig. 1 werden nachfolgend ausführlicher beschrieben.

Scannereinheit 33

Die drei nachfolgend beschriebenen Schritte der Informationseingabeprozedur (82) umfassen die Eingabe von Daten über die Form des Mundes 18 des Patienten 12 sowie über die Form der einzelnen Zähne darin für die Analyse in digitaler Form in den Computer 30. Bei diesen Schritten werden digitalisierte Bilder und Meßdaten des Mundes 18 des Patienten 12, die vorzugsweise indirekt vom Modell 20 abgenommen wurden, gewonnen, so daß sich ein dreidimensionales mathematisches Modell des Mundes 18 des Patienten ergibt. Bei der bevorzugten erfindungsgemäßen Ausführung beinhaltet das mathematische Modell die Definition bestimmter Parameter des Unterkiefers und einzelner Zähne des Patienten, und es kann ferner einige Informationen über die ursprüngliche Position und Ausrichtung der Zähne im Mund 18 des Patienten 12 enthalten, damit der Umfang der Behandlung eingeschätzt werden kann.

Bei einigen erfindungsgemäßen Ausführungen werden die Eingangsinformationen 26 als ein vollständiges dreidimensionales Bild eingegeben und anschließend vereinfacht, indem sie auf eine

Vielzahl von Darstellungen in mehreren unterschiedlich ausgerichteten Ebenen oder ziemlich ebenmäßig gekrümmte Flächen reduziert werden, wobei jede im unabhängigen XY-Koordinatensystem der jeweiligen Fläche oder Ebene definiert ist. Bei der nachfolgenden Analyse werden diese Ebenen ausgerichtet, transformiert und gegeneinander verschoben, so daß eine Ableitung der idealen Zahnendpositionen sowie die Konstruktion des individuellen Apparates 25 erzielt wird. In Übereinstimmung mit der bevorzugten erfindungsgemäßen Ausführung werden die Kurven und Punkte auf den Konturen des Kiefers und der Zähne des Patienten 12 in Form anerkannter oder allgemein anwendbarer kieferorthopädischer Parameter ausgedrückt, so daß die manuelle und automatisierte Entscheidungsfindung das Optimum an kieferorthopädischer Kenntnis und Erfahrung mit der Effektivität und Präzision der Computeranalyse kombinieren und koordinieren kann, um den Zeitaufwand des Kieferorthopäden zu minimieren, die Behandlungsdauer des Patienten zu verkürzen und die endgültigen Behandlungsergebnisse zu optimieren.

Nachfolgend werden unterschiedliche Arten und Komponenten des Scanners 33 bei unterschiedlichen erfindungsgemäßen Ausführungen beschrieben.

Dateneingabeeinheit mit Scanner 43

Eine bevorzugte Form oder Komponente des Scanners 33 umfaßt eine Bilderzeugungseinheit 43 wie in Fig. 1A. Die Bilderzeugungseinheit 43 umfaßt eine oder mehrere Kameras 44, die jeweils zweidimensionale Bilder vom Mund 18 des Patienten erzeugen, vorzugsweise indem sie ein Bild des Modells 20 erzeugen. Werden zwei oder mehrere davon eingesetzt, erzeugt die Einheit 43 Stereobilder, die sich in drei Dimensionen auflösen lassen. Bei der dargestellten erfindungsgemäßen Ausführung wird eine einzelne Kamera 44 eingesetzt, so daß zweidimensionale Bilder einer Draufsicht des Unter- oder Oberkiefers 22 und 24 des Patienten von den Modellen 21 oder 23 in allgemein horizontalen XY-Ebenen erzeugt werden. In Übereinstimmung mit dieser Ausführung werden bevorzugt andere Formen oder Komponenten des Scanners 33 eingesetzt, um - wie unten beschrieben - dreidimensionale Informationen zu erstellen.

In Fig. 1A wird die Bilderzeugungseinheit 43 in der Fertigungsstätte 13 des Apparatherstellers als Aufriß dargestellt. In ihrer bevorzugten Form stellt die Bilderzeugungseinheit 43 eine grafische Schnittstelle Operator-Computer dar, die die Kamera 44 umfaßt, welche mit einer Videoschnittstellenkarte 44a im Eingabecomputer 30 verbunden ist. Die Kamera 44 ist auf den Ständer 45 montiert, so daß sie eine Draufsicht von oben auf eine der beiden Hälften 21 oder 23 des Modells 20 liefert wie die Ansicht des Unterkiefers 21 in Fig. 3, wobei sich dieser auf einem horizontalen auf der Grundplatte 45a des Ständers 45 angebrachten Träger 46 abstützt. Die Modellhälfte 21 oder 23 ist so auf den Träger 46 gelegt, daß die Zähne nach oben in Richtung der Kamera 44 zeigen und daß ihre Spitzen im wesentlichen in einer horizontalen Ebene liegen, die in einem bekannten festen Abstand zur Kamera 44 gehalten wird, so daß der Maßstab des von der Kamera 44 erzeugten Bildes bekannt ist. Das kann erreicht werden, indem der Träger 46 auf den Federn 46a gelagert wird, so daß die Modellhälften 21 oder 23 nach oben gegen eine durchsichtige horizontale Platte 45b gedrückt werden.

An den Eingabecomputer 30 ist ein Zeigegerät angeschlossen, bei dem es sich um eine Maus 47a handeln kann oder, wie dargestellt, um einen Digitalisierer 47 mit Maus. Die Kamera 44 erzeugt ein Grafik-Bild 48 auf dem Bildschirm 35 des Computers 30, das ein Operator 28 mittels eines

Positionierungsrasters *G* (Fig. 4) ausrichten kann. Mit Hilfe des Digitalisierers 47 wählt der Operator Punkte aus, indem er den Curser 48a auf dem Bildschirm 35 mittels der Maus 47a bewegt. Dadurch werden die XY-Koordinaten für jeden der ausgewählten Punkte gespeichert. Bei der Beschreibung des nachfolgenden bevorzugten Verfahrens stimmen die ausgewählten Punkte mit Grenzpunkten der Zähne und, anhand des Mandibularmodells 21, des Unterkiefers überein. Ausgehend von diesen Grenzpunkten der Draufsicht werden die Abmessungen der Zähne und des Unterkiefers berechnet. Die berechneten Abmessungen werden während der Analyse benutzt, um Gleichungen für die Unterkieferknochenstruktur oder die Mandibularalveolenmulde *MT* zu berechnen sowie aus der Mandibularalveolenmuldengleichung, den berechneten horizontalen Abmessungen und relativen Positionen der Merkmale an den einzelnen Zähnen die Endpositionen der Zähne zu ermitteln.

Als Alternative zur Auswahl von Punkten aus dem Bild 48 lassen sich dieselben Punkte in gleicher Weise aus einem Draufsicht-Bild eines digitalisierten dreidimensionalen Computerbilds der Zähne und Kiefer wie aus einem Bild auswählen, das durch Laserscanner, Moiré-Interferenzbild-Scanner, Ultraschallscanner, Stereokameras oder andere dreidimensionale Bilderzeugungsapparaturen erzeugt wird. Ausgewählte Ansichten 55a und 55b derartiger mit einem Laserscanner gemachter dreidimensionaler Computerbilder werden in Fig. 3A und 3B gezeigt. Ein solcher Laserscanner wird im folgenden im Zusammenhang mit Fig. 1B beschrieben.

Laserbild-Eingabeeinheit 51 für die Gewinnung von dreidimensionalen Bildern

Eine bevorzugte Form oder Komponente des Scanners 33 stellt die lasergestützte Einheit 50 fr die Erzeugung dreidimensionaler Bilder in Fig. 1B dar. Entsprechend Fig. 1B wird eine der Hälften 21 und 23 des Modells 20 auf dem Träger 51 befestigt, und das Lasergerät 52 richtet einen Laserstrahl 52a auf das Modell 21 oder 22. Der Laserstrahl 52a wird reflektiert, und der reflektierte Strahl wird von einem Sensor 53 erfaßt, der aus einer photoelektrischen Pixel-Matrix besteht, die mit einem Triangulationsverfahren arbeitet, um eine Positionsveränderung am Sensor in eine Veränderung des Abstands zwischen der Einheit 50 und dem Modell 21 oder 23 umzuwandeln, die so montiert ist, daß eine Parallelverschiebung zum Modell 21 oder 23 auf einem Träger 54 erfolgt, so daß das Modell mit dem Laserstrahl abgetastet wird. Um Bilder mit Hilfe von Lasertechnik auf diese Weise zu erzeugen, gibt es handelsübliche Ausrüstungen zur Erstellung von dreidimensionalen Computerdarstellungen von Erzeugnissen oder anderen Objekten. Ein Beispiel für eine zu diesem Zweck geeignete Apparatur stellt das Cyber Scan™ Measurement System der Firma Cyber Optics Corporation in Minneapolis, Minnesota, dar. Mit einer derartigen Ausrüstung erzeugte Bilder sollten vorzugsweise vom Modell 20 abgenommene vollständige, ausführliche und dreidimensionale Bilddaten des Unter- und Oberkiefers 22 und 24 des Patienten umfassen, wobei sich die Zähne in ihrer ursprünglichen Position befinden. Die Daten werden von der beschriebenen Apparatur in Standard-ASCII-Dateien geschrieben und können vom Eingabecomputer 30 in die digitalisierte Informationsdatei 26 eingelesen werden.

Fig. 3A und 3B zeigen zwei Abschnitte des digitalisierten Unterkiefermodells, wobei ein Abschnitt 55a die vorderen Unterkieferschneidezähne T_{BR1} und T_{BL1} des Patienten 12 und ein Abschnitt 55b vom rechten Unterkiefer den zweiten Prämolar T_{BR5} und den ersten Molar T_{BR6} des Patienten 12 zeigt. Werden solche Bilder in eine horizontale Draufsicht gedreht, läßt sich eine Ableitung derselben Informationen erzielen, wie sie von der Bilderzeugungseinheit 43 von Fig. 1A

erhältlich ist; und es lassen sich daraus automatisch Punkte für die Digitalisierung mittels Software oder durch einen interaktiven Prozeß zwischen Operator und Computer auswählen, so z.B. mit dem Videoscanner 43. Das dreidimensionale Bild 55 kann in andere Richtungen gedreht werden, um andere Informationen in anderen unterschiedlichen Ebenen abzuleiten, wie beispielsweise Informationen über das vertikale Zahnprofil, die mit dem nachfolgend beschriebenen mechanischen Scanner 57 gewonnen werden. Zusätzlich können weitere Computerverfahren genutzt werden, um mit oder ohne Eingreifen oder Beeinflussung durch einen Operator auf automatischem Wege Informationen aus dem dreidimensionalen Bild 55 abzuleiten.

Digitale Scannereinheit mit mechanischem Abtaster 57

Als Alternative oder in Kombination mit anderen Scannerausrüstungen wie der Videoscanner-Einheit 43 von Fig. 1A oder der Laserscanner-Einheit von Fig. 1B kann zum Scanner auch eine Einheit mit mechanischem Abtaster 57 gehören, wie sie in Fig. 1C dargestellt ist. Die gesamte Einheit 57 wird bei der dargestellten erfindungsgemäßen Ausführung kombiniert mit dem Videoscanner 43 eingesetzt, um vom Modell 20 labial-linguale vertikale Profile der einzelnen Zähne abzuleiten, um die Informationen über Kiefer sowie über horizontale Abmessungen und Formen von Zähnen zu ergänzen, die von einem Bild abgeleitet sind, das mit dem Videoscanner 43 vom Modell 20 gemacht wurde. Andererseits können Teile dieser Einheit eingesetzt werden, um dieselben Informationen von dem dreidimensionalen Bild 55 zu gewinnen, das mit einer Einheit wie dem Laserscanner 50 erzeugt wurde.

Entsprechend Fig. 1C umfaßt die Einheit mit Abtaster 57 einen Meßabtaster 60, der sich über die einzelnen Zähne des Modells 21 bewegen läßt, so daß ein elektrisches Signal erzeugt wird, welches digitalisiert wird, um Punkte oder Profile von den Oberflächen der Zähne getrennt nach X und Y für jeden Zahn in den Computer einzugeben. Bei der dargestellten Ausführung des erfindungsgemäßen Verfahrens enthalten die vom Modell 21 abgenommenen Informationen 26 die Zahnprofilkurven PF_f in labial-lingualer Ebene in mesial-distaler Richtung.

Die Einheit mit Abtaster 57 umfaßt weiterhin eine magnetische Grundplatte 59, auf der das Modell 20 aufgebracht ist und aus der sich aufrecht ein vertikaler Ständer 58 erstreckt, an dem der Abtaster 60 montiert ist. Die Abtasterspitze 60a ist frei drehbar um eine vertikale Achse, auf der sich die Spitze befindet, wobei der Abtaster selbst aufgehängt ist, damit die Spitze Einkerbungen in den Oberflächen der Zähne des Modells 21 abtasten kann. Der Abtaster 60 ist so an dem Ständer 58 montiert, daß sie sich in X- und Y-Richtung in einer vertikalen Ebene bewegen kann, welche durch den Ständer 58 und den Abtaster 60 verläuft. Auf diese Weise ist die Abtasterspitze 60a so gelagert, daß sie die Oberfläche eines Zahns des Modells 21 in dieser Ebene abtasten kann. Der Abtaster 60 ist mit dem Ständer 58 durch zwei orthogonale Positionsmeßwertwandler 61 verbunden, die elektrische analoge Meßwerte der Positionen der Spitze des Abtasters 60 auf den entsprechenden Positionen der orthogonalen XY-Koordinaten erzeugen. Die Ausgangssignale der Meßwertwandler 61 werden an eine Schaltung geliefert, die eine Folge von periodischen Meßwerten der Wandler-meßwerte der Abtasterspitzenpositionen erzeugt, die anschließend digitalisiert werden. Diese Signale werden über die Leitungen 61a an Eingabecomputer 30 übertragen, vorzugsweise an einen seriellen Port.

Während der Benutzung wird eine Hälfte des Modells 20, beispielsweise das Unterkiefermodell 21, auf die Halterung eines auf der magnetischen Grundplatte 59 befindlichen stählernen Nivellierers 62 montiert, der bei geringem Druck auf der Grundplatte 59 gleitet, aber andererseits nicht verrutscht, so daß eine präzise Positionierung möglich ist. Die Halterung läßt sich heben, senken oder neigen, so daß Positionierung und Nivellierung möglich sind. Beim Betrieb wird der Abtaster 60 manuell durch einen Bediener 28 oder automatisch bewegt, damit er die Oberfläche jedes ausgewählten Zahns des Modells 21 abtastet, um Profilkurven *PF* eines Abschnitts jedes Zahns zu erzeugen, wie in Fig. 3C gezeigt wird. Zur Erzeugung des Profils *PF* können alle handelsüblichen serienmäßig hergestellten CAD/CAM- oder Abbildungs-Software-Programme verwendet werden wie beispielsweise VERSACAD™ der Firma Prime Computers, Inc. in Bedford, Massachusetts. Die Bilder der Profile *PF* werden auf dem Bildschirm 35 gezeigt, und die digitalisierten Profile werden als Bestandteil der Eingabeinformationen 26 im Permanentspeicher des Computers 30 abgelegt.

Anhand von Kurven wie dem auf diese Weise erstellten Profil *PF* kann ein Operator mit Hilfe des Zeigegrätes 47, indem er den Curser auf dem Profil auf dem Bildschirm 35 bewegt, Punktparameter des Zahns auswählen, deren Koordinaten sich dadurch digital in den Computer 30 eingeben lassen.

Apparatefertigungsausrüstung 38

Die Ausrüstung der Fertigungsanlage 38 der bevorzugten Ausführung der Erfindung umfaßt: eine Maschine 39 zum Fräsen und Bearbeiten der Brackets, die die Bracketbasis individuell bearbeitet, so daß sie auf die Zähne aufgesetzt werden kann, und die an Positionen und mit Winkeln, die genau berechnet sind, Bogendrahtschlitze in die Brackets fräst; eine Maschine 40 zum Biegen oder Bearbeiten des Apparatbogendrahts, die den Bogendraht präzise in eine Form biegt, die mit den individuellen Brackets zusammenwirkt, so daß korrigierende Kräfte auf die Zähne ausgeübt werden, bis sie sich in ihren berechneten Endpositionen befinden; sowie eine Bracketeinsetzhalter-Fertigungsanlage 41, die Bracketeinsetzhalter herstellt, die zu den Konturen der Zähne des Patienten passen, wie sie in den Profilen *PF* gespeichert sind. Die Halter werden vom Kieferorthopäden benutzt, um die individuellen Brackets an berechneten Positionen am Zahn zu plazieren.

Die Fertigungsausrüstung 38 wird von NC-Computerprogrammen gesteuert, die auf den Daten aus den Dateien 26 der digitalisierten Eingangsinformationen und den Dateien 36 aus den berechneten Patientendaten basieren.

Bracketfräsmaschine 39

Fig. 1D zeigt eine Maschine 39 zum Fräsen der Bracketschlitze. Die Maschine 39 umfaßt ein ortsfestes Untergestell 72, auf dem zwei aufrechtstehende Werkstückhalterstützen 72 montiert sind, an deren oberen Enden eine Werkstück- oder Bracketspannvorrichtung 73 drehbar gelagert ist. In die Vorrichtung ist ein vollständiger Satz 80a von Brackets 80 für den individuellen Apparat eingesetzt, die zuvor in einer Gruppe oder einer Packung von zwanzig oder vierundzwanzig Stück angeordnet worden sind. Die Spannvorrichtung 73 dreht sich um eine Achse 73a, die sich zwischen den Werkzeughalterstützen 72a erstreckt. In Richtung Achse 73a ist ein Winkelpositionsmotor 74 angeschlossen, der die Spannvorrichtung 73 und die darin befestigten Brackets 80 auf jeden beliebigen Winkel gegenüber der Horizontalen ausrichtet. Der Motor 74 verfügt über einen Eingang, an den der Computer 30c

angeschlossen ist, so daß mit Hilfe von NC-Steuersignalen die Neigung auf den Schlitzneigungswinkel der Bracketkonstruktion eingestellt wird.

Ebenfalls am Untergestell 72 befestigt, erhebt sich eine Fräserhalterung 72b. Am oberen Ende der Halterung 72b befinden sich ein Fräserantriebsmotor 75 sowie ein Satz von drei linearen Stellantrieben 76 für jede Richtung: ein X-Stellantrieb 76x, ein Y-Stellantrieb 76y und ein Z-Stellantrieb 76z, durch die ein Fräserhalterungsarm 77 aufgenommen und jeweils in die X-, Y- und Z-Richtung bewegt wird, d. h. horizontal in X-Richtung senkrecht zur Rotationsachse 73a der Bracketspann-vorrichtung 73, horizontal in Y-Richtung parallel zur Rotationsachse 73a der Werkstückspann-vorrichtung 73 und vertikal in Z-Richtung. Die Stellantriebe 76 sind mit dem Computer 30c verbunden, damit sie Positionierungssignale vom Computer 30c erhalten, so daß bogenförmige Schlitze in der XY-Ebene der Maschine 39 gefräst werden, und zwar aufgrund von NC-Steuersignalen entsprechend einer individuellen Apparatkonstruktion.

Am äußeren Ende des beweglichen Arms 77 befindet sich eine Schlitzfräseinheit 77a, die über eine Antriebsverbindung zum Motor 75 verfügt. Von der Einheit 77a geht eine Fräser-Antriebswelle 77b ab, an deren unterem Ende eine scheibenförmige Schlitzfrässchneide 77c befestigt ist. Die Schneide 77c befindet sich in der horizontalen XY-Ebene und weist die Dicke des Schlitzes auf, der für die Dicke des ausgewählten Bogendrahtes erforderlich ist. Die Bogendrähte haben normalerweise einen rechteckigen Querschnitt, damit sie ein Drehmoment auf das Bracket ausüben können, was mit einem Schlitz mit rechteckigem Querschnitt durch die Schneide 77c ermöglicht wird. Die Grundfläche des Schlitzes wird entsprechend den Steuersignalen vom Computer 30c gefräst, und zwar in einem Winkel in der XY-Ebene der Maschine 39, der tangential ist zur endgültigen Krümmung des Bogendrahts, den der Schlitz aufnehmen wird. Die Schlitzgrundfläche wird konvex ausgeführt, damit sie die Krümmung des Drahtes in der horizontalen Ebene aufnimmt. Die Neigung des Bracketschlitzes wird entsprechend den Steuersignalen vom Computer 30c durch den Winkel der Spannvorrichtung 73 erzielt. Der Computer 30c ist so programmiert, daß er Höhenveränderungen des Brackets 80 aufgrund der Verschiebung der Brackets zur Rotationsachse 73a berücksichtigt.

Drahtbiegemaschine 40

Die Drahtbiegevorrichtung 40 ist in Fig. 1E schematisch dargestellt. Die Leitsteuerung der Vorrichtung 40 erfolgt vorzugsweise durch einen IBM-PC-KLon, möglichst mit einem Mikroprozessor 80386 oder 80486 mit einem mathematischen Koprozessor mit eingebauter Bewegungssteuerungs-karte 65. Bei der Steuerungskarte 65 handelt es sich beispielsweise um eine 3-achsige MC300-Motion Controller-Karte der Firma Motion Engineering, Inc. Die MC300 ist eine Spezialbewegungssteuerkarte, die Signale an die MC-OLS-Schrittschalter-Schnittstellen 66a und 66b sendet und von dort empfängt. Die MC-OLS-Schrittschalter-Schnittstellen 66a und 66b senden Steuersignale an die Schrittmotor-Netzteile 67a und 67b, beispielsweise Compumotor S-Drive Schrittschalter-Netzteile #88-011483D, hinsichtlich der Drehzahl und Drehrichtung der Motoren.

Das Netzteil 67a hat einen Ausgang zu den Drahtzuführungswalzen 68, die sich auf beiden Seiten einer Drahtführung 68a befinden, die den Bogendraht 69 führt, der kontinuierlich von einer Spule zugeführt wird. Das Netzteil 67b hat einen Ausgang zur Drahtbiegewalzen-Einheit oder zum Drahtamboß 70.

Die Steuereinheit 66b ist außerdem dafür ausgelegt, daß sie Rückkopplungssignale in bezug auf die Position von einer Scheiben-Kodiereinrichtung 70a erhält, beispielsweise ein Dynapar/Veeder Root #E1000A76500, welche die Position einer Drahtbiegewalze 70b überwacht, so daß eine Regelkreissteuerung der Drahtbiegewalze 70b gegeben ist. Der Antrieb der Walze erfolgt durch einen Drahtamboß-Motor 70c, beispielsweise Compumotor #S/SX 57-102, über eine Antriebsspindel 70d, beispielsweise einen elektrischen Zylinder #X995A-2-M56-MT1-200-PS von Industrial Devices Corp. Die Spindel 70d wandelt die Winkelposition des Motors 70c in eine lineare Bewegung der Walze 70b um, so daß der Draht 69 umgelenkt und gebogen wird, während er von den Walzen 68 durch die Führung 68a zugeführt wird.

Durch Koordinierung des Ambosses 70 und der Drahtzuführung 68 lassen sich geformte Bogendrähte 64 in jeder beliebigen planaren Form herstellen. Die Walzen 68 drücken gegen den Draht und zwingen ihn in Richtung des Ambosses 70. Die Walze 70b des Ambosses 70 bewegt sich nach oben und unten mit variierendem Radius und bestimmt damit den Radius, auf den der Draht permanent umgeformt wird. Wenn es um das Formen von Bogendrähten mit Ablenkungspunkten, d. h. mit Biegungen in unterschiedliche Richtungen, geht, wird ein zweiter Amboß auf der anderen Seite des Drahtes 69 gegenüber dem Amboß 70 angebracht und synchron mit diesem gesteuert.

Ein Drahtpositionssensor 71 überprüft den fertigen Bogendraht, indem er die Weite des geformten Drahtes 64 mit der gewünschten Weite vergleicht. Der Sensor 71 ist gegenüber dem Amboß 70 und den Zuführungswalzen 68 so montiert, daß er die Position des geformten Bogendrahtes 64 erkennt, wenn dieser sich am Ende seines Formungsprozesses befindet. Diese Messung ergibt ein Rückkopplungssignal, das einen Ausgleich für Änderungen der Werkstoffeigenschaften ermöglicht, welche die gebildete Form und das Ausmaß des Umbiegens verursachen. Der Sensor 71 sendet Informationen darüber zurück an den Computer 30c, ob der Draht 64 akzeptabel oder zu stark bzw. zu schwach gebogen ist. Falls der Draht zu stark oder zu schwach gebogen ist, berechnet der Computer 30c die erforderliche Korrektur und modifiziert die Signale schrittweise über die Schnittstellen 66a und 66b, was einen Ausgleich bewirkt, so daß die nachfolgenden Bogendrähte fortschreitend korrigiert werden, bis das Ergebnis der Signale vom Sensor 71 durch den Computer 30c als akzeptabel bewertet werden.

Maschine 41 zur Fertigung der Bracketeinsetzhalter

Bei der Ausrüstung 41 zur Fertigung der Bracketeinsetzhalter handelt es sich vorzugsweise um eine übliche NC-Fräse, deren Aufbau in Fig. 1F dargestellt ist. Zu der Maschine 41 gehört die Standardfräse 81, die über einen nach unten gerichteten rotierenden Werkzeughalter 81a, an dem ein Schaftfräser 81b mit einem Durchmesser von beispielsweise 0,5 mm (0,020 Zoll), wenn ein Bogendraht von 0,55 mm (0,022 Zoll) eingesetzt wird, oder mit einem Durchmesser von 0,4 mm (0,016 Zoll), wenn ein Bogendraht von 0,45 mm (0,018 Zoll) eingesetzt wird.

Die Fräse 81 ist entweder an eine Steuereinheit, die mit dem vom Computer 30c erstellten CNC-Programmcode 42 zu laden ist, oder direkt an den Computer 30c angeschlossen. Die Fräse 81 ist mit der Werkzeuglagerung 81c versehen, ihr wird ein Satz von runden ABS-Kunststoff-Halterrohlingen 83, normalerweise zwanzig oder vierundzwanzig Stück, zugeführt, und zwar aus einem Zuführungsmechanismus 81d, der mit einem Magazin 81e von Sätzen 83a der Halterrohlinge

83 ausgerüstet ist. Der Werkzeughalter 81a läßt sich vertikal bewegen, um das Werkzeug 81b an die Halter 83 heranzuführen, sowie horizontal in XY-Richtung in Übereinstimmung mit den Pfadbefehlen vom Code 42.

ALLGEMEINE ARBEITSGÄNGE UND PROZEDUREN

Eine bevorzugte erfindungsgemäße Methode wird durch die im Flußdiagramm der Figur 2 dargestellten Arbeitsgänge und Prozeduren veranschaulicht.

Die Methode umfaßt vorzugsweise drei allgemeine Arbeitsgänge: (85) Beurteilung des Patienten, die vom Kieferorthopäden 14 in der Arztpraxis 11 am Patienten 12 durchgeführt wird; (87) computergestütze Analyse, Konstruktion und Herstellung des Apparats, die vorzugsweise zumindest zum Teil in der Fertigungsstätte 13 erfolgen, um den individuellen Apparat 25 herzustellen; und (89) Behandlung des Patienten, die die Behandlung des Patienten 12 durch den Kieferorthopäden 14 in der Arztpraxis 11 durch Einsetzen und Benutzen des Apparats 25 umfaßt.

(85) Arbeitsgang Beurteilung des Patienten

Entsprechend dem System-Schema von Fig. 1 und dem Flußdiagramm von Fig. 2 erfolgt die kieferorthopädische Beurteilung (85) in einer Arztpraxis 11. Der Arbeitsgang (85) umfaßt die folgenden Schritte: (90) die Untersuchung des Patienten 12, (91) die Anfertigung des Modells 20 von Mund und Zähnen des Patienten, (92) die Verordnung einer Behandlung durch den Kieferorthopäden 14 und (93) die Nachrichtenübermittlung zur Apparatefertigungsstätte 13.

Die Untersuchung (90) des Patienten 12, der eine kieferorthopädische Behandlung benötigt, wird vom Kieferorthopäden 14 durchgeführt, der eine Diagnose 15 zu den Gegebenheiten beim Patienten stellt und nötigenfalls eine Entscheidung über eine Behandlung trifft. Auf der Grundlage der Diagnose 15 stellt der Kieferorthopäde oder Arzt 14 die Informationen 16 zusammen, die für die Durchführung der verordneten Behandlung erforderlich sind.

Für die Zusammenstellung der Informationen 16 fertigt der Kieferorthopäde 14 (91) ein Modell vom Mund 18 des Patienten an, üblicherweise ein physisches Modell 20 von einem Abdruck vom Mund des Patienten, und zwar von den ursprünglichen Gegebenheiten zum Zeitpunkt der Diagnose 15. Zu dem Modell 20 gehört das Mandibularmodell 21 vom Unterkiefer 22 des Patienten sowie das Maxillarmodell 23 vom Oberkiefer 24 des Patienten.

Dann wird aufgrund der Diagnose 15 vom Kieferorthopäden 14 (92) eine bestimmte Behandlung festgelegt und diese Verordnung 27 in schriftlicher Form erstellt.

Anschließend reicht der Kieferorthopäde 14 die (92) Informationen 16 weiter, indem er beispielsweise das Modell 20, die Verordnung der Behandlung 27, eine Akte mit Informationen 17, die den Arzt 14 und den Patienten 12 identifizieren, zusammen mit Informationen 19 mit Angaben zur Statistik und Geschichte des Patienten 12 an eine Apparatkonstruktions- und Fertigungsstätte 13 an einem anderen Ort übersendet. In der Apparatkonstruktions- und Fertigungsstätte 13 werden die Informationen 16 in digitalisierte Daten umgewandelt und zur Analyse in den Computer 30 eingegeben.

Andererseits kann der Kieferorthopäde 14 die Informationen 16 in eine digitale, computerlesbare Form konvertieren und die digitalisierten Informationen an die Apparatkonstruktions- und Fertigungsstätte 13 übermitteln. In diesem Alternativfall wäre das System 10 so aufgebaut, daß sich

der Eingabecomputer 30 in der Praxis 11 des Kieferorthopäden befindet, und der Kieferorthopäde 14 oder sein Personal würden Teile der unten beschriebenen Dateneingabeprozedur (94) ausführen.

(87) Arbeitsgänge Analyse, Konstruktion und Herstellung

Wenn die Informationen 16, die beispielsweise das Modell 20, die Verordnung 27 sowie die Informationen 17 und 19 umfassen, entweder bei der Apparatkonstruktions- und Fertigungsstätte 13 eingehen oder zur Digitalisierung in der Praxis 11 des Kieferorthopäden zur Verfügung stehen, beginnt der (87) Arbeitsgang der Analyse, Berechnung der Zahnendpositionen sowie der Konstruktion und Herstellung des Apparates. Bei dem Arbeitsgang (87) werden die Informationen 16 verarbeitet, und der individuelle kieferorthopädische Apparat 25 zur Bewegung der Zähne des Patienten in eine optimale Endposition in Übereinstimmung mit der vom Kieferorthopäden 14 verordneten Behandlung wird hergestellt.

(94) Eingabeprozedur

Die Eingabeprozedur (94) ist im Flußdiagramm von Fig. 2A dargestellt. Bei der Prozedur (94) werden die erhaltenen Informationen 16 in digitaler Form in einen Computer 30 eingegeben, bei der dargestellten Ausführung durch den Operator 28 in der Fertigungsstätte 13. Auch wenn die Eingabe durch einen Operator in der Fertigungsstätte 13 erfolgt, kann ein Teil der Informationen 16, beispielsweise die Informationen 17 und 19, vom Kieferorthopäden in maschinenlesbarer Form erstellt und direkt in den Computer 30 eingegeben werden. Die Eingabeprozedur umfaßt fünf Schritte (100) - (500). Die Schritte der Eingabeprozedur (90) (muß eigtl. (94) sein) umfassen bei der dargestellten Ausführung bestimmte Unterschritte, die Bestandteil des Analyseschritts (92) sind, sie werden jedoch günstigererweise zum Zeitpunkt der Eingabe der Informationen in den Computer vorgenommen.

Die Eingabeschritte (100) und (200) betreffen die Eingabe von Hintergrundinformationen, die vom Kieferorthopäden 14 zusammengestellt worden sind. Während der Eingabeschritte (300), (400) und (500) werden die Positionen und Profile von Zähnen und Kiefer definiert, und zwar in Form kieferorthopädischer Parameter und Meßpunkte, die später vom Computer analysiert werden können, um die in die Verordnung 27 einfließenden kieferorthopädischen Kenntnisse, Fähigkeiten und Erfahrungen sowie die der kieferorthopädischen Profession insgesamt am besten umzusetzen, so daß automatisch und wirkungsvoll ein optimales Ergebnis erzielt wird.

(95) Analyse und Zahnpositionierung

Die Computeranalyse ist im Flußdiagramm von Fig. 2B dargestellt. Bei der Computeranalyse (95) werden die bei der Eingabeprozedur (94) eingegebenen Informationen analysiert, um die Zahnendpositionen zu berechnen, so daß der individuelle Apparat 25 in einer computergestützten Konstruktionsprozedur (96) entworfen und in einer computergesteuerten Herstellungsprozedur (97) produziert werden kann. Die Analyseprozedur (95) umfaßt sechs Schritte und Subroutinen (600) - (1100). Diese Schritte beinhalten folgendes:

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(600) Zahnanalyse, bei der die kieferorthopädischen Meßpunkte der Zähne identifiziert werden: Eine minimale Anzahl von Punkten auf den Zahnprofilen wird ausgewählt, die ausreichen, um die Kontaktpunkte zwischen den Zähnen zu bestimmen, die relevant sind für die Berechnung der Zahnendpositionen und die Konstruktion des Apparats.

(700) Schritt zur Bestimmung der Eckzahnanhebung, bei dem die Okklusion der oberen und unteren Zähne definiert wird.

(800) Schritt zur Positionierung der Unterkieferzähne, bei dem die Ebene der Unterkieferzähne definiert wird und die Zähne im Hinblick auf die Mandibularalveolenmulde positioniert werden. Dazu gehören folgende Schritte: Anordnen der Zähne, wobei ihre Kronenlängsachse CLA die Ebene der Mandibularalveolenmulde schneidet, entlang der Manibularalveolenmuldengleichung MTE; vertikale Angleichung der Zähne, so daß die Spitzen (ausgenommen die Eckzähne) in einer Ebene liegen; trigonometrische Berechnung eines horizontalen Versatzes für jeden Zahn, und zwar an seiner Kronenhöhe, und seines Längsachsenneigungswinkels LAI, um eine Mandibularalveolenmulden-Versatz-Gleichung MO zu definieren; Anordnen der Zähne entlang der Versatz-Gleichung MO und Bewegen der restlichen Zähne, wobei ihre mesialen Kontaktpunkte MCP an den distalen Kontaktpunkten DCP des vorangehenden Zahns angrenzen.

(900) Schritt der Best-fit-Berechnung für die Zahnhöcker, bei dem die Best-fit-Gleichung für den Mandibularbogen abgeleitet wird.

(1000) Schritt des Anordnens der Unterkieferzähne, bei dem die Positionen der Unterkieferzähne für die Anordnung auf der Best-fit-Bogengleichung berechnet werden.

(1100) Schritt des Anordnens der Maxilla, bei dem der Maxillarbogen für die Okklusion mit den bereits angeordneten Unterkieferzähnen abgeleitet wird.

Da die Okklusion der Vorderzähne nicht das Anliegen von Schneidezahnkante auf Schneidezahnkante bedeutet, wird die Best-fit-Bukkal-Höcker-Gleichung BFBCE modifiziert, so daß der Abstand von der BFBCE zu den labialen Kontaktpunkten der Unterkieferschneidezähne und -eckzähne sowie ein horizontaler oder labialer Zwischenraum gegenüber den Oberkieferzähnen berücksichtigt wird. Dadurch werden die Okklusionspunkte zu den Vorderzähnen des Oberkiefers definiert, und zwar am Schnittpunkt ihrer lingualen Flächen mit der Okklusionsebene MOC.

Anschließend wird die vertikale Positionierung der maxillaren Vorderzähne und Eckzähne vorgenommen, und zwar anhand der bereits beschriebenen vertikalen Okklusionsprozedur, so daß ein Übergreifen für die Schneidezähne sowie eine Eckzahnanhebung ermöglicht wird, wie sie in Schritt (700) festgelegt wurden. Dadurch wird das Übergreifen oder der Überbiß der Schneidezähne definiert.

Die Positionierung der hinteren Oberkieferzähne legt die Schnittpunkte der Randleistenbereiche und der zentralen Höckerfurchen gemäß der Schritte (400) bis (600) mit den Höckern der Unterkieferzähne fest, mit denen sie in Okklusion stehen. Die Bogenformen für die Positionierung der Oberkieferzähne sind in Fig. 4B dargestellt.

Die vertikale Positionierung der übrigen Zähne berücksichtigt die Okklusion sowie weitere Informationen der Verordnung, die in Schritt (200) eingegeben wurden. Die verbleibenden

Berechnungen werden im folgenden ausführlich beschrieben.

(96) Prozedur zur Konstruktion des Apparats

Bei der Apparatkonstruktionsprozedur (96), wie sie im Flußdiagramm von Fig. 2C dargestellt ist, werden die Abmessungen der Komponenten des Apparats berechnet, und zwar in einer Form, die in NC-Codes transformiert werden kann, um die NC-Maschinen zu betreiben, die die Apparatkomponenten herstellen, beispielsweise die Brackets und Bogendrähte sowie die Halter zum Einsetzen der Brackets an den richtigen Positionen auf den Zähnen des Patienten. Die Prozedur der Apparatkonstruktion (96) umfaßt die folgenden Schritte (1200) bis (1800):

(1200) Schritt zur Bestimmung der Unterkiefer-Bogendrahtebene, bei dem die Ebene des Bogendrahts für die Unterkieferzähne in bezug auf die Unterkieferzähne definiert wird. Der Bogendraht sollte vorzugsweise in einer buchstäblich flachen Ebene liegen und symmetrisch zur Mittellinie des Bogens angeordnet sein. Dann weist der Bogendraht die erforderliche Form auf, so daß es keine Rolle spielt, welche Seite nach oben eingesetzt wird.

(1300) Schritt zur Bestimmung der Unterkiefer-Schlitzneigung, bei dem die Winkel der Schlitze der Brackets des Apparats für die Unterkieferzähne berechnet werden.

(1400) Schritt zur Bestimmung der Oberkiefer-Bogendrahtebene, bei dem die Ebene des Bogendrahts für die Oberkieferzähne in bezug auf die Oberkieferzähne definiert wird.

(1500) Schritt zur Bestimmung der Oberkiefer-Schlitzneigung, bei dem die Winkel der Schlitze der Brackets des Apparats für die Oberkieferzähne berechnet werden.

(1600) Schritt zur Berechnung der inneren und äußeren Abmessungen von mandibularem Bogendraht und Bracket, bei dem die Schlitztiefe und die Bracketgeometrie für die Unterkieferbrackets berechnet wird.

(1700) Schritt der Berechnung der inneren und äußeren Abmessungen von maxillarem Bogendraht und Bracket, bei dem die Schlitztiefe und die Bracketgeometrie für die Oberkieferbrackets berechnet wird.

Bei der Bestimmung der inneren und äußeren Abmessungen werden die tiefsten und flachsten Schlitztiefen bestimmt, ebenso die stetigste Bogendrahtkrümmung, und zwar die mit der geringsten Radiusveränderung im Verlauf der Krümmung und möglichst ohne Ablenkungspunkte, die innerhalb der Tiefenbegrenzungen liegt.

(1800) Schritt der Konstruktion der Bracketeinsetzhalter, bei dem Einsetzhalter konstruiert werden, die zur richtigen Positionierung der individuellen Brackets an den Zähnen des Patienten dienen.

Fig. 8D zeigt einen Kunststoffhalter 82, der vollständig an Wänden und Boden des Bracketschlitzes anliegt. Zusätzlich wird der den Zahn berührende Abschnitt der Vorrichtung 82 so konstruiert, daß er sich genau der bekannten Kontur des Zahns anpaßt, wie es durch den Profileingabeschritt (500) festgelegt wurde. Dadurch wird sichergestellt, daß der Bracketschlitz und somit das Bracket beim Anbringen am Zahn genau in der richtigen Höhe plaziert werden.

(97) Prozedur der Apparatherstellung

Die Apparatherstellungsprozedur (97), dargestellt im Flußdiagramm von Fig. 2D, beinhaltet die Erzeugung von Steuereinheitcodes für die NC-Maschinen, die für die Herstellung der in der

Apparatkonstruktionsprozedur (96) entworfenen Brackets, Bogendrähte und Bracketeinsetzhalter sowie die Herstellung der Apparatkomponenten unter Einsatz der Maschinen, die mit diesen Codes gesteuert werden, bestimmt sind. Die Prozedur (97) umfaßt folgende Schritte:

(3000) Steuerung und Bedienung der Bracketherstellungsanlage 39, um die individuellen Brackets zu produzieren.

(3100) Steuerung und Bedienung der Drahtbiegeanlage 40, um die individuellen Bogendrähte herzustellen.

(3200) Steuerung und Bedienung der Einsetzhalterfertigungsanlage 41, um individuelle Einsetzhalter für die Plazierung der Brackets an den Zähnen des Patienten herzustellen.

(98) Versand der Apparate

Eine der abschließenden Zielsetzungen besteht darin, dem Kieferorthopäden 14 den individuellen kieferorthopädischen Apparat 25 zu übersenden, zusammen mit Vorrichtungen und Informationen, die für die richtige Installation des Apparates 25 im Mund des Patienten 12 erforderlich sind, um den Patienten durch Bewegen seiner Zähne in die berechneten Endpositionen zu behandeln. Das läßt sich am besten anhand von Fig. 1 verstehen.

Bezug nehmend auf Fig. 1 kann sich, wie oben erläutert wurde, die Konfiguration des bevorzugten Systems 10 unterschiedlich gestalten, je nach Art und Größe der Praxis des Kieferorthopäden. Günstigerweise findet der Konstruktionsanteil der Prozedur (87) vollständig oder zum größten Teil in der Apparatkonstruktions- und Fertigungsstätte 13 statt, obwohl bei einer großen kieferorthopädischen Klinik der gesamte Prozeß am Behandlungsort des Patienten ausgeführt werden könnte. Dennoch erfolgen üblicherweise die Arbeiten des Konstruktionscomputers 30b oder des Konstruktionsteils des Computers 30 in der Konstruktions- und Fertigungsstätte 13, ebenso wie einige der die Herstellung betreffenden Funktionen des Herstellungssteuerungscomputers 30c und der Ausrüstung 38 zur Herstellung der Apparate.

Im Fall der Konfiguration, bei der gemäß Abbildung der Apparat 25 teilweise oder vollständig in der Fertigungsstätte 13 hergestellt wird, wird der individuelle Apparat 25 an den Kieferorthopäden 14 geschickt. Zusammen mit dem Apparat 25 wird eine Dokumentation in Form eines Ausdrucks übersandt, und zwar mit den vom Konstruktionscomputer 30b erstellten Informationen 37, die außerdem eine Dokumentation der Eingabedaten umfassen können, die aus den Daten 26 und den Informationen über die Verordnung 27 bestehen, sowie ein Ausdruck der vom Fertigungscomputer 30c gespeicherten Parameter.

Der übersandte Apparat 25 umfaßt einen Satz Bogendrähte 64, wie sie in den Fig. 8E und 8F dargestellt sind, einen kompletten Satz individueller Brackets 80, wie sie in Fig. 8D und 8F dargestellt sind, sowie die Einsetzhalter, wie sie in Fig. 8D und 9T bis 9W dargestellt sind. Zu den Haltern 82 gehört ein Satz von Paßstücken 84, die dazu dienen, die Schlitze 80b der Brackets 80 nach den koplanaren Schlitzen 84a der Halter 82 auszurichten. Der Apparat und die Bracketeinsetzhalter ähneln sich deshalb im Fall von lingualen Apparaten, wobei ein dazugehöriges Bracket an dem Zahn in Fig. 8G dargestellt, während der linguale Apparat in seiner Positionierung an den Unterkieferzähnen in Fig. 8H gezeigt wird.

Weiterhin werden dem Kieferorthopäden 14 individuelle Bogendrähte 64 zugesandt. Bei diesen Bogendrähten handelt es sich um Bogendrähte in der exakten Form, wie sie in Fig. 8E dargestellt sind, damit die Zähne in ihre berechneten Endpositionen bewegt werden, wie es beispielsweise für die unteren Zähne in Fig. 4D gezeigt wird. Der Bogendraht 64 in Fig. 4D ist im spannungsfreien Zustand dargestellt (oder mit nomineller Restspannung, die zuweilen Kieferorthopäden dazu veranlaßt, eine Überkorrektur zu verordnen), den er erreicht, wenn der Apparat 25 die Zähne des Patienten in die berechneten Endpositionen bewegt hat. Hier handelt es sich um die gleiche Form wie bei dem an den Kieferorthopäden 14 gesandten Bogendraht von Fig. 8E. Dieser für die Finalbehandlung gedachte Bogendraht ist aus einem Material und von einer Steifheit, die dazu dienen sollen, die Zahnendposition zu erreichen. In Abhängigkeit von der Stärke der ursprünglichen Fehlpositionierung der Zähne des Patienten können aber auch weniger steife oder temporäre Bogendrähte für den Beginn der kieferorthopädischen Behandlung angefordert werden. Dem Kieferorthopäden 14 werden also zusätzliche Bogendrähte 64 mit unterschiedlichen Eigenschaften, jedoch mit der in Fig. 8E gezeigten Form angeboten. Weiterhin oder als Alternative zu diesen zusätzlichen Bogendrähten werden dem Kieferorthopäden 14 Zeichnungen in Originalgröße oder Schablonen mit der in Fig. 8E gezeigten Form zur Verfügung gestellt, damit er Bogendrähte für eine Vorbehandlung oder Grundpositionierung formen kann.

Bei anderen Konfigurationen könnten Informationen in maschinenlesbarer Form von einem Konstruktionskomputer 30b, beispielsweise per Diskette 34 oder Modem, zu einem Fertigungscomputer 30c gesandt werden, der an eine oder mehrere Fertigungsanlagen 38 für Apparatkomponenten angeschlossen ist.

(89) Behandlung der Patienten

Die Behandlung der Patienten umfaßt zunächst die Zusammenstellung der entsprechenden Kombination von Bracket 80, Halter 82 und Paßstück 84, wie es in Fig. 8D dargestellt ist, sowie das damit erfolgende Einsetzen der Brackets 80 an den Zähnen des Patienten. Dazu gehört das Aufbringen eines Klebemittels, im allgemeinen in der Mitte der Zahnfläche, labial oder lingual, an der die Brackets 80 angebracht werden sollen. Das wird anhand des Beispiels in Fig. 8D (?) veranschaulicht, wobei ein Bracket 80 an der labialen Fläche eines Unterkieferschneidezahns $T_{0,1}$ befestigt ist. Die Anordnung wird am Zahn positioniert, wobei das Blatt des Halters 82 im allgemeinen in senkrechter labial-linguale Querrichtung durch das ungefähre Zentrum des Zahns ausgerichtet wird, in einer Ebene, die auch als Kronenlängsachse CLA des Zahnes bezeichnet werden kann.

Wenn das Klebemittel ausgehärtet ist, wird der Bracketeinsetzhalter 82 entfernt, indem zunächst das Paßstück 84 mesiodistal herausgezogen und anschließend der Halter 82 von der Schneidkante des Zahns abgezogen wird, wobei das Bracket in der berechneten Position zurückbleibt.

Nachdem sich nun die Brackets 80 an den Zähnen befinden, wird der Bogendraht 64 eingesetzt. Für gewöhnlich ist der zuerst eingesetzte Bogendraht weniger steif als der letzte. Beim Beispiel von Fig. 8F werden die Unterkieferzähne in der in Fig. 4 und 4A gezeigten Ausgangsposition gezeigt. Die Brackets werden genau in denselben Positionen an den Zähnen angebracht, wie sie anhand der berechneten Endpositionen in Fig. 4D dargestellt sind. Da sich die Zähne noch nicht in

ihrer idealen Endposition befinden, wird der Bogendraht 64, wenn er in die Bogendrahtschlitze eingesetzt und an den Brackets 80 befestigt wird, gemäß Fig. 8F in einem elastisch deformierten Zustand gespannt. Dieser gespannte Zustand des Bogendrahts 64 bewirkt, daß die Kräfte auf die Zähne ausgeübt werden, die sie in ihre idealen Positionen von Fig. 4D zwingen, ohne daß der Kieferorthopäde den Draht künstlich biegen muß. Diese Kraft bleibt solange bestehen, bis die Zähne sich an ihre Endpositionen bewegt haben. Bei einigen verordneten Behandlungsformen sind Draht und Brackets so ausgelegt, daß sie die Zähne in eine leicht überkorrigierte Position bringen, so daß nach Entfernen des Apparats 25 eine Entspannungsbewegung erfolgen kann.

EINZELHEITEN DER SCHRITTE DER APPARATANALYSE, ZAHNPOSITIONSBERECHNUNG SOWIE APPARATKONSTRUKTION UND -FERTIGUNG (87)

Wie oben bereits erwähnt umfaßt der Arbeitsgang der Analyse, Konstruktion und Fertigung (87) die (94) Eingabe, (95) Analyse, (96) Konstruktion, (97) Fertigung und (98) Versendung bei einer computergestützten Fertigung individuell projektierter Apparate.

Digitalisiertes Eingabeverfahren (94)

Die Eingabe digitalisierter Informationen umfaßt (100) die Eingabe von Identifikationsdaten über Patient und Arzt, (200) die Eingabe von Hintergrundinformationen über den Patienten, (300) die Eingabe digitalisierter Informationen über die horizontalen Abmessungen von Unterkieferzähnen und Unterkieferknochen, (400) die Eingabe der horizontalen Abmessungen der Oberkieferzähne sowie (500) die Eingabe von Informationen über das vertikale labial-linguale Profil jedes einzelnen Zahnes.

(100) Schritt Eingabe von Identifikationsdaten

Die Eingabe der Arzt-Patient-Idenfikationsdaten 17 umfaßt Unterschritte, die ein Operator 28 entsprechend den Anforderungshinweisen für die Texteingabe an einem Computerterminal vornimmt, und zwar die Eingabe des Namens des Arztes, der Identifikation des Arztes und des Namens des Patienten. Anschließend ordnet der Computer 30 die (120) Identifikationsnummer des Patienten zu. Aufgrund dieser Informationen (125) wird eine patientenspezifische Floppy-Disk oder Diskette 34 formatiert.

(200) Schritt Eingabe von Hintergrundinformationen über den Patienten

Alle Hintergrundinformationen 19 über den Patienten sowie die Informationen über die vom Arzt verordnete Behandlung 27 umfassen von den Hintergrundinformationen 19 das Alter des Patienten, sein Geschlecht und seine Rasse sowie das Auswählen bestimmter Vorgaben aus einer Anzahl von vorgeschlagenen Vorgaben wie:

- ob die Behandlung eine Extraktion beinhaltet, und wenn ja, welcher Zähne;
- ob es sich beim Okklusionstyp um eine Gruppenfunktion oder um eine Eckzahnanhebung handelt, und wenn um eine Eckzahnanhebung, ob Mittelwerte oder ein individueller Kopffilm eingesetzt werden sollen;
- ob der Abstand zwischen den unteren Eckzähnen beibehalten oder eine Erweiterung zugelassen werden soll, und im Falle von letzterem, eine Erweiterung welchen Ausmaßes;
- ob die Okklusion vollständig ist oder nicht;

- ob ein Steiner-Kompromiß zulässig ist;
- ob eine Roth- oder Ricketts-Einlage an den oberen zweiten Schneidezähnen eingesetzt werden soll, und wenn ja, welche;
- ob ein oberer lateraler Überbiß nach Roth oder Andrews gegeben ist, und wenn ja, welcher;
- ob der Fall mit einem labialen oder einem lingualen Apparat behandelt werden soll;
- ob der Fall mit Hilfe von Symmetrie diagnostiziert werden soll oder nicht; oder
- wie der Winkel zwischen den Schneidezähnen bestimmt werden soll, nach dem Andrews-Verfahren, dem Verfahren 'parallele obere Schneidezähne zu Fazialachse' oder dem Ricketts-Verfahren.

(300) Schritt digitale Bildeingabe in bezug auf den Unterkiefer

Die Eingabe von Bildern oder Draufsichtgrafiken vom Unterkiefer des Patienten, einschließlich der Zähne, ist in Fig. 3 dargestellt und umfaßt die Digitalisierung und Verarbeitung von Daten über die Breite der Unterkieferzähne sowie von Größe und Form des Mandibularknochens oder Unterkieferknochens 22 des Patienten 12 aus der horizontalen Draufsicht des Unterkiefers wie in Fig. 4. Die Wurzeln der unteren Zähne des Patienten sind in der Mandibularalveolenmulde *MT* enthalten, die als Raum zwischen den Grenzen B_L und B_B von Fig. 4 definiert ist. Die äußere oder bukkale bzw. innere oder linguale Grenze B_B bzw. B_L werden günstigerweise durch den Operator 28 mittels interaktiver Selektion digitalisiert, und zwar aus einem Bild 48 der Kompakta des Unterkiefers 22 auf dem Bildschirm 35. Außerdem müssen die Unterkieferzähne in Kontakt miteinander im Bogen liegen. Jeder von ihnen nimmt einen Bogenabschnitt ein, der dem Abstand zwischen ihren mesialen und distalen Kontaktpunkte zum Nachbarzahn entspricht. Ein Raster *G* wird darübergelegt, um die XY-Koordinaten zu definieren, wobei die Y-Achse auf einer Mittellinie *ML* des Unterkiefers 22 und die X-Achse lotrecht zur Y-Achse durch einen ausgewählten Schnittpunkt oder Nullpunkt *0,0* verläuft, vorzugsweise an einem mesialen Kontaktpunkt der unteren mittleren Schneidezähne.

Der Operator wählt nacheinander jeden Punkt aus, zunächst für die einzelnen Zähne die Kontaktpunkte, dann die Kieferknochengrenzen. Aus den XY-Koordinaten von M_{xy}, M_x und M_y sowie von D_{xy}, D_x und D_y wird die mesiodistale Breite *MDW* eines jeden Zahns *I* auf beiden Seiten des Unterkiefers 22 mit Hilfe des Lehrsatzes des Pythagoras berechnet:

$$MD = \sqrt{(M_x + D_y)^2 + (M_y + D_y)^2}$$

worin

M_x die mandibulare X-Koordinate,

M_y die mandibulare Y-Koordinate,

D_x die distale X-Loordinate und

D_y die distale Y-Koordinate ist.

Aus den ausgewählten Schnittpunkten der Linien des Rasters *G* mit den Unterkiefergrenzen B_B und B_L

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werden die kartesischen Koordinaten $La_{x,y}$ und $Li_{x,y}$ der labialen und lingualen Grenzen der Kompakta auf beiden Seiten des Unterkiefers gebildet, und Mittelpunktkoordinaten MP_{xy} werden berechnet, ebenso wie die Knochenbreitenabstände zwischen jedem der jeweiligen labio-lingualen Paare *DLL*, und zwar forgendermaßen:

$$MP_x = La_x + \frac{Li_x - La_x}{2}; MP_y = La_y + \frac{Li_y - La_y}{2}$$

$$DLL = \sqrt{(La_x + Li_x)^2 + (La_y + Li_y)^2}$$

Die Summe der einzelnen Unterkieferzahnbreiten *MDW* ist gleich der Gesamtzahnlänge oder Mandibularbogenlänge *MAL*, die in der Mandibularalveolenmulden-Funktion *MTE* enthalten ist, welche durch die Punkte MP_{xy} konstruiert ist. *MAL* wird als Bogenumfang bezeichnet.

In diesem Stadium werden die Mittelpunkte normalerweise von rechts nach links gemittelt, um jede Asymmetrie auszuschalten, die aufgrund von leichten Meßfehlern vorhanden sein könnte, es sei denn, beim Patienten wurde eine asymmetrische Anatomie diagnostiziert.

Die in Fig. 4 gezeigte Mittellinie *ML* stellt die Achse derartiger Symmetriekorrekturen dar. Die Korrekturen für jeden Punkt $MP_{x,y}$ werden folgendermaßen berechnet:

$$S_x = MP_x + \frac{PR_x - PL_x}{2}; S_y = MP_y + \frac{PR_y - PL_y}{2}$$

worin

$S_{x,y}$ der einer Symmetrierung unterzogene Punkt $MP_{x,y}$,

$PR_{x,y}$ der Punkt $MP_{x,y}$ auf der rechten Seite, und

$PL_{x,y}$ der entsprechende Punkt auf der linken Seite der Mulde ist.

Nach Abschluß dieser Symmetrierung wird eine mathematische Funktion *MTE*, welche Größe und Form der Mandibularalveolenmulde beschreibt, abgeleitet, indem eine Kurve an die Punkte $MP_{x,y}$ angepaßt wird. Vorzugsweise wird diese Kurve abgeleitet, indem eine Reihe von Funktionen wie eine kubische Spline-Funktion angepaßt wird, damit sie glatt durch die Punkte verläuft, beispielsweise die gemittelten Mittelpunte $S_{x,y}$.

Anschließend werden die kubischen Funktionen vorzugsweise in bezug auf ihre Form umgewandelt in eine Reihe von Segmenten sich einander berührender Kreisfunktionen mit Anstiegen, die mit den Anstiegen der kubischen Splines an den Mittelpunkten identisch sind, ebenso wie mit den Anstiegen der angrenzenden Kreissegmente an den Segmentendpunkten oder an ihren Schnittpunkten an der Kurve. Um eine kubische Funktion mit Quadratwerten anzupassen, werden zwei Kreise *CS* und *CL* benutzt, um jedes Segment der *MTE* zwischen den Mittelpunkten zu beschreiben, wie in Fig. 5 dargestellt ist. Dadurch wird eine glatte aus tangentialen Kreisen bestehende Kurve ermöglicht, die die Mandibularalveolenmulde repräsentiert. Das Verfahren der

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Spline-Kreis-Umwandlung wird unten ausführlicher als Routine (2100) beschrieben.

Wie aus Fig. 4 ersichtlich, werden kartesische Koordinaten für die rechten und linken mandibulare Eckzahn-Höcker *CR* und *CL* eingegeben. Anschließend wird der Abstand *DCT* zwischen den Höckern *CR* und *CL* der beiden Unterkiefereckzähne berechnet:

$$DCT = \sqrt{(CR_x + CL_x)^2 + (CR_y + CL_y)^2}$$

Diese Angaben werden genutzt um zu berechnen, ob und wie der Abstand zwischen den Unterkiefereckzähnen verändert werden muß, und um einzuschätzen, ob die berechnete Endposition akzeptabel ist. In ähnlicher Weise werden kartesische Koordinaten der rechten und linken mesio-bukkalen Höcker *MR* und *ML* der ersten Unterkiefermolare berechnet, und der Abstand zwischen diesen Punkten *DMT* wird errechnet:

$$DMT = \sqrt{(MR_x + ML_x)^2 + (MR_y + ML_y)^2}$$

Diese Angaben dienen dazu, festzustellen, ob und wie der Abstand zwischen den Unterkiefermolaren zu ändern ist.

(400) Schritt digitale Bildeingabe in bezug auf den Oberkiefer

Ebenso wie bei den Informationen zum Unterkiefer, die im Zusammenhang mit Fig. 4 beschrieben werden, wird auf die gleiche Weise ein Computerbild vom oberen Modell 23 des Oberkiefers aus dem in Fig. 4A dargestellten Bild 48a erstellt.

Die Koordinaten $R_{x,y}$ und $L_{x,y}$ der mittleren Fossae des rechten und linken ersten Oberkiefermolars werden eingegeben. Anschließend wird der Abstand zwischen den mittleren Fossae *DCF* folgendermaßen berechnet:

$$DC = \sqrt{(R_x + L_x)^2 + (R_y + L_y)^2}$$

Diese Angaben werden, nachdem die Zahnendpositionen berechnet wurden, erneut berechnet, damit eine Übereinstimmung mit dem *DMT*-Abstand der ersten Unterkiefermolare gegeben ist. Außerdem werden diese Informationen mit der ersten Messung verglichen, als Indikator dafür, ob bei der Behandlung eine Veränderung der intermolaren Weite vorgenommen wird und, wenn ja, welches Ausmaß eine derartige Änderung haben muß.

(500) Schritt Eingabe der digitalisierten Abtaster-Zahnprofile

Bei diesem Schritt werden ausgewählte Profile von jedem der Zähne entweder vom Modell 20, von einer digitalisierten dreidimensionalen Darstellung der Zähne des Patienten oder vom Modell erstellt, wie aus Fig. 3A und 3B ersichtlich. Bei der dargestellten Ausführung wird für diesen Schritt die Abtaster-Einheit 57 von Fig. 1B eingesetzt.

Die Auswahl der Profilebene wird in Fig. 6 veranschaulicht, wobei ein erstes Profil PF_A durch das Zentrum des Zahn gezeigt ist, was daraus ersichtlich ist, daß die bukkalen Höcker fehlen, die die

maximale Kronenhöhe des Zahns darstellen. Anschließend wird das Profil PF_B mit bukkalem Höcker ausgewählt, wobei sich die Profilleiste offenbar im allgemeinen nach dem Tiefpunkt von PF_A ausrichtet. Andererseits kann das Profil nichtplanar sein, so daß es die wichtigen Merkmale beider Ebenen enthält. In diesem Fall ist das erzeugte Profil vergleichbar mit einer Projektion auf eine Ebene der relevanten äußeren Grenzen des Zahns. Die sich ergebenden Profile PF_I sind in Fig. 3C dargestellt.

(95) Prozedur Analyse und Berechnung Zahnendpositionen

Die Berechnung der Zahnendpositionen umfaßt, wie im Flußdiagramm von Fig. 2B gezeigt, (600) die Bestimmung der relativen Positionen der geometrischen Meßpunkte auf den Zahnflächen und Festlegung der Achsenneigung der Zähne, (700) die Berechnung der Eckzahnanhebung, (800) die anfängliche Positionierung der Unterkieferzähne, in vertikaler Richtung sowie im Verhältnis zur Mandibularalveolenmulde, (900) die Berechnung einer Best-fit-Höckerspitzen-Funktion für die Unterkieferzähne, und (1000) die Berechnung der Endpositionen der Unterkieferzähne auf der Best-fit-Funktion und (1100) die Berechnung der Endposition der Oberkieferzähne, mit der Best-fit-Funktion korrelieren, auf drei Bögen.

(600) Schritt Identifikationsanalyse der Zahnmeßpunkte

Die Eingabedaten 26 werden analysiert, um weitere Parameter für die Berechnung der Zahnendpositionen sowie für (96) die Konstruktion des Apparats 25 zu entwickeln oder abzuleiten. Bei der Zahnpositionierungsanalyse (95), wie sie im Ablaufschema von Fig. 2B dargestellt ist, wird eine (600) Zahnprofilanalyse durchgeführt, bei der in Abhängigkeit von dem zu analysierenden Zahn beispielsweise bestimmte anatomische Meßpunkte ausgewählt werden.

Beim Schritt der Zahnprofilanalyse werden einzelne Bilder 63 der Profilkurven PF_I jedes Zahns (Fig. 3C) getrennt auf den Bildschirm des Computers 30b geladen, um die Meßpunkte auszuwählen.

Unter Verwendung der Bilder 63 der Profilkurven PF_I werden spezifische Meßpunkte ausgewählt, zunächst für die Molare und Prämolare des Unterkiefers. Die ausgewählten Punkte werden gemäß Fig. 6 digitalisiert. Bei den ausgewählten Punkten handelt es sich um folgende:

Punkt P_1: Linguale (zungenseitiger) Schnittstelle zwischen Zahnfleisch und Zahn.

Punkt P_2: Vorsprung des lingualen Höckers.

Punkt P_3: Vorsprung des bukkalen (backenseitigen) Höckers.

Punkt P_4: Bukkale Schnittstelle zwischen Zahnfleisch und Zahn.

Aufgrund dieser Meßpunkte wird die (615) Kronenlängsachse *CLA* von jedem Molar und Prämolar, dessen Profil aufgenommen wurde, bestimmt. Diese Bestimmung erfolgt, indem eine erste Linie L_1 zwischen den Punkten P_2 und P_3 sowie eine zweite Linie L_2 zwischen den Punkten P_1 und P_4 konstruiert wird. Die Kronenlängsachse *CLA* eines Zahns ist die Linie zwischen den Mittelpunkten von L_1 und L_2.

Ein Punkt, der abstandsgleich zwischen den Punkten P_1 und P_4 auf der Linie L_2 liegt, wird berechnet, und ein Punkt, der abstandsgleich zwischen den Punkten P_1 und P_4 auf der Linie L_2 liegt, wird ebenfalls berechnet und als Gingivamittelpunkt *GCP* definiert.

Die Linie, die die Kronenlängsachse *CLA* definiert, wird mit Hilfe folgender Gleichung

konstruiert:

worin:

X_{2-3}, Y_{2-3} = X- und Y-Koordinaten des Mittelpunktes P_{2-3}

$$\frac{Y - Y_{2-3}}{X - X_{2-3}} = \frac{Y_{GCP} - Y_{2-3}}{X_{GCP} - X_{2-3}}$$

X_{GCP}, Y_{GCP} = X- und Y-Koordinaten des Gingivamittelpunktes $GCP_{x,y}$ ist.

Für Molare und Prämolare wird der Punkt P_3, die bukkale Höckerspitze, als Schneidkantenmittelpunkt *ICP* definiert.

In ähnlicher Weise werden die anatomischen Meßpunkte und Kronenlängsachsen für die Eck- und Schneidezähne des Unterkiefers bestimmt, wie in Fig. 6B dargestellt ist. Die in Fig. 6B mit P_1 bis P_4 bezeichneten Punkte werden folgendermaßen ausgewählt:

Punkt P_1: Linguale Schnittstelle von Zahnfleisch und Zahn.

Punkt P_2: Lingualer Aspekt der Schneidkante.

Punkt P_3: Bukkaler Aspekt der Schneidkante.

Punkt P_4: Faziale Schnittstelle von Zahnfleisch und Zahn.

Wie bei den Prämolaren und Molaren werden die Linien L_1 und L_2 konstruiert. Die Meßpunkte im Fall der in Fig. 6B dargestellten Zähne wurden deshalb gewählt, weil sie verhältnismäßig tolerant sind gegenüber Fehlern des Operators bei der Auswahl. Das wird anhand der gestrichelten Linien als mögliche Alternativen zu L_2 in Fig. 6B deutlich. Ausgehend von diesen Meßpunkten wird die Kronenlängsachse *CLA*, wie oben definiert, festgelegt, und zwar durch Verbindung der Mittelpunkte von L_1 und L_2.

Beim Oberkiefergebiß werden für jeden oberen Molar und Prämolar anatomische Meßpunkte identifiziert und ausgewählt, wie in Fig. 6C dargestellt, was die Auswahl eines fünften Punktes P_5 erforderlich macht.

Punkt P_5: Mesiale Randleiste des Zahns an der zentralen Höckerfurche.

Wie im folgenden in Fig. 6D dargestellt ist, werden anschließend Ausgangswerte für die Kronenlängsachsenneigung *LAI* für die Zähne festgelegt. Ursprünglich können solche Ausgangswerte von Analysen abgeleitet sein, die die faziale Achsenebene *FAP* durch den fazialen Achsenpunkt *FA* des Zahns identifizierten (die Mittelpunkte der Höhe der klinischen Kronen auf der fazialen Achse der klinischen Kronen).

Die Computerbilder, wie sie in Fig. 3C für jeden Zahn zusammengefaßt sind, werden anschließend gedreht, so daß die *CLA* nach dem gewünschten Winkel *LAI*, dem Längsachsenneigungswinkel, gegenüber der Mandibularalveolenmuldenebene *MT* ausgerichtet ist. Daraus errechnen sich die Endneigungen der Zähne, die in den Berechnungen unten enthalten sind. Das ergibt die ausgerichteten Profile *PF*, die in Fig. 6E zusammengefaßt sind.

Sind die Zahnprofile einmal in die Neigungswinkel *LAI* gedreht, lassen sich bestimmte vertikale Abmessungen und Grenzwerte festlegen. Ausgehend von den digitalisierten Profilkurven, die

im Speicher in Form einer Reihe von dicht beieinander liegenden Punkten abgelegt sind, werden die genauen Schneidkantenspitzen *IC*, wie in Fig. 6F, 6H und 6I dargestellt, an den Eckzähnen, den ersten und zweiten Schneidezähnen identifiziert.

Außerdem wird die Anhebung der Randleiste P_5 identifiziert. Die Randleistenanhebung *MRE*, die dem vertikalen Abstand zwischen P_3 und P_5 entspricht, wird an den hinteren Oberkieferzähnen identifiziert, weil diese die zentrischen Haltepunkte für die bukkalen Höcker der Molare und Prämolare des Unterkiefers darstellen. Die *MRE* wird als Bukkalhöckerhöhe *BCH* in den Berechnungen der Eckzahnanhebung und der Bogendrahtebenenstellung eingesetzt, wie unten in der Diskussion von Fig. 7A bzw. 8 beschrieben wird.

(700) Schritt Festlegung der Eckzahnanhebung

Die Eckzähne ($I = 3$) befinden sich nahe der Vorderseite des Mundes und sind daher weiter vom Gelenk- oder Drehpunkt *PP* des Kiefers entfernt als die hinteren Zähne ($I > 3$), wie aus den Abständen DJ_I in Fig. 7 ersichtlich ist. Das führt dazu, daß sich die Zähne, die weiter hinten im Mund liegen, weniger bewegen als die Eckzähne an der Öffnung. Diese Differentialrate der Bewegung muß in die Berechnung der Eckzahnanhebung mit einbezogen werden, sonst bleiben die hinteren Zähne in Kontakt, nachdem sich die Eckzähne gegeneinander geöffnet haben. Außerdem muß der Abstand *DPP* zwischen der Okklusionsebene und dem Drehpunkt *PP* der Kiefergelenke berücksichtigt werden, wie er in Fig. 7 dargestellt ist.

Wird eine Eckzahnanhebung zur Verbesserung der Okklusion verordnet, wird der Beitrag der Eckzahnanhebung vorzugsweise zwischen den Eckzähnen des Ober- und Unterkiefers aufgeteilt, wobei zwei Drittel der Eckzahnanhebung von den Oberkiefereckzähnen geleistet werden und ein Drittel von den Unterkiefereckzähnen.

Der ursprüngliche vertikale Abstand oder die Bukkalhöckerköhe *BCH* von P_3 zur Randleiste für jeden der rechten und linken maxillaren ersten Prämolare *T(U,4)*, der zweiten Prämolare *T(U,5)*, der ersten Molare *T(U,6)* und der zweiten Molare *T(U,7)* ist in Fig. 6C dargestellt. Ausgehend von anatomischen Untersuchungen wird dann die vertikale Eckzahnanhebungshöhe *CR*, die für die Bewegung des jeweiligen Zahnpaares in die erforderliche Stellung erforderlich ist, festgelegt, indem zunächst die Werte in Tabelle 1 berechnet werden, die von den Kieferabmessungen *DPP* und DJ_I in Fig. 7 abgeleitet sind.

1,67 x BCH von T(U,7)
1,50 x BCH von T(U,6)
1,36 x BCH von T(U,5) und
1,20 x BCH von T(U,4)

TABELLE 1

Anschließend wird von den Produkten der Multiplikation der Bukkalhöckerhöhe *BCH* mit dem oben aufgelisteten Anhebungsfaktor ausgehend der höchste Wert ausgewählt. Das betreffende Produkt stellt die Eckzahnanhebung dar, die erforderlich ist, um eine Bewegung des am meisten

vorragenden Höckers in die erforderliche Stellung und eine Gruppenfunktionsokklusion zu ermöglichen. Das wird durch BCH_6 in Fig. 7A veranschaulicht für den Fall, daß sich die ersten Molare zuletzt öffnen.

(800) Schritt Anordnung der Unterkieferzähne

Bei der ersten Berechnung werden die Spitzen der Unterkieferzähne auf einer Okklusionsebene angeordnet, vorläufig ohne letzte Feinheit der Anordnung, wie schematisch in Fig. 6E dargestellt ist. Bei diesem Schritt werden die Neigungen der Kronenlängsachsen *CLA* der Unterkieferzähne beibehalten, und die Zähne werden entlang ihrer *CLAs* nach oben bewegt, bis sich ihre Spitzen in Ausrichtung mit der Ebene der Oberkante des längsten Zahns befinden. Die *CLAs* werden so angeordnet, daß sie die *MTE* unterhalb des Zahn-*GCP* schneiden. Da die Zähne mit unterschiedlichen *LAIs* oder Längsachsenneigungswinkel geneigt sind, sind die Zahnspitzen jeweils unterschiedlich von der *MTE* verschoben und liegen somit nicht in einem glatten Bogen.

Der längste Unterkieferzahn außer den Eckzähnen wird identifiziert. In Fig. 6F wird das anhand des ersten Unterkieferschneidezahns veranschaulicht. Der längste Zahn ist der mit der größten Kronenhöhe *CH*. Die Kronenhöhe *CH* ist der Abstand in Y-Richtung (wobei die Zahnprofile ausgerichtet sind, wie in Schritt (600) beschrieben ist) zwischen dem *GCP*, dem Schnittpunkt der Linie L_2 mit der Kronenlängsachse *CLA*, und dem höchsten Punkt des bukkalen Höckers, z. B. von P_3 (für die hinteren Zähne), wie in Fig. 6F dargestellt, und (für die Vorderzähne) entweder zu den Schneidkantenmittelpunkten *ICP* oder vorzugsweise zu den Schneidkantenspitzen *IC*, wie in Fig. 6G dargestellt. Die Kronenhöhe *CH* des längsten Zahns ist die maximale Kronenhöhe *MCH* der Unterkieferzähne, wie anhand des mandibularen ersten Schneidezahns in Fig. 6F dargestellt ist.

Drei parallele Ebenen werden festgelegt:

- eine mit *MCHP* bezeichnete *MCH*-Referenzebene parallel zur X-Achse, die den Nullpunkt *0,0* durchläuft, und zwar am *GCP* des längsten Zahns (Fig. 6F und 6I);
- eine Bukkalhöckerebene *BCP* parallel zur X-Achse, die die Koordinaten *0,MCH* auf dem längsten Zahn durchläuft (Fig. 6F und 6I); und
- eine Eckzahnanhebungsebene *CRP* parallel zur X-Achse, die die Koordinaten *0,CR* durchläuft, wobei *CR* die Eckzahnanhebung ist, die im Schritt (700) berechnet worden ist, in dem die Eckzahnanhebungsoption gewählt wurde.

Wenn die Ebenen definiert sind, werden die ausgerichteten Unterkieferzähne so angeordnet, daß der höchste Punkt auf dem bukkalen Höcker P_3 oder die Schneidkantenspitze *IC* eines jeden die Bukkalhöckerebene *BCP* berührt, und zwar bei allen Zähnen außer den Eckzähnen, wie weiterhin in Fig. 6F dargestellt ist. Die *BCP* wird dabei als Okklusionsebene *MOC* festgelegt. Die Referenzebene *MCHP* wird mit der Ebene der Mandibularalveolenmulde *MT* gleichgesetzt. Dadurch wird der *GCP* des längsten Zahns auf die *MT* gebracht, wobei die *GCPs* der übrigen Zähne darüber liegen. Dadurch wird weiterhin die Okklusionsebene *MOC* in einem Abstand *MCH* von der Mandibularalveolenmulde *MT* festgelegt. Der absolut höchste Punkt auf einer Zahnkrone wird günstigerweise zur Ausrichtung der Zähne mit der *BCP* genutzt. Ein solcher Punkt kann durch eine zusätzliche Punktauswahl in Schritt (500) bestimmt werden, indem der Punkt *IC* für die präzise Schneidkantenspitze direkt ausgewählt

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wird oder indem vorzugsweise der höchste Punkt aus den Profilen von Fig. 3C oder aus den dreidimensionalen Bildern wie in Fig. 3A und 3B, nachdem die Zähne in ihre Endneigungswinkel *LAI* am Ende von Schritt (600) gedreht worden sind, berechnet wird.

An dieser Stelle werden die vertikalen Positionen der Unterkieferzähne berechnet, die sich zueinander verhalten wie in Fig. 6F und 7C. Dann werden die Zähne horizontal in vorübergehende Positionen gegenüber der *MTE* gebracht, die in der Ebene der Mandibularalveolenmulde *MT (MCHP)* liegt.

Das bevorzugte Ziel besteht darin, eher die Zahnspitzen im glattesten Bogen auf einer Okklusionsebene *MOC*, als ihre Gingiva-Aspekte im glattesten Bogen an der Mandibularalveolenmulde *MT* zu positionieren, so daß ein horizontaler Abstand *OFFSET* für jeden Zahn berechnet wird, und zwar auf der Grundlage des Zahns und der Kronenlängsachsenneigung *LAI*, die im Schritt (600) festgelegt wurde. Dieses Offset ist der horizontale Abstand zwischen der *MTE* und den Zahnspitzen, wenn ihre *GCPs* auf der *MTE* angeordnet sind.

Für die ersten und zweiten Schneidezähne sowie die Eckzähne des Unterkiefers wird das *OFFSET* durch Division berechnet, und zwar durch die Tangente *LAI*, den vertikalen Abstand zwischen (1) dem Schnittpunkt von Kronenlängsachse *CLA* und Schneidkantenspitze *IC* und dem Schnittpunkt von *CLA* und Referenzebene der maximalen Höckerhöhe, *MCHP*. Der vertikale Abstand zwischen *IC* und *MCHP* kann berechnet werden (gleich der Y-Koordinate des Punktes *IC*, was den vertikalen Abstand der Schneidkantenmitte, *ICD*, ergibt). Für die ersten und zweiten Schneidezähnen des Unterkiefers ist *ICD* gleich *MHC*. Für die Unterkiefereckzähne ist *ICD* gleich der mandibularen Eckzahnanhebungskomponente, die *MHC + (Total CR)/3* beträgt, wenn die Okklusion der Eckzahnanhebungsfunktion gewählt wurde. Die Berechnung des *OFFSET* für die ersten und zweiten Schneidezähne sowie die Eckzähne würde also für die ersten und zweiten Schneidezähne folgendermaßen vonstatten gehen:

OFFSET = ICD/tan(LAI).

Gemäß Fig. 6F wird für die Prämolare und Molare des Unterkiefers das *OFFSET* als horizontaler Abstand zwischen Punkt P_3 und dem Schnittpunkt von *CLA* und *MCHP* wie folgt berechnet:

OFFSET = [MCH/tan (LAI)] + HD,

worin *HD* gleich dem horizontalen Abstand zwischen Punkt P_3 und dem Schneidkantenmittelpunkt *ICP* ist.

Der Punkt der Anordnung der Mandibularalveolenmulde, *MTPP*, wird gemäß Fig. 6G und 6H als Schnittpunkt von *MCHP* und *CLA* definiert. Für den längsten Zahn entspricht *MTPP* seinem *GCP*, wie in Fig. 6I dargestellt ist. Der *MCHP* befindet sich in Höhe der Mandibularalveolenmulde und enthält die *MTE*. Der *MTPP* ist der Punkt am Zahn, der ursprünglich auf der *MTE* angeordnet ist.

Als nächstes werden unter Bezugnahme auf Fig. 7B und 7C die Zähne mit ihren *MTPPs* auf der Mandibularalveolenmulde angeordnet, jedesmal auf einer Seite. Um das zu erreichen, wird eine Zahnanordnungsroutine eingesetzt, bei der die Mandibularalveolenmulden-Funktion *MTE* zunächst für die Unterkieferschneidezähne angepaßt wird, so daß die Radii durch die Größe des zentralen *OFFSET* für den betreffenden Zahn vergrößert werden, wie oben definiert, um die Mandibularal-

veolenmulden-Offset-Kurve *MO(1)* von Fig. 4B zu bilden. Die genannten Radii der *MTE* sind diejenigen der *MTE*, die in der Kreissegmentform der in Schritt (300) erzeugten Funktion definiert wurden, und zwar mit der Spline-Kreis-Umwandlungsroutine. Die *OFFSETs* der Zähne sind unterschiedlich, die *MO* kann als unstetig angesehen werden, wenn sie auf diese Weise konstruiert wird und aus Segmenten besteht, von denen jedes die Spitze eines Zahns enthält und aufgrund der Größe des *OFFSET* des einzelnen Zahns labial-lingual mit Abstand von der *MTE* angeordnet wird.

Beginnend von der linken Seite wird der erste Schneidezahn angeordnet, wie in Fig. 7B dargestellt, indem sein mesialer Kontaktpunkt *MCP* am Schnittpunkt der Mittellinie *ML* mit der Offsetkurve *MO* für den Zahn angesetzt wird. Das führt dazu, daß der *MTPP* des Zahns, der den Schnittpunkt der *CLA* mit *MHCP* oder *MT* darstellt, auf der *MTE* und der Schneidkantenspitze *IC* des Zahns auf MO_1 plaziert wird. Die Zahnanordnung auf der Kreissegmentform einer Funktion wird bei der Beschreibung der Zahnanordnungsroutine ausführlich erläutert. Bei der Anordnung des ersten Schneidezahns wird ein Kreis C_1 konstruiert, und zwar mit einem Radius, der gleich der mesiodistalen Breite *MDW* des ersten Schneidezahns ist, sowie mit dem Mittelpunkt des Kreises C_1 am mesialen Kontaktpunkt *MCP* des Zahns am Schnittpunkt der Mittellinie *ML* mit der Offsetkurve MO_1. Anschließend wird der Kreis C_2 konstruiert mit einem Radius, der gleich *MDW/2* ist, und mit einem Mittelpunkt, der mit dem Mittelpunkt des Kreises C_1 zusammenfällt. Dann werden die Schnittpunkte der Mulden-Offsetkurve *MO* mit den Kreisen C_1 und C_2 ermittelt, wobei der Schnittpunkt mit dem Kreis C_1 der distale Kontaktpunkt *DCP* des Zahns ist und der Schnittpunkt mit dem Kreis C_2 der Zahnmittelpunkt *TMP* des ersten Schneidezahns ist. Der Zahnmittelpunkt *TMP* wird hierbei als Mittelpunkt der mesiodistalen Breite des auf einer Bogenform angeordneten Zahns definiert, wobei es sich um den Schnittpunkt der Bogenform mit einer labial-lingualen Ebene handelt, welche die CLA enthält. Dieser Mittelpunkt *TMP* des ersten Schneidezahns auf der *MO* ist die annähernde Position der Schneidkantenspitze *IC*.

Bei der Bestimmung der Schnittpunkte der Kreise mit der Offset-Muldenkurve *MO* oder den erweiterten Mandibularalveolenmulden muß festgelegt werden, welche Kreissektorlinien (Fig. 5-5P) die Kreise C_1 und C_2 schneiden. Sie werden identifiziert durch Vergleich der X-Koordinaten der Schnittpunkte mit den X-Koordinaten der distalen Kontaktpunkte *DCP* jedes der ersten Schneidezähne, so daß ermittelt wird, welche Segmente der MuldenFunktion genutzt werden, wie bei der Beschreibung des Zahnanordnungsverfahrens ausführlicher erläutert wird.

Abschließend wird eine distale Kontaktpunktlinie *DCPL* für den ersten Schneidezahn durch den *DCP* konstruiert, und zwar am Schnittpunkt des Kreises C_1 mit der *MO* und durch die Mitte des identifizierten Kreissegments der MO, der erweiterten *MTE*, auf der der *DCP* des Zahns liegt. Diese Linie läuft entlang dem Radius des Kreissegments der *MO*-Kurve durch den distalen Kontaktpunkt des ersten Schneidezahns. Ähnliche Linien *DTMP* werden für die Mitte des Zahns *TMP* konstruiert.

Für jeden verbleibenden Unterkieferzahn auf derselben Bogenseite wird in distaler Reihenfolge ein neues Mandibularalveolenmulden-Offset MO_1 berechnet, indem die *MTE* mit Krümmungsradii, die um die Größe des *OFFSET* des nächsten Zahns erhöht ist, sowie mit dem Mittelpunkt der Kreise C_1 und C_2 erweitert wird, die labial oder von der *MTE* nach außen bewegt werden, und zwar entlang der distalen Kontaktpunktlinie *DCPL* des vorhergehenden Zahns und um

die Größe des *OFFSET* des betreffenden Zahns. Das ist der *MCP* für den nächsten Zahn. Kreis C_1 für den Zahn wird mit einem Radius konstruiert, der gleich der mesiodistalen Breite des Zahns ist, wobei sein Mittelpunkt im Mittelpunkt *MCP* liegt. Kreis C_2 wird mit einem Radius konstruiert, der gleich der *MDW/2* ist, wobei der Mittelpunkt mit dem Kreis C_1 zusammenfällt.

Bei Prämolaren und Molaren kann der Zahnmittelpunkt *TMP* als ihr Punkt P_3 angesehen werden. Anschließend werden wie bei den ersten Schneidezähnen für diese Zähne die Schnittpunkte von *MO* und den Kreisen C_1 und *C* berechnet. Die distalen Kontaktpunkte *DCT* dieser Zähne liegen an den Schnittpunkten von *MO* für den Zahn und den entsprechenden Kreisen C_1. Die Zahnmittelpunkte *TMP* befinden sich an den Schnittpunkten von *MO* des Zahns und den entsprechenden Kreisen C_2. Die *MO*-Sektorsegmente, die die Kreise schneiden, werden identifiziert. Die Auswahl erfolgt, indem die XY-Koordinaten der Schnittpunkte mit den XY-Koordinaten der distalen Kontaktpunkte *DCP* verglichen werden. Abschließend wird eine distale Kontaktpunktlinie *DCPL* vom Mittelpunkt des ausgewählten Segments zur Ebene *DCP* konstruiert. Dasselbe geschieht für die Zahnmittelpunkte *TMP*. Wenn im folgenden von Zahnanordnung die Rede ist, wird vorzugsweise in dieser Reihenfolge vorgegangen.

(900) *Schritt Best-fit-Funktion für den Unterkieferbogen*

Die unstetige Offset-Funktion MO_C enthält die annähernden Zahnspitzen in der Okklusionsebene *MOC*, wobei die Zähne einen unregelmäßiges Offset, ausgedrückt durch die unstetigen *MO*-Linien in Fig. 4B, aufweisen. Um die Zahnspitzen in einem idealen Bogen anzuordnen, wird eine (900) Gleichung für eine abschließende bessere Anordnung der bukkalen Höcker und der Schneidkanten der Unterkieferzähne in einem stetigen Bogen entwickelt.

Es wird die Funktion statistisch entwickelt, die zu den Höckerspitzen und Schneidkanten der einzelnen Zähne am besten paßt: eine Best-fit-Bukkalhöcker-Funktion *BFBCE*. Bei der Formulierung der Funktion werden die Koordinaten der rechten und linken Zahnmittelpunkte *TMP*, die *ICPs* oder *ICs* in Fig. 7B, vorzugsweise gemittelt. Die Funktion *BFBCE* läßt sich mit Hilfe polynomer oder anderer Bézier- oder zumindest quadratischer statistischer Verfahren erhalten, so daß sich eine Best-fit-Funktion ergibt. Diese sind als serienmäßig produzierte Software-Packete erhältlich.

Eine derartige *BFBCE*-Funktion ist in Fig. 4B dargestellt. Ist die *BFBCE*-Funktion einmal festgelegt, kann sie nach dem Muster der oben beschriebenen Spline-Kreis-Umwandlungsroutine in eine Kreis-Segment-Funktion umgewandelt werden.

(1000) *Schritt Best-fit-Anordnung des Unterkieferbogens*

Nachdem die Best-fit-Funktion *BFBCE* statistisch abgeleitet ist, werden die (1000) Positionen der einzelnen Unterkieferzähne berechnet, so daß sie fazial, entweder labial oder lingual, bewegt werden können, damit ihre Spitzen in die Best-fit-Kurve fallen.

Um das zu erreichen, wird zunächst der mesiodistale Kontaktpunkt des ersten Unterkieferschneidezahns, der Punkt *MCP* in Fig. 7B, zunächst am Schnittpunkt der Mittellinie *ML* mit der *BFBCE* angeordnet, und zwar auf die gleiche Weise wie bei der Anordnung auf der *MO* in Schritt (900). Anschließend werden die oben definierten Kreise C_1 und C_2 für den Zahn konstruiert und ihre Schnittpunkte mit der *BFBCE*-Kurve ermittelt. Wie bei der Anordnung im obigen Schritt (800) ist der Schnittpunkt von C_1 mit der *BFBCE*-Kurve der distale Kontaktpunkt *DCP* des Zahns, und der

Schnittpunkt von C_2 mit der *BFBCE*-Kurve ist der Zahnmittelpunkt *TMP* (der nach *IC* ausgerichtet ist). Dadurch wird die Zahnsenkrechte zu dem Kreissegment der mit dem *TMP* verknüpften *BFBCE* bewegt. Anschließend werden neue Kreise C_1 und C_2 mit Mittelpunkten auf den distalen Mittelpunkten *DCP* konstruiert, und die Unterschritte werden wiederholt für alle Zähne auf derselben Seite und dann auf der gegenüberliegenden Seite des Unterkieferbogens.

Die Endpositionen der Unterkieferzähne sind in Fig. 7C dargestellt, in der die XY-Koordinaten denen der horizontalen Bogenebenen entsprechen. Eine vertikale Z-Koordinate, die lotrecht zur horizontalen XY-Ebene verläuft, wird nach den Y-Achsen der einzelnen Zahnprofilebenen ausgerichtet. Die X-Koordinaten der Profilebenen werden nach den labial-lingualen Richtungen *La-Li* in Fig. 7B ausgerichtet.

(1100) Schritt Anordnung der Oberkieferzähne

Die Okklusionskonstruktion erfordert ein Angleichen der Oberkieferzähne an die bereits positionierten Unterkieferzähne. Das wird erreicht, indem eine modifizierte Best-fit-Bukkalhöcker-Funktion *BFBCE* für die Oberkieferzähne abgeleitet wird. Bei den Oberkieferzähnen sind die Höckerspitzen der hinteren Zähne und die Schneidkanten der Vorderzähne nicht in einem einzigen Bogen angeordnet, sondern eher folgendermaßen: (1) die Punkte zentrale Höckerfurche - Randleisten der maxillaren Prämolare und Molare auf der *BFBCE*-Kurve; (2) die Oberkiefervorderzähne weichen labial von der *BFBCE*-Kurve ab, damit ein Übergreifen der Schneidezähne sowie ein Zwischenraum zwischen ihren lingualen Flächen und den labialen Flächen der Unterkieferzähne ermöglicht wird; und (3) die Eckzahnspitzen liegen im Bogen, im allgemeinen zwischen dem ersten maxillaren Prämolar und dem zweiten Schneidezahn. Die Bögen, auf denen die Oberkieferzähne angeordnet sind, sind, wie oben erklärt, in Fig. 4C dargestellt.

Für die Oberkieferschneidezähne umfaßt die Modifizierung der *BFBCE*-Kurve zunächst ein Mitteln der Abstände von Punkt P_2 zu Punkt P_3 auf der Schneidkante der Unterkieferschneidezähne sowie eine Division durch zwei, um den Bogen so anzuordnen, daß die labiale Fläche des Zahns an den Schneidkantenmittelpunkt *ICP* des Zahns angrenzt, wobei es sich im allgemeinen um Punkt P_3 handelt. Das ergibt einen gleichförmigen Abstand zwischen der Best-fit-Funktion und dem Kontaktpunkt der Fazialfläche auf der labialen Seite der Unterkiefervorderzähne mit dem Fazialpunkt auf der lingualen Seite der Oberkiefervorderzähne. Ein zusätzlicher Abstand, normalerweise 0,25 mm, wird zum gemittelten Abstand addiert, um einen geringfügigen *Zwischenraum* zwischen den oberen und unteren Vorderzähnen zu gewährleisten. Das wird in Fig. 7D dargestellt.

Das vordere Gebiß des Oberkiefers wird gegenüber der Okklusionsebene *MOC* in eine vertikale Position gebracht, und zwar in Übereinstimmung mit Okklusionskriterien, die ausgewählt wurden, um ein vorherbestimmtes Übergreifen zu gewährleisten. Vom Schritt Eckzahnanhebungsberechnung (700) sind die vertikalen Positionen der Oberkiefereckzähne in ihrer Relation zur mandibularen Okklusionsebene *NOC* bekannt. Bei den ersten und zweiten Schneidezähnen des Oberkiefers ermöglichen die vertikalen Positionen das Übergreifen entsprechend den vorgeschriebenen Kriterien, indem ihre lingualen fazialen Kontaktpunkte mit ihren Gegenstücken im Unterkiefer auf die *MOC*-Ebene gebracht werden. Alle Zähne sind gemäß den vorgeschriebenen Neigungswerten *LAI* der Kronenlängsachse *CLA* aus Schritt (600) geneigt.

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Bei der (1100) Anordnung der Oberkieferzähne oder des Oberkiefers 24 in bezug auf die Zähne des Unterkiefers oder den Unterkiefer 22 werden die maxillare vordere Bogenform *MAAF*, die Bogenform der zentralen Höckerfurchen und Randleisten *CGMRAF* sowie die maxillare Eckzahnbogenform *MCAF* definiert.

Die Berechnung der Größe der zur Festlegung der *MAAF* erforderlichen Kreissegment-Radiuserweiterung der *BFBCE*-Funktion wird durchgeführt am Mittelpunkt der mesiodistalen Breite beider erster Oberkieferschneidezähne, TMP_1 in Fig. 4C, der den Schnittpunkt mit der *BFBCE*-Kurve von Kreis C_2 in Fig. 7C darstellt. Der Zahn wird so auf der maxillaren Kontaktbogenformfunktion *MAAF* angeordnet, daß der mesiale Kontaktpunkt des Zahns auf dem Schnittpunkt der Mittellinie *ML* und der maxillaren Kontaktbogenform *MAAF* liegt (Fig. 4C). In bezug auf die ersten und zweiten oberen Schneidezähne wird die *MAAF* folgendermaßen definiert:

$$\text{MAAF} = \text{BFBCE} + \sum \frac{P_{xy} - P_{yx}}{\{t\}\{\text{Avg}\}} + \text{Zwischenraum}$$

worin

t = Anzahl der Zähne

Avg = 2 (für Mittelpunkt) ist.

Die *CGMRAF* stimmt mit der *BCBFE* gemäß Fig. 4B überein.

Bei den Oberkiefereckzähnen werden die Höckerspitzen auf einem stetigen Bogen zwischen *MAAF* und *CGMRAF* angeordnet. Vorzugsweise werden ihre Spitzen auf der *BFBCE* angeordnet, die erweitert wurde um den Durchschnitt der Abstände davon zur Schneidkantenspitze des zweiten Schneidezahns sowie zu den Bukkalhöckerspitzen der ersten Prämolare des Oberkiefers.

Die Informationen der Verordnung 27 des Kieferorthopäden 14 werden geladen, damit festgelegt werden kann, welches Verfahren zur vertikalen Okklusion der Oberkiefervorderzähne ausgewählt wurde, beispielsweise die Roth- oder Ricketts-Okklusion oder das bevorzugte Verfahren, bei dem sich die Oberkiefereckzähne um einen Strecke CR_{03} verlängern, die gleich 0,67 der Eckzahnanhebung *CR* unterhalb der Okklusionsebene *MOC* ist; die zweiten Schneidezähne um eine Strecke CR_{02} verlängern, die gleich 0,33 der Eckzahnanhebung *CR* unterhalb der Okklusionsebene *MOC* ist; und die ersten Schneidezähne um eine Strecke CR_{01} verlängern, die gleich 0,5 der Eckzahnanhebung *CR* unterhalb der Okklusionsebene *MOC* ist.

Vorzugsweise wird die horizontale Zahnanordnung mit einer Berechnung der Positionen der Zähne fortgesetzt, um die horizontale Okklusion zu gewährleisten, und zwar indem ein Abstand zwischen *LIMOC* und *ICP* für die ersten und zweiten Schneidezähne des Oberkiefers berechnet wird. Dieser Abstand wird als das maxillare vordere Offset *MAO* bezeichnet:

$$ICP = \frac{X_2 + X_3}{2}; \frac{Y_2 + Y_3}{2}$$

$MAO = LIMOC_x - ICP_{x1}$

Das Offset des ersten Oberkieferprämolars *MBO* wird berechnet als

$MBO = P_{5x} - P_{3x1}$ '

Apparatkonstruktionsprozedur (96)

Die Apparatkonstruktionsprozedur umfaßt die Schritte (1200) Bestimmung der Lage der mandibularen Bogendrahtebene im Verhältnis zu den berechneten Endpositionen der Unterkieferzähne, (1300) Berechnung eines jeden mandibularen Bracketschlitzes im Verhältnis zur Anbringungsfläche des entsprechenden Zahns, (1400) Bestimmung der Lage der maxillaren Bogendrahtebene im Verhältnis zu den berechneten Endpositionen der Oberkieferzähne, (1500) Berechnung eines jeden maxillaren Bracketschlitzes im Verhältnis zur Anbringungsfläche des entsprechenden Zahns, (1600) Berechnung der Gestalt des mandibularen Bogendrahts sowie der inneren und äußeren Abmessungen der Schlitze eines jeden mandibularen Brackets; (1700) Berechnung der Gestalt des maxillaren Bogendrahts sowie der inneren und äußeren Abmessungen der Schlitze eines jeden maxillaren Brackets und (1800) Berechnung der Konturen der Bracketeinsetzhalter für jeden Zahn.

(1200) Schritt mandibulare Bogendrahtebene

Der folgende Schritt besteht in der (1200) Festlegung der Position der Bogendrahtebene für die Unterkieferzähne. Die Bogendrahtebene kann sich in einer infiniten Anzahl von vertikalen Positionen befinden, da die Brackets und der Bogendraht so konstruiert werden, daß sie zu jeder gewählten Lage passen. Da das Übergreifen der Oberkieferzähne bekannt ist, wird für die Anbringung des labialen Brackets die mandibulare Bogendrahtebene festgelegt, um einen Bracketzwischenraum für die Oberkieferzähne bei der Endokklusion zu ermöglichen. Bei der Anbringung lingualer Brackets wird diese Überlegung in bezug auf die maxillare Bogendrahtebene angestellt, wie nachfolgend in Schritt (1300).

Da die Oberkieferzähne kein Problem der Bracketbehinderung für die labiale Bracketanbringung darstellen, können diese Brackets unter dem Gesichtspunkt des einfachen Einsetzens, aufgrund kosmetischer Erwägungen und im Hinblick auf die Gingivagesundheit positioniert werden. Dies trifft für die mandibulare Bracketpositionierung zu, wenn eine linguale Bracketanbringung vorgenommen wird. Normalerweise liegen die Brackets zentraler als die Brackets des anderen Bogens.

Genauer gesagt, werden für die Festlegung der Bogendrahtebene die ausgewählte vertikale

Okklusion und das entsrpechende vertikale Übergreifen von der *MOC* für Eckzähne, erste und zweite Schneidezähne abgerufen. Anschließend wird die Bukkalhöckerhöhe *BCH* für jeden Prämolar und Molar abgerufen. Als nächstes wird die maximale *BCH* oder das vordere vertikale Übergreifen als maximales vertikales Übergreifen *MVO* ausgewählt. Dann wird ein Abstand, der gleich dem *MVO* ist, von der *MCO* nach unten abgemessen. Abschließend wird die Hälfte der Brackethöhe (normalerweise 3,0 mm) plus zusätzliche 0,75 mm für den Okklusionszwischenraum addiert. Dadurch wird die mandibulare Bogendrahtebene *MAWP* definiert. Somit werden die Brackets bei möglichst vollständiger Okklusion angeordnet, wobei ein Zwischenraum von 0,75 mm gegenüber dem ungünstigsten Fall der maxillaren Okklusion gegeben ist.

(1300) Schritt mandibulare Schlitzneigung

Nachdem die Bogendrahtebenen in bezug auf die Zähne definiert sind, wird der (1300) Winkel zwischen der Apparatanbringungsfläche der Zähne und der Bogendrahtebene festgelegt. Dieser Winkel minus 90° stellt das faziale Drehmoment oder den Neigungswinkel dar, der in die Brackets hineingearbeitet werden muß. Dadurch wird auch die Höhe der Bracketschlitzanordnung definiert, die dem Abstand von der Spitze der Schneidkante zur Bogendrahtebene entspricht. Dieser Abstand wird lotrecht zur Bogendrahtebene berechnet.

Bracketkörper ohne Schlitz wurden jetzt annähernd positioniert. Dann wird ein glatter Bogendraht so konstruiert, daß er durch die Körper der Brackets hindurchpaßt. Der Bogendraht darf nicht zu tief in das Bracket einschneiden oder nicht einmal geringfügig an der Vorderfläche des Brackets vorstehen. Je nach Erfordernis werden Brackets mit unterschiedlicher Höhe gewählt. Ohne Modifizierung von Bukkalhülsenfertigungseinheiten können Standard-Bracketabstände von der Zahnoberfläche zum Zentrum des Schlitzes als Ausgangswerte eingesetzt werden. Anschließend wird die Bogendraht-Funktion mathematisch aus dem oben beschriebenen kubischen Spline-Verfahren oder dem Tangentialkreis-Verfahren abgeleitet. Beide Bogendrähte werden in ähnlicher Weise entwickelt.

Insbesondere wird die Bracketwinkelfestlegung (1300) erzielt, indem der Schnittpunkt der *MAWP* mit der labialen (bukkalen) Fläche eines jeden Unterkieferzahns im Fall von labialen Apparaten, und der Schnittpunkt der *MAWP* mit der lingualen Fläche eines jeden Zahns im Falle von lingualen Apparaten verwendet wird. Anschließend werden Kreise mit Mittelpunkten an den Schnittpunkten und mit Durchmessern konstruiert, die die okkluso-gingivalen (vertikalen) Abmessungen der Bracketklebeflächen (normalerweise 3,0 mm) repräsentieren. Die XY-Koordinaten der Kreisschnittpunkte mit der labialen (bukkalen) Zahnfläche werden in folgende Gleichungen eingesetzt:

$$R^2 = (X_1 - h)^2 + (Y_1 - K)^2$$

$$Y_2 = mX_2 + b_2$$

$$Y_3 = mX_3 + b_3$$

Die Anstiege zwischen den Schnittpunkten werden berechnet, so daß sich der faziale Neigungswinkel *FIA* ergibt.

h,k = Koordinaten des Kreismittelpunkts

X_2, Y_2, b_2 = Definition des ersten Liniensegments

X_3, Y_3, b_3 = Definition des zweiten Liniensegments

Dann werden, wie in Fig. 8A für labiale Apparate dargestellt, x/2-Radianten subtrahiert, so daß sich der Schlitzneigungswinkel *SIA* ergibt:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - x/2$$

(1400) Schritt maxillare Bogendrahtebene

Der nächste Schritt besteht darin, die (1400) maxillare Bogendrahtebene zu lokalisieren, wie es im Schema von Fig. 8 dargestellt ist. Bei den ersten Schneidezähne des Oberkiefers umfaßt dies das Ermitteln des vertikalen Abstands zwischen der Schneidkante und Punkt P_4. Der kleinste Wert wird gewählt und durch zwei dividiert, so daß sich die Schlitzanordnungshöhe für die ersten Oberkieferschneidezähne ergibt. Bei den terminalen Prämolaren des Oberkiefers wird der vertikale Abstand zwischen dem Bukkalhöcker und Punkt P_4 ermittelt. Der kleinste Wert wird ausgewählt und durch zwei dividiert. Das ergibt die Schlitzanordnungshöhe *SPH* für die terminalen maxillaren Prämolare.

Für die ersten Schneidezähne des Oberkiefers wird der Y-Wert des *FIMOC* vom Y-Wert für die Schlitzanordnungshöhe *SPH* subtrahiert. Dabei handelt es sich um den Abstand zwischen der *MOC* und der Schlitzmittellinie. Dann wird der Y-Wert von MOC vom Y-Wert für die Schlitzanordnungshöhe *SPH* für die terminalen Prämolare subtrahiert. Dies ist der Abstand zwischen MOC und Schlitzmittellinie. Dann wird die *SPH* für den terminalen Prämolaren von der SPH der ersten Oberkiefer-Schneidezähne subtrahiert(?). Dies ist die Anstiegsänderung *DH* des maxillaren Bogendrahts gegenüber *MOC* von den ersten Schneidezähnen bis zu den terminalen Prämolaren des Oberkiefers. Der Anstieg des maxillaren Bogendrahts *MXAWP* von der *MOC* oder Bogendrahthöhe *AHT* an jedem Zahn wird wie folgt berechnet:

$$AHT = K + DH + SPH - MOC_y + \text{vertikaler Übergriff}$$

worin *K* der Umwandlungsfaktor in Tabelle 2 ist.

Zahntyp	keine Extraktion	Extraktion (z.B. 2. Prämolar)
1. Schneidezahn des Oberkiefers	0,0	0,0
2. Schneidezahn des Oberkiefers	- 0,19	- 0,28
Eckzahn des Oberkiefers	- 0,42	- 0,62
1. Prämolar des Oberkiefers	- 0,68	- 1,00
2. Prämolar des Oberkiefers	- 1,00	-
1. Molar des Oberkiefers	- 1,32	- 1,46

TABELLE 2

(1500) *Schritt maxillare Schlitzneigung*

Nachdem die Bogendrahtebene festgelegt ist, wird der (1500) Schlitzneigungswinkel *SAI* für jedes der maxillaren Zahnbrackets festgelegt, und zwar in ähnlicher Weise wie beim Schritt Schlitzneigungsfestlegung für die Unterkieferbrackets (1300), indem zunächst der Schnittpunkt der maxillaren Bogendrahtebene *MXAWP* mit der labialen oder bukkalen Fläche jedes Oberkieferzahns ermittelt wird. Anschließend werden für jeden Oberkieferzahn Kreise beschrieben, deren Mittelpunkt mit dem Schnittpunkt zusammenfällt und deren Durchmesser gleich der okkluso-gingivalen oder vertikalen Abmessung der Bracketklebefläche ist, die normalerweise 4,0 mm beträgt. Aus diesen Kreisen werden die XY-Koordinaten der Schnittpunkte der Kreise mit der labialen oder bukkalen Zahnfläche wie folgt ermittelt:

$R^2 = (X_1 - h)^2 + (Y_1 - k)^2$;

$Y_2 = mX_2 + b_2$;

$Y_3 = mX_3 + b_3$.

Gemäß Fig. 8A werden nun die x/2-Radianten subtrahiert, so daß sich der Schlitzneigungswinkel *SIA* ergibt:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - x/2$$

(1600) Schritt Unterkieferbogendraht und Schlitztiefe

Der nächste Schritt besteht darin, den (1600) mandibularen Bogendraht sowie die innere und äußere Abmessung des Brackets festzulegen. Zunächst wird das Kreissegment der *BFBCE*, der dem *ICP* des ersten rechten Schneidezahns zugeordnet ist, ermittelt, wie in Fig. 8B dargestellt ist. Dann werden der Schneidkantenmittelpunkt und die Kreissegment-Mittelpunktsebene *ICPCDCPP* lotrecht zu den Bogenebenen erzeugt. Eine Schneidkantenmittelpunktlinie *ICPL* wird gezogen, die durch den *ICP* sowie einen dem Zahn zugeordneten besonderen Kreissegmentmittelpunkt *CSCP* verläuft. Nun wird ein pythagoreischer Abstand *PD* zwischen *CSCP* und *ICP* ermittelt. Anschließend wird der Abstand zwischen CSCP und ICP entsprechend dem Satz von Pythagoras bestimmt. Dann wird hinsichtlich des Zahns in der *ICPCSCPP*, wie in Fig. 8C dargestellt, eine Linie *NL* lotrecht zur *BFBCE* durch den *ICP* gezogen, der den Schnittpunkt von *CLA* und *BFBCE* darstellt. Noch immer mit Blick auf den Zahn in dieser Ebene wird als nächstes der Schnittpunkt *XP* von *NL* und *MAWP* bestimmt.

Weiterhin mit Blick auf den Zahn in der *ICPCSCPP* wird der X-Abstand *XD* zwischen der labialen Zahnfläche und *XP* bestimmt, und *PD* wird zu *XD* und dem unteren Grenzwert des Bracketschlitzes *LLBS* addiert. Der *LLBS* ist ein Abstand, der dem bestimmten Bracket zugeordnet ist, das an diesem Zahn eingesetzt wird. Es handelt sich um den tiefsten Schlitz, der für dieses Bracket zulässig ist. Dann wird der untere Grenzwert *LL* wie folgt berechnet:

$$LL = PD + XD + LLBS$$

In ähnlicher Weise wird *PD* zum *XD* und oberen Grenzwert des Bracketschlitzes *ULBS* addiert. Der *ULBS* stellt ebenfalls einen Abstand dar, der dem bestimmten Bracket zugeordnet ist, das an diesem Zahn eingesetzt wird. Es handelt sich um den flachsten Schlitz, der für dieses Brackt zulässig ist. Dann wird der obere Grenzwert wie folgt berechnet:

$$UL = PD + XD + ULBS$$

Dann wird bei Betrachtung der mandibularen Okklusion in einer Draufsicht und beim Bewegen entlang der *ICPL* von *CSCP* um den *LL*-Abstand werden die Punkte X und Y, $AWLL_{xy}$, im Verhältnis zu einem Nullpunkt am Schnittpunkt der *BFBCE* und der mandibularen Mittellinie *ML* bestimmt. Dann wird bei Betrachtung der mandibularen Okklusion in einer Draufsicht und beim Bewegen vom *CSCP* entlang der *ICPL* um den *UL*-Abstand werden die Punkte X und Y, $AWUL_{xy}$, im Verhältnis zum Schnittpunkt der *BFBCE* und der mandibularen Mittellinie *ML* bestimmt. Anschließend wird der Mittelpunkt von $AWLL_{xy}$ und $AWUL_{x<y}$ ermittelt und die Schritte für alle Unterkieferzähne wiederholt.

Dann werden der durchschnittliche Mittelpunkt und der Abstand von rechts nach links berechnet, um eine mandibulare Bogendrahtsymmetrie zu erzwingen:

$$S_x = MP_x + \frac{PR_x - PL_x}{2}$$

$$S_y = MP_y + \frac{PR_y + PL_y}{2}$$

Die glatteste Kurve *SC*, die zwischen allen Punkten $AWLL_{xy}$ und $AWUL_{xy}$ hindurchläuft, wird bestimmt, wie in Fig. 4E dargestellt. Vorzugsweise hat sie keine Abbiegepunkte. Sind ein oder mehrere Abbiegepunkte vorhanden, wird die logische Alternativlösung für das Bracket anhand der Stelle abgeleitet, an der die Abbiegung auftritt.

(1700) Schritt maxillarer Bogendraht und Schlitztiefe

Der nächste Schritt besteht darin, den (1700) maxillaren Bogendraht sowie die innere und äußere Abmessung des Brackets festzulegen. Wie bei dem Schritt der mandibularen Festlegung (1600) wird das Kreissegment der *BFBCE*, dem der *ICP* des rechten ersten Schneidezahns zugeordnet ist, bestimmt. Der Schritt ähnelt dem der Berechnung in Fig. 4E und 8C für die inneren und äußeren Abmessungen der mandibularen Bracketschlitze, außer daß die maxillaren ersten und zweiten Schneidezähne eher der *MAAF* und nicht der *BFBCE* zugeordnet sind, die maxillaren Eckzähne sind der *MCAF* zugeordnet und die Zähne nach dem Eckzahn der *BFBCE*.

Das Fräsen der Bracketschlitze wird bei der Diskussion von Schritt (3000) beschrieben.

(1800) Schritt Einsetzhalterkonstruktion

Informationen für die Konstruktion der Bracketeinsetzhalter, die dem Kieferorthopäden helfen, die Brackets an den richtigen Positionen auf den einzelnen Zähnen anzubringen, sind jetzt erhältlich. Die Konstruktion der Einsetzhalter erfolgt mit der Software, die zum unten beschriebenen Schritt Halterkonstruktion (3500) gehört, nach dem Laden ... (im Original nicht lesbar) ... der erforderlichen Daten aus den oben beschriebenen Berechnungen in den Fertigungs-Steuercomputer 30c.

(97) Prozedur der Apparatfertigung

Die Prozedur der Apparatfertigung (97) umfaßt die Schritte (3000) Fertigung der individuellen Brackets, (3200) Fertigung der individuellen Bogendrähte und (3500) Fertigung der individuellen Einsetzhalter für die Anbringung der individuellen Brackets an den Zähnen des Patienten. Diese Schritte werden nachfolgend ausführlich beschrieben für die Ausführung, bei der die gesamte Fertigung in der Apparatkonstruktions- und -fertigungsstätte 13 durchgeführt wird.

(3000) Schritt Bracketfertigung

Der Schritt Bracketfertigung (3000) erzeugt die individuellen Brackets, vorzugsweise, indem die Bracketrohlinge ausgewählt werden und einen zum Drehen bestimmten Schlitz für den Bogendraht 64 in das Bracket gefräst wird.

Der Computer 30c lädt die Daten jedes einzelne Bracket aus der Patientendatei 36.

Bei jedem Zahn und Bracket werden, als Standard oder als Anfangsauswahl, Brackets mit niedrigem Profil vorausgesetzt. Dann werden der Schlitzwinkel *FAI* und die inneren und äußeren Abmessungen des Schlitzes *IO* gelesen. Außerdem wird der Radius des Bogendrahts am Zahnmittelpunkt bestimmt.

Anschließend werden ein Haupt-CNC-Programm und die Programmschleifen zur Erzeugung des Codes für das Fräsen jedes Brackets erstellt, angefangen mit der Berechnung der Variablen für das Bracket, der Zuordnung der Variablen für jedes Bracket, so daß das Fräsen des Schlitzes im richtigen Winkel durch Drehen der Spannvorrichtung 73 und Einstellen des Fräsers 77c so festgelegt wird, daß eine vertikale Z- und eine horizontale X-Position zusammenwirken. Wenn die Position des Schlitzes außerhalb des Bracketbereichs liegt, wird ein Bracket mit dem geeigneten höheren Profil

vom Programm angefordert und geladen, entweder automatisch oder von einem Operator. Dann wird der Code erzeugt, um den Weg des Fräsers in der Y-Richtung zu steuern, so daß der Bogendrahtradius in den Schlitzboden gefräst wird.

Der CNC-Code wird vorzugsweise in eine NC-Steuereinheit heruntergeladen, und die Brackets werden bearbeitet, indem die Schlitze in eine Reihe von Bracketrohlingen gefräst werden, und ein (3080) Bericht wird angefertigt.

(3200) Schritt Bogendrahtfertigung

Der Schritt Bogendrahtfertigung (3200) erzeugt den Bogendraht 64, der um die Bogendrahtmittellinie *AML* symmetrisch ist und über die geeignete Endschenkelspannweite *TLS* verfügt, die von einer Reihe von Kreissegmenten gebildet wird.

Der Fertigungssteuercomputer 30c erzeugt einen CNC-Code zur Steuerung der Bogendrahtformvorrichtung 40. Das Programm beginnt damit, daß Dateien aus den berechneten Patientendaten 36 geöffnet und die Drahtlegierung sowie der verordnete Drahtquerschnitt gelesen werden, und es umfaßt ein Datenfeld, darin auch eine Reihe von Datensätzen über den Radius und die Sektorlänge aller Kreissegmente, aus denen die Bogendrahtkurve gebildet wird, sowie die berechnete kumulative Gesamtbogendrahtlänge. Zur Bogendrahtfunktion werden Radii und Sektorlängen addiert, so daß 12,5 mm eines geraden Segments an jedem Ende des Drahts erzeugt werden, damit parallele Endschenkelerweiterungen gebildet werden. Dann wird durch Berechnen der kumulativen Anstiege und Sektorlängen des Draht entlang der Funktion die Endschenkelspannweite *TLS* berechnet.

Die Anstiege der Drahtfunktion, die das Drahtverhalten beschreiben, werden berechnet durch: (1) Berechnen der Parabelkoeffizienten, (2) Eintragen des ersten Punkts eines Anstiegssystems, (3) Eintragen der mittleren Punkte eines Anstiegssystems, und (4) Eintragen des letzten Punkts eines Anstiegssystems. Anschließend wird die vertikale Auslenkung des Biegehebelarms *LA* zwischen den Kontaktpunkten der Walze 70b mit dem Draht 69 und den Kontaktpunkten der Walzen 68 mit dem Draht 69 für jedes Kreissegment der Bogendrahtfunktion festgelegt und die Daten dem System zugeführt.

Anschließend werden vorläufige Variablen für Sektorlänge, Hebelarmauslenkung, Radius und Endschenkelspannweite entlang der geraden Segmente des Bogendrahts definiert, die Steuerungskarte 65 des Computers 30c wird initialisiert, die Basisadresse der Steuereinheit sowie die Standardparameter werden festgelegt. Dann werden die Sequenzen der Sektorlängen und Hebelarmauslenkungen (1) über die Schaltungen 66a und 67a an den Antrieb der Zuführungswalzen 68 und (2) durch die Schaltungen 66a und 67a an die Amboßeinheit 70 übertragen.

Anschließend wird die Hebelarmauslenkung auf Null gebracht und die Drahtschenkellage wird von dem Sensor 71 bestimmt. Dieser Wert wird im Computer 30b in einen numerischen Wert umgewandelt, und jeder Unterschied zwischen der aktuell gemessenen Endschenkelspannweite und der gewünschten Endschenkelspannweite *TLS* wird berechnet. Liegt der Unterschied außerhalb der zulässigen Abweichung, wird eine Korrektur vorgenommen und ein anderer Draht geformt.

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(3500) Schritt Halterfertigung

Der Schritt Halterfertigung (3500) erzeugt Bracketeinsetzhalter, die individuell für jeden Zahn konstruiert werden, um das Anbringen der individuell konstruierten Brackets in den richtigen Positionen am Zahn zu erleichtern, damit der individuell konstruierte Bogendraht, wenn er in die individuell konstruierten und individuell angebrachten Brackets eingesetzt wird, die Zähne in ihre berechneten Endpositionen bewegt.

Die für die Konstruktion der individuellen Einsetzhalter erforderlichen Informationen sind bei der dargestellten erfindungsgemäßen Ausführung in der Patientendatei enthalten, aus den in der Prozedur Apparatkonstruktion (96) gemachten Berechnungen ersichtlich sowie in der Zahnprofildatei digitalisierter Informationen, die im Schritt (500) eingegeben wurden, befindlich. Die Konstruktion der individuellen Halter umfaßt in erster Linie eine Zusammenstellung bereits vorhandener Informationen und erfolgt bei der bevorzugten Ausführung im Verlauf der Erstellung des Steuercodes für die NC-gesteuerte Fertigungsausrüstung 41, die die Halter herstellt.

Bei der bevorzugten und dargestellten Ausführung handelt es sich bei der Halterfertigungsausrüstung 41 um eine Standard-CNC-Fräse, die mit einem kleinen Hartmetallfräser von beispielsweise 0,5 mm (0,020 Zoll) Durchmesser ausgestattet ist (Fig. 1F). Die Halter 82 selbst werden aus runden ABS-Kunststoffscheiben 83 hergestellt, deren Durchmesser etwa 2,5 cm (1 Zoll) und deren Dicke etwa 1,0 mm (0,040 Zoll) beträgt, obwohl beträchtliche Abweichungen in der Größe annehmbar sind.

Der Schritt Halterfertigung (3500) beginnt mit der Ausführung eines Programms bzw. einer Routine im Fertigungscomputer 30b und der Eingabe von Parametern, die den Patienten oder den Fall identifizieren. Nach dem Start des Programms wird die Patientendatei 36 geöffnet, die in der Prozedur der Zahnpositionsberechnung und Analyse (95) sowie in der Prozedur der Apparatkonstruktion (96) erstellt wurde, und die Informationen für jeden Zahn werden in Relation zu einem Zahnprofil *PF* entnommen, wie im Schema von Fig. 9I dargestellt ist. Bei den entnommenen Variablen handelt es sich um (a) den Schnittpunkt der Bogendrahtebene mit der labialen (oder lingualen, falls verordnet) Zahnfläche *TS* in der vertikal-labialen/lingualen Zahnprofilebene, und zwar in Form eines XY-Koordinatenpaares $TS_{x,y}$, (b) die inneren und äußeren Schlitzabmessungen *Elan* oder *IO*, (c) den Typ des Brackets, wodurch Zugang zur richtigen Stelle in einer Verweistabelle von Bracketabmessungen möglich ist, wie beispielsweise Bracketbasisdicke *BRel* und Bracketklebschichthöhe *BPH*, sowie (d) die Breite des zum Drehen bestimmten Schlitzes, 0,45 oder 0,55 mm, je nach Verordnung.

Dann wird die Bracketdatei geöffnet und die Bracketbasisdicke abgelesen, wie in Fig. 9J dargestellt ist.

Eine CAD-Programmdatei, die die Zahnprofile PF_i enthält, wird geladen. Die Profile *PF* bestehen, wie in Fig.3C dargestellt, aus eine Reihe von dicht beieinander liegenden Punkten in der Profilebene, von denen jeder durch XY-Koordinaten repräsentiert wird, wobei die Punkte durch Geradensegmente verbunden werden, um die Profilkurve *PF* zu definieren. Der Fräserdurchmesser *Endmill* wird ebenfalls eingegeben, der kleiner als der Bogendrahtdurchmesser oder die Bogendrahtschlitzbreite sein muß (0,45 oder 0,55 mm). Konstanten werden festgelegt, darunter der Durchmesser des Halterrohlings 83, der Fräsabstand an der Außenseite des Halters, die Anzahl der

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Anschließend folgt der Erstellung des Profil- und Bracket-Spielkompensations-Fräserwegs *ITP* bzw. *BCTP*. Dazu gehören die Erstellung einer anfänglichen inneren Fräserweglinie *IITP*, die aus einer Reihe von Geradensegmenten besteht, wobei eines jeweils parallel zu einem Liniensegment der Zahnprofilkurve verläuft, und zwar mit einem Abstand, der dem Fräserradius an der Innenseite der Profilkurve entspricht, wie in Fig. 9K , die Erstellung einer anfänglichen Bracketbasis-Kompensations-Fräserweglinie *IBCTP*, die aus einer Reihe von Geradensegmenten besteht, wobei eines jeweils parallel zu einem Liniensegment der Zahnprofilkurve verläuft, und zwar mit einem Abstand, der der Bracketbasisabmessung minus dem Fräserradius außerhalb der Profilkurve entspricht, und (3600) die Erstellung eines abschließenden Bracketbasis-Kompensations-Fäserwegs *(d)*, um von der inneren Fräserweglinie zur Basiskompensationslinie am oberen Ende der Bracketbasisklebschicht zu fräsen, so daß der Halter am unteren Ende der Schicht abgetrennt wird, wie in Fig. 9M ("oberes Ende" und "unteres Ende" dienen hier in einem Beispiel für die unteren Zähne und werden für die oberen Zähne umgekehrt).

Als nächstes wird ein Bogendrahtschlitz-Fräserweg *ASTP* erstellt, der aus der Sequenz der Schemata der Fig. 9N, 9O und 9P verständlich wird. Anschließend wird ein Referenz-Fräserweg *RefP* erstellt, und zwar auf einem Bild eines Halterrohlings 83, wie in Fig. 9Q dargestellt, und unter Bezugnahme darauf wird die äußere Haltergrenzenaussparung *CTP* hinzugefügt, wie in Fig. 2R, und dann wird der (3620) tatsächliche Fräserweg *TP* erstellt, wie in Fig. 9S dargestellt.

Anschließend wird der (3625) CNC-Maschinencode erzeugt, der in dem ausführlichen Flußschema der Fig. 2Z-6 dargestellt und in der Ausgabedatei niedergeschrieben ist. Dann werden (3630) die Variablen zurückgesetzt, (3635) die Endergebnisse am Monitor ausgegeben, und (3640) das Programm springt zurück auf Unterschritt (3560), bis der gesamte Brackethalter-Code errechnet ist. Dann wird (3645) die vervollständigte CNC-Datei an die Steuereinheit der CNC-Fräse übertragen, und ein Stapel von Scheiben 83a (Fig. 1F) zu einem Satz Bracketeinsetzhalter 82 gefräst. Ein Beispiel für einen der Halter ist in Fig. 9T bis 9W veranschaulicht.

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Geradensegmente verbunden werden, um die Profilkurve *PF* zu definieren. Der Fräserdurchmesser *Endmill* wird ebenfalls eingegeben, der kleiner als der Bogendrahtdurchmesser oder die Bogendrahtschlitzbreite sein muß (0,45 oder 0,55 mm). Konstanten werden festgelegt, darunter der Durchmesser des Halterrohlings 83, der Fräsabstand an der Außenseite des Halters, die Anzahl der Schleifen, bei 23 festgelegt, und die Zählerausgangseinstellungen.

Anschließend folgt der Erstellung des Profil- und Bracket-Spielkompensations-Fräserwegs *ITP* bzw. *BCTP*. Dazu gehören die Erstellung einer anfänglichen inneren Fräserweglinie *IITP*, die aus einer Reihe von Geradensegmenten besteht, wobei eines jeweils parallel zu einem Liniensegment der Zahnprofilkurve verläuft, und zwar mit einem Abstand, der dem Fräserradius an der Innenseite der Profilkurve entspricht, wie in Fig. 9K , die Erstellung einer anfänglichen Bracketbasis-Kompensations-Fräserweglinie *IBCTP*, die aus einer Reihe von Geradensegmenten besteht, wobei eines jeweils parallel zu einem Liniensegment der Zahnprofilkurve verläuft, und zwar mit einem Abstand, der der Bracketbasisabmessung minus dem Fräserradius außerhalb der Profilkurve entspricht, und (3600) die Erstellung eines abschließenden Bracketbasis-Kompensations-Fäserwegs *(d)*, um von der inneren Fräserweglinie zur Basiskompensationslinie am oberen Ende der Bracketbasisklebschicht zu fräsen, so daß der Halter am unteren Ende der Schicht abgetrennt wird, wie in Fig. 9M ("oberes Ende" und "unteres Ende" dienen hier in einem Beispiel für die unteren Zähne und werden für die oberen Zähne umgekehrt).

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Geradensegmente verbunden werden, um die Profilkurve *PF* zu definieren. Der Fräserdurchmesser *Endmill* wird ebenfalls eingegeben, der kleiner als der Bogendrahtdurchmesser oder die Bogendrahtschlitzbreite sein muß (0,45 oder 0,55 mm). Konstanten werden festgelegt, darunter der Durchmesser des Halterrohlings 83, der Fräsabstand an der Außenseite des Halters, die Anzahl der Schleifen, bei 23 festgelegt, und die Zählerausgangseinstellungen.

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Patentansprüche

1. Verfahren zur Herstellung eines individuellen kieferorthopädischen Apparats für die Bewegung der Zähne eines Patienten in gewünschte Endpositionen im Mund des Patienten, das folgende Schritte umfaßt: Vermessen der anatomischen Formen im Mund des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den anatomischen Formen, einschließlich der die Formen der einzelnen Zähne des Patienten darstellenden dreidimensionalen Zahnformdaten; Ableiten einer idealen Zahnbogenform durch Verarbeiten der digitalisierten Daten zu den anatomischen Formen mit Hilfe eines Computers, der für die Erstellung eines zumindest teilweise von den digitalisierten Daten zu den anatomischen Formen abhängigen digitalisierten mathematischen Bogenform-Modells programmiert ist; Ableiten der Zahnendpositionen aus den digitalisierten Daten zu den anatomischen Formen sowie des digitalisierten mathematischen Bogenform-Modells mit Hilfe des Computers zur mesiodistalen Anordnung der Zähne auf dem abgeleiteten idealen Zahnbogen und zur Bewegung der Zähne in bezug auf den abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; Konstruktion eines individuellen kieferorthopädischen Apparats anhand der dreidimensionalen Zahnformdaten, der vorgegebenen Apparatfixierpunkte und der abgeleiteten Zahnendpositionen mit Hilfe des Computers, so daß der individuelle kieferorthopädische Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihren entsprechenden Fixierpunkten und den Zähnen in den abgeleiteten Zahnendpositionen besteht; Erzeugen maschinenlesbarer Steuersignale, die mit den Ergebnissen des Apparatkonstruktionsschritts korrelierende geometrische Informationen enthalten; und automatisches Fertigen eines individuellen kieferorthopädischen Apparats mit Hilfe einer Fertigungsanlage, die mittels maschinenlesbarer Steuersignale steuerbar ist und den Apparat entsprechend den in den Steuersignalen enthaltenen geometrischen Informationen formt, so daß der individuelle kieferorthopädische Apparat mit der zuvor konstruierten Konfiguration ensteht.

2. Verfahren nach Anspruch 1, bei dem unter dem Begriff Zähne sowohl die Unterkiefer- als auch Oberkieferzähne zu verstehen sind und bei dem der Schritt Vermessen der anatomischen Form die Schritte Vermessen des Unterkiefers eines Patienten und auf dieser Grundlage Gewinnen digitalisierter Daten zur Form des Unterkiefers sowie Vermessen der

Unterkiefer- und Oberkieferzähne des Patienten und auf dieser Grundlage Gewinnen digitalisierter Daten zur Form der jeweiligen Unterkiefer- und Oberkieferzähne umfaßt; der Schritt Ableiten der Bogenform den Schritt Ableiten einer Mandibularskelettbogenform aus den digitalisierten Daten zur Unterkieferform mit Hilfe des Computers umfaßt; und der Schritt Ableiten der Zahnendposition den Schritt Ableiten der Zahnendpositionen aus den Zahnformdaten und der abgeleiteten Mandibularskelettbogenform umfaßt, so daß die Zähne unter Berücksichtigung der Mandibularskelettbogenform angeordnet werden.

3. Verfahren nach Anspruch 2, bei dem jeder Zahn eine Krone, eine Wurzel und eine Längsachse aufweist, die im allgemeinen senkrecht durch den Mittelpunkt der Krone verläuft und sich mit einem Gingivamittelpunkt schneidet, in dem die Krone an die Wurzel angrenzt, und bei dem der Schritt Vermessen des Unterkiefers den Schritt Digitalisieren von Punkten von Daten umfaßt, die eine die Wurzeln der Unterkieferzähne einschließende Mandibularalveolenmulde definieren; der Schritt Ableiten der Mandibularskelettbogenform den Schritt Anpassen einer glatten stetigen Mandibularalveolenmuldengleichung an die digitalisierten Punkte der Mandibularalveolenmuldendaten und Gewinnen einer digitalisierten Darstellung der Mandibularalveolenmuldengleichung umfaßt; der Schritt Ableiten der Zahnendposition das Ableiten von Positionen umfaßt, durch die jeder Unterkieferzahn mittig ausgerichtet wird, indem dessen Längsachse approximativ auf die Mandibularalveolenmuldengleichung nahe dem Gingivamittelpunkt des Zahns angeordnet wird, und durch die die obersten Zahnpartien der Unterkieferzähne auf eine glatte stetige Kurve gebracht werden, die durch Anpassen der Mandibularalveolenmuldengleichung abgeleitet wurde; und bei dem der Schritt der Apparatkonstrution die Festlegung der Apparatkonfiguration mit Hilfe einer Reihe aus der glatten stetigen Kurve abgeleiteter digitaler Werte umfaßt.

4. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Daten zur Form des Unterkiefers des Patienten durch Digitalisieren den Grenzen der Kompakta des Patienten entsprechender Grenzpunkte und der Schritt Ableiten der Bogenform den Schritt Ableiten einer die Form der Kompakta des Patienten mathematisch darstellenden Skelettbogenform aus den digitalisierten Daten mit Hilfe einer aus den digitalisierten Grenzpunkten abgeleiteten glatten stetigen Gleichung umfaßt.

5. Verfahren nach Anspruch 4, bei dem die glatte stetige Gleichung eine kubische Spline-Funktion durch Punkte ist, die mit den digitalisierten Grenzpunkten in Beziehung stehen.

6. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Ableiten der Bogenform den Schritt Definieren einer Kurve auf der Grundlage der digitalisierten Daten zur anatomischen Form und Glätten der Kurve mit Hilfe eines statistischen Best-fit-Verfahrens zur Gewinnung einer glatten stetigen Bogenformgleichung umfaßt, wobei der Schritt Ableiten der Endposition und der Schritt Konstruktion der Apparatkonfiguration zumindest teilweise auf der Bogenformgleichung basieren.

7. Verfahren nach einem der vorstehenden Ansprüche, das zudem die Schritte digitale Darstellung der abgeleiteten Bogenform durch eine Bogenformgleichung mittels Computer; und Darstellung der Bogenformgleichung durch eine Reihe von einander berührenden Kreissegmenten beinhaltet; und bei dem der Schritt Konstruktion des Apparats den Schritt Konstruktion eines bogenförmigen Apparats zumindest teilweise in Übereinstimmung mit einer Reihe von digitalen Werten, die die Kreissegmentlängen und -radien darstellen, die ihrerseits aus den Kreissegmenten der Bogenformgleichung abgeleitet wurden, und der Schritt Fertigen des Apparats den Schritt Umwandeln der Segmentlängen und -radien in eine Reihe von Befehlen zur Gewinnung von Steuersignalen und, gesteuert durch diese Signale, schrittweises Formen des Apparats mit einem einer jeden Segmentlänge des Apparats entsprechenden Radius in Übereinstimmung mit der berechneten Apparatkonfiguration umfaßt.

8. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Entfernungen zwischen den mesialen und distalen Kontaktpunkten eines jeden Zahns zur Definition der mesial-distalen Breiten eines jeden Zahns; der Schritt Ableiten der Zahnendpositionen den Schritt Ableiten der Zahnendpositionen, wobei aneinander angrenzende mesiale und distale Kontaktpunkte benachbarter Zähne miteinander in Kontakt zu bringen sind, wodurch ein Zahnanordnungsbogen gebildet wird, der in bezug auf die Gestalt mit der abgeleiteten Bogenform übereinstimmt und etwa die gleiche Länge wie die Summe der mesial-distalen Breiten der darauf angeordneten Zähne aufweist; und der Schritt Konstruktion des Apparats den Schritt Konstruktion der Apparatkonfiguration teilweise anhand der mesial-distalen Breiten und des Zahnanordnungsbogens umfaßt.

9. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der für jeden Zahn gewonnenen Zahnprofildaten in Form einer Reihe digitalisierter Punkte von Daten, die die Gestalt der Zahnoberfläche zumindest entlang eines sich im allgemeinen senkrecht und labial-lingual erstreckenden Zahnprofils darstellen; der Schritt Vorgeben des Fixierpunktes den Schritt örtliches Zuweisen eines Apparat-fixierpunktes auf der Oberfläche eines jeden einer Anzahl von Zähnen entlang dem Zahnprofil; und der Schritt Konstruktion des Apparats den Schritt Konstruktion der vorgegebenen Fixierpunkte und der abgeleiteten Zahnpositionen aus einer Reihe die Gestalt der Zahnoberfläche darstellender Punkte digitalisierter Daten umfaßt.

10. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Ableiten der Bogenform die Schritte Vergleichen entsprechender einander gegenüberliegender Punkte auf einander gegenüberliegenden Seiten der Bogenform und auf der Grundlage dieses Vergleichs Berechnen einer modifizierten Bogenform mit seitlicher Symmetrie gegenüber ihrer Mittellinie sowie Konstruktion des Apparats zumindest teilweise auf der Grundlage der modifizierten Bogenform umfaßt.

11. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Daten von Punkten an den labialen und lingualen Flächen eines jeden Zahns einer Anzahl von Zähnen des Patienten umfaßt, und das des weiteren beinhaltet: Ableiten einer digitalen Darstellung der Ausrichtung einer Kronenlängsachse eines jeden Zahns in bezug auf die Punkte aus den digitalisierten Daten der labialen und lingualen Fläche sowie Berechnen der Endpositionen der Zähne anhand der digitalisierten Daten und der digitalen Darstellungen der Kronenlängsachsen der Zähne, wobei die berechneten Endpositionen bevorzugte Kronenlängsachsenrichtungen einschließen.

12. Verfahren nach Anspruch 11, das ferner die Schritte Berechnen der bevorzugten Kronenlängsachsenrichtungen für eine Anzahl von Patienten und Dokumentieren der berechneten bevorzugten Kronenlängsachsenrichtungen; Dokumentieren der Personendaten eines jeden Patienten, Zuordnen der Personendaten zu den berechneten bevorzugten Kronenlängsachsenrichtungen und Klassifizieren der Patienten in Populationsgruppen auf der Basis dieser Zuordnung; sowie Erstellen einer Statistik zu den bevorzugten Kronenlängsachsenrichtungen bei den Patienten der Populationsgruppen umfaßt.

13. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Konstruktion des Apparats den Schritt Konstruktion der Apparateinsetzhalterkonfigurationen anhand der Zahnformdaten umfaßt, wobei für jede Konfiguration eine Halteroberfläche vorgesehen wird, die mit der jeweiligen Zahnoberfläche übereinstimmt, wodurch die Festlegung der Anordnung des Fixierpunktes und die Fixierung des Apparats an der Zahnoberfläche erleichtert werden; der Schritt Erzeugen der Steuersignale den Schritt Erzeugen von Steuersignalen umfaßt, die zumindest zu einem Teil mit den konstruierten Apparateinsetzhalterkonfigurationen übereinstimmen; und der Schritt Fertigen des Apparats den Schritt automatische Fertigung der Apparateinsetzhalter entsprechend den Steuersignalen zur Gewährleistung der Übereinstimmung mit den berechneten Einsetzhalterkonfigurationen umfaßt.

14. Verfahren nach Anspruch 13, bei dem der Schritt Konstruktion der Apparateinsetzhalterkonfigurationen die Schritte Berechnen der Haltergeometrie anhand der digitalisierten Zahnformdaten und der definierten Fixierpunkte umfaßt, wobei eine Halteranlagefläche, die mit dem individuellen Abschnitt der Kronenaußenfläche eines Zahns übereinstimmt, und eine Apparatangriffsfläche, die hinsichtlich der Lage mit der Halteranlagefläche genauso übereinstimmt, wie der individuelle Abschnitt der Außenfläche mit dem Fixierpunkt am Zahn, definiert werden, so daß die Fertigungsanlage bei Steuerung anhand der Steuersignale einen Halter fertigt, der bei Einsatz am Zahn einen Apparat, auf den er am Fixierpunkt des Zahns zum Befestigen daran aufgesetzt wird, am Ort fixiert und ausrichtet.

15. Verfahren nach Anspruch 14, bei dem der Schritt Festlegen des Fixierpunktes den Schritt Berechnen der Fixierpunkte anhand der digitalisierten Zahnformdaten; und der Schritt Berechnen der Haltergeometrie den Schritt Festlegen der Apparatangriffsfläche unter dem Aspekt umfaßt, daß diese hinsichtlich der örtlichen Zuordnung mit der Halteranlagefläche in gleicher Weise übereinstimmt, wie der individuelle Abschnitt der Außenfläche mit dem berechneten Fixierpunkt am Zahn übereinstimmt.

16. Verfahren nach Anspruch 14 oder 15, bei dem zum Apparat eine Anzahl von Brackets gehört, wobei je eines zum Befestigen an je einem Fixierpunkt an einem Zahn bestimmt ist und jedes Bracket einen Schlitz zur Aufnahme des Bogendrahts aufweist; der Schritt Konstruktion der Apparatkonfiguration Bracketformdaten, so auch eine digitale Darstellung der Position und Neigung des Schlitzes im Bracket, einschließt; und der Schritt Berechnen der Haltergeometrie den Schritt Festlegen der Apparatangriffsfläche umfaßt, so

daß ein Teil des Apparats einbezogen ist, der fluchtend auf den Schlitz des Brackets ausgerichtet wird, wenn der Apparat in das Bracket eingesetzt wird.

17. Verfahren nach Anspruch 16, bei dem der Schritt Konstruktion des Apparats den Schritt Berechnen der Bracketauslegung für die Aufnahme eines bogenförmig gestalteten Bogendrahts umfaßt.

18. Verfahren nach Anspruch 16 oder 17, bei dem der Schritt Konstruktion des Apparats den Schritt Auswählen eines optimalen Rohlings für die Fertigung des Brackets entsprechend der digitalen Schlitzdarstellung unter einer Anzahl von Bracketrohlingen umfaßt.

19. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Vermessen der Formen der einzelnen oberen und unteren Zähne und der Unterkieferform des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den Formen der oberen und unteren Zähne sowie zur Unterkieferform umfaßt, wobei die Zahnformdaten auch Daten der Schneidkanten der unteren vorderen Schneidezähne und der bukkalen Höcker der unteren hinteren Zähne sowie des zentralen Kamm- oder des Randleistenbereichs der oberen hinteren Zähne beinhalten; der Schritt Ableiten der Zahnendposition die Schritte Ableiten einer Konfiguration des mit Zähnen bestückten Unterkiefers unter Berücksichtigung der Anordnung der unteren Zähne entlang der unteren Bogenkonfiguration mit miteinander kontaktierenden benachbarten Zähnen, und der unteren Bogenkonfiguration; senkrechtes Ausrichten eines jeden unteren Zahns unter dem Aspekt, daß die Schneidkanten der unteren Vorderzähne und die bukkalen Höcker der unteren hinteren Zähne im wesentlichen die gleiche Okklusionsebene einnehmen und einen angestrebten Neigungswinkel aufweisen; Anpassen der mit Zähnen bestückten unteren Bogenkonfiguration zur Erzielung einer Endkonfiguration des mit Zähnen bestückten Unterkiefers durch labial-linguale Positionierung der unteren Zähne, um deren Schneidkanten und bukkalen Höcker auf einen glatten Bogen in der Okklusionsebene auszurichten, wobei benachbarte Zähne miteinander kontaktieren; und Ableiten einer Endkonfiguration des mit Zähnen bestückten Oberkiefers umfaßt, bei der die zentralen Höckerfurchen bzw. die Randleisten der hinteren Zähne horizontal mit der Endkonfiguration des mit Zähnen bestückten Unterkiefers und vertikal mit der Okklusionsebene übereinstimmen; die Vorderzähne mit ihren Schneidkanten unterhalb der Okklusionsebene angeordnet sind, so daß sie eine festgelegte Überdeckung und ein horizontales Offset in labialer Richtung gegenüber der Endkonfiguration des mit Zähnen bestückten Unterkiefers erhalten, damit ein bestimmter Abstand

zwischen den lingualen Seiten der unteren Vorderzähne und den labialen Seiten der unteren Vorderzähne hergestellt wird; der Schritt Konstruktion des Apparats den Schritt Berechnen einer Bracketkonfiguration für die Brackets der einzelnen oberen und unteren Zähne einschließlich des Schlitzwinkels und der Schlitztiefe jedes Brackets und Berechnen der Bogendrahtform für den oberen und unteren Bogendraht, und zwar auf der Grundlage der berechneten Zahnendpositionen, der festgelegten Ebenen für den oberen und unteren Bogendraht, der Zahnformen und der Fixierpositionen; und der Schritt Fertigen des Apparats die Schritte Fertigen des oberen und unteren Bogendrahts in Übereinstimmung mit den berechneten Bogendrahtformen und Fertigen der Brackets entsprechend den berechneten Bracketkonfigurationen umfaßt.

20. Verfahren nach einem der vorstehenden Ansprüche, zu dem ferner die Schritte Bereitstellen von Kriterien für die Beschreibung der Abstände zwischen den einzelnen Zähnen und der Drehachse des Unterkiefers gehören, und bei dem der Schritt Ableiten der Zahnendstellung die Schritte Berechnen einer Molarenanhebungskomponente aus den Kriterien und den Zahnformdaten; und vertikales Ausrichten der oberen und unteren Molaren umfaßt, so daß ihre Höcker entsprechend unterhalb oder oberhalb in einem Abstand zur Okklusionsebene angeordnet werden, der mit der berechneten Molarenanhebung in einer bestimmten Beziehung steht.

21. Verfahren nach Anspruch 20, wenn dieser von Anspruch 19 abhängig ist, bei dem der Schritt Ableiten der Endkonfiguration des mit Zähnen bestückten Oberkiefers das Ableiten der Konfiguration umfaßt, bei der die Schneidkanten der oberen Vorderzähne so weit unterhalb der Okklusionsebene angeordnet sind, daß festgelegte Überdeckungen erreicht werden, die in einer bestimmten Beziehung zur berechneten Molarenanhebung stehen.

22. Verfahren nach Anspruch 20 oder 21, bei dem der Schritt Berechnen der Molarenanhebungskomponente die Schritte Bestimmen der Okklusionspaare der entsprechenden oberen und unteren hinteren Zähne des Patienten und Bestimmen eines senkrechten Abstands zwischen dem höchsten Punkt des unteren Zahns des Paars und dem tiefsten Punkt des oberen Zahns des Paars für ein jedes Paar aus den digitalisierten Zahnformdaten, wenn sich die Kiefer in geschlossener Stellung befinden; Ausgleichen eines jeden ermittelten vertikalen Abstands mittels eines Faktors, der einem Abstand eines jeden Paares zur Drehachse proportional ist, und Auswählen des größten ausgeglichenen vertikalen Abstands, indem aus den digitalisierten Daten die Endpositionen der Unterkieferzähne des

Patienten berechnet werden, bei denen sich die höchsten Punkte dieser Zähne hinsichtlich der vertikalen Position an einer weitestgehend flachen Okklusionsfläche befinden; und Berechnen der Endpositionen der sich entsprechend bis unter und über die Okklusionsfläche erstreckenden oberen und unteren Molaren des Patienten umfaßt.

23. Verfahren nach einem der vorstehenden Ansprüche, zu dem des weiteren die Schritte Bereitstellen eines Systems für die Konstruktion und zum Fertigen kieferorthopädischer Apparate einschließlich eines Dateneingabe-Untersystems zur Digitalisierung der Eingabedaten von gemessenen anatomischen Formen und zur Erzeugung von Eingangssignalen als Träger der digitalisierten Eingabedaten, eines Datenverarbeitungs-Untersystems zur Verarbeitung der digitalisierten Eingangssignale und zur Erzeugung entsprechender Ausgangssignale als Träger der Steuersignale und eines Apparatfertigungs-Ausrüstungsuntersystems mit der dazugehörigen Fertigungsanlage zur durch die Ausgangssignale gesteuerten Herstellung eines individuellen kieferorthopädischen Apparats für die Behandlung des Patienten durch Bewegen der Zähne des Patienten in die bevorzugten Endpositionen; und Erzeugen von Ausgangssignalen für die Steuerung des Apparatfertigungs-Ausrüstungsuntersystems mit Hilfe des Datenverarbeitungs-Untersystems aus der abgeleiteten Bogenform zur Herstellung eines individuellen kieferorthopädischen Apparats; sowie Fertigen des individuellen kieferorthopädischen Apparats mit der individuellen Konfiguration mit Hilfe des Apparatfertigungs-Ausrüstungsuntersystems entsprechend dem Ausgangssignal und den Steuersignalen gehören.

24. Verfahren nach Anspruch 23, bei dem zum individuellen kieferorthopädischen Apparat ein Bogendraht in gebogener Form, die mathematisch in Beziehung steht zur Skelettbogenform der Mandibularalveolenmulde; zum Apparatfertigungs-Ausrüstungsuntersystem eine Drahtbiegevorrichtung, die durch Signale gesteuert wird, für die das Ausgangssignal als Träger dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Drahtbiegevorrichtung gehören, so daß sie mit einem Draht gespeist wird und das Biegen des zugeführten Drahts entsprechend der individuellen Bogendrahtkonfiguration erfolgt, um den Bogendraht an den Zähnen eines Kiefers an den entsprechenden Fixierpunkten fixieren zu können.

25. Verfahren nach Anspruch 24, bei dem die digitalisierten Eingabedaten Informationen enthalten, aus denen der Fixierpunkt des Apparats und die Neigung der Fläche am Fixierpunkt abgeleitet werden können; bei dem zum individuellen kierferorthopädischen

Apparat eine Anzahl von Brackets, und zwar je Fixierpunkt des Zahns eines, gehört, wobei jedes eine Basis, die sich am entsprechenden Fixierpunkt fixieren läßt, und einen für die Aufnahme des Bogendrahts bestimmten Bogendrahtschlitz aufweist; zum Apparatfertigungs-Ausrüstungsuntersystem eine Bracketfertigungsvorrichtung gehört, die mittels Steuersignale gesteuert wird, für die das Ausgangssignal als Träger dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Bracketfertigungsvorrichtung gehört, die dazu dienen, jedes Bracket mit dem Bogendrahtschlitz in einer solchen Richtung zur Basis ausgerichtet zu fertigen, daß dieser einen Punkt am Bogendraht bezüglich des Fixierpunktes des entsprechenden Zahns stützt und orientiert und so eine Kraft zwischen diesen Punkten überträgt und schließlich den Zahn in Richtung seiner Endposition drückt.

26. Verfahren nach Anspruch 25, bei dem die digitalisierten Eingabedaten Informationen zum Zahnumriß enthalten; zum individuellen kieferorthopädischen Apparat ein Bracket-einsetzhalter für jedes Bracket mit einer Fläche zur individuell paßgerechten Positionierung des Halters an der Zahnfläche und zur Positionierung des Brackets am Zahn an dessen Fixierpunkt gehört; zum Apparatfertigungs-Ausrüstungsuntersystem eine Bracketeinsetz-halter-Fertigungsvorrichtung gehört, die mit Hilfe der Steuersignale gesteuert wird, für die als Träger das Ausgangssignal dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Vorrichtung für die Fertigung von Bracketeinsetzhaltern gehört.

27. Verfahren nach Anspruch 25 oder 26, bei dem der Schritt Apparatfertigung die Schritte Bereitstellen einer Anzahl von Bracketrohlingen; und Herstellen eines Brackets aus dem Bracketrohling durch Ausbilden eines Bogendrahtschlitzes in jedem der Bracketrohlinge in einer solchen Weise umfaßt, daß jeder Schlitz beim Befestigen des Brackets am Fixier-punkt eines Zahns in einer Bogendrahtebene angeordnet ist, wobei sich der Zahn in seiner abgeleiteten Endposition befindet.

28. Verfahren nach Anspruch 27, bei dem der Schritt Ableiten der Bogenform den Schritt aus den digitalisierten Daten vorgenommenes Ableiten einer Skelettbogenform umfaßt, die mathematisch die Form der Kompakta des Patienten mittels einer glatten stetigen Gleichung darstellt, die ihrerseits von den digitalisierten Grenzpunkten abgeleitet wurde, die den Grenzen der Kompakta des Patienten entsprechen und die Bogenformgleichung mit Hilfe einer Reihe von einander berührenden Kreissegmenten darstellen; der Schritt Bracketschlitz-fräsen den Schritt Ausführen des Schlitzes bis auf eine Tiefe, die durch das Sichschneiden der Bogenformgleichung mit dem Bracket bestimmt wird, wenn das Bracket am Fixierpunkt

eines in seiner abgeleiteten Endposition befindlichen Zahns befestigt ist; und der Schritt Bracketschlitzfräsen den Schritt Ausführen des Schlitzes bis zu einer Schlitzgrundflächenkurve mit dem Radius des schneidenden Kreissegments der Bogenformgleichung umfaßt.

29. Verfahren nach einem der vorstehenden Ansprüche, bei dem zur Gewährleistung eines optimalen Zwischenraums zwischen dem Apparat und der Gingiva eines Patienten sowie eines optimalen Zwischenraums zu den Zähnen des anderen Kiefers des Patienten der Schritt Festlegen der Position des Fixierpunktes die Schritte Digitalisieren der Geometrie von Teilen des Apparats; anhand der digitalisierten Zahnformdaten erfolgendes Berechnen der Beziehungen zwischen Punkten auf den Zahnflächen der gegenüberliegenden Kiefer des Patienten; anhand der digitalisierten Daten erfolgendes Berechnen der Stellen an den Oberflächen der Zähne eines Kiefers des Patienten, an denen der Apparat zu fixieren ist, damit ein optimaler Zwischenraum zwischen dem Apparat und der Gingiva eines Patienten und ein optimaler Zwischenraum zu den Zähnen des anderen Kiefers des Patienten gewährleistet wird; sowie Konstruktion der Apparatkonfiguration entsprechend den berechneten Orten für die Fixierung des Apparats an den Zähnen des Patienten umfaßt.

30. Verfahren nach einem der Ansprüche 1 bis 23, bei dem zu dem individuellen kieferorthopädischen Apparat ein Bogendraht gehört; der Schritt Konstruktion des Apparats den Schritt Ableiten der digitalen Bogendrahtformdaten, die zumindest teilweise auf der abgeleiteten Bogenform basieren; und der Schritt Erzeugen des Steuersignals den Schritt anhand der digitalen Bogendrahtformdaten erfolgendenes Erzeugen eines Drahtform-Steuersignals, so daß von der Bogendrahtformvorrichtung, wenn dies an die Vorrichtung angelegt wird, ein individueller kieferorthopädischer Apparat entsprechend den anatomischen Formgegebenheiten des Mundes des Patienten hergestellt wird; und Formen einer Länge des kieferorthopädischen Bogendrahtmaterials in eine angestrebte Form entsprechend dem Drahtform-Steuersignal zwecks Herstellung eines individuellen Bogendrahts umfaßt.

31. Verfahren nach Anspruch 30, bei dem der Schritt Erzeugen eines Steuersignals die Schritte Bereitstellen von Materialeigenschaftsdaten des Bogendrahts; und Erzeugen des Drahtbiegesteuersignals anhand der Materialeigenschaftsdaten des Bogendrahts umfaßt.

32. Verfahren nach Anspruch 30 oder 31, das ferner die Schritte Messen der Bogendrahtspannweite zwischen zwei Punkten an dem hergestellten individuellen Bogendraht;

Berechnen einer Konstruktions-Bogendrahtspannweite aus den abgeleiteten Bogendrahtformdaten; Vergleichen der gemessenen Bogendrahtspannweite mit der Konstruktions-Bogendrahtspannweite und Übermitteln eines Ergebnisses des Vergleichs; sowie Erzeugen des Drahtbiege-Steuersignals entsprechend dem übermittelten Vergleichsergebnis umfaßt.

33. Fertigungskomplex für die Herstellung eines individuellen kieferorthopädischen Apparats, zu dessen Bestandteilen zählen: technische Mittel (30, 30a, 33, 43, 50, 57) zum Vermessen der anatomischen Formen (20 bis 24) des Mundes (18) des Patienten (12) und darauf aufbauend zur Erzeugung digitalisierter Daten zur anatomischen Form (26) einschließlich dreidimensionaler Zahnformdaten, die die Formen der einzelnen Zähne des Patienten darstellen, und ein digitaler Computer (30b, 30c) einschließlich der Programme zur Ableitung einer idealen Zahnbogenform aus den digitalisierten Daten (26) mit Hilfe eines speziell programmierten Computers (30b) zur Gewinnung eines digitalisierten Bogenformmodells, das zumindest teilweise von den digitalisierten Daten zur anatomischen Form abhängt; zum Ableiten der Zahnendpostionen aus den digitalisierten anatomischen Daten (26) und der abgeleiteten digitalisierten idealen Bogenform mit Hilfe des Computers zur mesiodistalen Anordnung der Zähne auf der abgeleiteten idealen Zahnbogenform und zur Bewegung der Zähne in bezug auf den abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; zum Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; zur Konstruktion einer Apparatkonfiguration anhand der digitalisierten Zahnformdaten, der vorgegebenen Apparatfixierpunkten und der abgeleiteten Zahnendpositionen unter dem Aspekt, daß der entsprechend diesen Daten gefertigte individuelle Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihrem jeweiligen Fixierpunkt und den Zähnen in den abgeleiteten Zahnendpositionen besteht; zum Erzeugen eines Maschinencodes (42), der mit der konstruierten Apparatkonfiguration in einer bestimmten Beziehung stehende geometrische Informationen enthält; und eine Fertigungsanlage (38, 39, 40, 41) zum automatischen Fertigen eines individuellen kieferorthopädischen Apparats (25) durch Formen des Apparats (25) entsprechend dem Maschinenkode (42) in Übereinstimmung mit den geometrischen Informationen, so daß auf diese Weise der Apparat (25) mit der konstruierten Konfiguration entsteht.

34. Fertigungskomplex nach Anspruch 33, bei dem zur Fertigungsanlage (38) eine Bogendrahtformvorrichtung (40) mit technischen Mitteln (66 bis 71) zum Formen einer Länge

von kieferorthopädischem Bogendrahtmaterial (69) in eine angestrebte Form entsprechend einem an diese technischen Mittel angelegten Drahtform-Steuersignal; sowie Programmeinheiten mit Einheiten zur Erzeugung eines Drahtform-Steuersignals in Übereinstimmung mit den digitalen Bogendrahtformdaten gehören, so daß bei Anliegen des Signals an der Bogendrahtformvorrichtung diese einen individuellen kieferorthopädischen Bogendraht (64) entsprechend der jeweiligen anatomischen Form des Mundes (18) des Patienten herstellt.

35. Fertigungskomplex nach Anspruch 34, bei dem die abgeleiteten digitalen Bogendrahtformdaten die mit einer Längenkomponente der abgeleiteten digitalen Bogendrahtformdaten in einer Beziehung stehenden Drahtlängendaten und die mit einer Krümmungskomponente der abgeleiteten digitalen Bogendrahtformdaten in einer Beziehung stehenden Drahtkrümmungsdaten enthalten, die eine Funktion der Längenkomponente sind; bei dem zum Drahtform-Steuersignal ein als Träger der Drahtlängendaten dienendes Drahtzuführungssteuersignal und ein als Träger der Drahtkrümmungsdaten dienendes Drahtbiegesteuersignal gehören; bei dem zu den Programmeinheiten Einheiten zur Erzeugung des Drahtzuführungssteuersignals und Einheiten zur Erzeugung eines Drahtbiegesteuersignals und zur Übertragung der Steuersignale an die Bogendrahtformvorrichtung gehören; und bei dem zur Bogendrahtformvorrichtung (40) eine Zuführungsvorrichtung (68) zur Zuführung des kieferorthopädischen Bogendrahtmaterials (69) in Längsrichtung entsprechend dem Drahtzuführungssteuersignal und eine Vorrichtung (70) zum Biegen des mit Hilfe der Drahtzuführungsvorrichtung (68) zugeführten Bogendrahtmaterials (69) in Querrichtung entsprechend dem Drahtbiegesteuersignal und synchron mit der Zuführung des Bogendrahtmaterials (69) gehören.

36. Fertigungskomplex nach Anspruch 34, bei dem die digitalen Bogendrahtformdaten eine digitale Darstellung einer Reihe von zusammenhängenden Drahtsegmenten sind, von denen ein jedes eine Längenkomponente und eine Krümmungskomponente aufweist; und zur Bogendrahtformvorrichtung eine Vorrichtung zur Zuführung einer Reihe von Längen des kieferorthopädischen Bogendrahtmaterials in Längsrichtung entsprechend den jeweiligen Drahtlängenkomponenten in Übereinstimmung mit den Drahtlängendaten und eine Vorrichtung (70) zum Biegen einer jeden zugeführten Länge des Bogendrahtmaterials (69) in eine Form mit einer Krümmung entsprechend der jeweiligen Drahtkrümmungskomponente in Übereinstimmung mit den Drahtkrümmungsdaten gehören.

37. Fertigungskomplex nach Anspruch 36, bei dem jedes Drahtsegment die Form eines Kreissegments mit einer Segmentlängenkomponente als Ausdruck für eine tangentiale Länge des Bogendrahtmaterials und mit einer Segmentkrümmungskomponente als Ausdruck eines konstanten Krümmungsradius des Materials über die tangentiale Länge des Segments aufweist; und zur Zuführungsvorrichtung (68) eine Vorrichtung für die Zuführung einer Reihe von tangentialen Längen des kieferorthopädischen Bogendrahtmaterials (69) und zur Biegevorrichtung (70) eine Vorrichtung zum Biegen einer jeden zugeführten Länge des Bogendrahtsegments in einer Form mit gleichbleibendem Radius entsprechend den Drahtkrümmungsdaten gehören.

38. Fertigungskomplex nach Anspruch 37, bei dem die Zuführungsvorrichtung (68) für die fortlaufende Zuführung einer Reihe von Längen des Bogendrahtmaterials, die den Längenkomponenten der Kreissegmente gleich sind, entsprechend dem Drahtzuführungssignal auf einer längs ausgerichteten Bahn vorgesehen ist; bei dem zur Biegevorrichtung (70) ein Biegeelement (70b), das entsprechend dem Drahtbiegesignal quer zur Bahn bewegt werden kann, um so die Biegung in Querrichtung auf das Segment zu übertragen, und ein Querrichtungspositionssensor zur Erzeugung eines auf die Biegung ansprechenden Rückkopplungssignals gehören; und bei dem zum Computer (30b, 30c) eine Einheit zur Modifizierung des Drahtbiegesteuersignals entsprechend dem Rückkopplungssignal zur Gewährleistung der geschlossenen Steuerung des Biegeelements gehört.

39. Fertigungskomplex nach einem der Ansprüche 36 bis 38, zu dem des weiteren eine Vorrichtung zum Messen der Bogendrahtspannweite zwischen Punkten am ersten und letzten Segment der Reihe von hergestellten individuellen kieferorthopädischen Bogendrähten (64) gehört; bei dem zu den Programmeinheiten Einheiten zur Berechnung einer Bogendraht-Konstruktionsspannweite anhand der abgeleiteten Bogendrahtformdaten; sowie Einheiten zum Vergleich der gemessenen Bogendrahtspannweite mit der Bogendraht-Konstruktionsspannweite und zum Speichern der Vergleichsergebnisse gehören; und bei dem die Programmeinheiten für die Erzeugung des Drahtformsteuersignals entsprechend einem gespeicherten Vergleichsergebnis vorgesehen sind.

40. Fertigungskomplex nach einem der Ansprüche 36 bis 39, bei dem zu den Programmeinheiten mit den Einheiten zur Erzeugung der Drahtformsteuersignale im Datenaustausch stehende Einheiten für den Empfang der Materialeigenschaftsdaten des Bogendrahtmaterials und für die Modifizierung des Drahtbiegesteuersignals entsprechend den

Eigenschaftsdaten gehören, wodurch ein Ausgleich der elastischen Eigenschaften des Materials ermöglicht wird.

41. Fertigungskomplex nach einem der Ansprüche 33 bis 40, bei dem zur Fertigungsanlage (38) eine Bracketfertigungsvorrichtung (39) mit einer Spannvorrichtung (73) einschließlich dazugehörender Elemente zur Aufnahme eines Bracketrohlings (80) für die Herstellung; und Elemente (75 bis 77) zur Bearbeitung mindestens einer Oberfläche eines in der Spannvorrichtung (73) eingespannten Bracketrohlings (80) entsprechend einem Fertigungsanlagensteuersignal, das in Übereinstimmung mit dem Steuersignal an diese angelegt wurde, einschließlich einem Element (77) zur Bearbeitung des in der Spannvorrichtung (73) eingespannten Bracketrohlings (80) zur Fertigung eines Brackets, das mit einem Schlitz mit einer berechneten geometrischen Beziehung zur Befestigungsfläche der Bracketbasis ausgeführt wird, gehören.

42. Fertigungskomplex nach Anspruch 41, bei dem jeder Schlitz durch eine im allgemeinen parallele Ober- und Unterseite, die eine Schlitzneigung definieren, und eine Schlitzgrundfläche an einem seiner Enden in größter Nähe zur Bracketbasis, die eine Schlitzposition definiert, gekennzeichnet ist; und jede berechnete geometrische Beziehung eines Schlitzes zur Befestigungsfläche eines Brackets durch die Schlitzneigung und eine Schlitzanordnung in bezug auf die Befestigungsfläche gekennzeichnet ist; bei dem das erzeugte Fertigungsanlagensteuersignal als Träger der Fertigungsanlagensteuerbefehle zur Betätigung der Fertigungselemente (75 bis 77) für die Bearbeitung des Bracketrohlings (80) zwecks Herstellung eines Brackets mit einem Schlitz (80b) mit der berechneten Schlitzneigung und -anordnung bezüglich der Befestigungsfläche dient; bei dem der Schlitz (80b) jedes Brackets so ausgeführt ist, daß ein Bogendraht (64) mit einer individuellen Krümmung unmittelbar am Zahn, an dem das Bracket befestigt werden soll, aufgenommen wird; bei dem jede berechnete geometrische Beziehung eines Schlitzes zur Befestigungsfläche eines Brackets durch eine mit der individuellen Krümmung des unmittelbar daran anliegenden Bogendrahts (64) übereinstimmende Schlitzgrundflächenkrümmung gekennzeichnet ist; und das erzeugte Fertigungsanlagensteuersignal als Träger von Fertigungsanlagensteuerbefehlen zur Betätigung der Fertigungselemente für die Bearbeitung des Bracketrohlings zwecks Herstellung eines mit einem Schlitz mit der berechneten Schlitzgrundflächenkrümmung ausgeführten Brackets dient.

43. Fertigungskomplex nach Anspruch 41 oder 42, bei dem zu den Fertigungselementen (75 bis 77) Elemente (77) zum Fräsen eines Schlitzes (80b) entsprechend dem Steuersignal gehören.

44. Fertigungskomplex nach einem der Ansprüche 41 bis 43, bei dem die Spannvorrichtung (73) und die Fertigungselemente (75 bis 77) an einem Ständer (72) montiert sind; und zu dem technische Mittel (74) zum Ausrichten der Spannvorrichtung (73) auf einen bestimmten Winkel bezüglich des Ständers (72) und der Fertigungselemenete (75 bis 77) sowie technische Mittel (75, 76) zum Bewegen der Fertigungselemente (77) relativ zum Ständer (72) und zur Spannvorrichtung (73) entsprechend dem Steuersignal gehören.

45. Fertigungskomplex nach einem der Ansprüche 33 bis 44, bei dem zur Fertigungsanlage (38) eine Halterfertigungsvorrichtung einschließlich der technischen Mittel (81) zur Fertigung eines Halters für das Einsetzen eines individuellen kieferorthopädischen Apparats am Zahn eines Patienten, einschließlich der dazugehörenden technischen Mittel (81) zum Bearbeiten der Konturen einer Fläche eines Halterrohlingsmaterials (83) entsprechend einem dieser Vorrichtung zugeführten Steuersignal gehört; zu den technischen Mitteln zur Vermessung (30, 30a, 33, 43, 50, 57) Einheiten zur Bereitstellung einer digitalisierten Aufzeichnung der Zahnformen eines Patienten (12) und der mit dieser Zahnformaufzeichnung verknüpften Stellen der Apparatfixierpunkte auf den Zahnoberflächen gehören; zu den Programmeinheiten Einheiten zur anhand der Aufzeichnung der digitalisierten Zahnformen und der Fixierpunkte erfolgenden Berechnung der Haltergeometrie, die eine Halteranlagefläche definiert, die einem individuellen Abschnitt der Kronenaußenfläche eines Zahns entspricht, und eine Apparatangriffsfläche definiert, die die gleiche örtliche Zuordnung gegenüber der Halteranlagefläche hat wie der individuelle Abschnitt der Außenfläche gegenüber dem Fixierpunkt am Zahn, gehören; und zu den Einheiten für die Erzeugung von Signalen Einheiten für die Erzeugung eines Fertigungsanlagensteuersignals als Träger der Fertigungsanlagensteuerbefehle für die Fertigung eines Halters (82) entsprechend der berechneten Haltergeometrie gehören.

46. Fertigungskomplex nach Anspruch 45, bei dem zum Apparat eine Anzahl von Brackets (80), und zwar je eines zum Fixieren an jedem Fixierpunkt an einem Zahn gehören; und zu dem des weiteren Einheiten zur Bereitstellung digitalisierter Bracketformdaten einer Außenfläche eines jeden an einem Fixierpunkt zu befestigenden Brackets gehören; und bei dem zur Haltergeometrieberechnungseinheit eine Einheit zur Festlegung der Halteranlage-

fläche am Apparat gehört, damit, auch gemäß den digitalisierten Bracketformdaten, eine Übereinstimmung mit der vorgegebenen Apparatgeometrie gewährleistet wird.

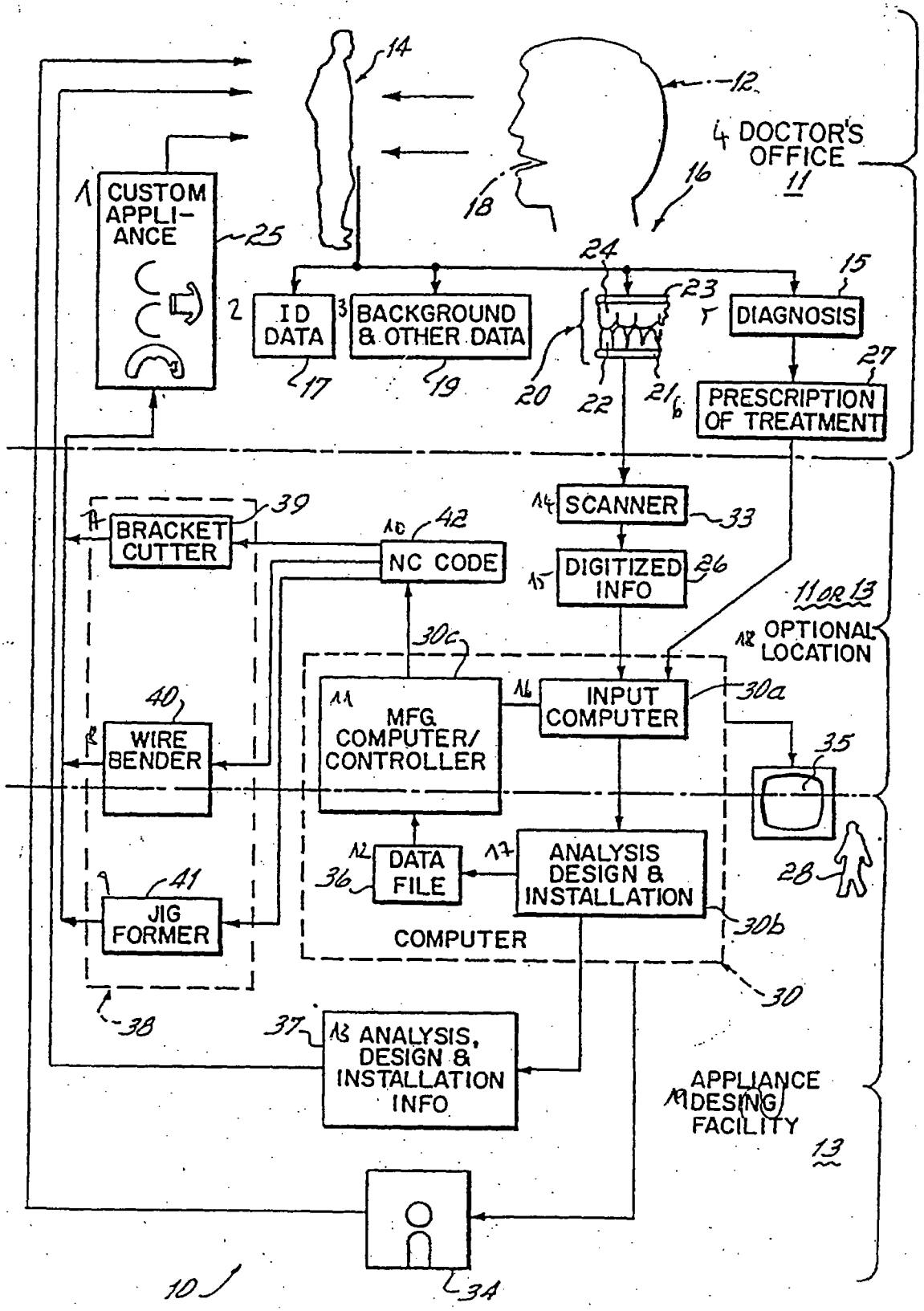

14
12
4 DOCTOR'S OFFICE
11
16
18
1 CUSTOM APPLI-ANCE
25
24
15
23
2 ID DATA
3 BACKGROUND & OTHER DATA
DIAGNOSIS
17
19
20
22
21
27
PRESCRIPTION OF TREATMENT
39
BRACKET CUTTER
10
42
NC CODE
14 SCANNER
33
15 DIGITIZED INFO
26
11 OR 13
12 OPTIONAL LOCATION
30c
40
WIRE BENDER
11 MFG. COMPUTER/ CONTROLLER
16 INPUT COMPUTER
30a
35
28
12 DATA FILE
36
17 ANALYSIS DESIGN & INSTALLATION
41
JIG FORMER
COMPUTER
30b
30
38
37
13 ANALYSIS, DESIGN & INSTALLATION INFO
APPLIANCE DESING FACILITY
13
34
10

FIG. 1

Fig. 1

1) individueller Apparat
2) Identifikationsdaten
3) Hintergrund- und andere Daten
4) Arztpraxis
5) Diagnose
6) Verordnung der Behandlung
7) Bracketfertigungsvorrichtung
8) Drahtbiegevorrichtung
9) Halterbearbeitungsvorrichtung
10) NC-Code
11) Computer/Steuereinheit
12) Dateien
13) Informationen über Analyse, Konstruktion und Einsetzen
14) Scanner
15) digitalisierte Informationen
16) Eingabecomputer
17) Analyse, Konstruktion und Einsetzen
18) mögliche Zusatzeinrichtungen
19) Apparatfertigungsstätte

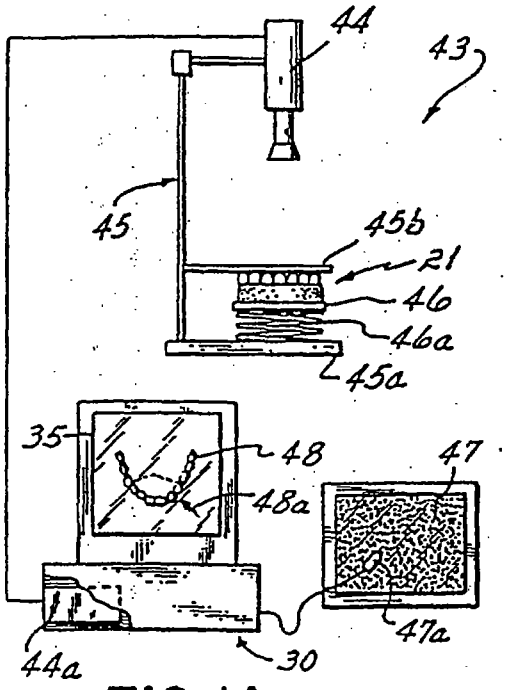


FIG. IA

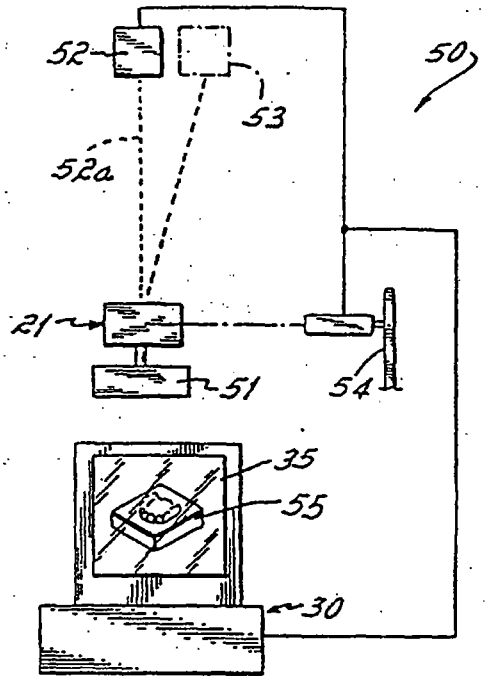


FIG. IB

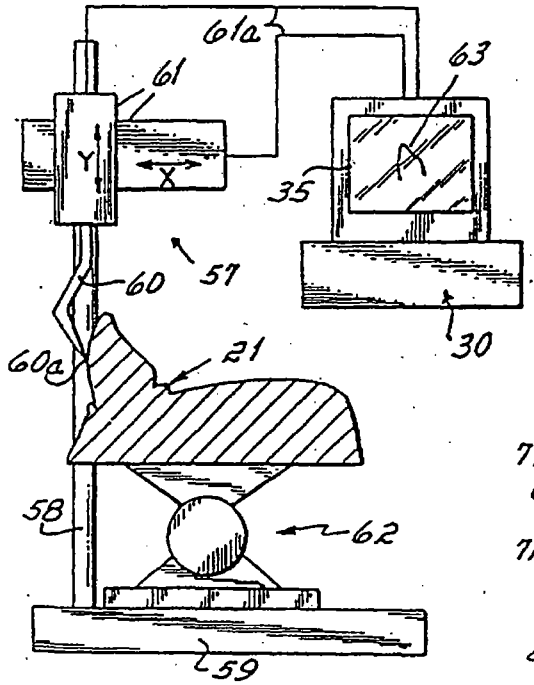


FIG. IC

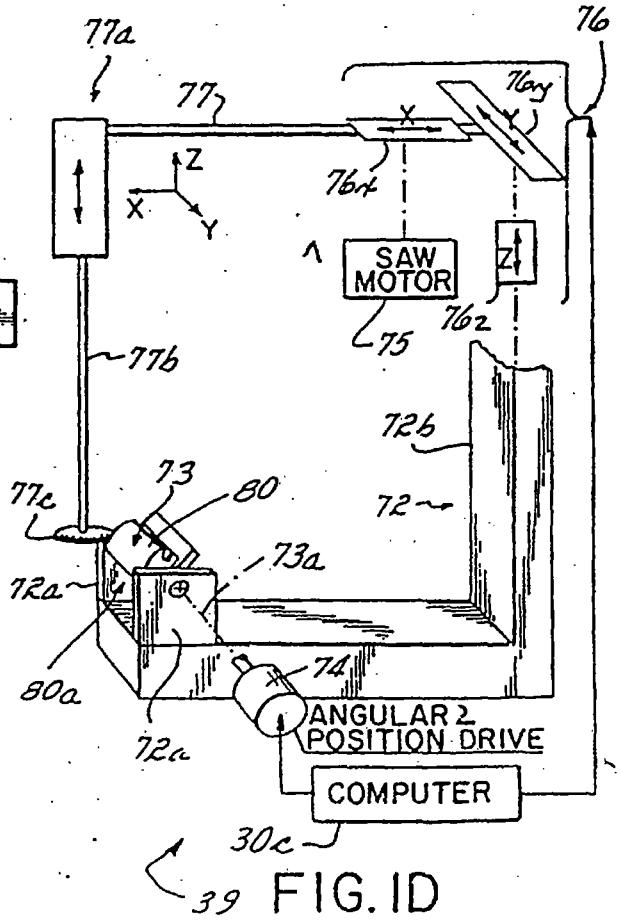


FIG. ID

Fig. 1D

1) Fräsermotor
2) Winkelpositionsantrieb

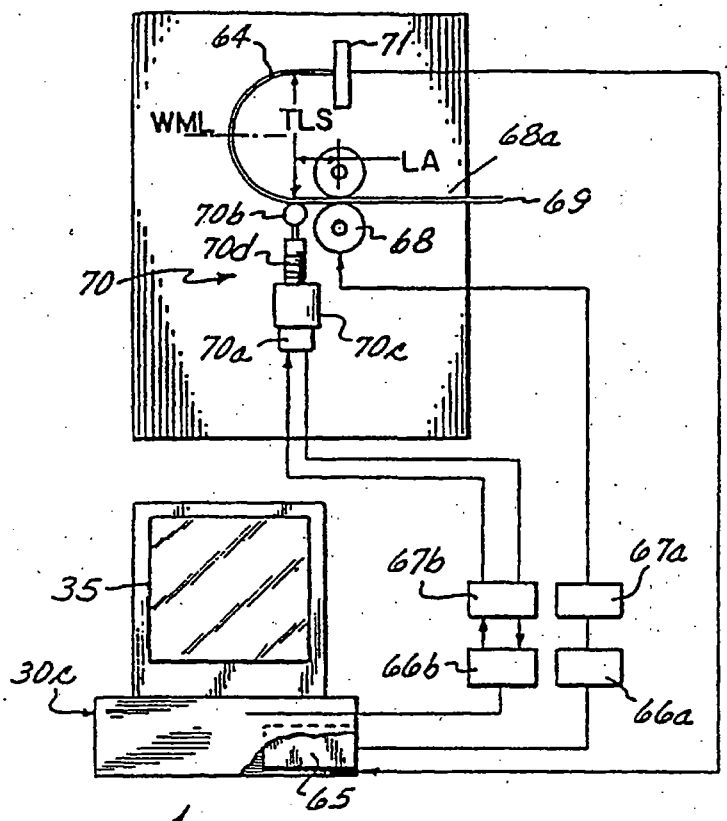

64
71
WML
TLS
LA
68a
69
70b
70d
68
70
70a
70c
35
67b
67a
66b
66a
30c
65
40

FIG. 1E

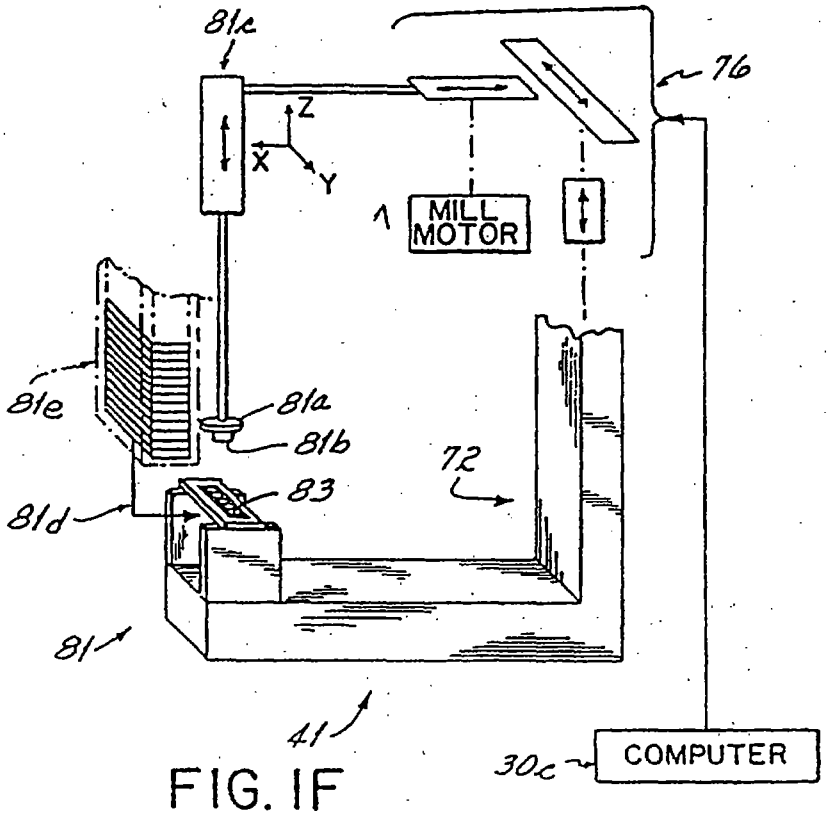

81c
76
Z
X
Y
1
MILL MOTOR
81e
81a
81b
72
83
81d
81
41
30c
COMPUTER

FIG. 1F

Fig. 1F

1) Fräsermotor

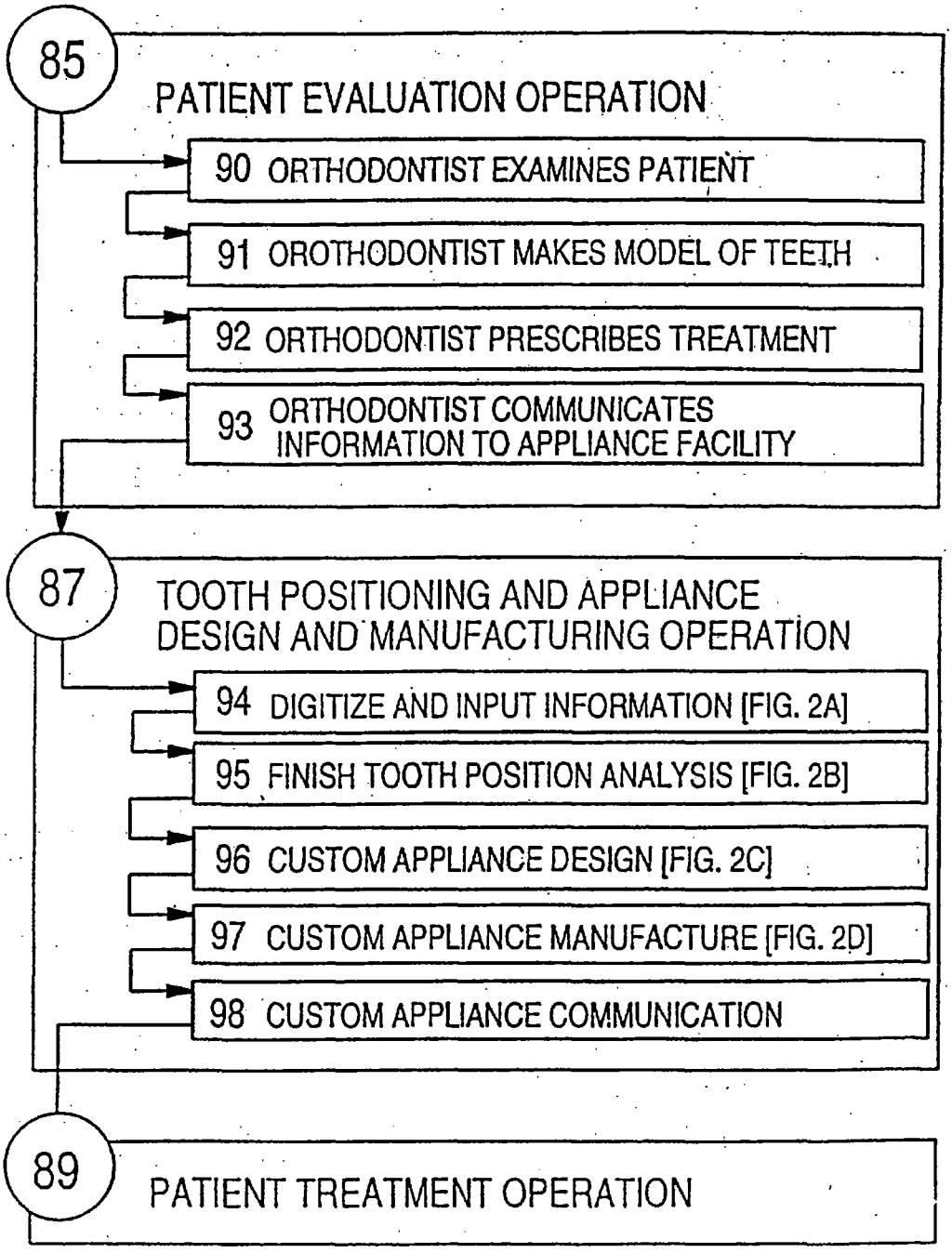

85
PATIENT EVALUATION OPERATION
90 ORTHODONTIST EXAMINES PATIENT
91 OROTHODONTIST MAKES MODEL OF TEETH
92 ORTHODONTIST PRESCRIBES TREATMENT
93 ORTHODONTIST COMMUNICATES INFORMATION TO APPLIANCE FACILITY
87
TOOTH POSITIONING AND APPLIANCE DESIGN AND MANUFACTURING OPERATION
94 DIGITIZE AND INPUT INFORMATION [FIG. 2A]
95 FINISH TOOTH POSITION ANALYSIS [FIG. 2B]
96 CUSTOM APPLIANCE DESIGN [FIG. 2C]
97 CUSTOM APPLIANCE MANUFACTURE [FIG. 2D]
98 CUSTOM APPLIANCE COMMUNICATION
89
PATIENT TREATMENT OPERATION

FIG. 2

Fig. 2

85) Arbeitsgang Einschätzung des Patienten

90) Kieferorthopäde untersucht Patienten

91) Kieferorthopäde fertigt Zahnmodell an

92) Kieferorthopäde verordnet Behandlung

93) Kieferorthopäde übermittelt Informationen an Fertigungsstätte

87) Arbeitsgang Zahnpositionierung, Apparatkonstruktion und Fertigung

94) Digitalisierung und Eingabe der Informationen (Fig. 2A)

95) Analyse der Zahnendpositionen (Fig. 2B)

96) Konstruktion des individuellen Apparats (Fig. 2C)

97) Fertigung des individuellen Apparats (Fig. 2D)

98) Kommunikation über individuellen Apparat

89) Arbeitsgang Behandlung des Patienten

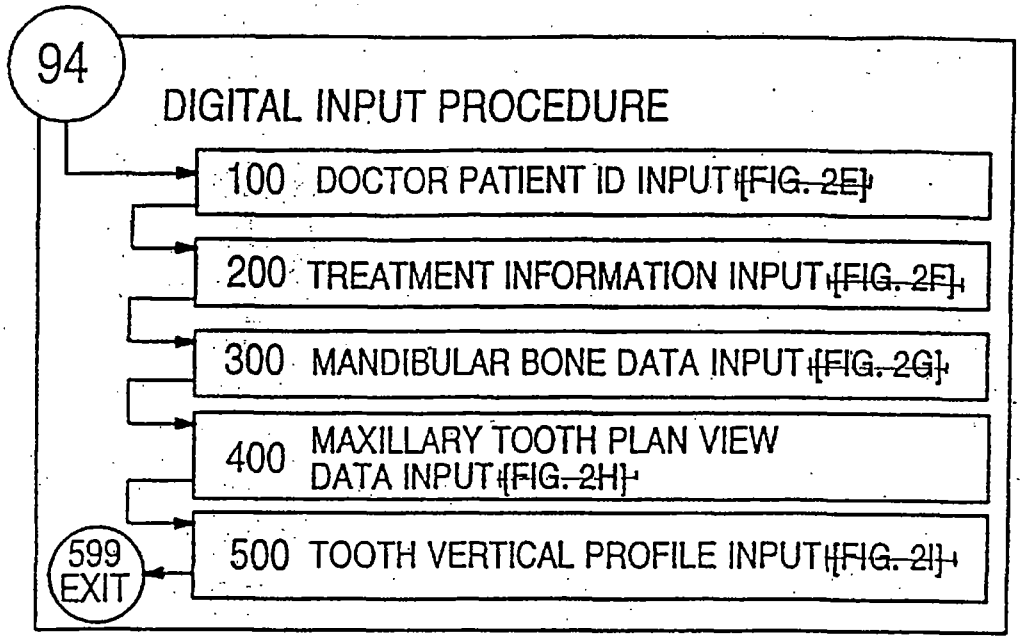

94
DIGITAL INPUT PROCEDURE
100 DOCTOR PATIENT ID INPUT {FIG. 2E}
200 TREATMENT INFORMATION INPUT {FIG. 2F}
300 MANDIBULAR BONE DATA INPUT {FIG. 2G}
400 MAXILLARY TOOTH PLAN VIEW DATA INPUT {FIG. 2H}
500 TOOTH VERTICAL PROFILE INPUT {FIG. 2I}
599 EXIT

FIG. 2A

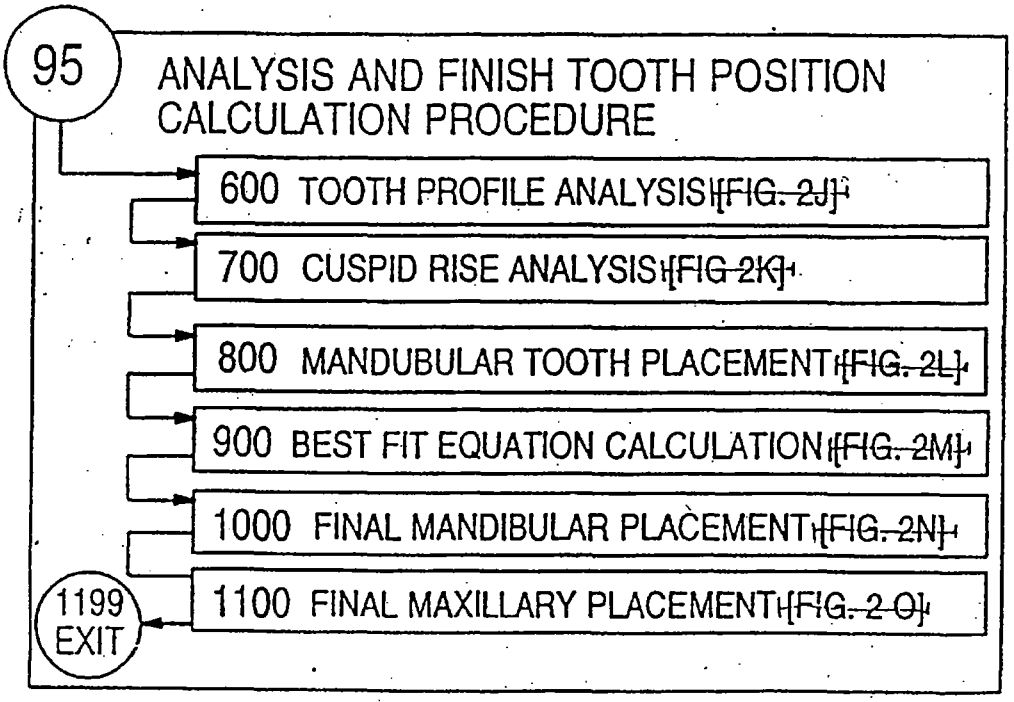

95
ANALYSIS AND FINISH TOOTH POSITION CALCULATION PROCEDURE
600 TOOTH PROFILE ANALYSIS {FIG. 2J}
700 CUSPID RISE ANALYSIS {FIG 2K}
800 MANDUBULAR TOOTH PLACEMENT {FIG. 2L}
900 BEST FIT EQUATION CALCULATION {FIG. 2M}
1000 FINAL MANDIBULAR PLACEMENT {FIG. 2N}
1100 FINAL MAXILLARY PLACEMENT {FIG. 2 O}
1199 EXIT

FIG. 2B

Fig. 2A

94) Prozedur der digitalen Eingabe

100) Eingabe der Identifikationsdaten ID über Arzt und Patient

200) Eingabe der Informationen über Behandlung

300) Eingabe der Daten über Unterkieferknochen

400) Eingabe der Daten zu einer Draufsicht der Oberkieferzähne

500) Eingabe eines vertikalen Zahnprofils

Fig. 2B

95) Prozedur der Analyse und Berechnung der Zahnendposition

600) Zahnprofilanalyse

700) Analyse der Eckzahnanhebung

800) Anordnung der Unterkieferzähne

900) Berechnung nach Best-fit-Funktion

1000) abschließende Unterkieferanordnung

1100) abschließende Oberkieferanordnung

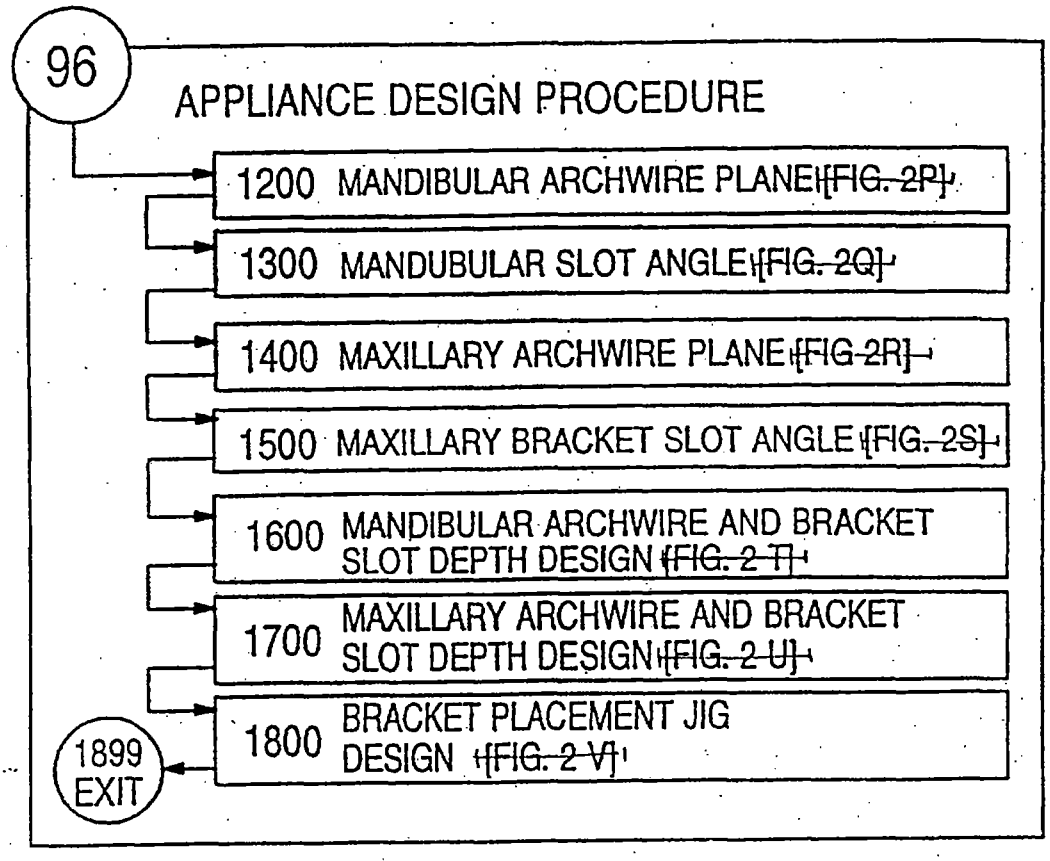

96
APPLIANCE DESIGN PROCEDURE
1200 MANDIBULAR ARCHWIRE PLANE {FIG. 2P}
1300 MANDUBULAR SLOT ANGLE {FIG. 2Q}
1400 MAXILLARY ARCHWIRE PLANE {FIG 2R}
1500 MAXILLARY BRACKET SLOT ANGLE {FIG. 2S}
1600 MANDIBULAR ARCHWIRE AND BRACKET SLOT DEPTH DESIGN {FIG. 2 T}
1700 MAXILLARY ARCHWIRE AND BRACKET SLOT DEPTH DESIGN {FIG. 2 U}
1800 BRACKET PLACEMENT JIG DESIGN {FIG. 2 V}
1899 EXIT

FIG. 2C

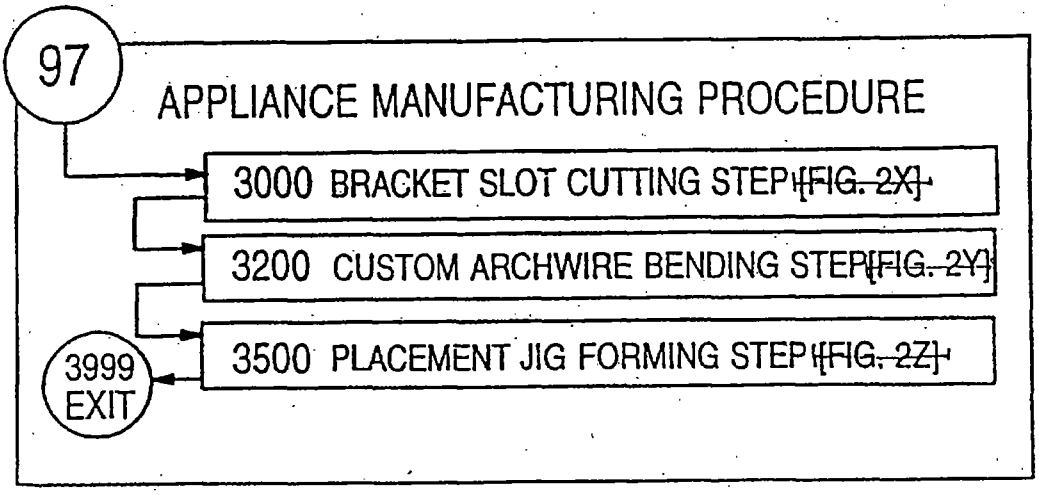

97
APPLIANCE MANUFACTURING PROCEDURE
3000 BRACKET SLOT CUTTING STEP {FIG. 2X}
3200 CUSTOM ARCHWIRE BENDING STEP {FIG. 2Y}
3500 PLACEMENT JIG FORMING STEP {FIG. 2Z}
3999 EXIT

FIG. 2D

Fig. 2C

96) Prozedur der Apparatfertigung
1200) mandibulare Bogendrahtebene
1300) mandibularer Schlitzwinkel
1400) maxillare Bogendrahtebene
1500) maxillarer Bracketschlitzwinkel
1600) Konstruktion des Bogendrahts und der Bracketschlitztiefe für Unterkiefer
1700) Konstruktion des Bogendrahts und der Bracketschlitztiefe für Oberkiefer
1800) Konstruktion Bracketeinsetzhalter

Fig. 2D

97) Prozedur der Apparatfertigung
3000) Schritt Bracketschlitzfräsen
3200) Schritt Biegen des individuellen Bogendrahts
3500) Schritt Bearbeitung der Einsetzhalter

Fig. 2

85) Arbeitsgang Einschätzung des Patienten

90) Kieferorthopäde untersucht Patienten

91) Kieferorthopäde fertigt Zahnmodell an

92) Kieferorthopäde verordnet Behandlung

93) Kieferorthopäde übermittelt Informationen an Fertigungsstätte

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97) Fertigung des individuellen Apparats (Fig. 2D)

98) Kommunikation über individuellen Apparat

89) Arbeitsgang Behandlung des Patienten

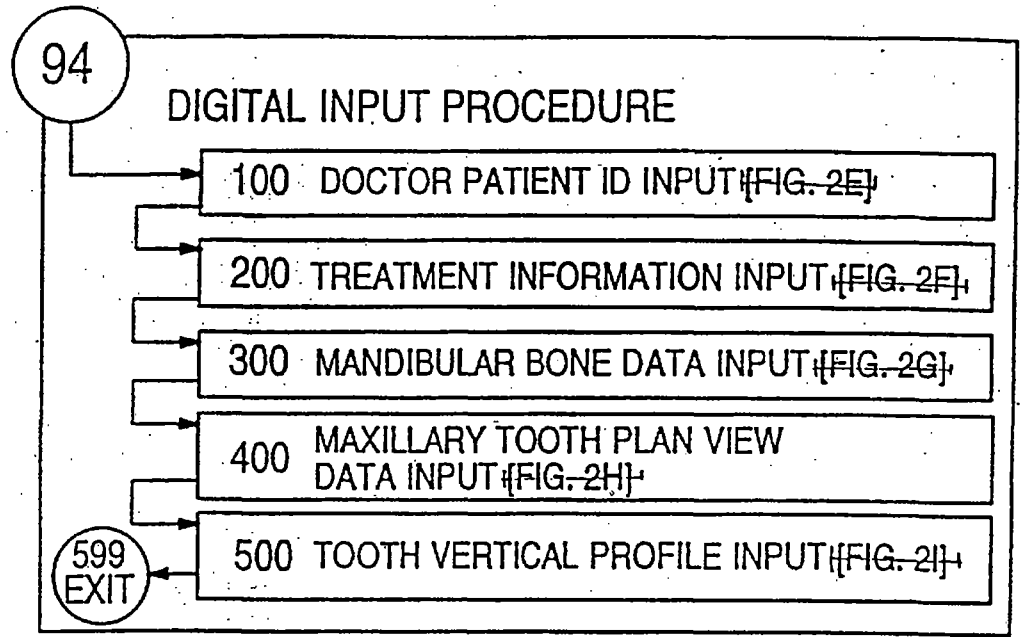

94
DIGITAL INPUT PROCEDURE
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400 MAXILLARY TOOTH PLAN VIEW DATA INPUT {FIG. 2H}
500 TOOTH VERTICAL PROFILE INPUT {FIG. 2I}
599 EXIT

FIG. 2A

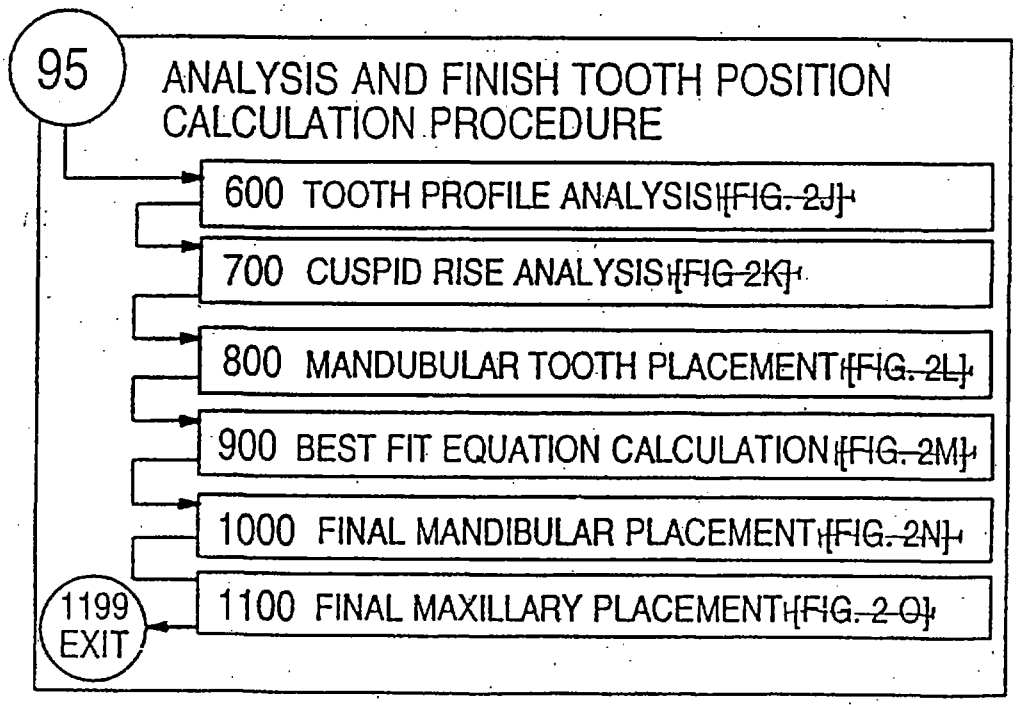

95
ANALYSIS AND FINISH TOOTH POSITION CALCULATION PROCEDURE
600 TOOTH PROFILE ANALYSIS {FIG. 2J}
700 CUSPID RISE ANALYSIS {FIG 2K}
800 MANDUBULAR TOOTH PLACEMENT {FIG. 2L}
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1000 FINAL MANDIBULAR PLACEMENT {FIG. 2N}
1100 FINAL MAXILLARY PLACEMENT {FIG. 2 O}
1199 EXIT

FIG. 2B

Fig. 2A

94) Prozedur der digitalen Eingabe

100) Eingabe der Identifikationsdaten ID über Arzt und Patient

200) Eingabe der Informationen über Behandlung

300) Eingabe der Daten über Unterkieferknochen

400) Eingabe der Daten zu einer Draufsicht der Oberkieferzähne

500) Eingabe eines vertikalen Zahnprofils

Fig. 2B

95) Prozedur der Analyse und Berechnung der Zahnendposition

600) Zahnprofilanalyse

700) Analyse der Eckzahnanhebung

800) Anordnung der Unterkieferzähne

900) Berechnung nach Best-fit-Funktion

1000) abschließende Unterkieferanordnung

1100) abschließende Oberkieferanordnung

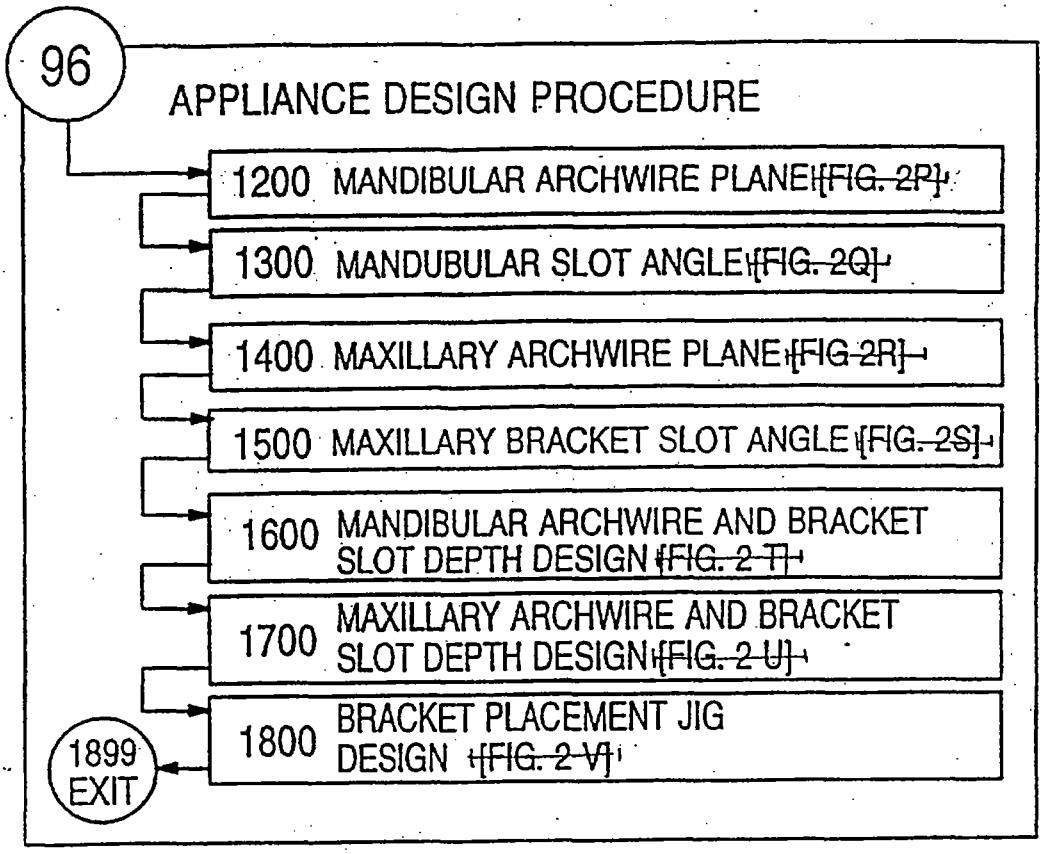

96
APPLIANCE DESIGN PROCEDURE
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1300 MANDUBULAR SLOT ANGLE {FIG. 2Q}
1400 MAXILLARY ARCHWIRE PLANE {FIG 2R}
1500 MAXILLARY BRACKET SLOT ANGLE {FIG. 2S}
1600 MANDIBULAR ARCHWIRE AND BRACKET SLOT DEPTH DESIGN {FIG. 2 T}
1700 MAXILLARY ARCHWIRE AND BRACKET SLOT DEPTH DESIGN {FIG. 2 U}
1800 BRACKET PLACEMENT JIG DESIGN {FIG. 2 V}
1899 EXIT

FIG. 2C

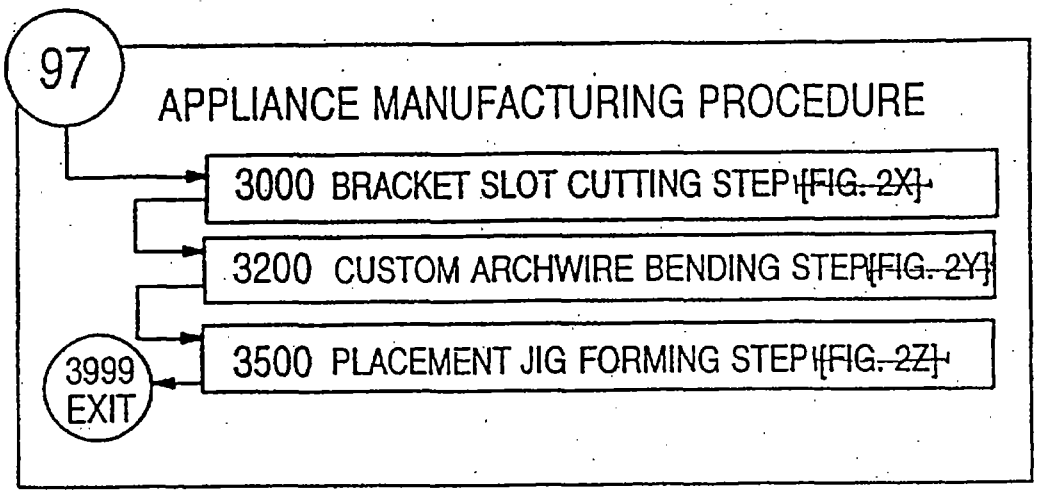

97
APPLIANCE MANUFACTURING PROCEDURE
3000 BRACKET SLOT CUTTING STEP {FIG. 2X}
3200 CUSTOM ARCHWIRE BENDING STEP {FIG. 2Y}
3500 PLACEMENT JIG FORMING STEP {FIG. 2Z}
3999 EXIT

FIG. 2D

Fig. 2C

96) Prozedur der Apparatfertigung
1200) mandibulare Bogendrahtebene
1300) mandibularer Schlitzwinkel
1400) maxillare Bogendrahtebene
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1700) Konstruktion des Bogendrahts und der Bracketschlitztiefe für Oberkiefer
1800) Konstruktion Bracketeinsetzhalter

Fig. 2D

97) Prozedur der Apparatfertigung
3000) Schritt Bracketschlitzfräsen
3200) Schritt Biegen des individuellen Bogendrahts
3500) Schritt Bearbeitung der Einsetzhalter

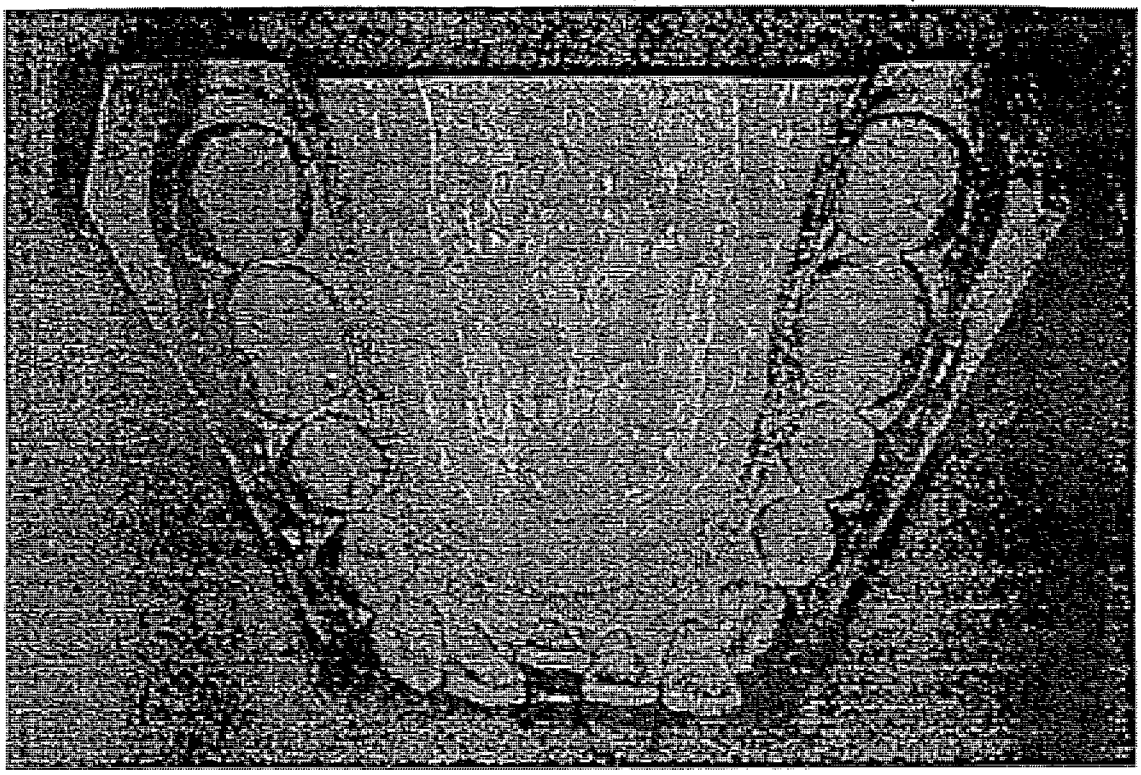
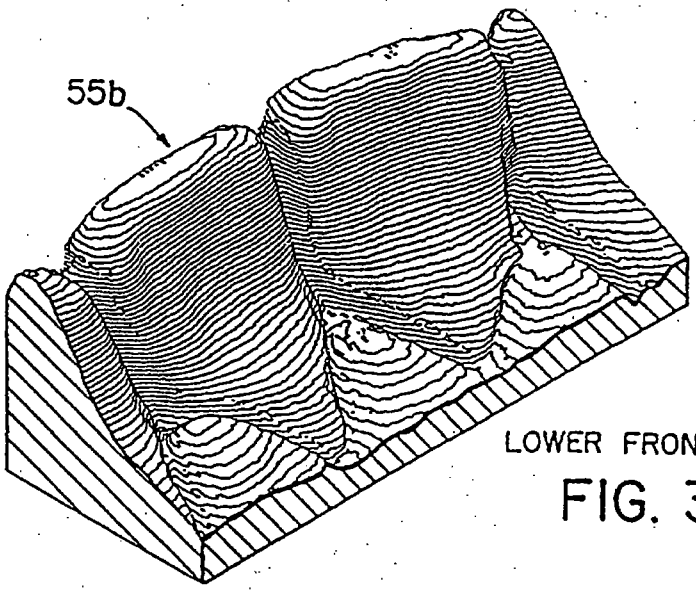
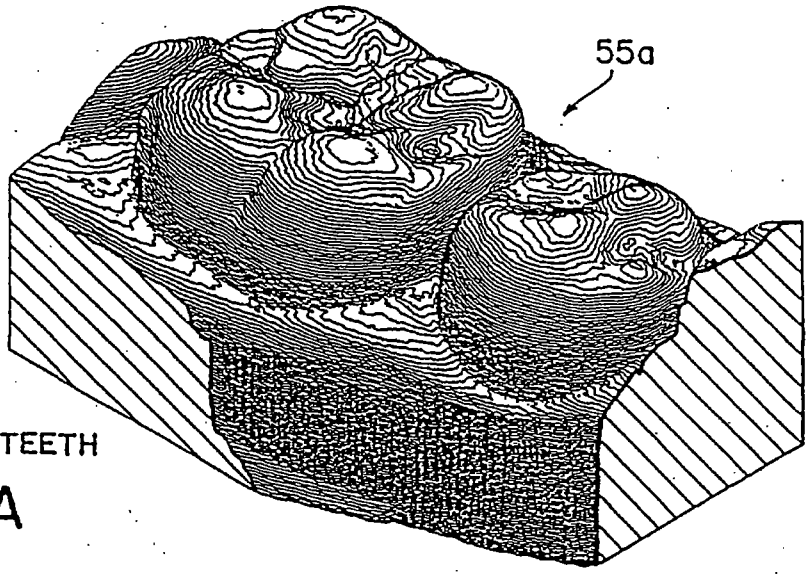


FIG. 3



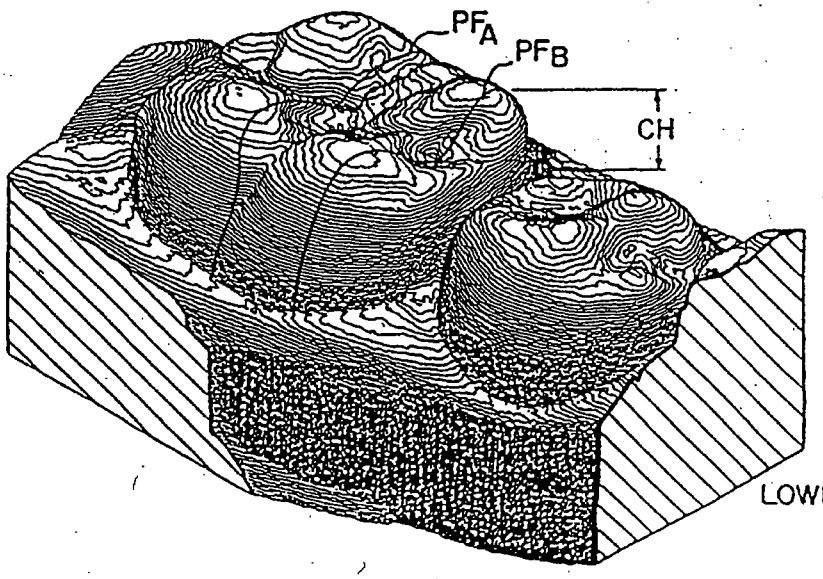
LOWER FRONT TEETH

FIG. 3B



LOWER RIGHT TEETH

FIG. 3A



LOWER RIGHT TEETH

FIG. 6

Fig. 3A
untere rechte Zähne

Fig. 3B
untere Vorderzähne

Fig. 6
untere rechte Zähne

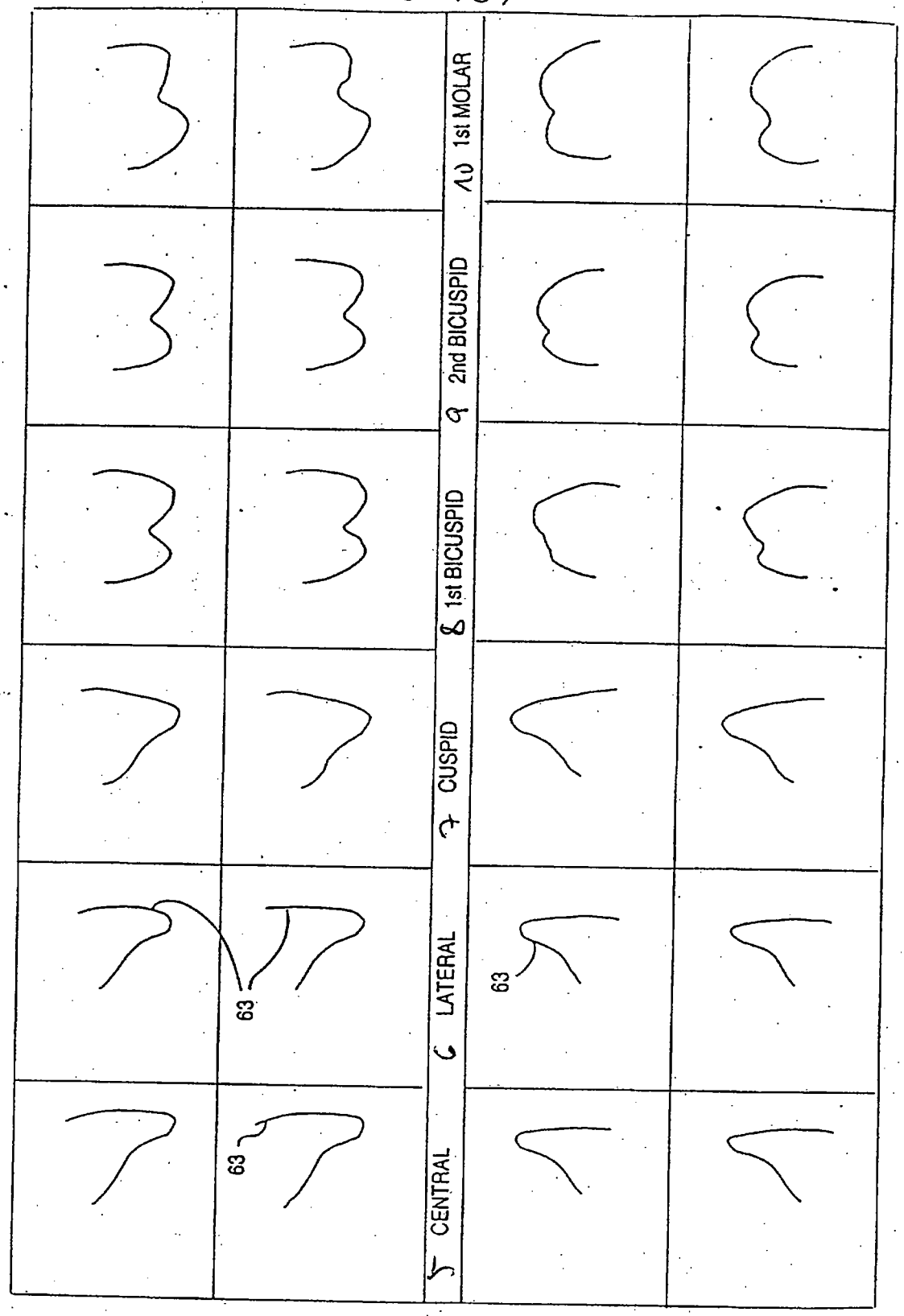

3 CENTRAL
6 LATERAL
7 CUSPID
8 1st BICUSPID
9 2nd BICUSPID
10 1st MOLAR
63
63
63
RIGHT
MAX-LARY
LEFT
RIGHT
MAND-BULAR
LEFT

FIG.3C

B 31-03-00

Fig. 3C

1) Oberkiefer
2) Unterkiefer
3) rechts
4) links
5) 1. Schneidezahn
6) 2. Schneidezahn
7) Eckzahn
8) 1. Prämolar
9) 2. Prämolar
10) 1. Molar

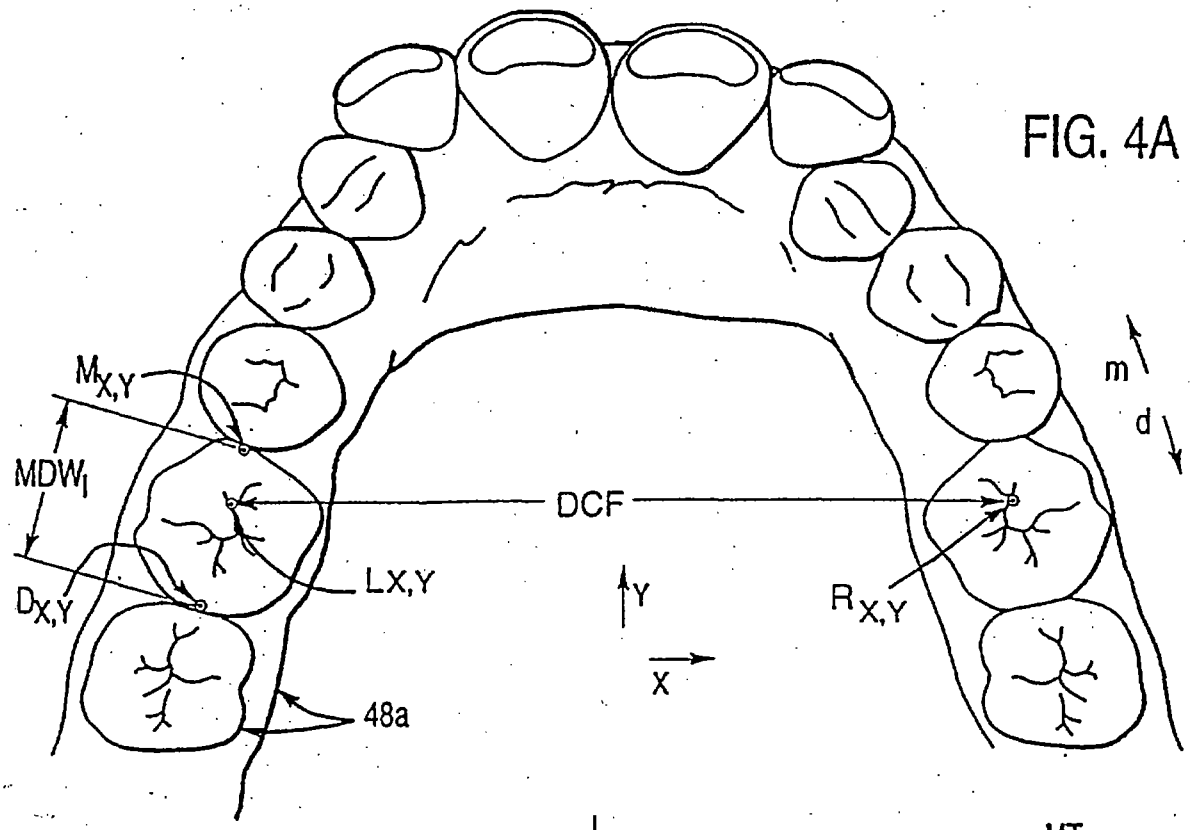

$M_{X,Y}$
MDW_I
$D_{X,Y}$
DCF
$L_{X,Y}$
Y
X
$R_{X,Y}$
48a
m
d

FIG. 4A

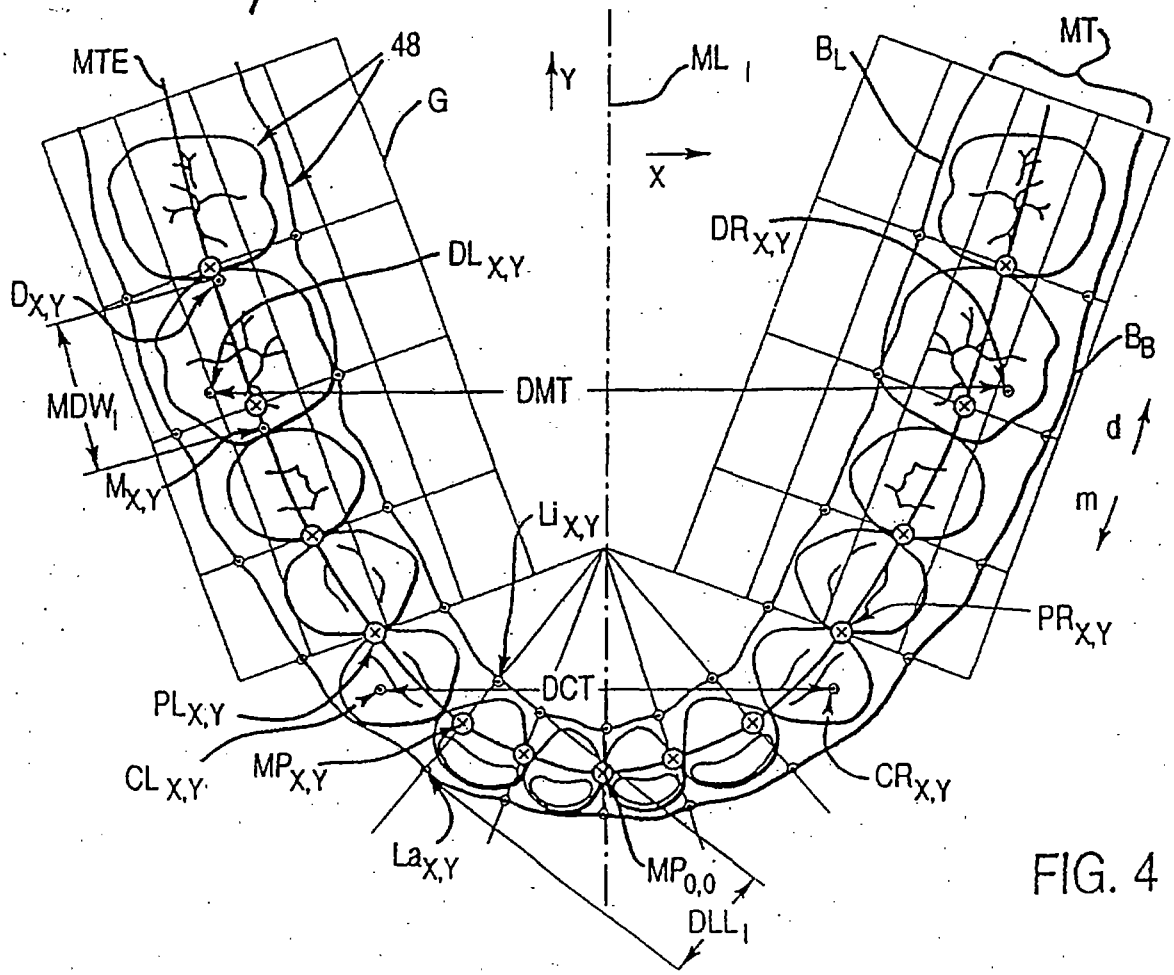
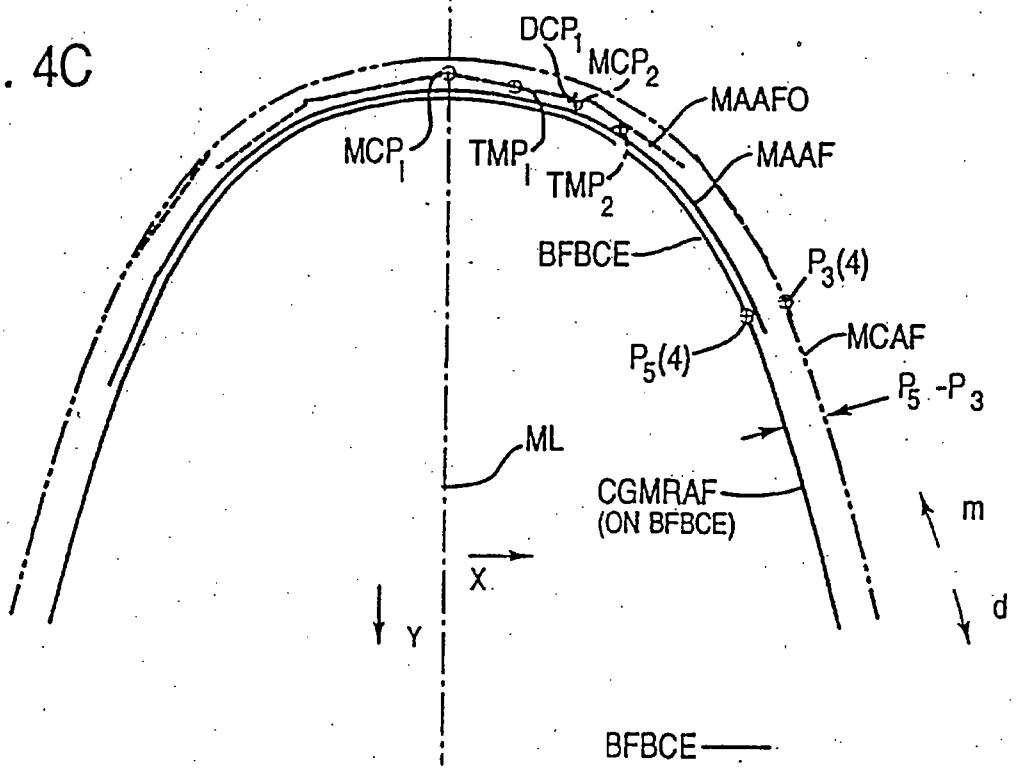

MTE
48
G
Y
ML_I
X
B_L
MT
$DR_{X,Y}$
$DL_{X,Y}$
$D_{X,Y}$
B_B
DMT
MDW_I
d
$M_{X,Y}$
m
$Li_{X,Y}$
$PR_{X,Y}$
DCT
$PL_{X,Y}$
$CL_{X,Y}$
$MP_{X,Y}$
$CR_{X,Y}$
$La_{X,Y}$
$MP_{0,0}$
DLL_I

FIG. 4

FIG. 4C


DCP1
MCP2
MAAFO
MCP1
TMP1
TMP2
MAAF
BFBCE
P3(4)
P5(4)
MCAF
P5 -P3
ML
CGMRAF
(ON BFBCE)
m
X
Y
d
BFBCE

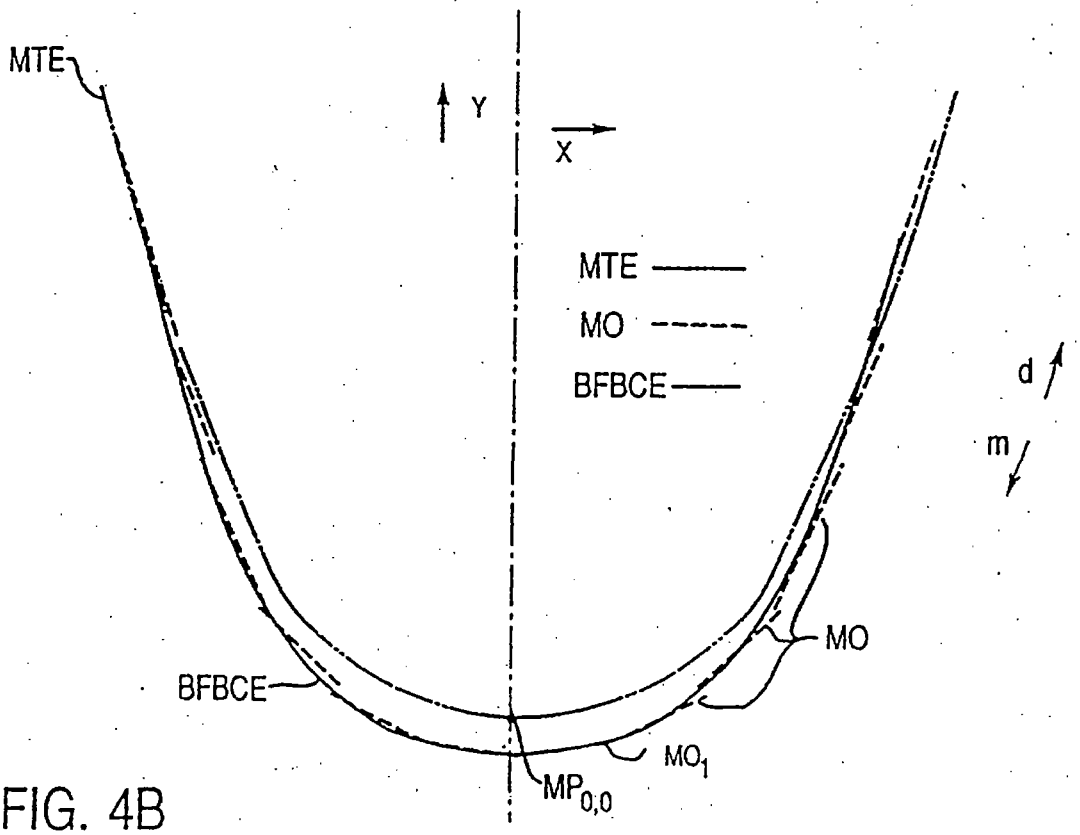
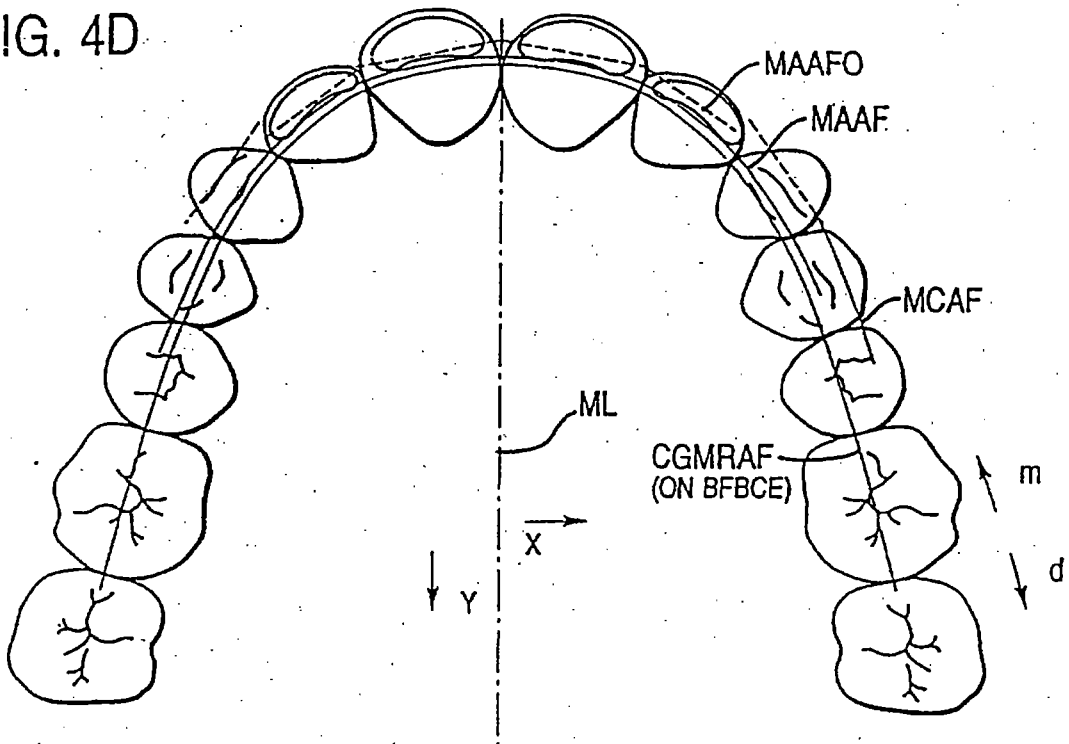

MTE
Y
X
MTE
MO
BFBCE
d
m
MO
BFBCE
MO1
MP0,0

FIG. 4B

FIG. 4D


MAAFO
MAAF
MCAF
ML
CGMRAF
(ON BFBCE)
m
d
X
Y

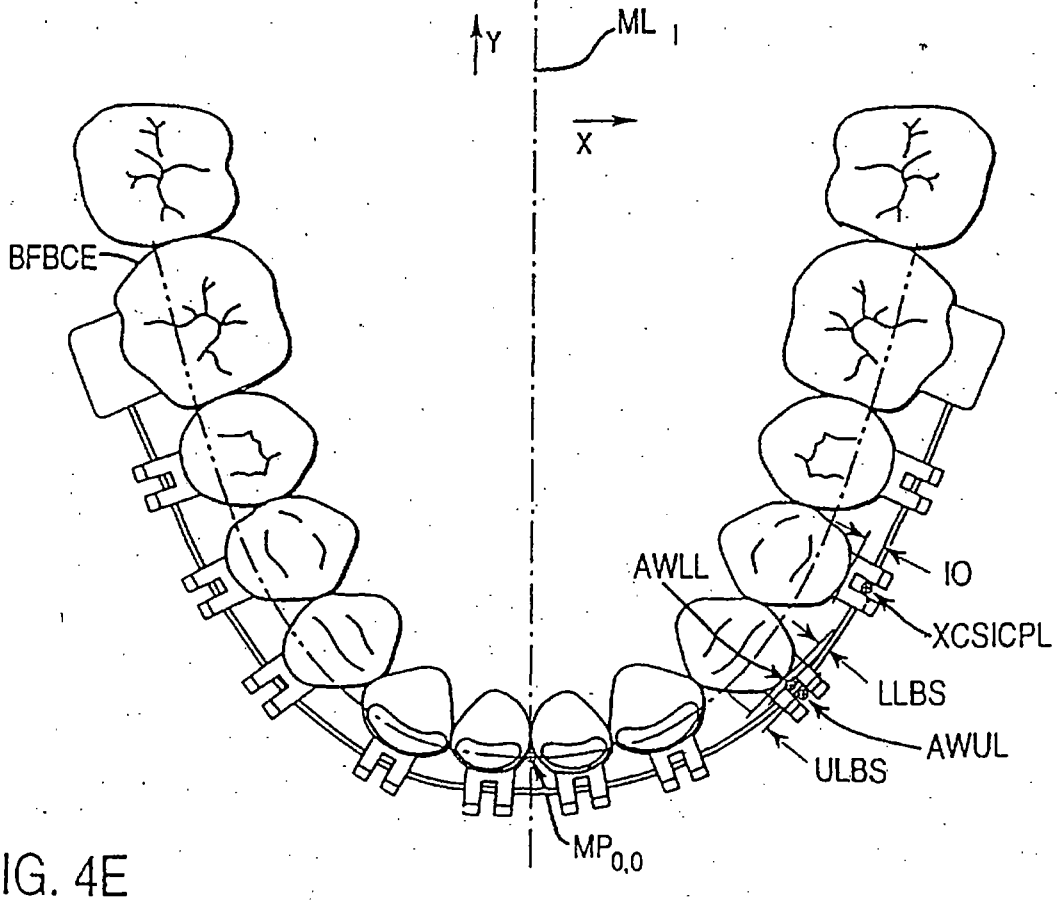

Y
ML
X
BFBCE
AWLL
IO
XCSICPL
LLBS
AWUL
ULBS
MP0,0

FIG. 4E

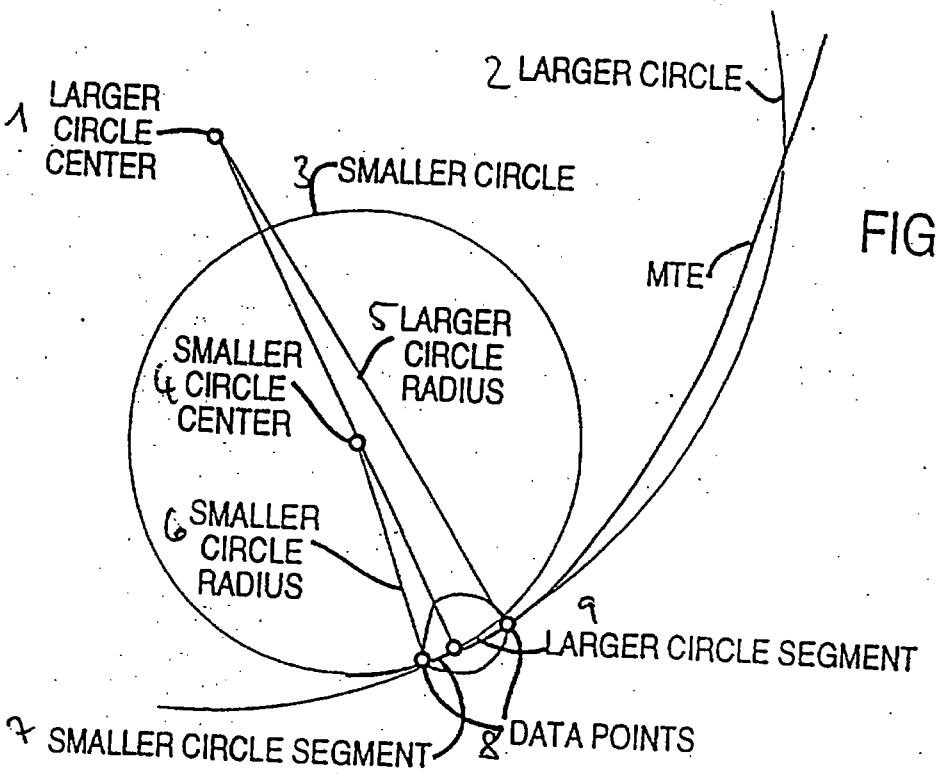

1 LARGER CIRCLE CENTER
2 LARGER CIRCLE
3 SMALLER CIRCLE
4 SMALLER CIRCLE CENTER
5 LARGER CIRCLE RADIUS
6 SMALLER CIRCLE RADIUS
7 SMALLER CIRCLE SEGMENT
8 DATA POINTS
9 LARGER CIRCLE SEGMENT
MTE

FIG. 5

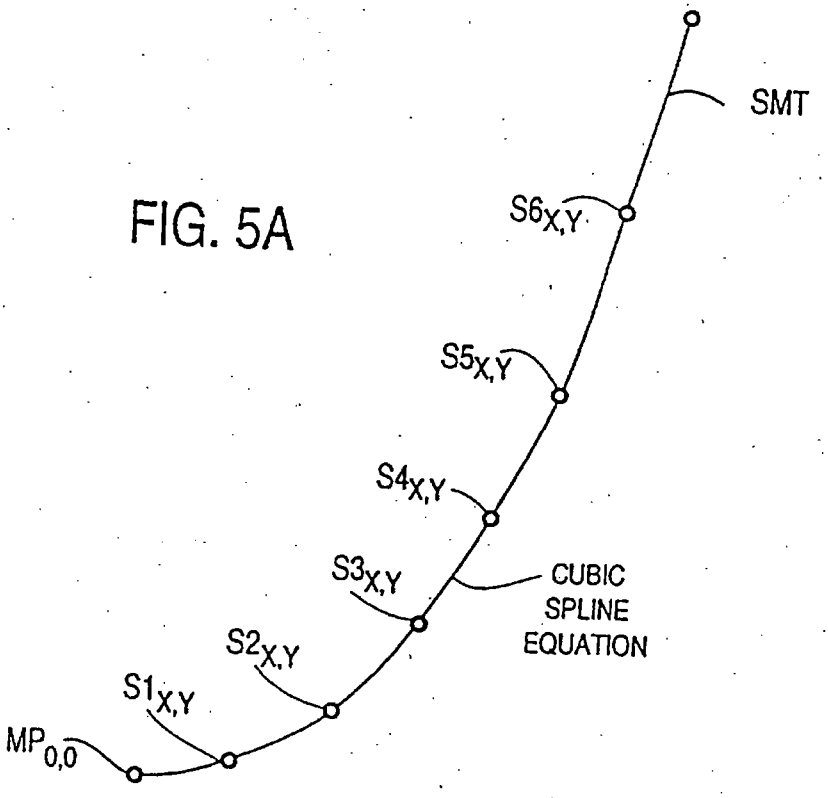

SMT
S6X,Y
S5X,Y
S4X,Y
S3X,Y
S2X,Y
S1X,Y
MP0,0
CUBIC SPLINE EQUATION

FIG. 5A



Fig. 5

1) Mittelpunkt des größeren Kreises
2) größerer Kreis
3) kleiner Kreis
4) Mittelpunkt des kleineren Kreises
5) Radius des größeren Kreises
6) Radius des kleineren Kreises
7) Segment des kleineren Kreises
8) Datenpunkte
9) Segment des größeren Kreises



Fig. 5A

kubische Spline-Funktion

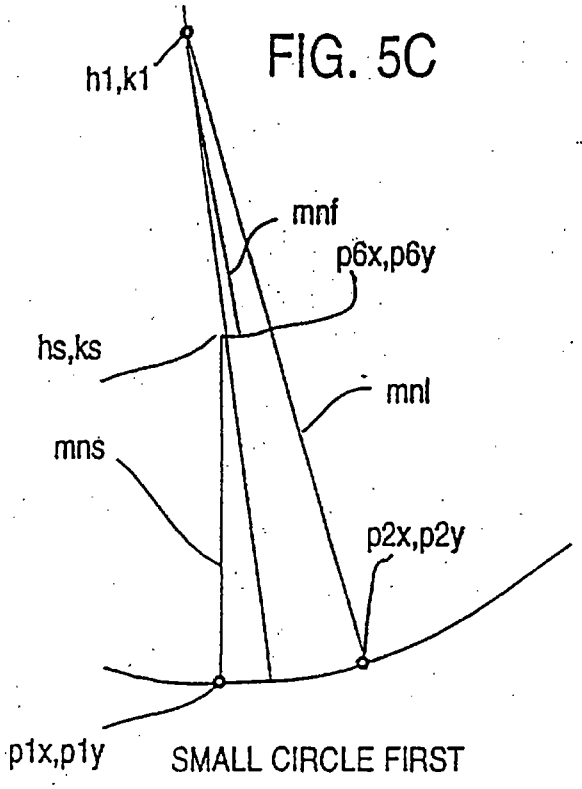


FIG. 5C

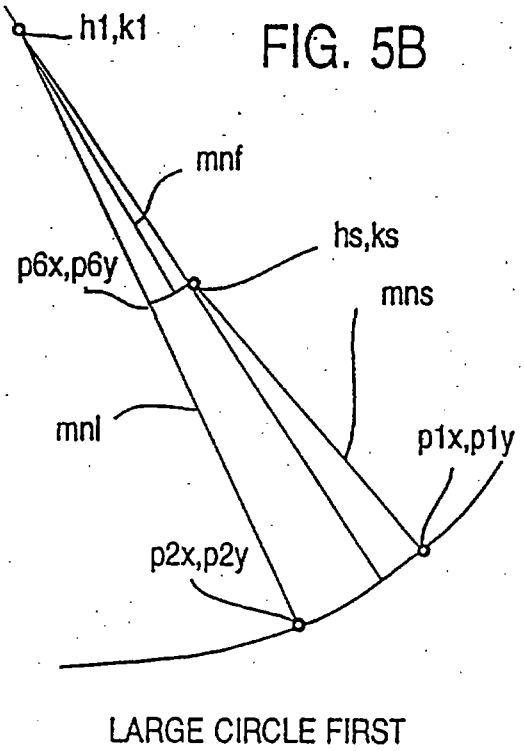


FIG. 5B

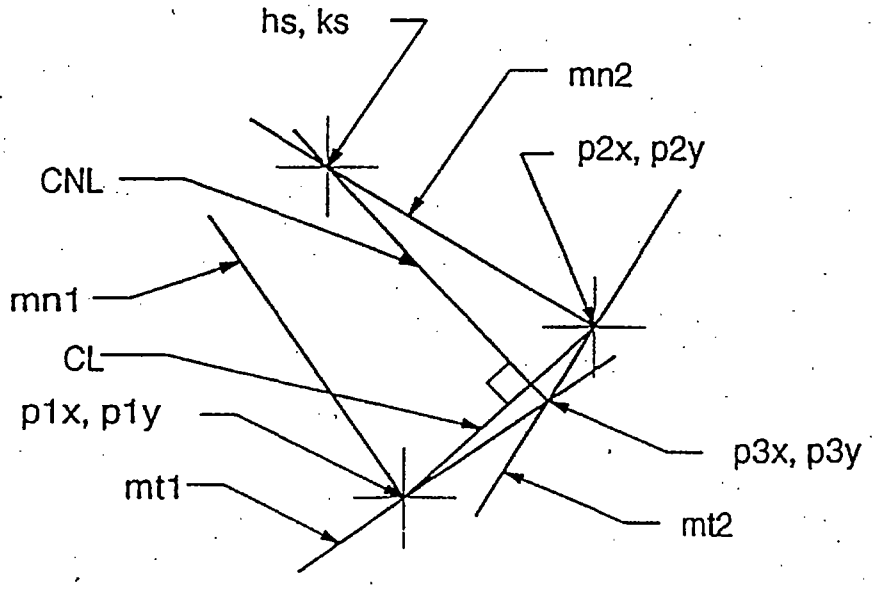
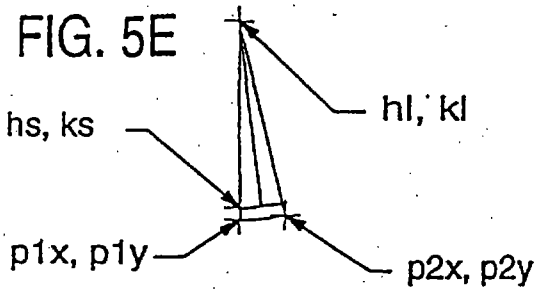


FIG. 5D

Fig. 5B
kleiner Kreis zuerst

Fig. 5B
großer Kreis zuerst

FIG. 5E



1 Spline Seg. No. 1
2 Circle Seg. Nos. 1 and 2

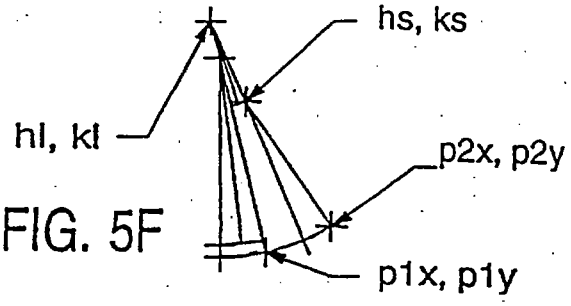
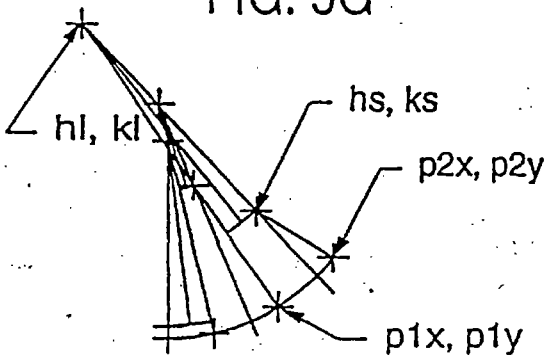


FIG. 5F

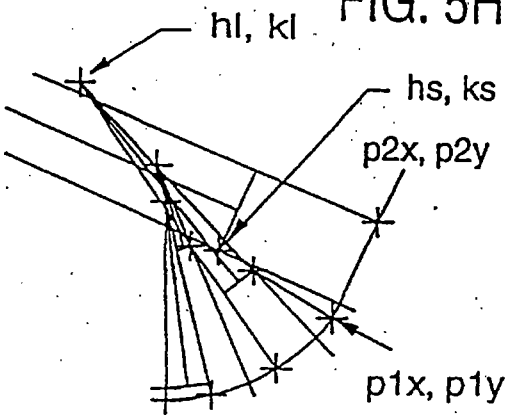
1 Spline Seg. No. 2
2 Circle Seg. Nos .3 and 4

FIG. 5G

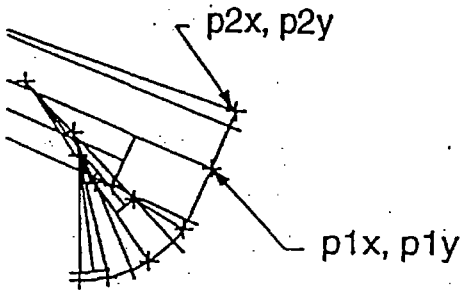


1 Spline Seg. No. 3
2 Circle Seg. Nos. 5 and 6

FIG. 5H

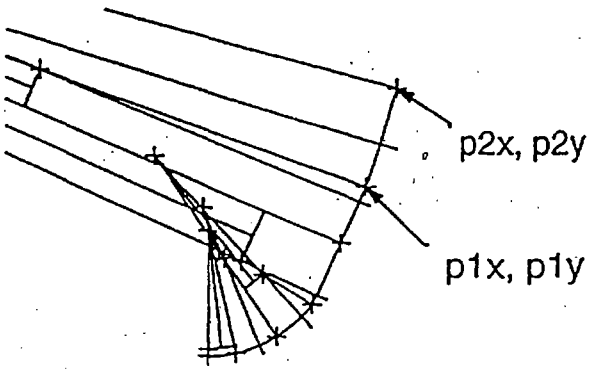


1 Spline Seg. No. 4
2 Circle Seg. Nos. 7 and 8



1 Spline Seg. No. 5
2 Circle Seg. Nos.9 and 10

FIG. 5I



1 Spline Seg. No. 6
2 Circle Seg. No.'s 11 and 12

FIG. 5J

Fig. 5E - 5J

1) Spline-Segment Nr.
2) Kreis-Segment Nr.

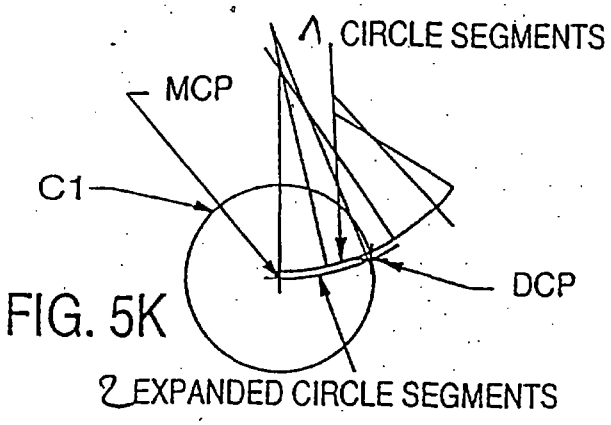


FIG. 5K

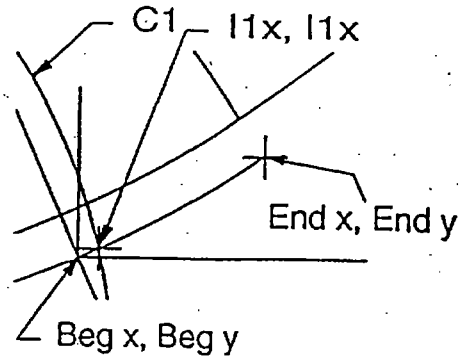


FIG. 5L

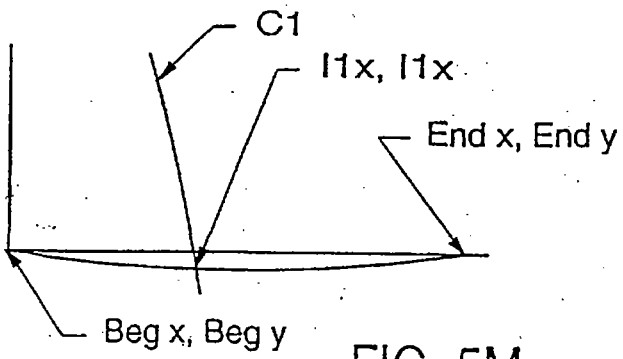


FIG. 5M

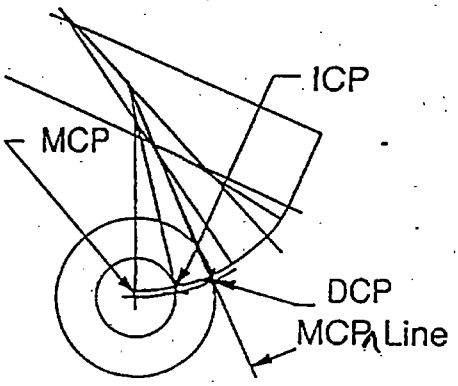


FIG. 5N

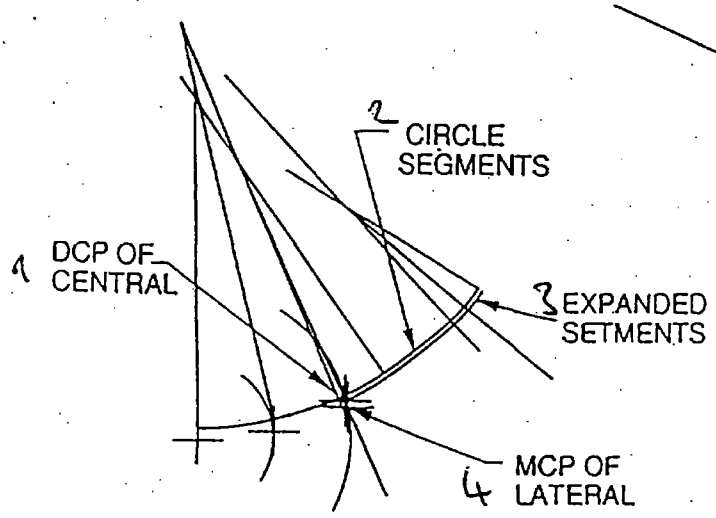


FIG. 5O

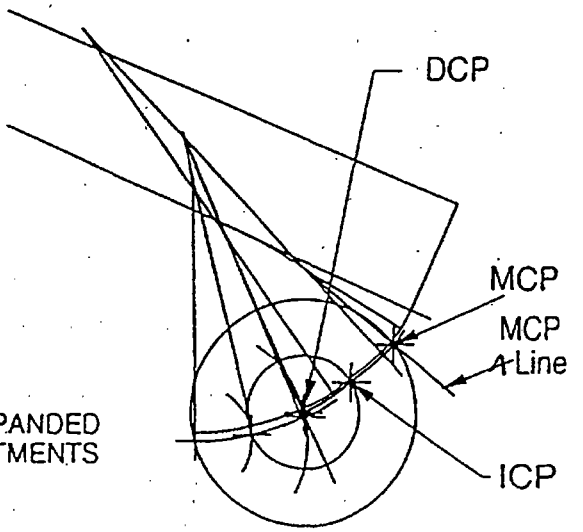


FIG. 5P

Fig. 5K

1) Kreissegmente
2) erweiterte Kreissegmente

Fig. 5O

1) DCP des 1. Schneidezahns
2) Kreissegmente
3) erweiterte Kreissegmente
4) MCP des 2. Schneidezahns

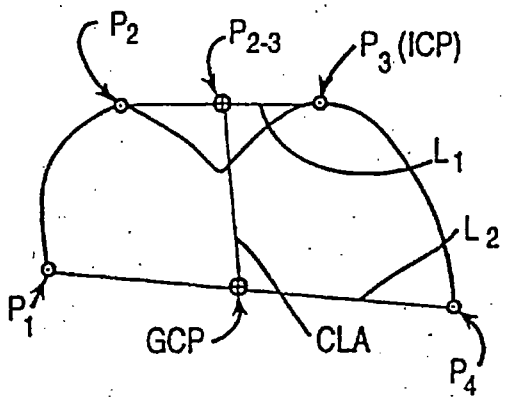


FIG. 6A

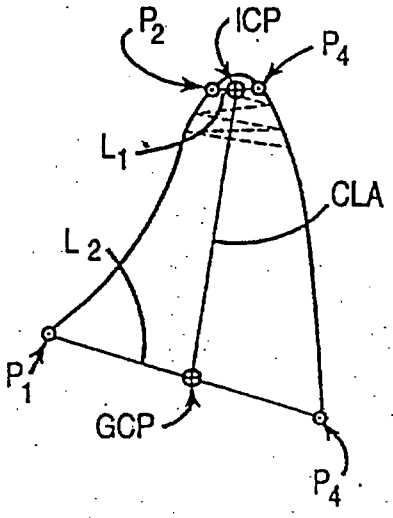


FIG. 6B

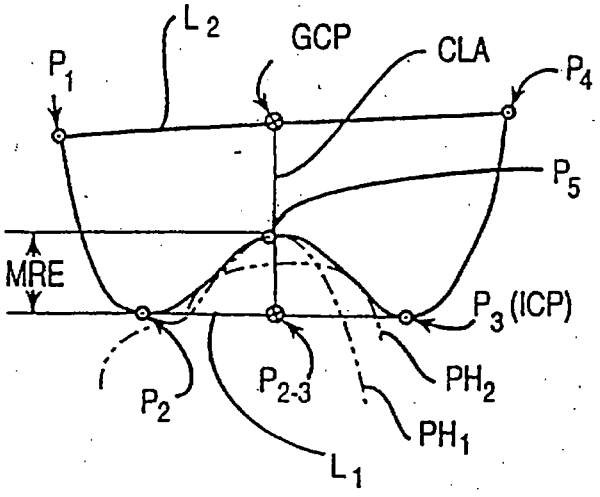


FIG. 6C

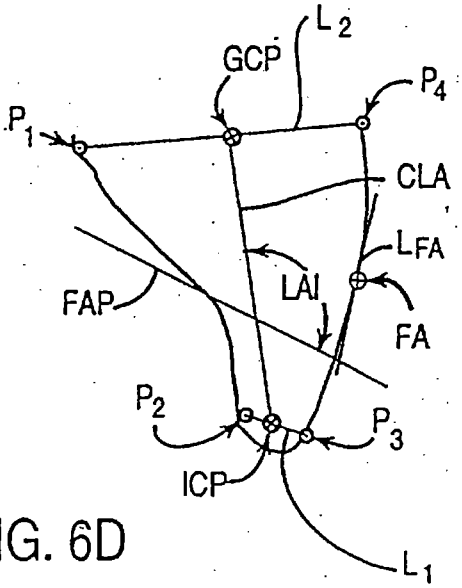


FIG. 6D

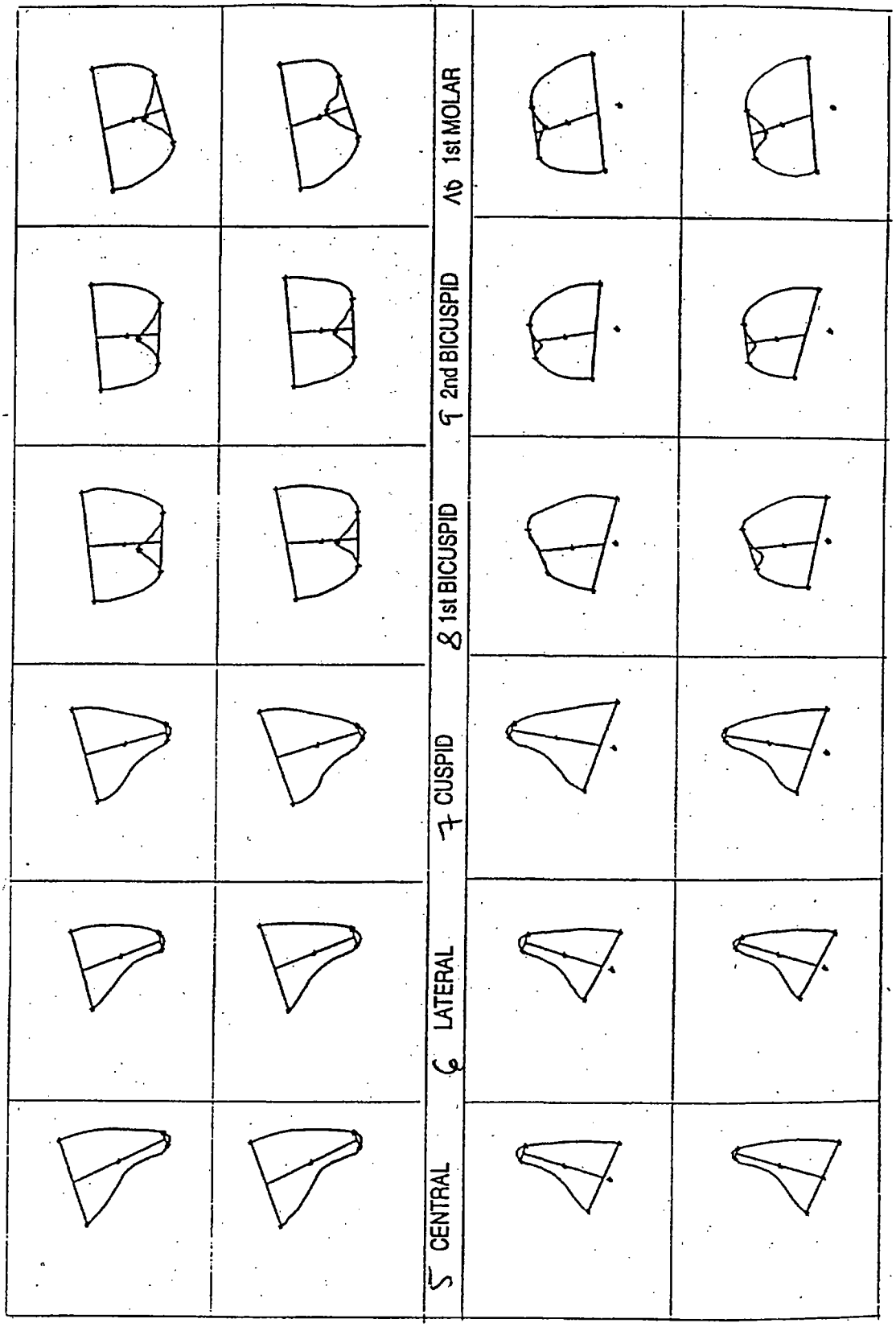

5 CENTRAL
6 LATERAL
7 CUSPID
8 1st BICUSPID
9 2nd BICUSPID
10 1st MOLAR
MAX—LARY
RIGHT
LEFT
MAND—BULAR
RIGHT
LEFT
1
2

FIG.6E

Fig. 6E

1) Oberkiefer
2) Unterkiefer
3) rechts
4) links
5) 1. Schneidezahn
6) 2. Schneidezahn
7) Eckzahn
8) 1. Prämolar
9) 2. Prämolar
10) 1. Molar

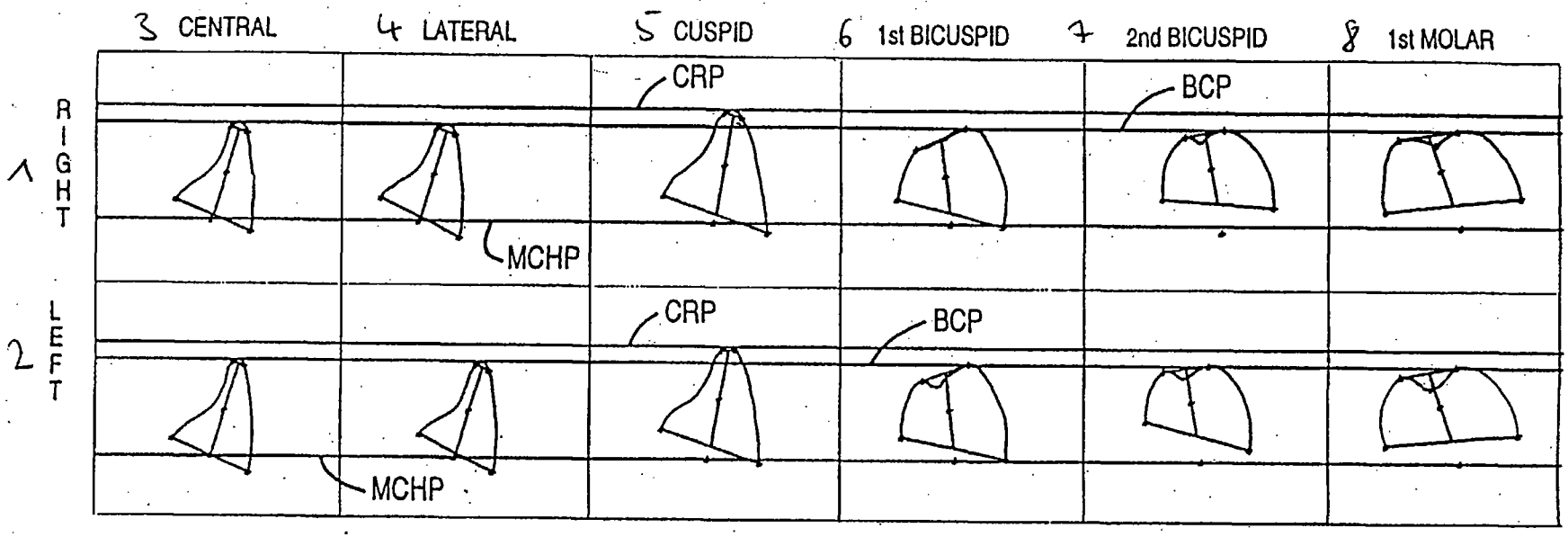


FIG. 6F

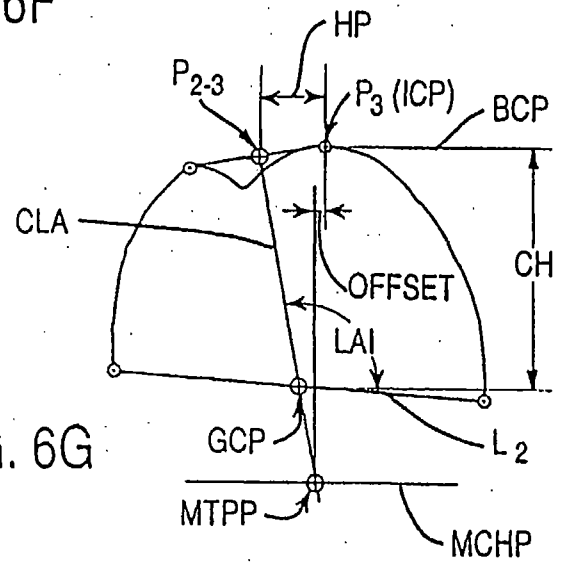


FIG. 6G

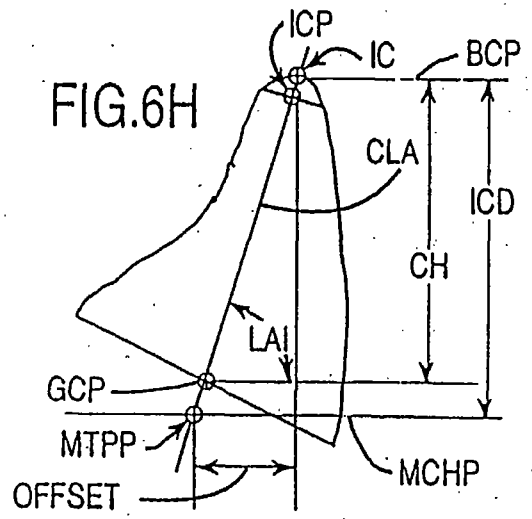


FIG.6H

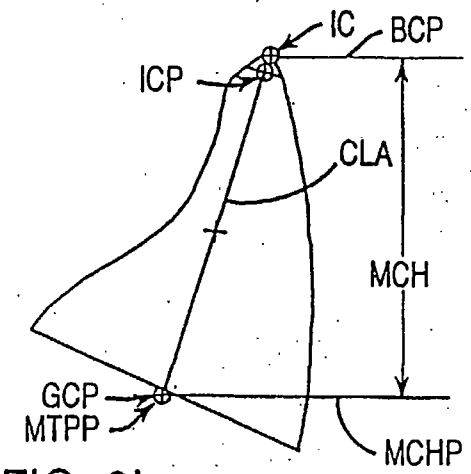


FIG. 6I

ClearCorrect Exhibit 1010, Page 479 of 1447

Fig. 6F

1) rechts
2) links
3) 1. Schneidezahn
4) 2. Schneidezahn
5) Eckzahn
6) 1. Prämolar
7) 2. Prämolar
8) 1. Molar

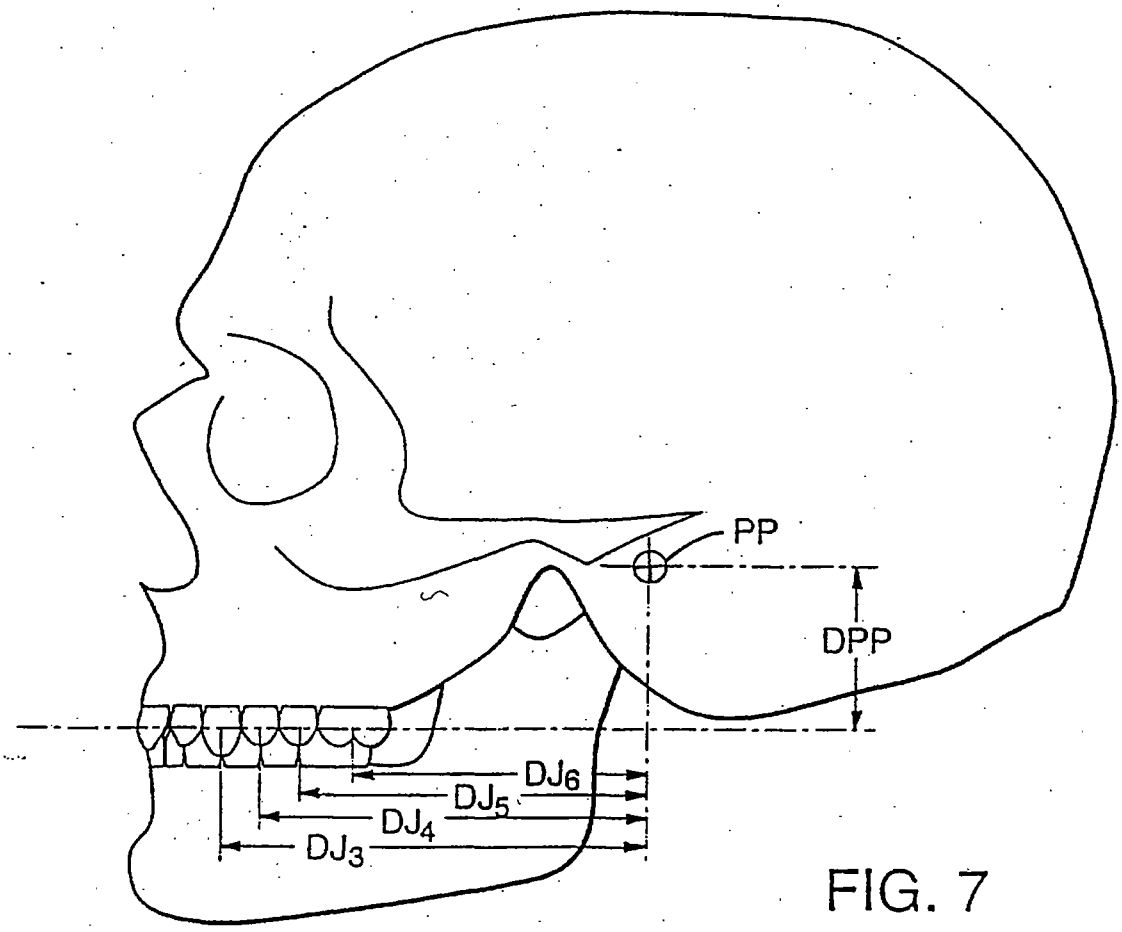


FIG. 7

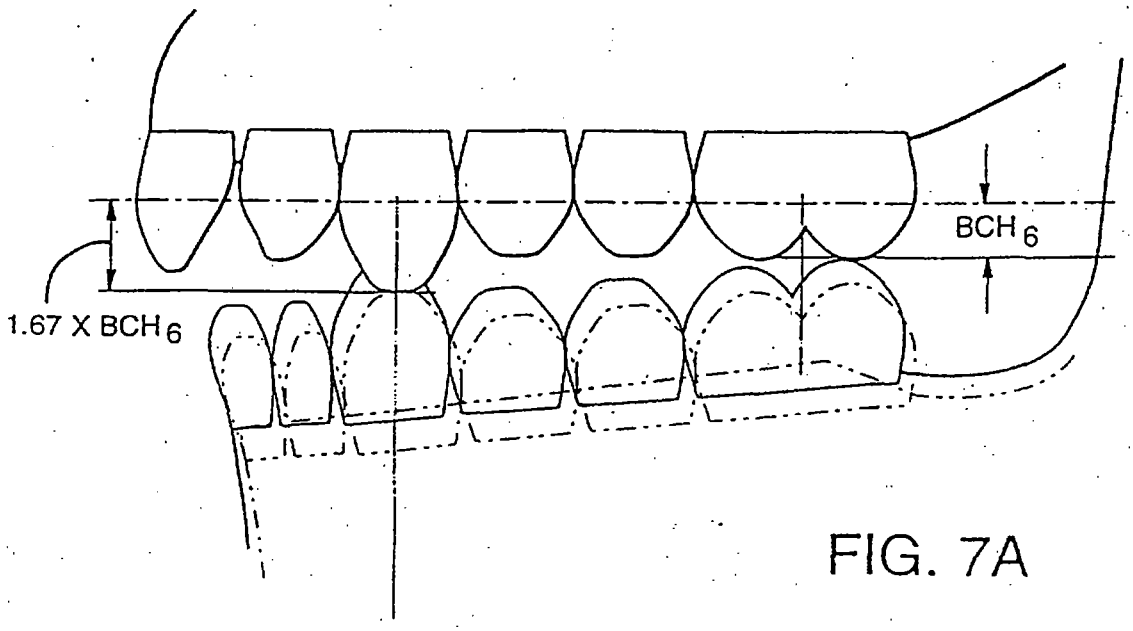


FIG. 7A

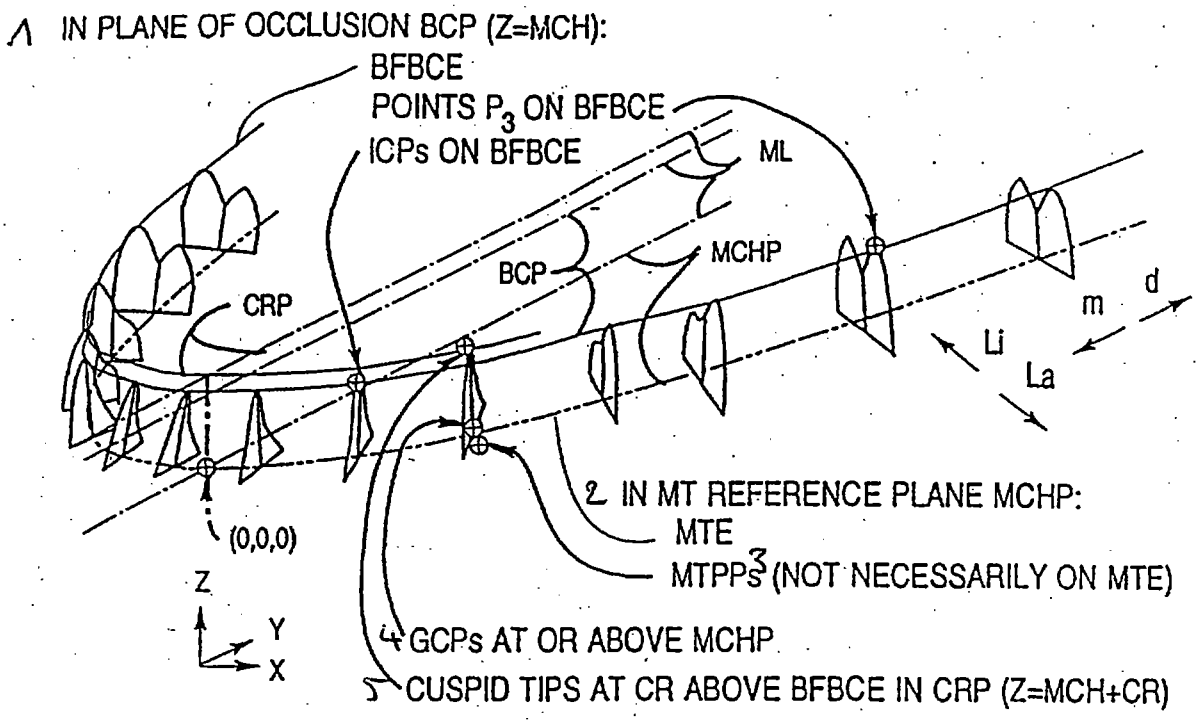

1 IN PLANE OF OCCLUSION BCP (Z=MCH):
BFBCE
POINTS P_3 ON BFBCE
ICPs ON BFBCE
ML
MCHP
BCP
CRP
m
d
Li
La
(0,0,0)
Z
Y
X
2 IN MT REFERENCE PLANE MCHP:
MTE
3 MTPPs (NOT NECESSARILY ON MTE)
4 GCPs AT OR ABOVE MCHP
5 CUSPID TIPS AT CR ABOVE BFBCE IN CRP (Z=MCH+CR)
6 PROFILE PLANE COORDINATES:
Y COORDINATE = Z IN ARCH PLANES
X COORDINATE = LABIAL (La) DIRECTION IN ARCH PLANES

FIG. 7C

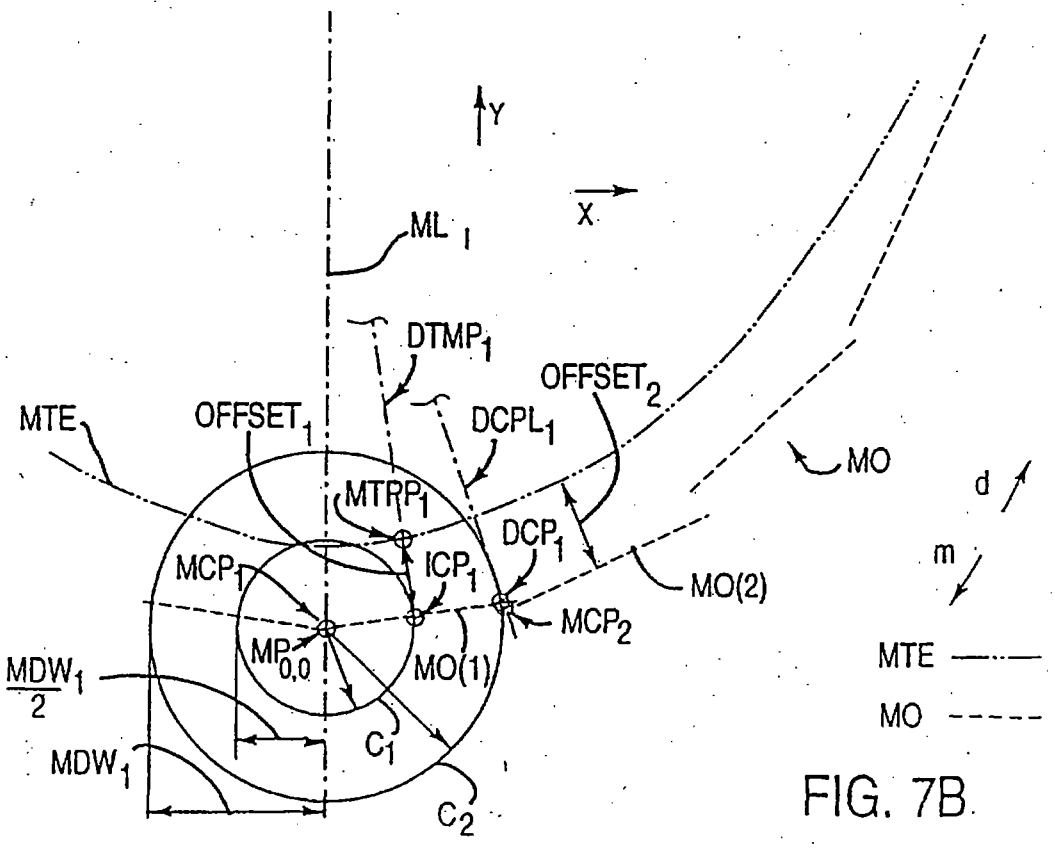

Y
X
ML 1
DTMP1
OFFSET2
DCPL1
MTE
OFFSET1
MO
d
m
MTRP1
DCP1
MCP1
ICP1
MO(2)
MCP2
MP0,0
MO(1)
MDW1/2
C1
MDW1
C2
MTE
MO

FIG. 7B

Fig. 7C

1) in Okklusionsebene
2) in MT-Referenzebene
3) (nicht notwendigerweise auf MTE)
4) GCPs in oder über MCHP
5) Eckzahnspitzen bei CR über BFBCE in CRP
6) Profilebenenkoordinaten:

   Y-Koordinate = Z in Bogenebenen

   X-Koordinate = Labiale (La) Richtung in Bogenebenen

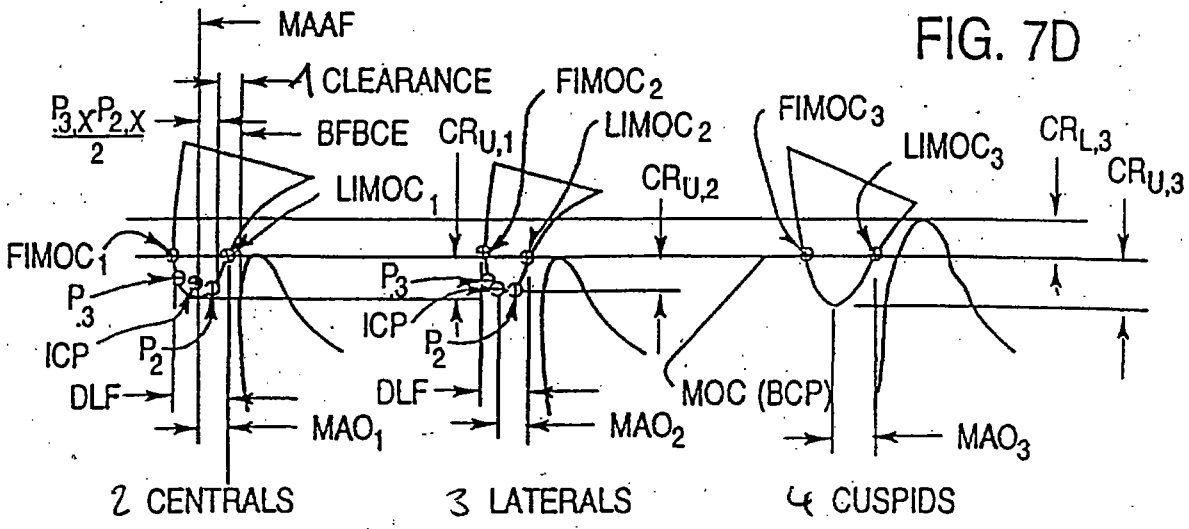
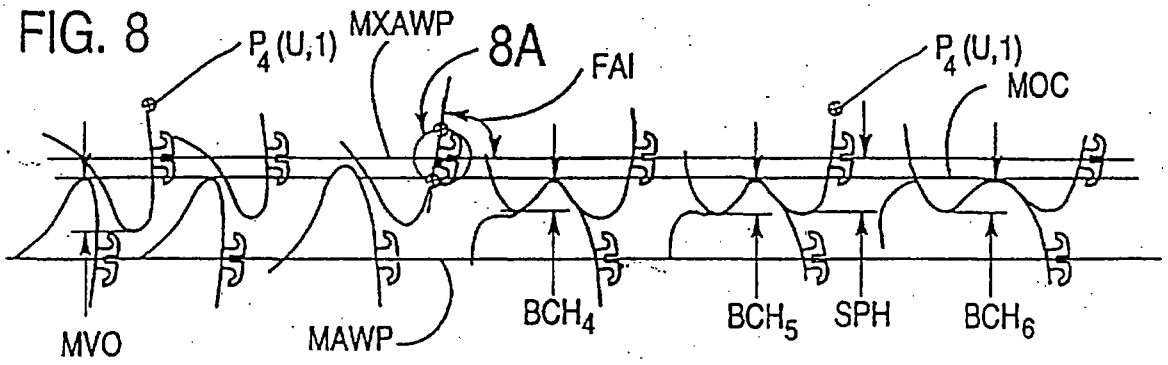


FIG. 7D

FIG. 8



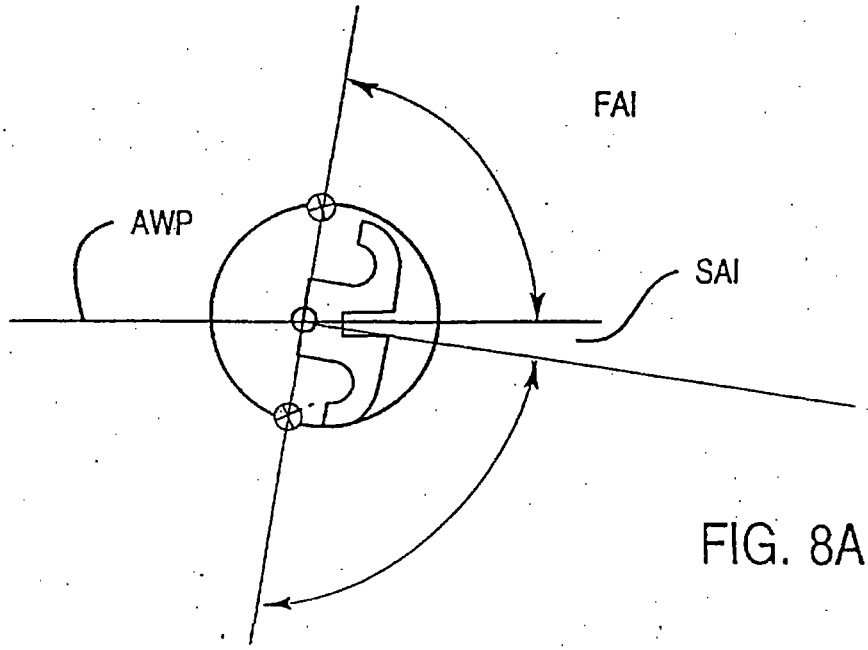


FIG. 8A

Fig. 7D

1) Zwischenraum
2) 1. Schneidezähne
3) 2. Schneidezähne
4) Eckzähne

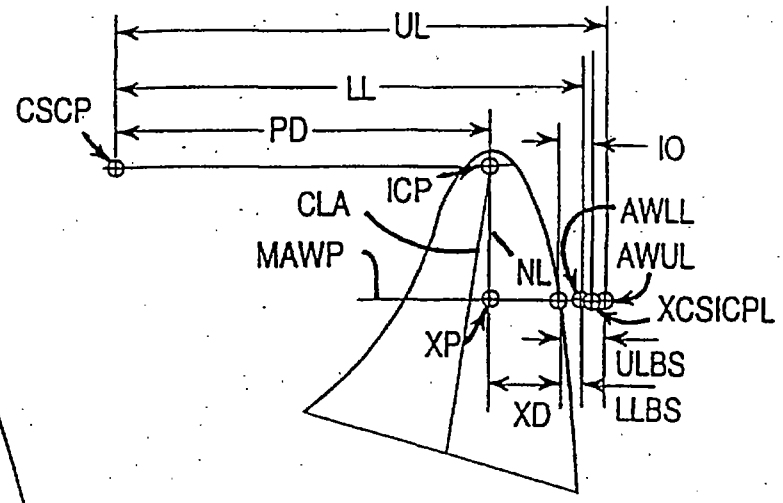

UL
LL
CSCP
PD
IO
ICP
CLA
AWLL
MAWP
NL
AWUL
XCSICPL
XP
ULBS
XD
LLBS

FIG. 8C

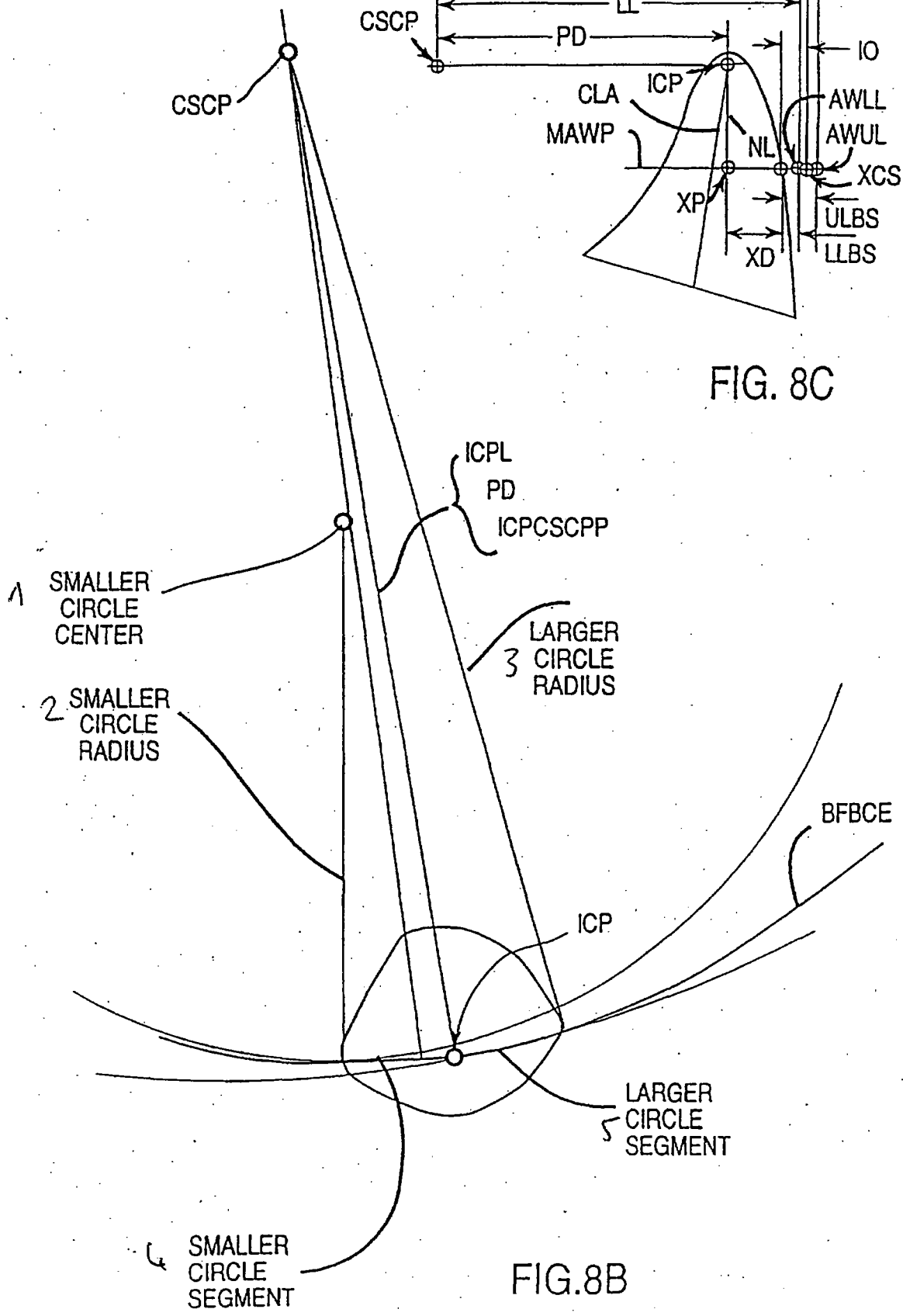

CSCP
ICPL
PD
ICPCSCPP
1 SMALLER CIRCLE CENTER
3 LARGER CIRCLE RADIUS
2 SMALLER CIRCLE RADIUS
BFBCE
ICP
LARGER CIRCLE SEGMENT
4 SMALLER CIRCLE SEGMENT

FIG.8B

Fig. 8B

1) Mittelpunkt des kleineren Kreises
2) Radius des kleineren Kreises
3) Radius des größeren Kreises
4) Segment des kleineren Kreises
5) Segment des größeren Kreises

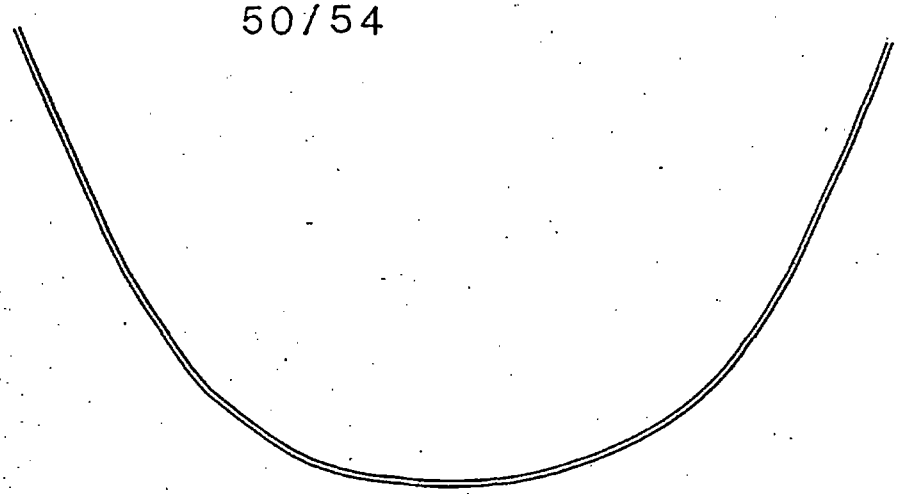


FIG. 8E

FIG. 8D

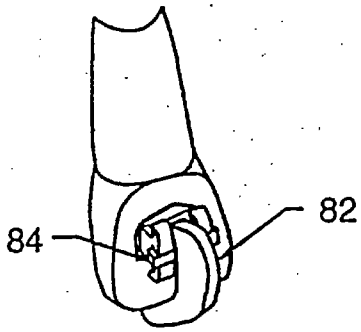


FIG. 8F

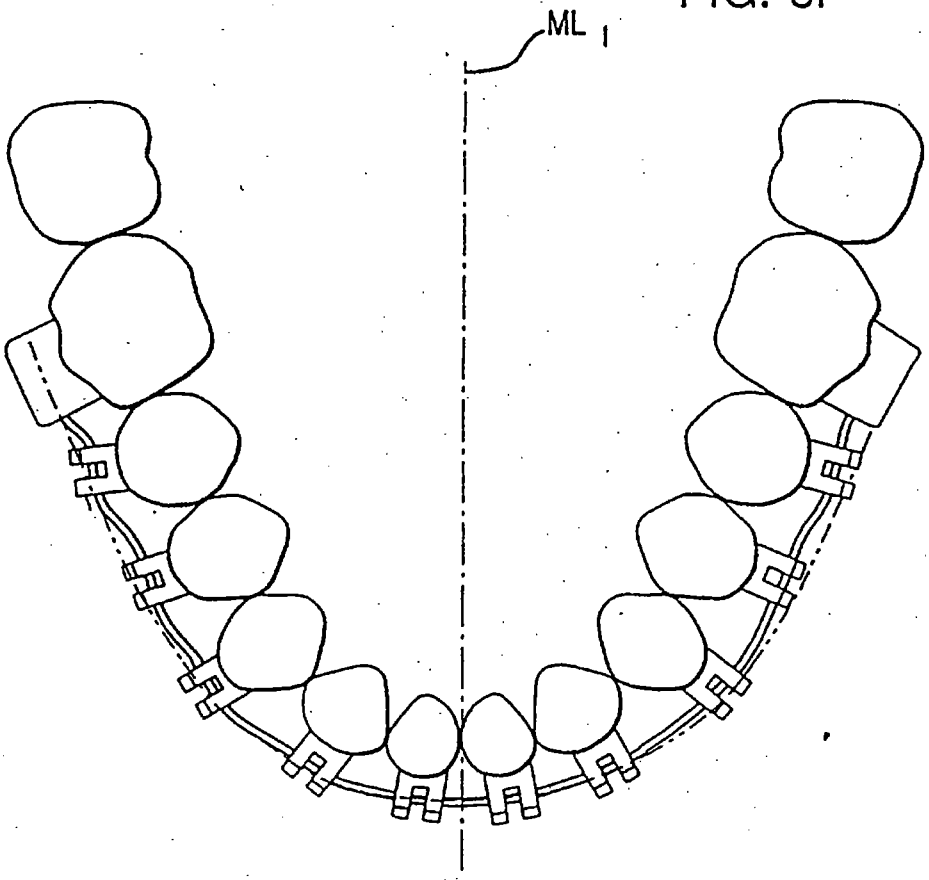
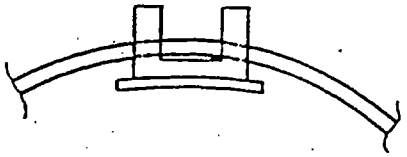


FIG. 8I



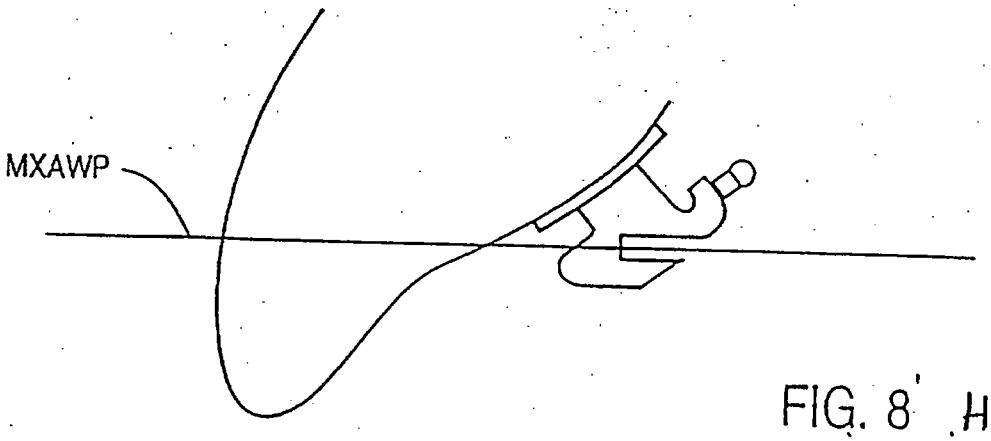


FIG. 8' H

FIG. 8' G

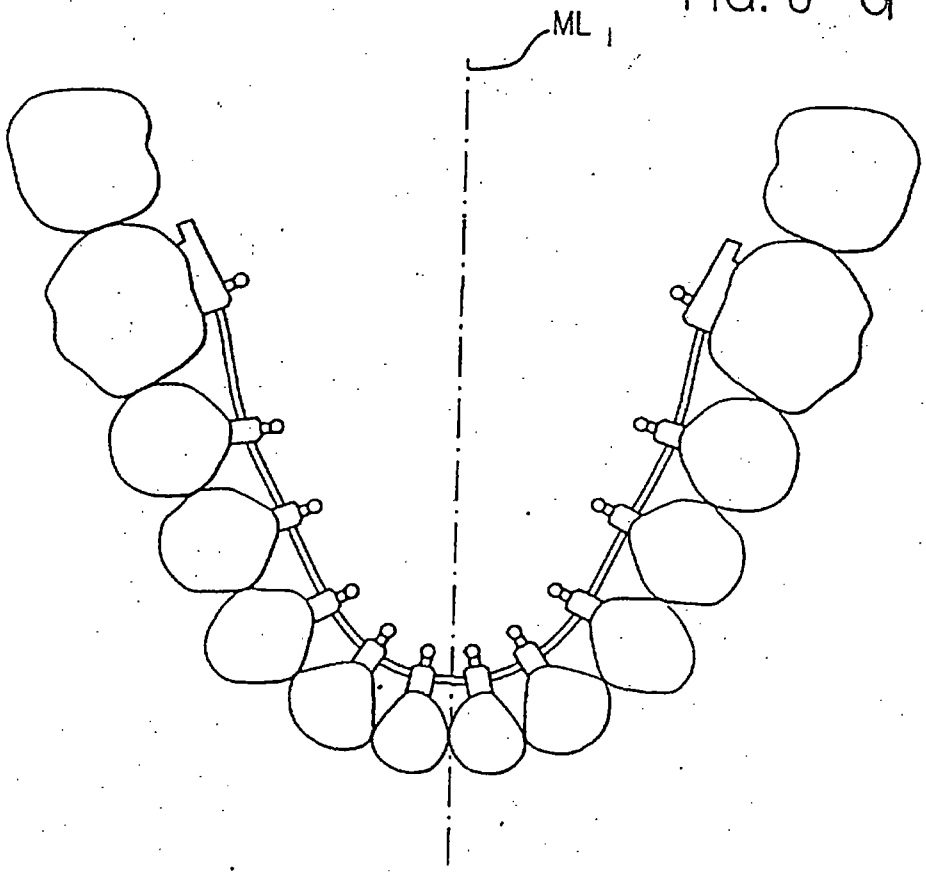
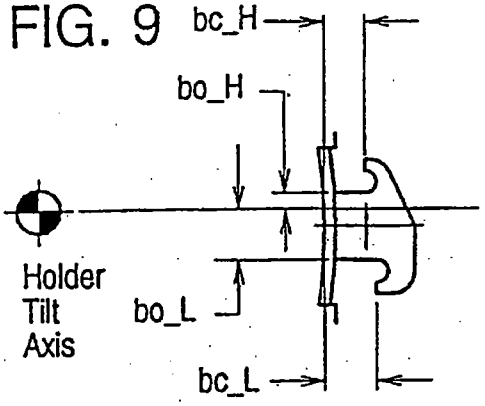


FIG. 9



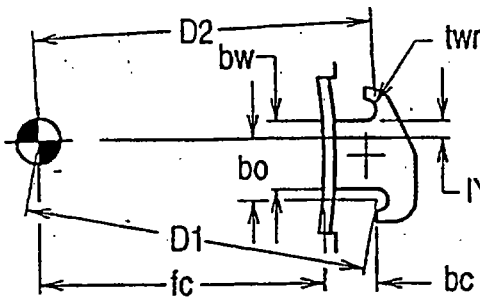


FIG. 9A

FIG. 9B

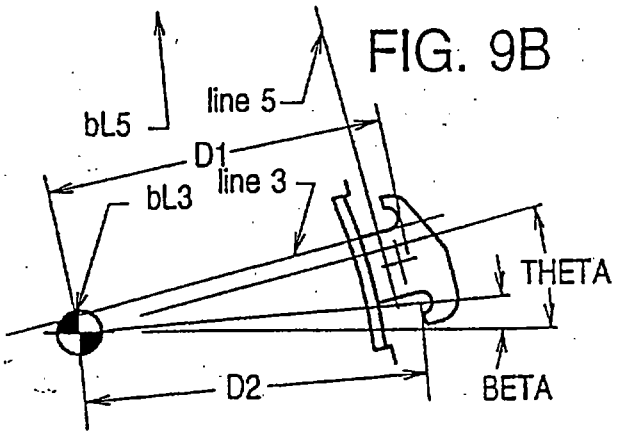


FIG. 9C

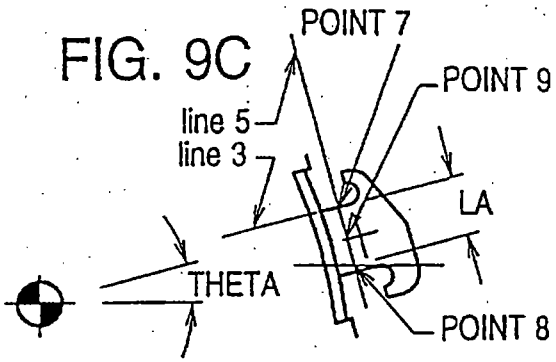


FIG. 9D

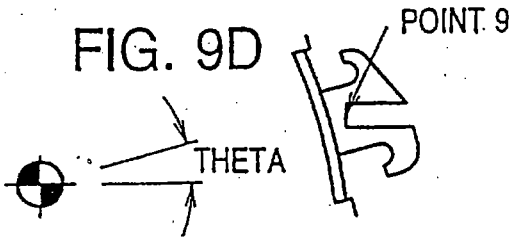


FIG. 9E

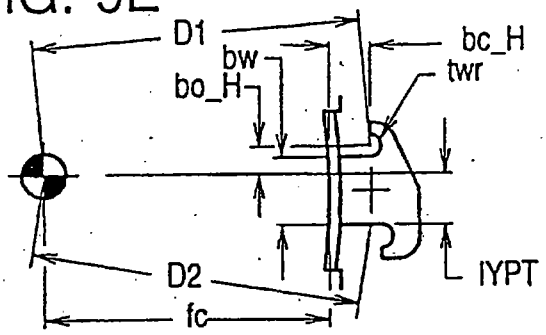
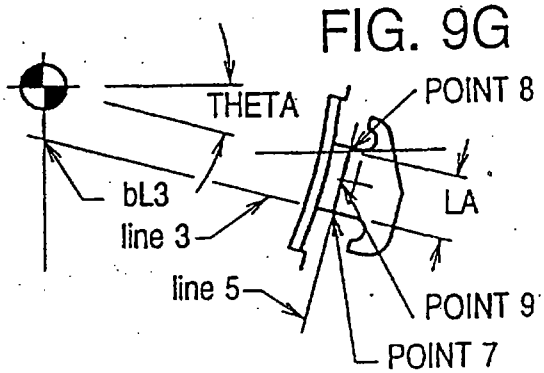


FIG. 9G



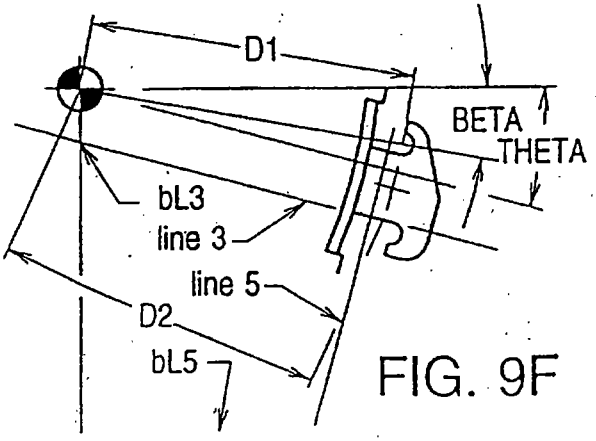


FIG. 9F

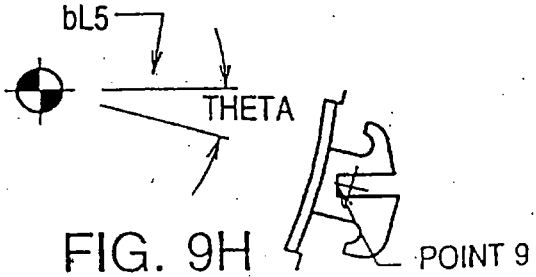


FIG. 9H

Fig. 9

1) Neigungsachse des Halters

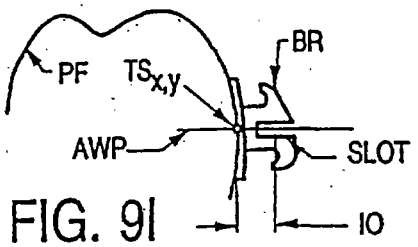


FIG. 9I

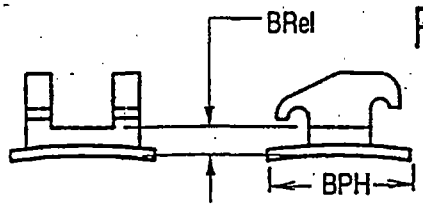


FIG. 9J

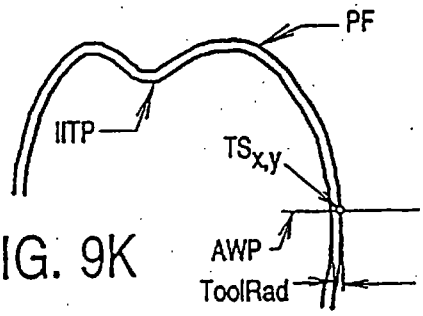


FIG. 9K

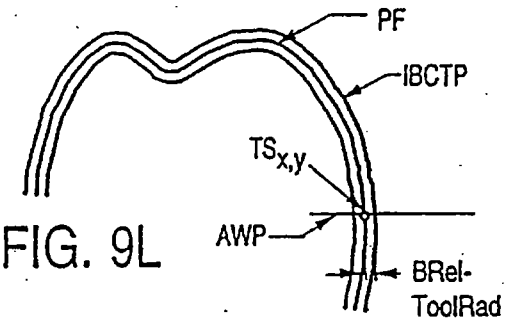


FIG. 9L

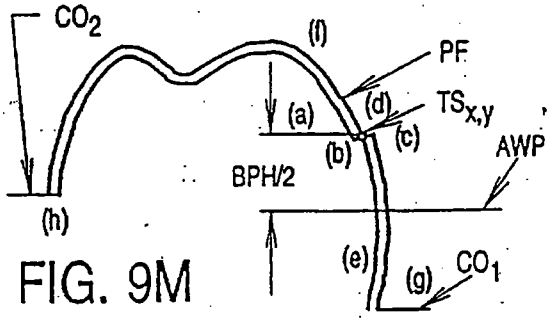


FIG. 9M

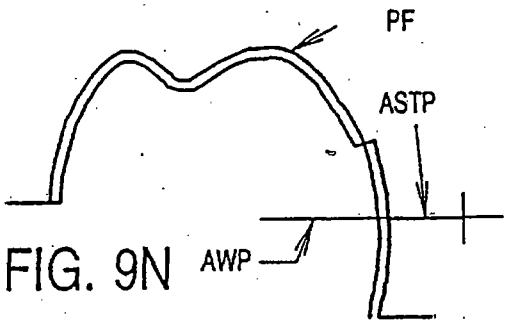


FIG. 9N

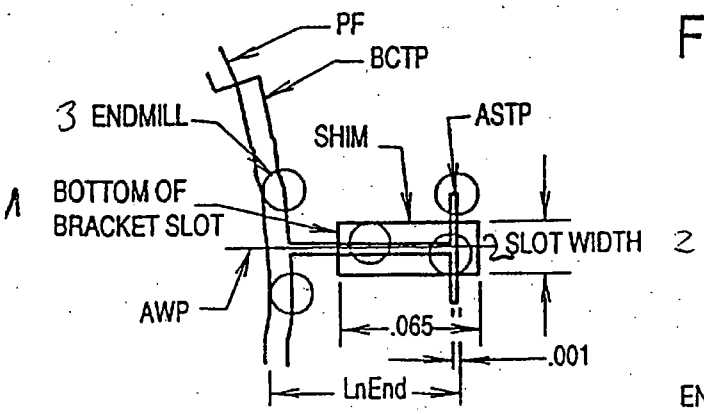


FIG. 9O

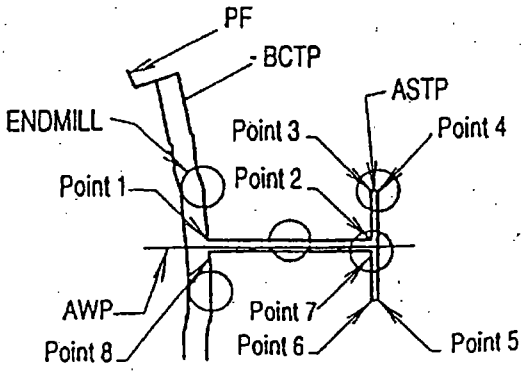


FIG. 9P

Fig. 9O

1) Grundfläche des Bracketschlitzes
2) Schlitzbreite
3) Schaftfräser

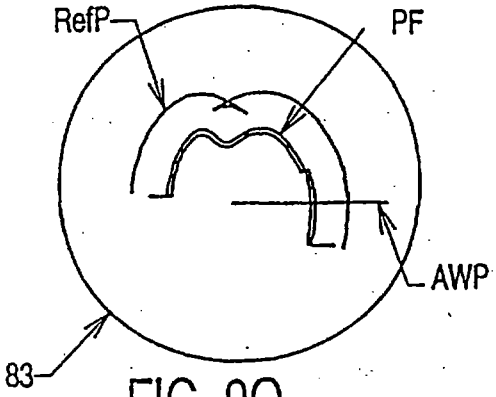


FIG. 9Q

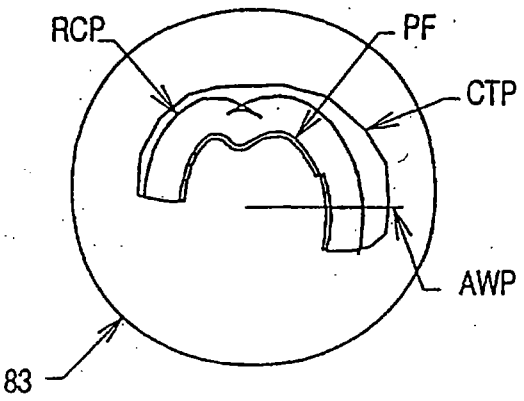


FIG. 9R

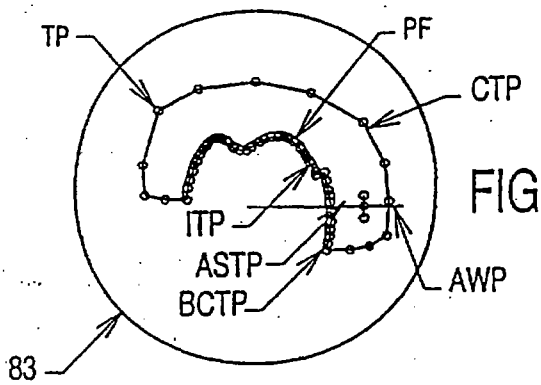


FIG. 9S

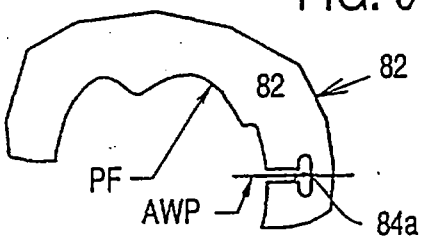


FIG. 9T

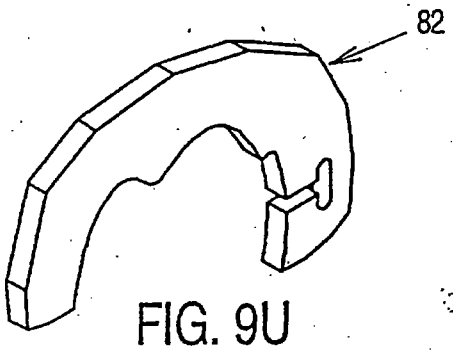


FIG. 9U

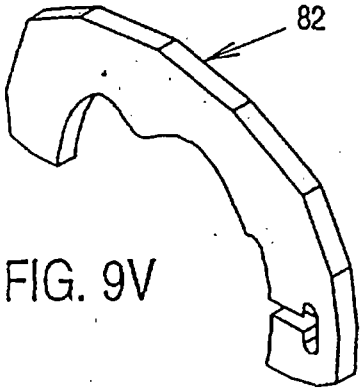


FIG. 9V

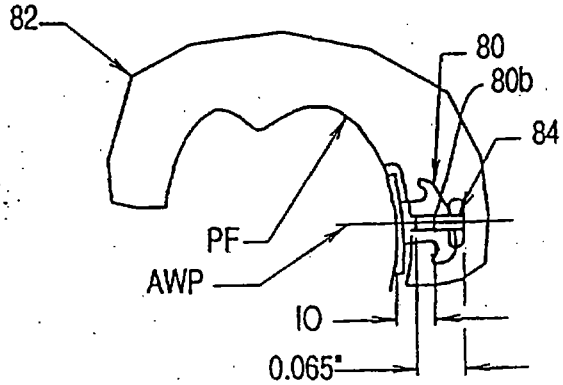


FIG. 9W

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 731 673 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
30.05.2001 Bulletin 2001/22

(21) Application number: **95934383.1**

(22) Date of filing: **03.10.1995**

(51) Int Cl.[7]: **A61C 13/00**

(86) International application number:
PCT/SE95/01131

(87) International publication number:
WO 96/10371 (11.04.1996 Gazette 1996/16)

(54) **METHOD AND DEVICE FOR A PRODUCT INTENDED TO BE INTRODUCED INTO THE HUMAN BODY.**

VERFAHREN UND VORRICHTUNG FÜR EIN PRODUKT , VORGESEHEN UM IN DEN MENSCHLICHEN KÖRPER EINGEFÜHRT ZU WERDEN

PROCEDE ET DISPOSITIF CONCUS POUR UN PRODUIT DESTINE A ETRE INTRODUIT DANS LE CORPS HUMAIN

(84) Designated Contracting States:
AT BE CH DE DK ES FR GB GR IE IT LI LU NL SE

(30) Priority: **04.10.1994 SE 9403345**

(43) Date of publication of application:
18.09.1996 Bulletin 1996/38

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402 26 Göteborg (SE)

(56) References cited:
EP-A- 0 025 911
EP-A- 0 541 500

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EP 0 731 673 B1

Description

TECHNICAL FIELD

[0001] The present invention relates to a method for manufacturing a product which can be used in the human body, preferably a dental bridge, with the aid of a model comprising different parts, for example preparations, and utilizing a scanning unit by means of which the contours of the parts are scanned and represented by electrical (digital) representations, and a computer unit having a computer screen which operates with data/information items which are related to the representations and therefore to said contours and which are arranged in files. With the aid of a computer program, for example a CAD program, the computer processes the said data in cooperation with an operator in order to represent, on the computer screen, a construction which is based on the scanned representations, whereby processing information representing the said construction being obtained from the computer unit for use in equipment for manufacturing the product. The invention also relates to a device according to the preamble of the following claim 8.

STATE OF THE ART

[0002] In the manufacture of dental bridges, for example, it is already known to use a scanning unit and computer for simulating a construction based on the scanning. The computer can also, in a known case, calculate machining coordinates for production of the construction in question.

[0003] In EP-A 541 500 it is disclosed a sensor-apparatus for sensing the contours of only one tooth and thereafter controlling a milling-tool. This reference doesn't discuss how to adjust several tooth-models in relation to each other or how to perform the registration of mutual positions of several casts of teeth.

[0004] EP-A-25911 shows that it is possible to obtain relative positions of several teeth in a row in a model. The reference shows the use of overlapping pictures of the entire model taken by means of a camera. A computer generates image information signals by means of said pictures. The relative positions are determined by means of the scanned images.

DESCRIPTION OF THE INVENTION

TECHNICAL PROBLEM

[0005] There is a need to be able to produce dental bridges, for instance, in a relatively technically simple and computerized manner. In this case it is important to be able to indicate correctly not only the different shapes of the dental bridges, but also the relationship between the parts, at the same times as an appropriate and rapid scanning function can be used. The invention solves this problem, among others. It is then important to bring each tooth-model or preparation into a good position where the tooth-model can be scanned by the used scanner without arising problems from for example undercuts. There is no solution to such a problem in the references mentioned above.

[0006] In the manufacture of dental products, it has been found to be advantageous to use a scanning unit in which the reading function (the beam, needle, etc) is directed obliquely to the axis of the respective dental bridge part, at the same time as the dental bridge part is rotated about its said axis. In this way it is possible to operate in the polar coordinates system, which reduces reading times, data quantities, etc., despite which complicated contours can also be read off. However, there is a clear problem in combining such a tracer principle with computer-aided construction in accordance with the above. The invention solves this problem too.

[0007] It is important that equipment known per se, such as scanning apparatuses, computers, computer programs, etc., can be used. Thus, for example, it is advantageous if standard software can be used. The invention also solves this problem and permits the use of CAD programs which are known per se for producing the product or construction.

SOLUTION

[0008] The feature which can principally be regarded as characterizing for a method according to the invention is defined by a first step in which the mutual positions of the parts/preparations in the model are determined by means of a levelling apparatus which is functionally separate from the scanning unit and in which position data/position information items related to said mutual positions are generated, which position data/position information items are transmitted to the computer unit; and a second step in which the parts/preparations of the model are moved to the scanning unit and scanned for effecting the contour data/contour information items of the parts; and a third step in which said position data/position information items are run concurrently with the contour data/contour information items in the computer unit, whereby the operator of the computer unit can indicate both the contours and the mutual positions of the preparations in the construction.

[0009] Preferred embodiments of the novel method are evident from the attached sub-claims 2-7 related to the method.

[0010] The feature which can principally be regarded, as characterizing the novel device according to the present invention is evident from the characterizing clause of attached Patent Claim 8.

ADVANTAGES

[0011] By means of what has been proposed above, reading equipment which is known at present can be

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used for inputting basic data for construction of bridges in a computer. By means of the invention, it is possible for data describing the positions of the individual preparations relative to one another to be collected along the scanning function.

DESCRIPTION OF THE FIGURES

[0012] A presently proposed method and device according to the invention will be described hereinbelow, at the same time with reference to the attached drawings in which:

Figures 1 - 7 show successive manufacturing stages for production of a construction unit based on a model, and

Figure 8 shows, in circuit diagram form, processing stations included in processing equipment according to the invention.

DETAILED EMBODIMENT

[0013] In Figure 1, reference number 1 indicates a plane which can consist of a support platform of a levelling apparatus known per se. A model 2 is applied on the platform. The plane or the platform has an axis 3 which extends at right angles to the plane 1. The axis 3 represents a reading position. The model is displaceably arranged on the platform in the directions of the arrows 4, 5. The platform operates with two axes which are at right angles to one another and which are here designated as the X and Z axes. The plane or the platform 1 can be turned about the said axes in the directions of the arrows 6 and 7. The model 2 includes a number of preparations 8, 9, 10, etc. The model can alternatively be fixed in the platform 1 in a manner known per se, in which case the platform in turn can be displaceable in the directions of the arrows 4 and 5. In this way, each preparation can be brought one at a time into line with the reading position which is represented by the line 3. Equipment 11 is in this case arranged to trace the X and Z positions as well as the current angles of rotation of the axes 6 and 7. The tracing can be effected in a manner known per se.

[0014] In Figure 2, the model 2 has been displaced with the aid of the platform 1 so that the axis 12 of the preparation 8 coincides with the axis 3 which represents the tracer position. This movement of the platform is indicated by tracer signals i1 and i2 in Figure 1, which tracer signals are input to the tracer equipment 11.

[0015] The next stage is to orient the preparation 8 in the vertical direction. According to Figure 1, the preparation is inclined in relation to the axis 3 by an angle gamma. This inclination can mean that undercuts and certain areas are inaccessible for the scanning which is effected in the subsequent operational step. There is therefore a need to carry out the said straightening of the preparation 8. In accordance with Figure 3, this is done by the plane 1 being turned about the axes X and Z. In this way, the axis 12 of the preparation 8 can be made to coincide fully with the axis 3 or to coincide essentially with this axis. These changes in the angle of rotation of the axes are represented in Figure 1 by signals i3 and i4. These signals too are recorded in the tracer equipment 11.

[0016] In accordance with Figure 4, the preparation 8 can be provided with a handle 13 or other gripping member, with which the preparation can be transferred to a scanning unit according to Figure 5. The scanning unit too has a rotating platform 14 on which the preparation 8 can be applied or fixed in a defined position. The scanning apparatus is of the type which has a tracer function 15 in the form of a needle, optical tracer, etc. A rotation arrow for the said platform 14 is indicated by 16. The longitudinal axis of the tracer member or tracer function is indicated by 17. The tracer apparatus is characterized by the fact that the platform 14 is rotated, at the same time as the tracer member 15 and the preparation 8 move reciprocally in the vertical direction 18. Either the platform can be stationary in the vertical direction and the tracer function can move in the vertical direction, or vice versa. Alternatively, both the platform and the tracer function can be vertically displaceable. The handle can be removed during this tracing operation. The attachment of the handle 13 can also be made on a part of the preparation which will not be traced by the scanning equipment, which means that the handle is not in the way.

[0017] Figure 6 shows a computer screen 19 of a computer which is known per se and which is used in this connection. The preparations forming part of the bridge or equivalent are transformed on the basis of the read-off data which is input to a random CAD program. On the said preparations, a bridge will be constructed in accordance with Figure 7. The construction procedure takes place in a manner known per se by interaction between the computer and a user or operator. In Figure 7, a bridge produced on the preparations 8', 9' and 10' is indicated by 20. The bridge is constructed and sectioned in the computer. The parts are then transformed back so that the milling takes place about the axis of rotation 14a which is used during the reading-off.

[0018] Figure 8 shows the entire chain of production. The levelling function described above is carried out at a first station. The said scanning function takes place at a second station 22. The axis of rotation is indicated by 14a'. The reference labels in other respects correspond to those which are used in Figure 5, but with a prime symbol added. The digital representation which is obtained from the scanning function is shown by 23 in Figure 8. The computer used in this connection is arranged at a station 24 and functions in accordance with the above. The computer is provided with a terminal 25 for the said interaction with a user. Machining or milling information is indicated by 26, and machining equipment

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by 27. The machining from a blank 28 also takes place in the polar coordinates system. A tool 29 is indicated in principle and symbolizes a milling cutter or other tool. The blank is rotated about a vertical axis 30. The axis 31 of the tool is inclined, in relation to the axis 32 of the blank, by an angle beta. In a preferred embodiment, the angle beta is the same size as the angle alpha and alpha'. The levelling equipment has the effect that the computer can be fed information which can relate to the said signals i1, i2, i3 and i4, which information constitutes digital information 23'. The last-mentioned information is arranged too in files in association with the computer. The data in the files for the information 23, 23' is run concurrently and is used by the computer for producing the construction on the computer screen.

[0019] Since the reading-off function can read off only one preparation at a time, the data describing the mutual relationship between the preparations must therefore be collected in another apparatus in accordance with the above. This is called a levelling apparatus according to the above, since the rows of teeth can be straightened both as regards angle and translation.

[0020] Collection of the data which is required can be carried out in the following way:

1. The preparation in question is translated in the X and Z directions so that it is placed in the "read-off position" on the levelling platform.
2. The preparation is straightened by means of the platform being rotated about the X and Z axes so that it can be read off without any undercuts or the like arising.
3. The position of the preparation in the X and Z directions and also the angles about the X and Z axes are read off.
4. A "handle" is secured on the preparation. With the aid of the "handle", the preparation can be transferred easily to the reading-off function. The preparation is then read off in a known manner.

[0021] The data which has been read off in the levelling apparatus is now used for transforming the read-off files so that they can be seen in their correct positions in a random CAD program. The bridge can then be constructed in the CAD program using the input preparations as basis.

[0022] The bridge constructed in the CAD program is sectioned in the computer and is transformed back so that the production basis for the inner shapes of the included parts is milled about the centre of rotation with which they were read off. That is to say, the read-off file functions as production basis in the same way as for single crowns. This is to ensure that the transforms will not have an adverse effect on the accuracy. The accuracy requirements are lower as regards the outer shapes, which are thus those which are transformed.

[0023] The bridge parts are thereafter joined together in the usual way, by laser welding 33 in a known manner.

Claims

1. Method for manufacturing a product which can be used in the human body, preferably a dental bridge, with the aid of a model (2) comprising different parts, for example preparations (8, 9, 10), and utilizing a scanning unit (14, 15) by means of which the contours of the parts are scanned and represented by electrical (digital) representations (23), and a computer unit (19, 25) having a computer screen which operates with data/information items which are related to the representations and therefore to said contours and which are arranged in files, and with the aid of a computer program, for example a CAD program, processes the said data in cooperation with an operator in order to represent, on the computer screen, a construction (20) which is based on the scanned representations, whereby processing information representing the said construction being obtained from the computer unit for use in equipment for manufacturing the product, characterized by

   a) a first step in which the mutual positions of the parts/preparations (8, 9, 10) in the model are determined by means of a levelling apparatus which is functionally separate from the scanning unit and in which position data/position information items (23') related to said mutual positions are generated, which position data/position information items are transmitted to the computer unit,

   b) a second step in which the parts/preparations (8, 9, 10) of the model are moved to the scanning unit and scanned for effecting the contour data/contour information items of the parts, and

   c) a third step in which said position data/position information items are run concurrently with the contour data/contour information items in the computer unit (19, 25), whereby the operator of the computer unit (19, 25) can indicate both the contours and the mutual positions of the preparations in the construction (20).

2. Method according to Patent Claim 1, characterized in that the model is applied on a support platform of the levelling apparatus (1), in that the said parts/preparations (8, 9, 10) are brought one at a time to one or more reading-off positions on the support platform, in that the support platform is turned about two axes (x,z), which extend through the plane and are at right angles to one another, in order to provide for the respective part/preparation, a vertical position corresponding to a vertical scanning position in the scanning unit (14, 15) so that the latter is able

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to scan the whole contour of the respective part/preparation, and in that information on the position of the model (2) on said support platform and the said angles of rotation about the said axes (x,z) is supplied and is used by the computer unit (19, 25), in order to effect the determination of the correct mutual positions of the parts/preparations in the construction (20).

3. Method according to Patent Claim 1 or 2, characterized in that the respective part/preparation (8, 9, 10) is provided with a handle (13) or equivalent holding member, by means of which the part/preparation is transferred to the scanning unit (14, 15) for said scanning of the contour of the part/preparation.

4. Method according to Patent Claim 1, characterized in that the scanning unit (14, 15) operates with a scanning function along an axis (17) which is inclined in relation to the axis (14a) of the part/preparation, and in that the part/ /preparation is rotated about its axis (14a) during the scanning, at the same time as the part/preparation and/or the scanning unit (its scanning axis) moves in the vertical direction (18).

5. Method according to any one of the preceding patent claims, characterized in that the construction (20) produced using the program is sectioned in the computer unit (19, 25) and in that the machining information (26) includes information on the structure of the sections and their mutual positions/locations.

6. Method according to any one of the preceding patent claims, characterized in that the machining/milling is carried out in a similar way to the scanning of the preparation (8, 9, 10) of the respective section/part, and each scanning file can serve as production basis in the same way as in manufacture of individual parts/dental crowns, etc.

7. Method according to any one of the preceding patent claims, characterized in that the sections or the bridge parts are joined together by means of laser welding.

8. Device for manufacturing a product which can be used in the human body, preferably a dental bridge, with the aid of a model comprising different parts, for example preparations (8, 9, 10) and including a scanning unit (14,15) by means of which the contours of the parts can be scanned and represented by electrical (digital) representations (23), and a computer unit (19, 25) having a computer screen, which computer unit can receive the electrical representations (23) and stores in files data/information corresponding the electrical representations (23), and which computer unit can process i.a. said data/information by means of a computer program, for example a CAD-program, in cooperation with an operator when designing a construction (20) on the screen, whereby processing information (26) representing said construction can be transmitted to equipment (29, 33) for manufacturing of the product, characterized in that the device also comprises a levelling apparatus which operates separately from the scanning unit, in that the levelling apparatus having a support platform (1) adapted to receive the model (2) and allow side displacements (4, 5) of the model in order to make it possible to position each of the respective parts/preparations (8, 9 or 10) in read-off positions at the levelling apparatus/support platform, in that the support platform (1) also is adapted to be tiltable around two axes (x,z) extending through the platform and right angled to one another in order to make it possible to adjust the inclination of a respective part/preparation (8, 9 or 10) in said read-off position with aid of tiltings of the support platform around said axes (x, z), in that a tracer equipment (11) senses respective side displacement positions of the model and tilting positions of the support platform for each part/preparation (8, 9, 10) and obtains information (23') about these last mentioned positions to the computer unit individually and a further platform (14) included in said scanning unit, on which further platform (14) parts/preparations can be placed individually in a scanning position related to the position it had on the support platform of the levelling apparatus when sensed by said tracer equipment (11), and in that the information (23') obtained by the tracer equipment (11) is adapted to be used concurrently with said data/information by the computer unit (19, 25) in order to determine the correct mutual positions of the parts/preparations in the construction.

Patentansprüche

1. Verfahren zur Herstellung eines im menschlichen Körper verwendbaren Produktes, vorzugsweise einer Zahnbrücke, mit Hilfe eines Modells (2) mit unterschiedlichen Teilen, z. B. Zahnaufbauten (8, 9, 10) und mittels einer Abtasteinheit (14, 15), mit der die Konturen der Teile abgetastet und durch elektrische (digitale) Darstellungen (23) dargestellt werden, und einer Computereinheit (19, 25) mit einem Computerbildschirm, der mit Daten/Informationsinhalten arbeitet, die auf die Darstellungen und damit die Konturen bezogen sind und in Dateien angeordnet sind, und der mittels eines Computerprogramms, z. B. eines CAD-Programms, die Daten in Zusammenarbeit mit einem Bediener verarbeitet, um auf dem Computerschirm eine Konstruktion (20) darzustellen, die auf den abgetasteten Darstellun-

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gen beruht, wobei von der Computereinheit eine die Konstruktion repräsentierende Verarbeitungsinformation enthalten wird, die in einer Einrichtung zur Herstellung des Produktes verwendbar ist, **gekennzeichnet** durch

a) einen ersten Schritt, in welchem die gegenseitigen Positionen der Teile/Aufbauten (8, 9, 10) in dem Modell mittels eines Nivellierapparats bestimmt werden, der funktional getrennt von der Abtasteinheit ist und in welchem den gegenseitigen Positionen zugeordnete Positionsdaten/Positionsinformations-Inhalte (23') erzeugt werden, die zu der Computereinheit übertragen werden,

b) einen zweiten Schritt, in dem die Teile/Aufbauten (8, 9, 10) des Modells zu der Abtasteinheit bewegt und abgetastet werden, um die Konturdaten/Konturinformations-Inhalte der Teile zu bewirken, und

c) einen dritten Schritt, in dem die Positionsdaten/Positionsinformations-Inhalte gemeinsam mit den Konturdaten/Konturinformations-Inhalten in der Computereinheit (19, 25) abgespielt werden, wobei der Bediener der Computereinheit (19, 25) sowohl die Konturen als auch die gegenseitigen Positionen der Aufbauten in der Konstruktion (20) anzeigen kann.

2. Verfahren nach Anspruch 1, dadurch **gekennzeichnet,** daß das Modell auf einer Tragplattform des Nivellierapparats (1) angeordnet wird, daß die Teile/Aufbauten (8, 9, 10) eines nach dem anderen in eine oder mehrere Ablesepositionen auf der Tragplattform gebracht werden, daß die Tragplattform um zwei Achsen (x, z) gedreht wird, die durch deren Ebene verlaufen und rechtwinklig zueinander sind, um für den jeweiligen Teil oder Aufbau eine Vertikalposition zu erhalten, die einer vertikalen Abtastposition in der Abtasteinheit (14, 15) entspricht, so daß die letztere die gesamte Kontur des betreffenden Teils/Aufbaus abtasten kann, und daß Information über die Position des Modells (2) auf der Tragplattform und über die Rotationswinkel um die Achsen (x, z) geliefert und von der Computereinheit (19, 25) verwendet wird, um die Bestimmung der korrekten gegenseitigen Positionen der Teile/Aufbauten in der Konstruktion (20) zu bewirken.

3. Verfahren nach Anspruch 1 oder 2, dadurch **gekennzeichnet,** daß der jeweilige Teil/Auf bau (8, 9, 10) mit einem Griff (13) oder entsprechendem Haltelement versehen ist, mit dem der Teil/Aufbau zu der Abtasteinheit (14, 15) für das Abtasten der Kontur des Teils/Aufbaus überführt wird.

4. Verfahren nach Anspruch 1, dadurch **gekennzeichnet,** daß die Abtasteinheit (14, 15) mit einer Abtastfunktion längs einer Achse (17) arbeitet, die zu der Achse (14a) des Teils/Aufbaus geneigt ist, und daß der Teil/Aufbau um seine Achse (14a) während des Abtastens rotiert wird und gleichzeitig der Teil/Aufbau und/oder die Abtasteinheit (ihre Abtastachse) in der Vertikalrichtung (18) bewegt wird.

5. Verfahren nach einem der vorangehenden Ansprüche, dadurch **gekennzeichnet,** daß die mittels des Programms erzeugte Konstruktion (20) in der Computereinheit (19, 25) sektioniert wird und daß die Bearbeitungsinformation (26) Informationen über die Struktur der Sektionen und ihre gegenseitigen Positionen/Stellungen enthält.

6. Verfahren nach einem der vorangehenden Ansprüche, dadurch **gekennzeichnet,** daß das Verarbeiten/Fräsen in ähnlicher Weise wie das Abtasten des Aufbaus (8, 9, 10) der jeweiligen Sektion/Teils durchgeführt wird und daß jede Abtastdatei als Produktionsbasis in gleicher Weise wie bei der Herstellung von einzelnen Teilen/Zahnkronen usw. dienen kann.

7. Verfahren nach einem der vorangehenden Ansprüche, dadurch **gekennzeichnet,** daß die Sektionen oder Brückenteile mittels Laserschweißung miteinander verbunden werden.

8. Vorrichtung zur Herstellung eines im menschlichen Körper verwendbaren Produktes, vorzugsweise einer Zahnbrücke, mit Hilfe eines Modells aus verschiedenen Teilen, z. B. Aufbauten (8, 9, 10), mit einer Abtasteinheit (14, 15), mit der die Konturen der Teile abgetastet und durch elektrische (digitale) Darstellungen (23) dargestellt werden können, und einer Computereinheit (19, 25) mit einem Bildschirm, die die elektrischen Darstellungen (23) empfangen kann und den elektrischen Darstellungen (23) entsprechende Daten/Informationen in Dateien speichert, wobei die Computereinheit u. a. die Daten/Informationen mittels eines Computerprogramms, z. B. eines CAD-Programms, in Kooperation mit einem Bediener beim Entwerfen einer Konstruktion (20) auf dem Bildschirm verarbeiten kann, wobei eine die Konstruktion darstellende Verarbeitungsinformation (26) zu einer Einrichtung (29, 33) zum Herstellen des Produktes übertragen werden kann, dadurch **gekennzeichnet,**
daß die Vorrichtung ferner einen Nivellierapparat aufweist, der separat von der Abtasteinheit arbeitet, daß der Nivellierapparat eine Tragplattform (1) für die Aufnahme des Modells (2) aufweist, der seitliche Verschiebungen (4, 5) des Modells ermöglicht, um jeden der jeweiligen Teile/Aufbauten (8, 9 oder 10) in eine Ablesepositon auf dem Nivellierapparat

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bzw. der Tragplattform zu bringen, daß die Tragplattform (1) ferner um zwei Achsen (x, z) kippbar ist, die sich durch die Plattform und rechtwinklig zueinander erstrecken, um die Neigung eines jeweiligen Teils/Aufbaus (8, 9, 10) in der Ableseposition durch Kippen der Tragplattform um die Achsen (x, z) einzustellen, daß eine Erfassungeinrichtung (11) die jeweiligen zeitlichen Verschiebungspositionen des Modells und Kipp-Positionen der Tragplattform für jeden Teil/Aufbau (8, 9, 10) erfaßt und Information (23') über diese Positionen der Computereinheit einzeln zuführt, und eine in der Abtasteinheit enthaltene weitere Plattform (14), auf der Teile/Aufbauten einzeln in einer Abtastposition angeordnet werden können, die der Position zugeordnet ist, die sie auf der Tragplattform des Nivellierapparates beim Abtasten mittels der Erfassungseinrichtung (11) eingenommen hatten, und daß die von der Erfassungeinrichtung (11) erhaltene Information (23') gemeinsam mit den Daten/Informationen von der Computereinheit (19, 25) verwendet werden kann, um die korrekten gegenseitigen Positionen der Teile/Aufbauten in der Konstruktion zu bestimmen.

Revendications

1. Procédé pour fabriquer un produit qui peut être utilisé dans le corps humain, de préférence un bridge dentaire, à l'aide d'un modèle (2) comportant différentes parties, par exemple des préparations (8, 9, 10), et utilisant une unité de balayage (14, 15) par l'intermédiaire de laquelle les contours des parties sont balayés et représentés par des représentations électriques (numériques) (23), et une unité informatique (19, 25) ayant un écran d'ordinateur qui fonctionne avec des éléments de données/informations qui sont associés aux représentations et par conséquent auxdits contours, et qui sont agencés en fichiers, et à l'aide d'un programme informatique, par exemple un programme CAO, qui traite lesdites données en coopération avec un opérateur afin de représenter, sur l'écran d'ordinateur, une construction (20) qui est basée sur les représentations balayées, de manière à traiter des informations représentant ladite construction qui est obtenue à partir de l'unité informatique pour être utilisée dans un équipement de fabrication du produit, caractérisé par

   a) une première étape dans laquelle les positions mutuelles des parties/préparations (8, 9, 10) du modèle sont déterminées par l'intermédiaire d'un dispositif de mise à niveau qui est fonctionnellement séparé de l'unité de balayage et dans lequel sont générés des éléments de données de position/informations de position (23') associés auxdites positions mutuelles, lesquels éléments de données de position/informations de position sont transmis à l'unité informatique,
   b) une deuxième étape dans laquelle les parties/préparations (8, 9, 10) du modèle sont déplacées vers l'unité de balayage et balayées pour réaliser les éléments de données de contour/informations de contour des parties, et
   c) une troisième étape dans laquelle lesdits éléments de données de position/informations de position sont exécutés en même temps que les éléments de données de contour/informations de contour dans l'unité informatique (19, 25), de sorte que l'opérateur de l'unité informatique (19, 25) peut indiquer à la fois les contours et les positions mutuelles des préparations de la construction (20).

2. Procédé selon la revendication 1, caractérisé en ce que le modèle est appliqué sur une plate-forme de support du dispositif de mise à niveau (1), en ce que lesdites parties/préparations (8, 9, 10) sont amenées en une seule fois vers une ou plusieurs positions de lecture sur la plate-forme de support, en ce que la plate-forme de support est tournée autour de deux axes (X, Z), qui s'étendent à travers le plan et qui sont à angles droits l'un par rapport à l'autre, afin de fournir pour la partie/préparation respective, une position verticale correspondant à une position de balayage verticale de l'unité de balayage (14, 15) de sorte que cette dernière est capable de balayer le contour entier de la partie/préparation respective, et en ce que des informations concernant la position du modèle (2) sur ladite plate-forme de support et lesdits angles de rotation autour desdits axes (X, Z) sont délivrées et sont utilisées par l'unité informatique (19, 25), afin d'effectuer la détermination des positions mutuelles correctes des parties/préparations de la construction (20).

3. Procédé selon la revendication 1 ou 2, caractérisé en ce que la partie/préparation respective (8, 9, 10) est munie d'une poignée (13), ou d'un élément de support équivalent, par l'intermédiaire de laquelle la partie/préparation est transférée vers l'unité de balayage (14, 15) pour ledit balayage du contour de la partie/préparation.

4. Procédé selon la revendication 1, caractérisé en ce que l'unité de balayage (14, 15) fonctionne avec une fonction de balayage le long d'un axe (17) qui est incliné par rapport à l'axe (14a) de la partie/préparation, et en ce que la partie/préparation est mise en rotation autour de son axe (14a) pendant le balayage, en même temps que la partie/préparation et/ou l'unité de balayage (son axe de balayage) se déplacent dans la direction verticale (18).

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5. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que la construction (20) produite en utilisant le programme est sectionnée dans l'unité informatique (19, 25) et en ce que les informations d'usinage (26) comportent des informations concernant la structure des sections et leurs positions/emplacements mutuels.

6. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'usinage/fraisage est effectué d'une manière similaire au balayage de la préparation (8, 9, 10) de la section/partie respective, et chaque fichier de balayage peut servir en tant que base de production de la même manière que dans la fabrication de parties/couronnes dentaires individuelles, etc.

7. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les sections ou les parties de bridge sont réunies ensemble par l'intermédiaire d'un soudage laser.

8. Dispositif pour fabriquer un produit qui peut être utilisé dans le corps humain, de préférence un bridge dentaire, à l'aide d'un modèle comportant différentes parties, par exemple des préparations (8, 9, 10) et incluant une unité de balayage (14, 15) par l'intermédiaire de laquelle les contours des parties peuvent être balayés et représentés par des représentations électriques (numériques) (23), et une unité informatique (19, 25) ayant un écran d'ordinateur, laquelle unité informatique peut recevoir les représentations électriques (23) et mémorise dans des fichiers des données/informations correspondant aux représentations électriques (23), et laquelle unité informatique peut traiter entre autres lesdites données/informations par l'intermédiaire d'un programme informatique, par exemple un programme CAO, en coopération avec un opérateur lors de la conception d'une construction (20) sur l'écran, de sorte que des informations de traitement (26) représentant ladite construction peuvent être transmises à un équipement (29, 33) pour la fabrication du produit, caractérisé en ce que le dispositif comporte également un dispositif de mise à niveau qui fonctionne séparément de l'unité de balayage, en ce que le dispositif de mise à niveau a une plate-forme de support (1) adaptée pour recevoir le modèle (2) et permettre des déplacements latéraux (4, 5) du modèle afin de rendre possible le positionnement de chacune des parties/préparations respectives (8, 9 ou 10) à des positions de lecture au niveau du dispositif de mise à niveau/plate-forme de support, en ce que la plate-forme de support (1) est également adaptée pour pouvoir s'incliner autour de deux axes (X, Z), s'étendant à travers la plate-forme et perpendiculaires l'un par rapport à l'autre afin de pouvoir ajuster l'inclinaison d'une partie/préparation respective (8, 9 ou 10) dans ladite position de lecture à l'aide des inclinaisons de la plate-forme de support autour desdits axes (X, Z), en ce qu'un équipement de traçage (11) détecte des positions de déplacement latéral respectives du modèle et des positions d'inclinaison de la plate-forme de support pour chaque partie/préparation (8, 9, 10) et obtient individuellement des informations (23') concernant ces positions dernièrement mentionnées dans l'unité informatique et une autre plate-forme (14) incluse dans ladite unité de balayage, sur laquelle autre plate-forme (14) peuvent être placées individuellement des parties/préparations à une position de balayage associée à la position qu'elles avaient sur la plate-forme de support du dispositif de mise à niveau lorsqu'elles sont détectées par ledit équipement de traçage (11), et en ce que les informations (23') obtenues par l'équipement de traçage (11) sont adaptées pour être utilisées en même temps que lesdites données/informations par l'unité informatique (19, 25) afin de déterminer les positions mutuelles correctes des parties/préparations de la construction.

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Fig.1

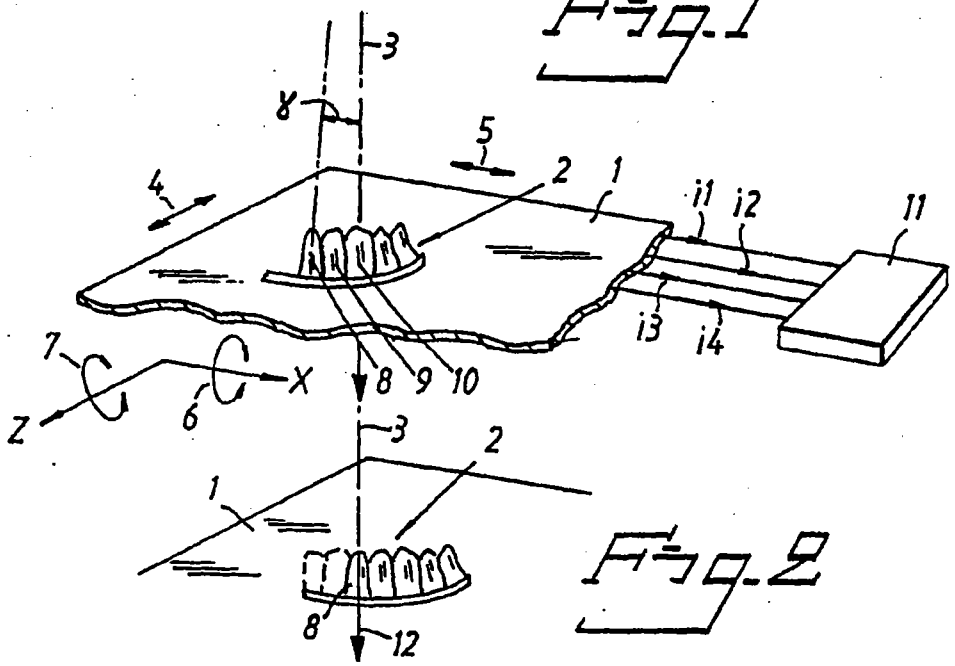


Fig.2

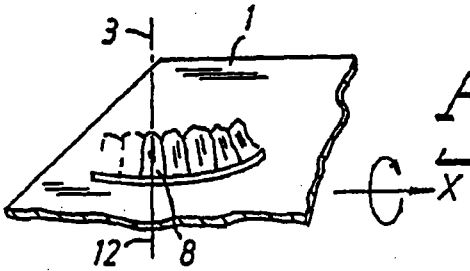


Fig.3

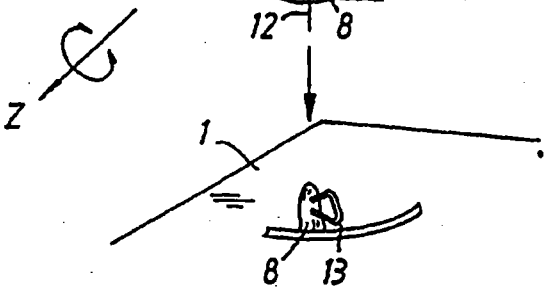


Fig.4

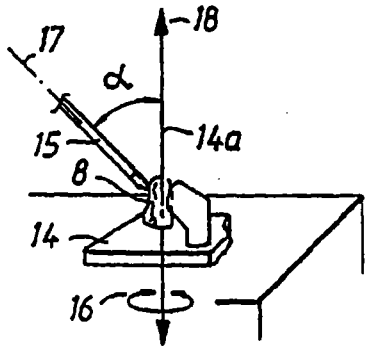


Fig.5

Fig. 6

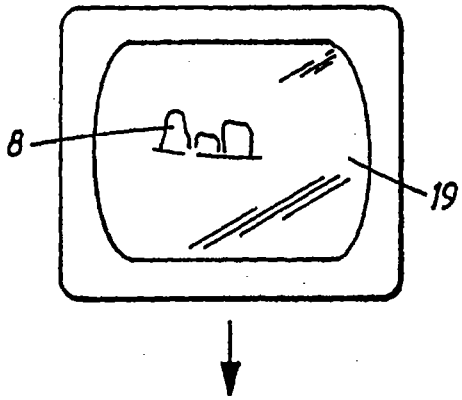


Fig. 7

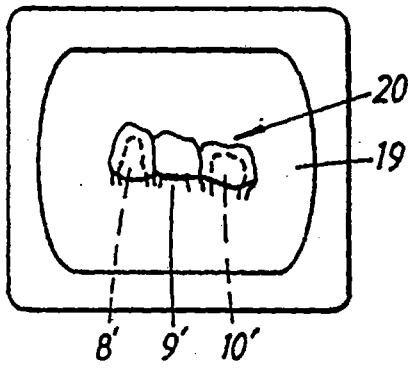
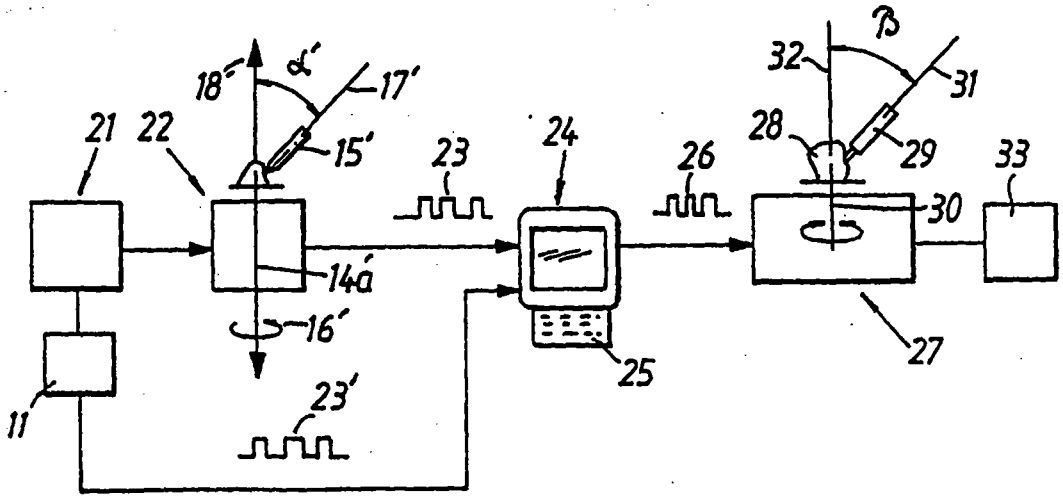


Fig. 8



Espacenet

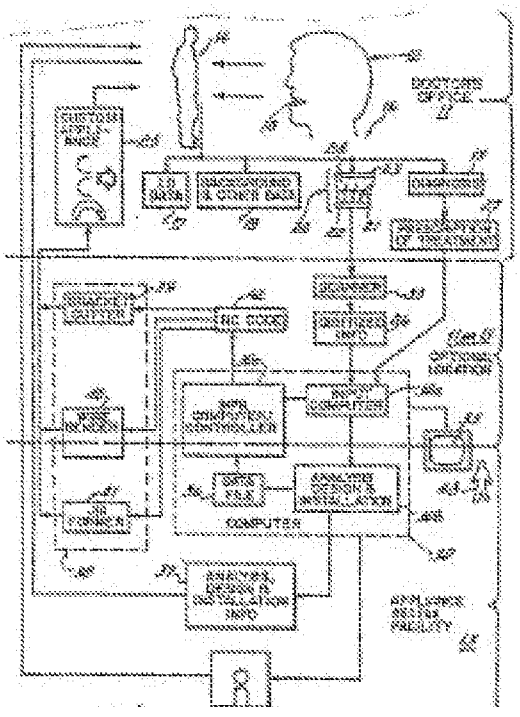
Bibliographic data: AU5598894 (A) — 1994-06-08

Custom orthodontic appliance forming method and apparatus

Inventor(s):	ANDREIKO CRAIG A; PAYNE MARK A ±	
Applicant(s):	ORMCO CORP ±	
Classification:	**- international:**	***A61C7/00; A61C7/14; A61C7/20; A61C7/28; A61C13/00; A61C13/097; A61C9/00;*** (IPC1-7): A61C13/00; A61C7/00
	- European:	A61C7/00; A61C7/14P; A61C7/20
Application number:	AU19940055988D 19931109	
Priority number (s):	WO1993US10858 19931109; US19920973844 19921109; US19920973947 19921109; US19920973965 19921109; US19920973973 19921109	
Also published as:	WO9410935 (A1) US5683243 (A) JPH08508174 (A) EP0667753 (A1) EP0667753 (B1) more	

Abstract not available for AU5598894 (A)
Abstract of corresponding document: WO9410935 (A1)

A system (10) and method by which an orthodontic appliance (25) is automatically designed and manufactured from digital lower jaw and tooth shape data (26) of a patient (14) provides for scanning, preferably from a model (20) of the patient's mouth, to produce two or three dimensional images, and digitizing contours and selected point on the patient's teeth and jaw. From the scanned individual patient data, a computer (30) constructs archforms and calculates finish tooth positions, then designs an appliance (25), preferably including archwires and brackets, to move the teeth to the calculated positions. Lower teeth are positioned at the gums on an arch defined by the lower jaw bone and modified to best fit the tooth tips on a smooth curve. Then upper archforms are derived from the lower archform. Crown long axes of the



teeth are derived and optimally inclined in the treatment which places all lower teeth but the cuspids in a plane and fits the occluding teeth to them. Overlaps for the upper incisors and cuspid rise are calculated. Brackets each have a base and an archwire support in which an archwire slot is to be cut to a custom inclination, depth, location and curvature, in a blank clamped to an inclinable holder, using a blade of a cutting machine (39). The holder and blade are moved by commands from a computer (30c). An archwire is automatically formed by a wire bender (40) into an optimize smooth arcuate shape and optimal low profile bracket design. Arch equations preferably start with a cubic spline equation and are converted to the form of a series of circle segments for machine control instructions for a numerically forming equipment. Placement jigs, simultaneously designed and automatically made with numerically controlled machinery (41) for positioning and orienting the appliance at connection points on the teeth, each have a surface custom shaped to the contour of a tooth. The machines (38-41) for making the brackets, wires and jigs are driven by commands derived from digitized tooth and jaw shape data and from digital representations of the tooth finish positions and appliance design.

Last updated: 14.03.2012 Worldwide Database 5.7.38; 93p

Electronic Acknowledgement Receipt

EFS ID:	13400523
Application Number:	13470681
International Application Number:	
Confirmation Number:	5655
Title of Invention:	MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS
First Named Inventor/Applicant Name:	Chunhua Li
Customer Number:	107046
Filer:	Vernon A. Norviel/Steven Dieu (MIRO)
Filer Authorized By:	Vernon A. Norviel
Attorney Docket Number:	22773-826.201 (022900US)
Receipt Date:	02-AUG-2012
Filing Date:	14-MAY-2012
Time Stamp:	11:04:06
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
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Information:					
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54	Non Patent Literature	Z-BURSTONE-Interview-part-1-442-1979.pdf	483042 b3fb0b7e896507e10e805c1b3623b526b7c6d1a5	no	7
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If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

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New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Requested document: DE2749802 click here to view the pdf document

Orthodontic treating device and method of manufacturing same

Patent Number:	US4504225
Publication date:	1985-03-12
Inventor(s):	YOSHII OSAMU [JP]
Applicant(s):	YOSHII OSAMU [JP]
Requested Patent:	DE2749802
Application Number:	US19830531558 19830913
Priority Number (s):	JP19760132323 19761105
IPC Classification:	A61C7/00
EC Classification:	A61C7/08, A61K6/093
Equivalents:	AU3031677, AU517102, CA1121955, ES463897, FR2369828, GB1550777, JP53058191, US4505673

Abstract

Original models of plaster are obtained from impressions of the dentition of the upper and lower jaws of a patient with malocclusion. The teeth are then separated from the base of the models and reset in wax to a normal occlusion. The realigned teeth are fixed in place with wax, and impressions of the upper and lower models are taken to duplicate the rearranged models, forming working models made of plaster. The working models are mounted on an anatomic dental articulator and a wax occluding model is constructed of the new occlusion to cover both upper and lower arches. The working upper and lower models, together with the wax occluding model are buried in plaster in a split cast. The wax occluding model in the split cast is heated and the wax is melted and discharged out of the cast. Silicone resin is then placed into the impression of the occluding model and cured.

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(51) Int. Cl. ²: A 61 C 7/00

(19) BUNDESREPUBLIK DEUTSCHLAND

DEUTSCHES PATENTAMT

DE 27 49 802 A 1

(11) Offenlegungsschrift 27 49 802

(21) Aktenzeichen: P 27 49 802.8

(22) Anmeldetag: 7. 11. 77

(43) Offenlegungstag: 11. 5. 78

(30) Unionspriorität:

(32) (33) (31) 5. 11. 76 Japan 51-132323

(54) Bezeichnung: Zahntechnische Behandlungsvorrichtung und ihr Herstellungsverfahren

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DE 27 49 802 A 1

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München, den 7. November 1977

unsere Akte: S 1718/Ro/He

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Patentansprüche

1. Verfahren zur Herstellung einer zahntechnischen Silikonharz-Behandlungsvorrichtung, dadurch gekennzeichnet, daß

a) Gipsmodelle des Ober- und Unterkiefers eines Patienten zubereitet werden, wobei sich die Zähne in einer Falschlage befinden,

b) die zentrische Beziehung zwischen den oberen und unteren Zähnen des Patienten bestimmt wird, indem ein Wachsabdruck genommen wird,

c) ein Frontbügel-Abdruck (face-bow transfer) der oberen Zähne des Patienten genommen wird, um die Beziehung des Oberkiefers zum Kopf und Gesicht festzustellen und zu reproduzieren,

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d) der Frontbügel in einem anatomischen Artikulator angeordnet wird,

e) die oberen und unteren Modelle nach Stufe a) in dem anatomischen Artikulator angeordnet werden, wobei der Frontbügel und der Wachsabdruck nach Stufe b) verwendet werden, um die Beziehung von Oberkiefer zu Unterkiefer des Patienten zu reproduzieren und die Modelle in Gips so fixiert werden, daß sie an dem Artikulator befestigt werden,

f) die Zähne von den Modellen entfernt werden und die Zähne in Wachs in normale Stellung wiederausgerichtet werden,

g) die normale Stellung der Modelle mit einem Vervielfältigungsmaterial verdoppelt wird, um negative Abdrücke zu bilden,

h) positive Gipsmodelle von den negativen Abdrücken gebildet werden,

i) der Artikulator geöffnet wird, um einen Raum von 3 bis 5 mm zwischen der oberen und unteren Schneidezahnkante zu schaffen,

j) Wachs in dem Raum angeordnet wird, um einen Abdruck der oberen und unteren Zähne in normaler Stellung zu erhalten,

k) die Zähne der unteren und oberen Gipsmodelle nach Stufe h) in den Wachsabdrücken nach Stufe j) angeordnet werden,

l) die sich ergebende Kombination nach Stufe k) mit Wachs so bedeckt wird, daß das Wachs im wesentlichen die gleiche Form und Dicke wie die Silikonharz-Behandlungsvorrichtung aufweist,

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m) die mit Wachs bedeckte Modellkombination nach Stufe 1) in einem geteilten Formstück angeordnet wird,

n) dieses das mit Wachs bedeckte Modell enthaltende Formstück einer Wärme ausgesetzt wird, die ausreichend ist, um das Wachs zu schmelzen und eine Lücke zu erzeugen,

o) das Wachs entfernt wird,

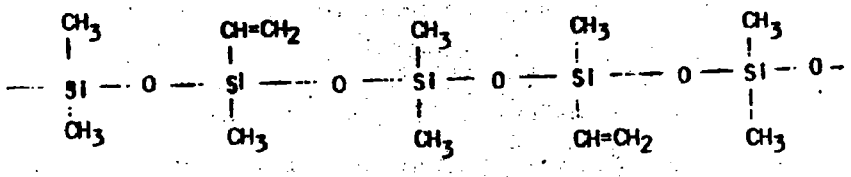
p) die Lücke mit Silikonharz gefüllt und das Harz gehärtet wird, und

q) die Silikonharz-Behandlungsvorrichtung entfernt wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das Harz bei einer Temperatur von ungefähr 100 bis 130°C gehärtet wird.

3. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das Silikonharz eine Zusammensetzung ist, welche

a) ein Silikonharz mit folgender Formel

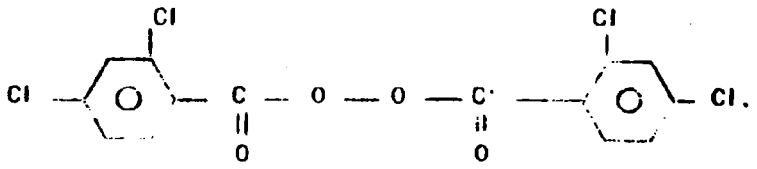


und

b) eine Katalysatorzusammensetzung enthält, die

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1) eine Zusammensetzung mit der Formel



und

2) ein Silikonöl enthält.

4. Verfahren zum Herstellen einer zahntechnischen Silikonharz-Behandlungsvorrichtung, dadurch gekennzeichnet, daß

a) Gipsmodelle von dem Ober- und Unterkiefer eines Patienten einschließlich der Zähne in Fehlausrichtung zubereitet werden,

b) die zentrische Beziehung zwischen den oberen und unteren Zähnen des Patienten durch Abnehmen eines Wachsabdruckes bestimmt wird,

c) ein Frontbügelabdruck von den oberen Zähnen des Patienten genommen wird, um die Beziehung des Oberkiefers zum Kopf und Gesicht festzustellen und zu reproduzieren,

d) der Frontbügel in einem anatomischen Artikulator angeordnet wird,

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e) die oberen und unteren Modelle nach Stufe a) in dem anatomischen Artikulator angeordnet werden, wobei der Frontbügel und Wachsabdruck nach Stufe b) verwendet werden, um die Beziehung von Ober- und Unterkiefer des Patienten zu reproduzieren und die Modelle in Gips so fixiert werden, daß sie an dem Artikulator befestigt werden,

f) die Zähne von den Modellen entfernt werden, und die Zähne in Wachs in normaler Lage wiederausgerichtet werden,

g) die normale Lage der Modelle mit einem Vervielfältigungsmaterial verdoppelt wird, um negative Abdrücke zu bilden,

h) von den negativen Abdrücken positive Gipsmodelle gebildet werden,

i) die Wachsmodelle aus dem Artikulator entfernt werden und sie durch die Gipsmodelle nach Stufe h) ersetzt werden, wobei die gleiche Beziehung von Ober- zu Unterkiefer beibehalten wird,

j) der Artikulator geöffnet wird, um einen Raum von 3-5 mm zwischen der oberen und unteren Schneidezahnkante zu bilden,

k) wärmehärtbares Silikonharz um die oberen und unteren Zähne herum gebildet und das Harz gehärtet wird, und

l) die sich ergebende Behandlungsvorrichtung entfernt wird.

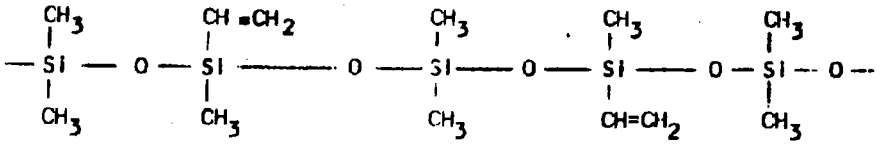
5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß das Harz bei einer Temperatur von ungefähr 100 bis 130°C gehärtet wird.

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6. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß das Silikonharz eine Zusammensetzung ist, welche

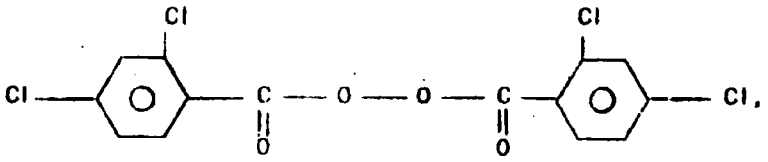
a) ein Silikonharz mit der folgenden Formel



und

b) eine Katalysatorzusammensetzung enthält, welche

1) eine Verbindung mit der Formel



und

2) ein Silikonöl enthält.

~~7. Verfahren zum vollständigen Behandeln einer Fehlausrich-~~ tung bzw. falschen Stellung von Zähnen eines Patienten mit einer zahntechnischen Silikonharz-Behandlungsvorrichtung, welche negative Abdrücke aufweist, die die Zähne verdoppelt und sie in die gewünschte Stellung bewegt, dadurch gekennzeichnet, daß

a) der Mund des Patienten geöffnet wird, um den Oberkiefer, den Unterkiefer und die Zähne freizulegen,

b) die Vorrichtung durch Fingerdruck über die oberen Zähne ~~gedrückt wird,~~ 809819/0957

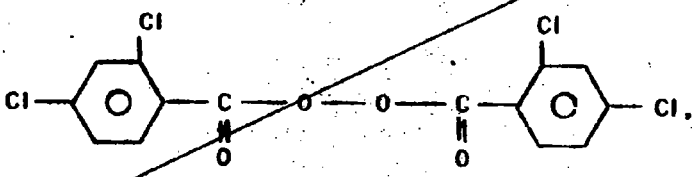
ClearCorrect Exhibit 1010, Page 523 of 1447

nachträglich geändert

-8- 7

~~b) eine Katalysatorzusammensetzung enthält, welche~~

1) eine Verbindung mit der Formel



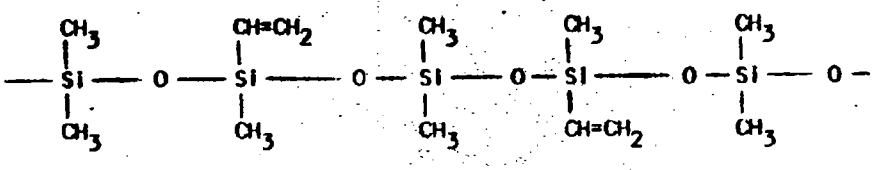
und

~~2) ein Silikonöl enthält.~~

7
~~9.~~ Zahntechnische Silikonharz-Behandlungsvorrichtung zum vollständigen Behandeln der Zähne eines Patienten, dadurch gekennzeichnet, daß sie obere und untere negative Eindrücke aufweist, welche die oberen und unteren Zähne des Patienten verdoppeln, und die Zähne während der Behandlung in die gewünschte Lage bewegen.

8 7
~~10~~. Vorrichtung nach Anspruch ~~9~~, dadurch gekennzeichnet, daß das Silikonharz eine Zusammensetzung ist, welche

a) ein Silikonharz mit der Formel

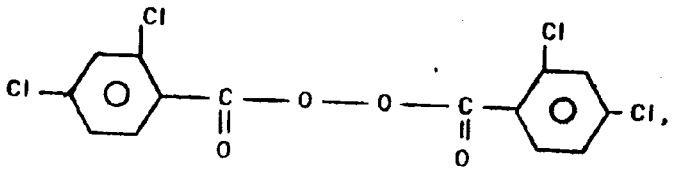


und

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b) eine Katalysatorzusammensetzung enthält, welche

1) eine Verbindung mit der Formel



und

2) ein Silikonöl enthält.

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"Zahntechnische Behandlungsvorrichtung und ihr Herstellungsverfahren"

Eine herkömmliche zahntechnische Behandlung wird mit Metallbändern ausgeführt, die mit einer Befestigung versehen sind, welche den Zähnen angepaßt werden kann und an den Zähnen mit Zement befestigt wird, und es ist ein Metalldraht vorgesehen, der sich dadurch erstreckt, um die Zähne zu bewegen. In diesem Fall verwendet die Korrigierkraft (Spannung, um die Zähne zu bewegen) primär die Federkräfte des Metalldrahtes selbst; sie wird im allgemeinen weitgehend als zahntechnische Behandlungsvorrichtung verwendet.

Jedoch wurde bei der zahntechnischen Behandlung, wobei diese Mehrfachschienen-Technik mit dem Abbiegen des Metalldrahtes in komplizierte Formen verwendet wird, gefunden, daß beträchtliche Energiemengen und Fachkönnen sowie lange Aus-

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bildungszeiten erforderlich sind. Auch verursacht eine solche Behandlung nicht nur ein Unbehagen für den Patienten, sondern ebenfalls andere Probleme wie beispielsweise schlechte oder entkalkte Zähne oder Zahnkrankheiten, die sich aus Nahrungsmittelpartikeln ergeben, die während der zahntechnischen Behandlung an den Zähnen anhaften, wobei weiterhin die Kosten enorm ansteigen.

Die vorliegende Erfindung schafft eine zahntechnische Behandlungsvorrichtung, mit welcher eine falsche Einlagerung bzw. falsche Stellung, Ausrichtung bzw. Lage der Zähne behandelt werden kann, wobei einfach die elastische Kraft von Silikonharzen als funktionelle Kraft anstatt des bisher verwendeten Metalldrahtes verwendet wird, und da sie leicht lösbar ist, gibt es kein Unbehagen für die Patienten, so daß eine zahntechnische Behandlung durchgeführt werden kann, wenn die Vorrichtung zur Bettzeit und anderen geeigneten Stunden verwendet wird, wie dies erforderlich ist.

Zunächst ist es notwendig, ein elastisches hochmolekulares Material auszuwählen, welches ausreichend den besonderen Bedingungen einer intra-oralen Behandlung genügt. Es wurde gefunden, daß Silikonharze ein elastisches Material darstellen, das für eine zahntechnische Behandlung geeignet ist und die besten Ergebnisse aus dem Gesichtspunkt der Wissenschaft, Technik und klinischer Untersuchung mit sich bringt. Das Ma-

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terial weist eine wissenschaftliche und technische Qualität auf, sodaß es seine Elastizität nicht verschlechtert, während es sich im Mund befindet, weist eine ausreichende Bruchfestigkeit auf und verformt sich während langer Zeitperioden auf Grund von Kräften während der Behandlung nicht. Wegen dieser wesentlichen Eigenschaften kann die erfindungsgemäße Behandlungsvorrichtung verwendet werden, um Patienten von dem anfänglichen Stadium bis zur Beendigung der Behandlung zu behandeln.

Weiterhin kann durch Ändern des Härter-Anteiles der Silikonharze und Katalysatoren und deren Vermischung die Härte des geformten Silikonharzes frei geändert werden. Es können Kräfte von einer leichten Kraft bis zu einer großen Kraft geschaffen werden, was aus dem klinischen Gesichtspunkt vorteilhaft ist. Die Vorrichtung hält einen rohen Durchlässigkeitsgrad aufrecht, ohne einen Geschmack oder einen Geruch zu haben und wird aus einer Zusammensetzung zubereitet, welche dem menschlichen Körper keinen Schaden zufügt. Diese Eigenschaften können nicht in anderen Kautschukmaterialien gefunden werden.

Zusätzlich zu dem Silikonharz haben Polyurethanharze in etwa ähnliche Eigenschaften, wie sie oben erwähnt sind, aber Silikonharze schaffen zusätzliche Vorteile wie beispielsweise

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kürzere Härtezeiten im Vergleich mit dem Polyurethanharz, und das Herstellungsverfahren kann einfach durchgeführt werden, sodaß zwischen diesen beiden Harzen ein bemerkenswerter Unterschied besteht. Wo Polyurethanharze verwendet werden, um ähnliche Vorrichtungen zuzubereiten, brechen derartige Harze in dem Mund des Patienten und sind nicht transparent. Demzufolge werden derartige Vorrichtungen lediglich während der letzten Behandlungsstufe verwendet, und sie können nicht von Anfang an eingesetzt werden.

Demzufolge wurde gefunden, daß die erfindungsgemässe Vorrichtung, welche zum ersten Mal aus Silikonharzen hergestellt ist, eine Einrichtung zum Behandeln eines Patienten vom Anfang bis zum Ende schafft. Bislang war dies lediglich möglich mit den bekannten Verfahren, wobei Metallbänder verwendet wurden.

Die vorliegende Erfindung schafft eine zahntechnische Behandlungsvorrichtung und ein Verfahren zur Herstellung, wobei die Eigenschaften des Silikonharzes verwendet werden, wie dies oben erwähnt ist.

Die Erfindung wird nachfolgend an Ausführungsbeispielen anhand der beigefügten Zeichnung näher erläutert.

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In der Zeichnung zeigen:

Fig. 1 eine Ansicht eines ursprünglichen Modelles mit einer falschen Lage bzw. Ausrichtung,

Fig. 2 eine Seitenansicht der von dem Modell nach Fig. 1 getrennten Zähne,

Fig. 3 ein Modell, das durch Wiederanordnen in Wachs der Zähne aus dem ursprünglichen Modell in einer normalen Anordnung bzw. Ausrichtung erhalten wurde,

Fig. 4 die gesamte zahnmedizinische Behandlungsvorrichtung,

Fig. 5 eine Vorderansicht der zahntechnischen Behandlungsvorrichtung,

Fig. 6 eine Schnittansicht längs der Linie VI-VI in Fig. 5,

Fig. 7 eine Schnittansicht längs der Linie VII-VII in Fig. 4,

Fig. 8 einen Vergleich, wobei Fig. 8A die Anordnung vor der zahntechnischen Behandlung und Fig. 8B dieselbe nach der medizinischen Behandlung zeigt,

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Fig. 9 die erste Ausführungsform gemäss Erfindung, wobei Fig. 9A eine Endansicht zeigt, wobei ein geteiltes Formstück getrennt ist und Fig. 9B eine Schnittansicht zeigt, in welcher Silikonharz in das Formstück eingefüllt ist und Fig. 9C die Anordnung zeigt, in welcher die getrennten Teile des Formstückes miteinander verbunden sind,

Fig. 10 eine zweite Ausführungsform gemäss Erfindung, wobei Fig. 10A eine obere Ansicht eines anatomischen Artikulators und Fig. 10B eine Seitenansicht zeigt, wobei das Wachsplattenmaterial, das notwendig ist, um die oberen und unteren Gipsmodelle zu fixieren, geschmolzen und abgelassen ist, Fig. 10C eine Seitenansicht zeigt, wobei das Silikonharz unter Druck mit der Oberfläche des Arbeitsmodelles in Kontakt gebracht ist, um die zahntechnische Behandlungsvorrichtung zu erzeugen, Fig. 10D eine Schnittansicht längs der Linie X-X in 10A zeigt.

Die Erfindung betrifft ein erstes Verfahren zur Herstellung einer zahntechnischen Silikonharzbehandlungsvorrichtung, indem a) Gipsmodelle des Ober- und Unterkiefers eines Patienten zubereitet werden, wobei die Zähne in einer Fehlstellung sind, b) die zentrische Beziehung zwischen den oberen und unteren Zähnen des Patienten bestimmt wird, indem ein Wachsabdruck genommen wird, c) ein Frontbügelabdruck (face-bow transfer)

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der oberen Zähne des Patienten genommen wird, um der Beziehung des Oberkiefers zu dem Kopf und dem Gesicht festzustellen, d) der Frontbügel in einem anatomischen Artikulator angeordnet wird, e) die oberen und unteren Modelle aus Stufe a) in dem Artikulator angeordnet werden, wobei der Frontbügel und der Wachsgipsabdruck nach Stufe b) verwendet werden, um die Beziehung des Ober- und Unterkiefers des Patienten zu reproduzieren und die Modelle in Gips so zu fixieren, daß die Modelle an dem Artikulator befestigt sind, f) die Zähne von den Modellen entfernt werden und die Zähne in Wachs in normaler Ausrichtung bzw. Anordnung wieder ausgerichtet werden, g) die normale Lage der Modelle mit einem Vervielfältigungsmaterial verdoppelt bzw. nachgeahmt wird, um negative Abdrücke zu bilden, h) positive Gipsmodelle von den negativen Abdrücken gebildet werden, i) der Artikulator geöffnet wird, um einen Raum von 3-5 mm zwischen der oberen und unteren Schneidezahnkante zu bilden, j) Wachs in dem Raum angeordnet wird, um einen Abdruck der oberen und unteren Zähne in normaler Stellung zu erhalten, k) die Zähne der unteren und oberen Gipsmodelle nach Stufe h) in den Wachsabdrücken nach Stufe j) angeordnet werden, l) die sich ergebende Kombination aus Stufe k) mit Wachs bedeckt wird, sodaß das Wachs im wesentlichen die gleiche Form und Dicke wie die Silikonharzbehandlungsvorrichtung aufweist, m) die mit Wachs bedeckte Modellkombination nach Stufe l) in einem geteilten Formstück (split-cast) angeordnet wird, n) dieses das mit Wachs bedeckte Modell enthaltende Formstück einer Wärme ausgesetzt wird, die ausreicht, um das Wachs zu schmelzen und

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eine Lücke zu erzeugen, o) das Wachs entfernt wird, p) die Lücke mit Silikonharz gefüllt wird und das Harz gehärtet wird und q) die Silikonharzbehandlungsvorrichtung entfernt wird.

Die Erfindung betrifft ebenfalls ein zweites Verfahren zum Erzeugen der zahntechnischen Silikonharzbehandlungsvorrichtung, indem im wesentlichen die Stufen a) bis h), wie sie oben erwähnt sind, wiederholt werden und zusätzlich folgende Stufen vorgesehen werden: i) die Wachsmodelle werden aus dem Artikulator entfernt und mit den Gipsmodellen nach Stufe h) ersetzt, während die gleiche Beziehung des Ober- und Unterkiefers aufrechterhalten wird, j) der Artikulator wird geöffnet, um einen Raum von 3-5mm zwischen der oberen und unteren Schneidezahnkante zu schaffen, k) ein wärmehärtbares Silikonharz wird um die oberen und unteren Zähne angeordnet, und das Harz wird gehärtet und l) die sich ergebende Behandlungsvorrichtung wird entfernt.

Obwohl jedes der obenerwähnten Verfahren verwendet werden kann, um die erfindungsgemässe zahntechnische Behandlungsvorrichtung zu schaffen, ist das erste Verfahren bevorzugt, da es die Einrichtung zum Anwenden eines adäquaten Druckes schafft, um das Silikonharz in jede Ritze zu zwingen, welche die Zähne umgibt, und die sich ergebende Behandlungsvorrichtung schafft eine genaue Vervielfältigung bzw. Nachahmung der Zähne des Patienten in normaler Stellung.

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Die vorliegende Erfindung wird in einem Verfahren ausgeführt, bei dem folgende Stufen verwendet werden:

a) Zubereiten von Gipsmodellen des Ober- und Unterkiefers des Patienten einschließlich der Zähne, welche sich in falscher Ausrichtung bzw. schlechter Lage befinden.

Ein Abdruck wird von den oberen und unteren Zähnen des Patienten und von dem umgebenden Gewebe genommen, indem ein Vervielfältigungsmaterial verwendet wird, um einen negativen Abdruck zu erhalten. Das Vervielfältigungsmaterial wird von den Zähnen entfernt, und in dem Material wird eine Lücke ausgebildet. Gips wird in die Lücke des negativen Abdruckes gegossen, um eine positive Gipsform der oberen und unteren Zähne des Patienten zu erhalten.

b) Bestimmung der zentrischen Beziehung zwischen den oberen und unteren Zähnen des Patienten durch Nehmen eines Wachsabdruckes.

Wachs wird zwischen den oberen und unteren Zähnen des Patienten angeordnet, um einen Eindruck des Bisses zu erhalten, um die zentrische Lage der oberen und unteren Zähne zu bestimmen. Dieser Wachsabdruck wird später in dem Verfahren verwendet, um zweckmässig die oberen und unteren Gipsmodelle auszurichten, die in Stufe a) zubereitet sind.

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c) Nehmen eines Frontbügel-Abdruckes (face-bow transfer) der oberen Zähne des Patienten, um die Beziehung des Oberkiefers zu dem Kopf und dem Gesicht herzustellen und zu reproduzieren.

Ein Frontbügel wird verwendet, um einen Wachsabdruck von den oberen Zähnen des Patienten zu nehmen, um die Beziehung des Oberkiefers zu Kopf und Gesicht zu reproduzieren. Diese Stufe ist kritisch für das erfindungsgemässe Verfahren, da sie die einzige Einrichtung zum genauen Reproduzieren der letztlichen Beziehung beziehungsweise Lage des Ober- und Unterkiefers des Patienten schafft, und dieses Verfahren dient als Basis zum zweckmässigen Ausrichten der Gipsmodelle, aus denen die zahntechnische Behandlungsvorrichtung zuzubereiten ist. Die Vorrichtung muss dasselbe Verhältnis von Ober- und Unterkiefer wie der Patient haben, sodaß, wenn die Vorrichtung verwendet wird, die Zähne zweckmässig in die Vorrichtung passen, um zu verursachen, daß sich die Zähne zu der normalen Lage hin bewegen.

d) Anordnen des Frontbügels in einem anatomischen Artikulator.

Der Frontbügel mit dem Wachsabdruck der oberen Zähne des Patienten wird an einem anatomischen Artikulator befestigt, um die oberen und unteren Gipsmodelle zweckmässig auszurichten.

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e) Anordnen der oberen und unteren Gipsmodelle aus Stufe a) in dem anatomischen Artikulator, wobei der Frontbügel und der Wachsabdruck nach Stufe b) verwendet werden, um die Beziehung des Ober- und Unterkiefers des Patienten zu reproduzieren und die Modelle in Gips zu fixieren, sodaß die Modelle an dem Artikulator befestigt sind.

Das Verfahren wird durchgeführt, indem die Zähne des oberen Gipsmodelles, zubereitet in Stufe a) in dem Wachsabdruck des Frontbügels angeordnet werden, der an dem anatomischen Artikulator befestigt ist. Gips wird auf die Oberseite des oberen Modelles angeordnet und gegen die Oberseite des Artikulators gedrückt, wobei ein Trocknen erlaubt wird, um so zu verursachen, daß das obere Modell an der Oberseite des Artikulators befestigt ist. Wenn der Gips einmal trocken geworden ist, wird der Frontbügel von dem Artikulator entfernt. Das obere Modell ist nunmehr in dem Artikulator in der gleichen Beziehung wie die natürliche Lage der oberen Zähne und des Kiefers des Patienten angeordnet.

Der Wachsbißabdruck, wie er in Stufe b) zubereitet ist, wird über die Zähne des oberen Modelles angeordnet und geklebt oder befestigt. Das untere Gipsmodell aus Stufe a) wird in den unteren Abschnitt des Wachsabdruckes eingesetzt, der an dem oberen Modell befestigt ist. Gips wird über die Oberfläche des unteren Modelles gegossen, und der Artikulator wird geschlossen, und der Gips kann trocknen, sodaß das untere Modell an dem Artikulator befestigt wird.

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Bis zu diesem Punkt des erfindungsgemässen Verfahrens sind die oberen und unteren Gipsmodelle an dem Artikulator in einer solchen Weise befestigt, daß eine genaue Reproduktion der Beziehung des Kiefers und der Zähne des Patienten hergestellt worden ist.

f) Entfernung der Zähne aus den Modellen und Wiederausrichten der Zähne in Wachs in normaler Stellung.

Die Gipszähne werden einzeln von den Gipsmodellen mit Hilfe einer dünnen Blattsäge entfernt. Dann wird ein Wachsmaterial auf dem Boden der Gipsmodelle angeordnet, von welchen die einzelnen Zähne entfernt worden sind, und die Zähne werden in dem Wachs und in normaler Stellung angeordnet. In diesem Augenblick sind die Zähne des oberen und unteren Modelles in einer solchen Weise angeordnet, daß die zahntechnische Silikonharz-Behandlungsvorrichtung, welche mit dem erfindungsgemässen Verfahren herzustellen ist, die Zähne in die Lage bewegen wird, die von den Wachsmodellen gebildet ist.

g) Vervielfältigen der normalen Lage bzw. Besetzung der Modelle mit einem Vervielfältigungsmaterial, um negative Abdrücke herzustellen.

Ein Vervielfältigungsmaterial wird um die Wachsmodelle angeordnet, um negative Abdrücke in normaler Lage zu bilden. Das Material wird von den Modellen entfernt, und die Abdrücke zeigen Lücken der Zähne in normaler Stellung.

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h) Bilden positiver Gipsmodelle von dem negativen Abdruck.

Gips wird in die Lücken des negativen Abdruckes gegossen, um positive Gipsmodelle zuzubereiten, welche die Lage der Zähne des Patienten nach Behandlung mit der erfindungsgemässen zahntechnischen Behandlungsvorrichtung zeigen.

i) Öffnen des Artikulators, um einen Raum von 3-5mm zwischen der oberen und unteren Schneidezahnkante zu schaffen.

Der Artikulator wird so geöffnet, daß ein Raum von 3-5mm, vorzugsweise 4 mm zwischen der oberen und unteren Schneidezahnkante geschaffen wird. Dieser Raum ist notwendig, um zweckmässig die zahntechnische Behandlungsvorrichtung zu bilden, indem das Silikonharz den Raum zwischen den Zähnen füllen wird, und wenn der Patient abwärts auf das Harz während der zahntechnischen Behandlung beisst, unterstützen die Beißkraft und die Nachgiebigkeit des Harzes das Bewegen der Zähne.

j) Anordnen von Wachs in dem Raum, um einen Abdruck der oberen und unteren Zähne in normaler Stellung zu erhalten.

Diese Stufe ist notwendig, um die geeignete Beziehung zwischen den oberen und unteren Zähnen zu erzielen. Dieser Eindruck wird später verwendet, um die Wachsmodelle mit den Gipsmodellen nach Stufe h) in dem Artikulator zu ersetzen.

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k) Anordnen der Zähne der oberen und unteren Gipsmodelle nach Stufe h) in den Wachsabdrücken nach Stufe j).

Die Gipsmodelle in normaler Lage, wie sie in Stufe h) zubereitet sind, werden in dem Wachsabdruck angeordnet, wie er in Stufe j) erhalten ist. Der Wachsabdruck wird verwendet, um zweckmässig die oberen und unteren Gipsmodelle auszurichten. Diese Kombination oder Anordnung wird separat und außerhalb des Artikulators ausgeführt.

l) Bedecken der sich ergebenden Kombination aus Stufe k) mit Wachs, sodaß das Wachs im wesentlichen die gleiche Form und Dicke wie die Silikonharzbehandlungsvorrichtung aufweist.

Wachs wird über die gesamten Oberflächenbereiche der Zähne und den das Gewebe der oberen und unteren Modelle darstellenden Abschnitt angeordnet, der das Wachsmaterial einschließt, das zwischen den Zähnen in Stufe k) angeordnet ist. Das Wachsmaterial sollte im wesentlichen die gleiche Form und Dicke wie die Silikonharzbehandlungsvorrichtung aufweisen, die während des Verfahrens zuzubereiten ist, wie dies nachfolgend erläutert wird.

m) Anordnen der mit Wachs bedeckten Modellkombination nach Stufe l) in einem geteilten Formkasten (split-cast).

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Die Kombination nach Stufe l) wird in der unteren Hälfte eines Formkastens angeordnet, und Gips wird in die Form gegossen, um die gesamte untere Hälfte des Kombinationsmodelles zu bedecken. Der Gips kann trocknen und härten, und ein Trennmittel wird über der gehärteten Gipsschicht angebracht.

Der Formkasten wird gewendet, und Gips wird in die Form gegossen, welche so geschlossen wird, daß der freigelegte obere Abschnitt der Kombination vollständig in dem weichen Gips eingebettet ist. Es sollte ausreichend Gips verwendet werden, sodaß der Gips die gesamte Oberfläche des Kombinationsmodelles bedeckt, was durch überschüssigen Gips nachgewiesen wird, der aus der Form fließt. Die Form wird dann verschlossen, und der Gips kann trocknen.

n) Aussetzen der das mit Wachs bedeckte Modell enthaltenden Form einer Wärme, die ausreichend ist, um das Wachs zu schmelzen und eine Lücke zu schaffen.

Die gesamte Form, welche das Modell aus der Stufe m) enthält, wird erwärmt, indem sie beispielsweise in kochendem Wasser während einer Zeit angeordnet wird, die ausreichend ist, um das Wachs zu schmelzen.

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o) Entfernen des Wachses.

Die Form wird geöffnet, und das geschmolzene Wachs wird entfernt, wobei eine Lücke um die Zähne und Gewebe des Gipsmodelles einschließlich des Raumes zwischen den oberen und unteren Zähnen gelassen wird.

p) Füllen der Lücke mit einem wärmehärtbaren Silikonharz und Härten des Harzes.

Ein weiches Silikonharzmaterial wird in der Lücke in Mengen vorgesehen, die ausreichend sind, um vollständig die Lücke zu füllen. Die Form wird fest verschlossen, sodaß das Harzmaterial jeden Raum und jede Ritze vollständig füllt, und überschüssiges Material fließt aus der Lücke. Die Form wird dann einer Hitze wie beispielsweise siedendem Wasser während einer Zeitperiode von ungefähr 4o Minuten ausgesetzt, um das Silikonharzmaterial zu härten.

q) Entfernen der Silikonharzbehandlungsvorrichtung.

Die Form wird entfernt, gekühlt, geöffnet, und die sich ergebende zahntechnische Silikonharzbehandlungsvorrichtung wird entfernt.

Als abschließende Stufe kann die sich ergebende Behandlungsvorrichtung mit einer Silikonharzlösung beschichtet werden,

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welche zwei unterschiedliche Silikonharze einschließlich eines Katalysators umfaßt, um eine klare, unsichtbare glatte Oberfläche zu schaffen. Die beiden Lösungen werden in einem Verhältnis von ungefähr lo:1 gemischt. Das obenbeschriebene Verfahren ist das bevorzugte Verfahren, weil die Behandlungsvorrichtung als Ergebnis gebildet wird, wobei eine Form verwendet wird, um das Silikonharz in jeden Raum und jede Ritze der Lücke in dem Gipsmodell zu drücken.

Bei einer zweiten Ausführungsform gemäss Erfindung wird ein ähnliches Verfahren verwendet mit Ausnahme, daß lediglich die Stufen a) bis h) des ersteren Verfahrens wiederholt werden. Die zweite Ausführungsform wird mit folgenden Stufen durchgeführt:

a) Zubereiten von Gipsmodellen des Ober- und Unterkiefers des Patienten einschließlich der Zähne in schlechter Stellung bzw. falscher Lage.

Ein Abdruck wird von den oberen und unteren Zähnen des Patienten und von dem umgebenden Gewebe genommen, indem ein Vervielfältigungsmaterial verwendet wird, um einen negativen Abdruck zu erhalten. Das Vervielfältigungsmaterial wird von den Zähnen entfernt, und eine Lücke wird in dem Material gebildet. Gips wird in die Lücke des negativen Abdruckes gegossen, um eine positive Gipsform von den oberen und unteren Zähnen des Patienten zu erhalten.

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b) Bestimmung der zentrischen Beziehung zwischen den oberen und unteren Zähnen des Patienten durch Nehmen eines Wachsabdruckes.

Wachs wird zwischen den oberen und unteren Zähnen des Patienten vorgesehen, um einen Eindruck des Bisses zu erhalten, um die zentrische Beziehung der oberen und unteren Zähne zu bestimmen. Dieser Wachsabdruck wird später in dem Verfahren verwendet, um die oberen und unteren Gipsformen geeignet auszurichten, welche in Stufe a) vorbereitet sind.

c) Frontbügelabdruck der oberen Zähne des Patienten, um die Beziehung des Oberkiefers zu dem Kopf und dem Gesicht herzustellen und zu reproduzieren.

Ein Frontbügel wird verwendet, um einen Wachsabdruck der oberen Zähne des Patienten zu nehmen und die Beziehung des Oberkiefers zu dem Kopf und dem Gesicht zu reproduzieren. Diese Stufe ist für das erfindungsgemässe Verfahren kritisch, da sie die einzige Einrichtung zum genauen Reproduzieren der letztlichen Beziehung des Ober- und Unterkiefers des Patienten schafft, und dieses Verfahren dient als Basis zum zweckmässigen Ausrichten der Gipsmodelle, mit denen die zahntechnische Behandlungsvorrichtung zuzubereiten ist. Die Vorrichtung muss die gleichen Verhältnisse des Ober- und Unterkiefers wie der Patient aufweisen, sodaß, wenn die Vorrichtung verwendet wird, die Zähne geeignet in die Vorrichtung passen,

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um zu verursachen, daß sich die Zähne zu normaler Lage hin bewegen.

d) Anordnen des Frontbügels in einem anatomischen Artikulator.

Der Frontbügel mit dem Wachsabdruck der oberen Zähne des Patienten wird an einem anatomischen Artikulator befestigt, um zweckmässig die oberen und unteren Gipsmodelle auszurichten.

e) Anordnen der oberen und unteren Modelle nach Stufe a) in dem anatomischen Artikulator unter Verwendung des Frontbügels und des Wachsabdruckes nach Stufe b), um die Beziehung des Ober- und Unterkiefers des Patienten zu reproduzieren und die Modelle in Gips zu fixieren, sodaß die Modelle an dem Artikulator befestigt sind.

Dieses Verfahren wird durchgeführt, indem die Zähne des oberen Gipsmodelles, zubereitet in Stufe a), in dem Wachsabdruck des Frontbügels angeordnet werden, der an dem anatomischen Artikulator befestigt ist. Gips wird auf die Oberseite des oberen Modells gegossen und gegen die Oberseite des Artikulators gedrückt, worauf er trocknen kann, um so zu verursachen, daß das obere Modell an der Oberseite des Artikulators befestigt wird. Wenn der Gips einmal getrocknet ist, wird der Frontbügel von dem Artikulator entfernt. Das obere Modell wird nun in dem Artikulator in der gleichen Beziehung wie die natürliche Lage der oberen Zähne und des Kiefers des Patienten angeordnet.

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Der Wachsbißabdruck nach Stufe b) wird über den Zähnen des oberen Modelles angeordnet und verklebt oder befestigt. Das untere Gipsmodell aus Stufe a) wird in den unteren Abschnitt des Wachsabdruckes eingesetzt, der an dem oberen Modell befestigt ist. Gips wird über die Oberfläche des unteren Modells gegossen, und der Artikulator wird geschlossen, und der Gips kann trocknen, sodaß das untere Modell an dem Artikulator befestigt wird.

Bis zu diesem Punkt des erfindungsgemässen Verfahrens sind die oberen und unteren Gipsmodelle an dem Artikulator in der Weise befestigt, daß eine exakte Reproduktion der Beziehung des Kiefers und der Zähne des Patienten festgesetzt ist.

f) Entfernen der Zähne von den Modellen und Wiederausrichten der Zähne in Wachs zu normaler Stellung.

Die Gipszähne werden einzeln von den Gipsmodellen mit Hilfe einer dünnen Blattsäge entfernt. Dann wird Wachsmaterial auf dem Boden der Gipsmodelle angeordnet, von denen die einzelnen Zähne entfernt worden sind, und die Zähne werden in Wachs und in normaler Stellung angeordnet. Zu diesem Punkt weisen die oberen und unteren Modelle die Zähne auf, die in einer solchen Weise angeordnet sind, daß die zahntechnische Silikonharzbehandlungsvorrichtung, die durch das erfindungsgemässe Verfahren herzustellen ist, die Zähne zu der Lage hin bewegen wird, die von den Wachsmodellen gebildet ist.

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g) Verdoppeln der normalen Lage der Modelle mit einem Vervielfältigungsmaterial, um negative Abdrücke zu bilden.

Ein Vervielfältigungsmaterial wird um die Wachsmodelle ausgebildet, um negative Abdrücke in normaler Lage zu bilden. Das Material wird von den Modellen entfernt, und die Abdrücke zeigen Lücken der Zähne in normaler Lage.

h) Bilden von positiven Gipsmodellen aus dem negativen Abdruck.

Gips wird in die Lücken des negativen Abdruckes gegossen, um positive Gipsmodelle zuzubereiten, welche die Lage der Zähne des Patienten nach der Behandlung mit der erfindungsgemässen zahntechnischen Behandlungsvorrichtung zeigen.

i) Entfernen der Wachsmodelle von dem Artikulator und Ersetzen durch Gipsmodelle nach Stufe h), während die Beziehung des Ober- und Unterkiefers aufrechterhalten wird.

Die verdoppelten Gipsmodelle, wie sie in Stufe h) zubereitet sind, werden an dem Artikulator in Übereinstimmung mit den folgenden Stufen angeordnet:

1) Das obere Wachsmodell wird von dem Artikulator entfernt, und das obere Gipsmodell wird auf dem unteren Wachsmodell vorgesehen, sodaß das Gipsmodell genau die gleiche Beziehung zu dem unteren Wachsmodell wie das obere Wachsmodell aufrecht erhält, das entfernt

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worden ist. Zu diesem Punkt ist das obere Modell aus Gips hergestellt, und das untere Modell weist die Zähne auf, die in Wachs angeordnet sind.

2) Gips wird auf die Oberseite des oberen Gipsmodelles gegossen und der Artikulator so geschlossen, daß, wenn der Gips trocknet,das obere Gipsmodell an dem Artikulator befestigt ist.

3) Das untere Wachsmodell wird von dem Artikulator entfernt und mit dem unteren Gipsmodell nach Stufe h) ersetzt, indem das untere Gipsmodell in Ausrichtung mit dem oberen Modell angeordnet wird, das nun in der beschriebenen Weise an dem Artikulator befestigt ist. Gips wird dann über die Oberfläche des unteren Gipsmodelles gegossen, der Artikulator geschlossen, und mit Trocknen des Gipses wird das untere Modell an dem Artikulator befestigt.

j) Öffnen des Artikulators, um einen Raum von ungefähr 3-5 mm zwischen der oberen und unteren Schneidezahnkante zu bilden.

Wiederum ist dieser Raum notwendig, um zweckmässig die Silikonharzbehandlungsvorrichtung zu formen, wie dies oben in Stufe i) des ersten Verfahrens diskutiert ist.

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k) Ausbilden von wärmehärtbarem Silikonharz um die oberen und unteren Zähne herum und Härten des Harzes.

Weiches Silikonharz wird von Hand über die gesamten Oberflächenbereiche der Zähne gedrückt, um den Raum zu füllen, der in der vorhergehenden Stufe geschaffen ist. Das Harz wird zu der abschließenden Form der Behandlungsvorrichtung geformt, indem überschüssiges Material beseitigt wird. Die Gesamtanordnung wird dann Wärme ausgesetzt wie beispielsweise in siedendem Wasser während ungefähr 4o Minuten angeordnet, um das Harz zu härten. Es sei verstanden, daß in jedem Verfahren der Erfindung das Harz gehärtet werden kann, indem auf eine Temperatur von 100 bis 130°C mit Hilfe von beispielsweise siedendem Wasser oder heißer Luft erhitzt wird.

l) Entfernen der sich ergebenden Behandlungsvorrichtung.

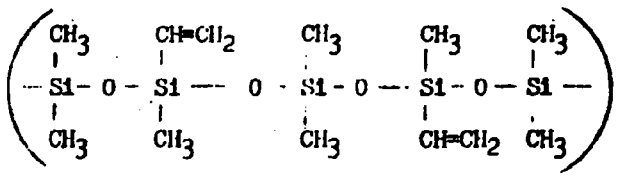
Nach Härten des Harzes wird die gesamte Anordnung des Gipsmodelles mit dem Silikonharzmaterial abgekühlt, der Artikulator geöffnet und die sich ergebende Behandlungsvorrichtung von dem Gipsabdruck entfernt.

Die Vorrichtung kann dann mit der Zweikomponenten-Silikonharzlösung beschichtet werden, wie dies oben beschrieben ist, um ein abschließendes Produkt mit einer glatten Oberfläche zu schaffen.

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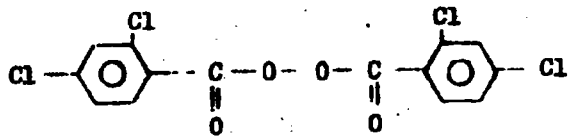
Es können verschiedene Arten von Silikonharzmaterialien gemäss Erfindung verwendet werden, vorausgesetzt, daß sie die geeigneten physikalischen Eigenschaften haben, um die Zähne eines Patienten aus der Fehlausrichtung in normale Lage zu bewegen. Die bei der Erfindung verwendeten Silikonharzmaterialien umfassen Harze, die leicht härtbar sind, indem sie Wärme in dem Temperaturbereich von 100 - 130°C ausgesetzt werden, keinen Geruch, Geschmack oder chemische Ingredienten haben, welche für den Körper schädlich wären. Zusätzlich sind die Harze gemäss Erfindung transparent, so daß die Zähne des Patienten und Harze durch die Behandlungsvorrichtung während der Behandlung beobachtet werden können.

Die bei der vorliegenden Erfindung verwendeten Silikonharzmaterialien werden in einer Zusammensetzung zubereitet, welche a) ein Material auf Silikonharzbasis und b) einen Katalysator umfaßt, welcher ein Öl wie beispielsweise Silikonöl einschließt. Obwohl verschiedene Arten von Silikonharzmaterialien verwendet werden können, welche die oben erwähnten Eigenschaften aufweisen, umfassen Beispiele Materialien mit der folgenden Formel:

(a) 

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Der in der Silikonharzzusammensetzung verwendete Katalysator umfaßt solche, die durch folgende Formel dargestellt werden:

(b) 

Die Katalysatorzusammensetzung umfaßt ein Öl wie beispielsweise Silikonöl. Die Katalysatorzusammensetzung enthält ungefähr 4o bis ungefähr 5o% des Katalysators und ungefähr 5o bis ungefähr 6o % des Öles. Das Verhältnis von Silikonharzmaterial zu Katalysatorzusammensetzung kann ungefähr loo g von a) zu von ungefähr 1 bis ungefähr 2 g von b) entsprechend sein.

Die Silikonharzzusammensetzung kann zubereitet werden, indem a) und b) in einem Mischer während einer Zeit gemischt werden, die ausreichend ist, um eine vollständige physikalische Mischung der Materialien zu erhalten. Die sich ergebende Zusammensetzung kann dann in einem kühlen Bereich wie beispielsweise in einem Kühlschrank gelagert werden.

Die Eigenschaften des Silikonharzmaterials, das erfindungsgemäss zu verwenden ist, sind folgendermassen:

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1)	Härte (JIS)	ungefähr 4o bis ungefähr 6o
2)	Zugfestigkeit	ungefähr 8 bis ungefähr 13o kg/cm^2
3)	Verformung	ungefähr 4oo bis ungefähr 56o%
4)	Molekulargewicht	ungefähr 6×10^5 (Basis Silikon)
5)	2oo%-Modul	ungefähr 35 bis ungefähr 45 kg/cm^2

Fig. 1 zeigt das ursprüngliche Gipsmodell nach Nehmen eines Abdruckes der schlechten Zahnausrichtung eines Patienten, die zu behandeln ist, einschließlich der Zähne 1, die ebenfalls aus Gips bestehen.

Fig. 2 zeigt die entsprechenden Zähne, die von dem ursprünglichen Modell nach Fig. 1 entfernt worden sind und

Fig. 3 zeigt den Zustand, in dem die Zähne in der normalen Lage wieder angeordnet sind, wobei Wachs 2 verwendet wird, um die Zähne anzuordnen und zu fixieren.

Fig. 4 zeigt die vollständige zahntechnische Behandlungsvorrichtung, wobei Silikonharz 14 verwendet wird, und

Fig. 5 zeigt die Vorrichtung mit Ventilationslöchern 3 zum Atmen, wobei die Zähne, die in gestrichelten Linien gezeigt sind, Negativabdrücke der Zähne sind, die in normaler Ausrichtung wieder angeordnet sind. Die schlecht sitzenden Zähne des Patienten, die zu behandeln sind, sind in die

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Vorrichtung eingesetzt, welche die negativen Abdrücke durch den Patienten aufweist, der seine Kiefer zusammenschließt. Wenn die Silikonharzvorrichtung von den Zähnen verformt wird, wird die Rückdtellkraft des Harzes erzeugt, und die entsprechende Kraft verursacht, daß sich die Zähne in die normale Schließlage der Vorrichtung bewegen.

Fig. 6 ist eine Schnittansicht längs der Linie VI-VI der vorhergehenden Zeichnung, und

Fig. 7 ist eine Schnittansicht längs der Linie VII-VII nach Fig. 4, wobei eine konkave Form 4 der Vorrichtung zum Einsetzen eines Teiles des oberen Kiefers und eine konkave Form 5 für ein Teil des unteren Kiefers gezeigt sind.

Fig. 8 ist ein Vergleich, wobei die Zustände vor und nach der zahntechnischen Behandlung mit der erfindungsgemässen Vorrichtung gezeigt sind, wobei Fig. 8A den Zustand vor der zahntechnischen Behandlung und Fig. 8B ihn nach der zahntechnischen Behandlung zeigt. Dabei sind auch ein Vorderzahn 6 des Oberkiefers und ein Vorderzahn 7 des Unterkiefers gezeigt. Fig. 8A zeigt Spalte an der Lippenseite des oberen Vorderzahnes und an der Zungenseite des unteren Vorderzahnes. Fig. 8B zeigt diesen Spalt nicht auf Grund der Bewegung des Zahnes durch die Kraft, die von der Rückstellkraft des Harzes während der Behandlung erzeugt wird.

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Fig. 9 zeigt die erste Ausführungsform gemäss Erfindung, und Fig. 9A zeigt den Zustand, in welchem das Formstück 9 getrennt ist und die Gipsmodelle enthält, wobei die Zähne in normaler Lage in Gips 12 eingebettet sind. Fig. 9B zeigt den Zustand, in welchem Silikonharz 8 in die untere Hälfte des Formstückes gefüllt oder gegossen ist und Fig. 9C zeigt den Zustand, in welchem die getrennte Form verbunden ist und das Silikonharz vollständig die Zähne umgibt, wobei ein Verbindungsglied 1o für die Form gezeigt ist.

In Fig. 1o ist eine zweite Ausführungsform der Erfindung, in Fig. 1oA eine Draufsicht des anatomischen Artikulators 11 und Fig. 1oB der Artikulator in Seitenansicht gezeigt, wobei der Zustand dargestellt ist, in welchem die Wachsplatte geschmolzen und entfernt ist, und in dieser konditionellen Lage ist das Silikonharz durch Druck über die Gipsmodelle geformt, um die zahntechnische Behandlungsvorrichtung zu bilden. Fig. 1oC ist eine Seitenansicht der zahntechnischen Behandlungs- bzw. Versetzungsvorrichtung, die mit dem Silikonharz gebildet ist, und wenn diese Vorrichtung mit heissem Wasser oder heisser Luft gehärtet ist, ist ein abschliessendes Produkt gebildet. Fig. 1oD ist eine Querschnittsansicht entlang der Linie X-X in Fig. 1oA. Dabei ist ein Arbeitsmodell 12 und die zahntechnische Behandlungsvorrichtung 14 gezeigt.

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Die Silikonharzbehandlungsvorrichtung, welche wie oben beschrieben zubereitet ist, hat negative Eindrücke oder Lücken, welche die Zähne des Patienten vervielfältigen bzw. nachahmen und die Zähne in eine gewünschte Lage wie beispielsweise eine normale Stellung während der Behandlung bewegen. Eine vollständige zahntechnische Behandlung wird durchgeführt, indem a) der Mund des Patienten geöffnet wird, um die oberen und unteren Kiefer und Zähne freizulegen, b) die Vorrichtung angepaßt wird, indem der Fingerdruck verwendet wird, um die Vorrichtung über die oberen Zähne zu drücken und c) der Unterkiefer geschlossen wird, um die Vorrichtung über die unteren Zähne zu drücken. Die tatsächliche Bewegung der Zähne wird durchgeführt durch d) die oberen und unteren Zähne während kurzer Zeitperioden gedrückt bzw. zusammengepreßt werden, vorzugsweise ungefähr 1o-2o Sekunden, um zu verursachen, daß die Vorrichtung Druck ausübt oder gegen die Zähne drückt, wobei die Kiefer gelöst werden, um den Druck freizulassen, und wobei das Zusammenpressen und Freilassen während der bestimmten Behandlungsstunden des Patienten wiederholt wird; e) die Vorrichtung wird über den Zähnen des Patienten während des Schlafes gehalten und f) die Stufen b) und e) während einer Zeitperiode wiederholt, die ausreichend ist, um die Zähne in die gewünschte Lage zu bewegen.

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Es sei hervorgehoben, daß, wenn die Fehlausrichtung bzw. falsche Stellung ernsthaft ist, sodaß die Zähne über beträchtliche Entfernungen bewegt werden müssen, es notwendig sein kann, verschiedene Behandlungsvorrichtungen gemäss Erfindung zu verwenden, sodaß die Zähne über kurze Entfernungen mit jeder Behandlung gemäss den obigen Behandlungsverfahren bewegt werden können. Wenn weiterhin verschiedene Vorrichtungen zwecks Behandlung notwendig sind, kann jede Vorrichtung gemäss den oben beschriebenen Verfahren zubereitet werden.

Die zahntechnische Behandlungsvorrichtung, die gemäss Erfindung erhalten wird, erzeugt eine normale Lage bzw. Stellung auf der Basis der wieder angeordneten Zähne des Patienten. Da die Zähne graduell korrigiert werden, nachdem die Vorrichtung in dem Mund angeordnet ist, übt sie keine unnötige Spannung auf die Zähne oder die Zahnstruktur aus, sodaß die Korrigierkraft der Vorrichtung arbeitet und als Ergebnis die zahntechnische Behandlung durchgeführt wird.

Wegen ihrer Eigenschaften kann die zahntechnische Behandlungsvorrichtung, die aus Silikonharz geformt ist, nicht dauernd verformt werden, und sie ist frei von Änderungen auf Grund der Spannung. Ihre Härte kann frei geändert werden, und sie kann transparent ohne Geschmack und Geruch

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ausgeführt werden, sodaß sie vorteilhafte Merkmale aufweist, indem sie nicht nur eine exzellente zahntechnische Behandlung schafft, sondern auch für den Patienten leicht zu benutzen ist.

Insbesondere ist die vorliegende Erfindung vorteilhaft im Vergleich mit bekannten Polyurethanharzen, da die Zeit zum Polymerisieren des Polyurethans ungefähr 2o Minuten beträgt und demzufolge mit der Erfindung die Herstellungszeit beträchtlich verkürzt wird. Auch bildet das Polyurethanharz Schaum aus Kohlendioxydgas in grossen Mengen, wenn es mit dem Wasser in dem Gips zur Reaktion gebracht wird, und demzufolge muß das Arbeitsmodell hergestellt werden, indem besondere Harze verwendet werden, wobei der Nachteil besteht, daß Verformungen hervorgerufen werden auf Grund des großen Schrumpfens, das sich aus dem Härten des Harzes durch Wärme ergibt. Demzufolge kann im Fall der Verwendung von Silikonharz gemäss Erfindung Gips verwendet werden, um das Arbeitsmodell herzustellen, und es ist absolut keine Verformung vorhanden, und als Ergebnis kann die zahntechnische Behandlungsvorrichtung mit verbesserter Genauigkeit hergestellt werden.

Durch Verwendung von Polyurethanharzen ist das Handhaben der unverdünnten Flüssigkeit mit Gefahr verbunden, und es

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ist auch eine Behandlung während des Rührprozesses mit einer Vakuumpumpe erforderlich, um das Schäumen des Polyurethans zu verhindern. Weiterhin muß ein Kompressor hohen Druckes und ein Autoklav verwendet werden, und weiterhin ist beim Formen eine Schleifvorrichtung grosser Abmessung erforderlich, sodaß sich komplizierte Betriebsverfahren und Nachteile durch Verwendung besonderer Maschinen ergeben. Demgegenüber ist die erfindungsgemässe Vorrichtung und das Verfahren äußerst sicher, da es Silikonharz verwendet, was ein Entschäumen während des Rührprozesses und Polieren und Endbearbeitungen eliminiert; demzufolge ist sie mit vielen ausgezeichneten Wirkungen behaftet.

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Leerseite

Nummer: 27 49 802
Int. Cl.²: A 61 C 7/00
Anmeldetag: 7. November 1977
Offenlegungstag: 11. Mai 1978

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FIG. 1

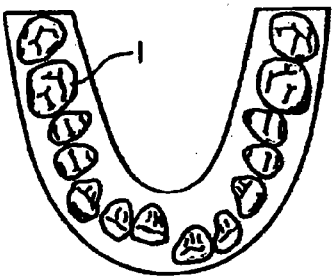


FIG. 2

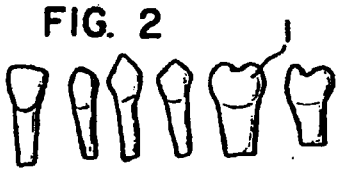


FIG. 3

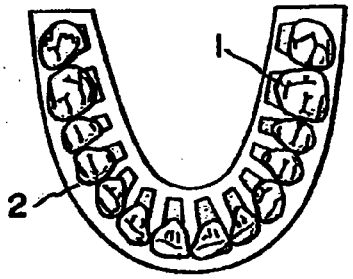


FIG. 4

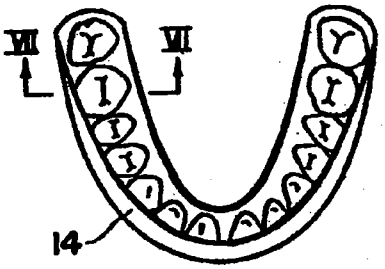


FIG. 5

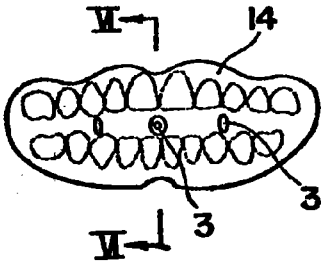


FIG. 6

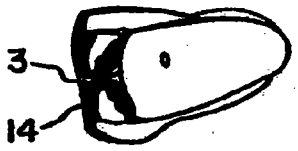


FIG. 7



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FIG. 8A

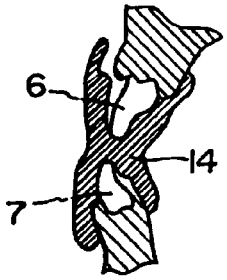


FIG. 8B

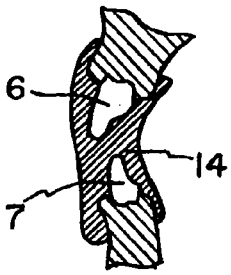


FIG. 9A

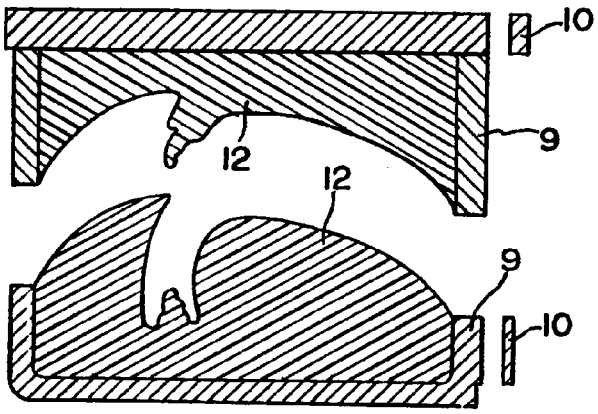
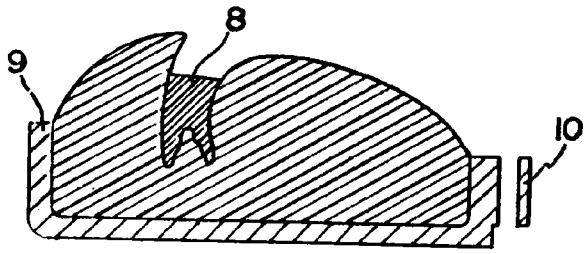


FIG. 9B



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FIG. 9c

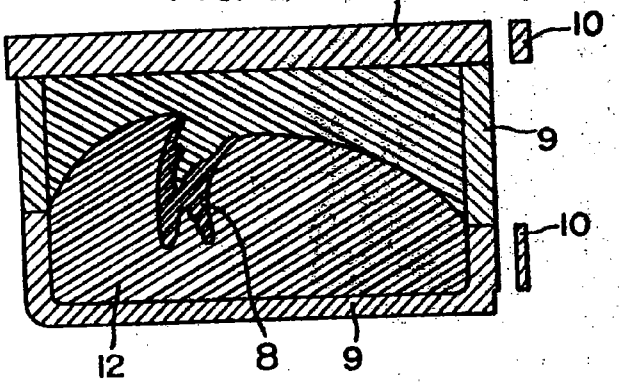


FIG. 10A

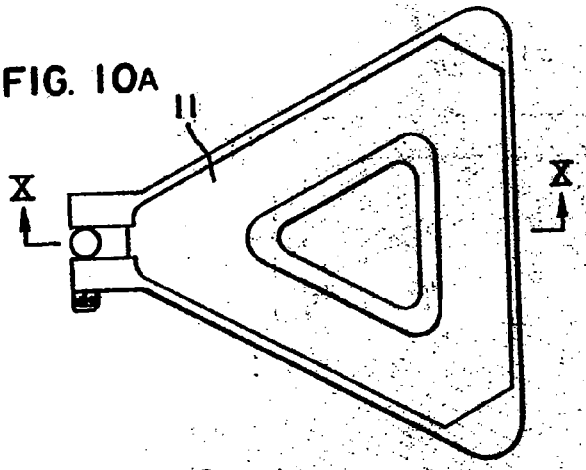
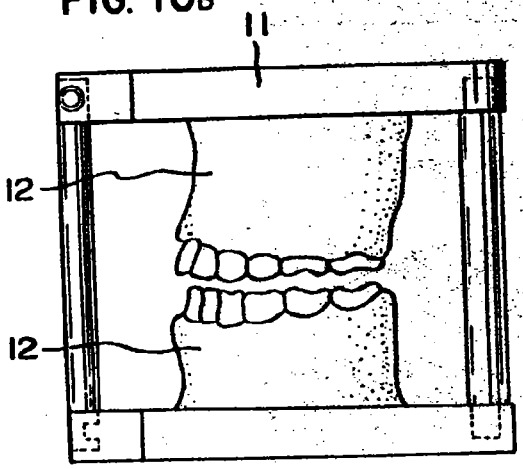


FIG. 10B



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FIG. 10C

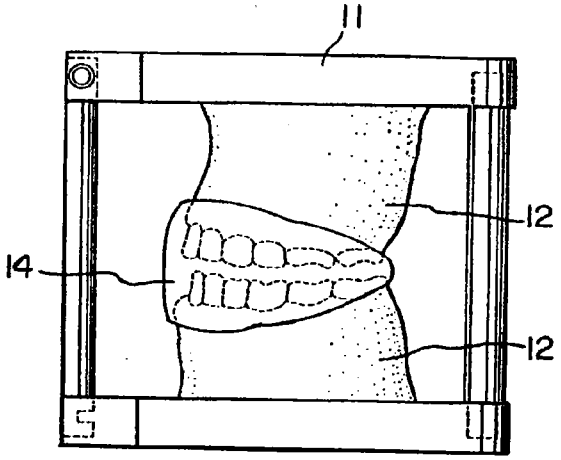
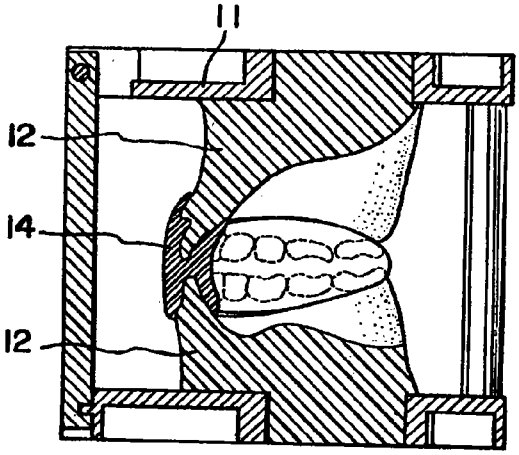


FIG. 10D



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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 541 500 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **92850249.1**

(22) Date of filing: **23.10.92**

(51) Int. Cl.[5]: **G05B 19/42**, A61C 13/00, G01B 5/20

(30) Priority: **01.11.91 SE 9103204**

(43) Date of publication of application: **12.05.93 Bulletin 93/19**

(84) Designated Contracting States: **AT BE CH DE DK ES FR GB GR IT LI NL SE**

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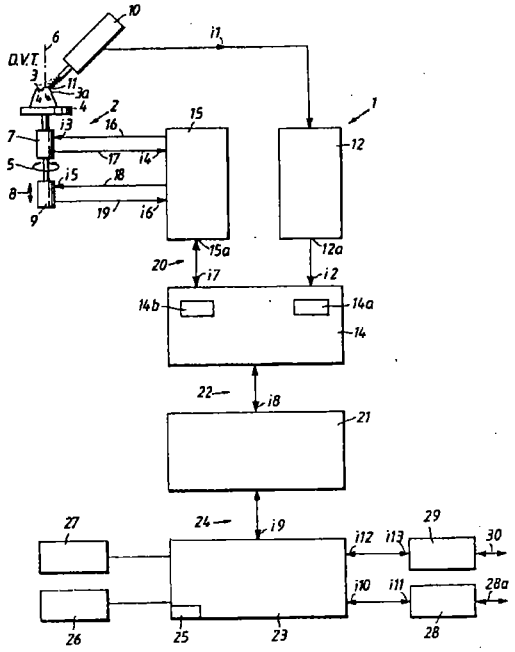
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(54) Scanning device.

(57) A sensing device senses a contour (3a) of a model (3) and generates, in response to the sensing, a representation (i1). The representation is used to control tool equipment for producing, for example, dental implants, support members, etc. or tools for producing such implants, members, etc. The representation (i1) is fed to computer equipment (23) which generates a signal array (i13). This latter effectuates or is included in the control of the tool equipment. The signal array (i13) is selected or compressed so that it will be sufficient to enable the tool equipment to perform with its expected degree of accuracy/tolerance in production.

Fig.1



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TECHNICAL FIELD

The present invention relates to a device for generating, by means of a scanning function applied to a scannable contour on a model, a representation which may be used for controlling a tool which operates with a high degree of precision in connection with the production of a body, or a tool for such a body, which is to be implanted in a human being. As examples of such bodies, mention may be made of dental implants, support members, etc. The model preferably consists of a three-dimensional model.

BACKGROUND ART

It is known in the art, in the production of replacement parts, support members etc. in the human body, to utilize a copy milling cutter in which a model is applied in the cutter and is sensed and in response to the sensing a tool processes a blank in order to produce from the blank a body or a tool part with the same shape as the model.

Our Swedish patent application No. 9003967-8 describes a system in which the sensing or scanning of the model is separate from the processing equipment and control signals for the latter are generated with the aid of computer equipment.

SUMMARY OF THE INVENTION

TECHNICAL PROBLEM

The use of copy milling cutters has its limitations in respect of production speed. Moreover, there is an additional disadvantage in that the read-off function and processing function must be located in the same premises. The appearance of the model is strictly linked to the structure of the copy milling cutter, which means that variations and additions to the shape of the model in question, enlargements of the contours etc. cannot be put into effect with the desired freedom of choice.

In connection with equipment in which it is desired that the sensing and processing functions be located in different premises, it is a matter of urgency that an expedient read-off function and processing of the thus obtained representation may be put into effect. The representation and the control must be capable of co-ordination so that unambiguous scanning and sensing can be adapted to an optimum or to the greatest possible extent minimized control signal function.

The quantity of read-off data/information should be kept to a minimum so that the processing and selection functions in the computer equipment may be simplified/reduced while retaining the accuracy of control. The scanning and sensing principles and storage function in the data processing equipment are therefore of crucial importance in this context.

In the case when a telecommmunications medium (e.g. communication via the public telephone network) is to be employed to transmit information from one place to another, it is vital that the quantity of requisite control signals can be reduced. In addition to operating with small scanning and processing quantities, it may be relevant to extract by means of data processing equipment characteristic parts of the read-off information and to transmit these characteristic parts via the medium, and also reconstruct replicas on the reception side with the aid of the above-mentioned characteristic parts so that sufficient control signals for the accurate control of the tool equipment can be obtained.

In the scanning and sensing function with contact devices/ sensing signals, it is also essential for the shape of the organ in the part co-operating with the contour to be put in relation to the shape of that part of the tool by means of which a blank is processed. An optimum relationship leads to significantly reduced read-off and processing information.

It is also esssential for the sensing and control functions to be related to one another without the quantity of processed data or information growing in the data processing equipment. A relationship between read-in and read-out of information entered in the computer must also be established in such a manner that, for example, the read-off function will be separated from the read-in function so that the control generation causes the processing function to be carried out more quickly than the read-out function.

In one embodiment, the present invention will comprise a contour sensing portion interactable with the contour and having a curved surface which may be brought into abutment against the surface of the contour. The dimensions of the curved area, e.g. a spherical area, are to be put into relation with the details of the contour so that a reduced sensing degree (resolution) is obtained.

The tool equipment must, for example in the production of dental implants, bridges, etc., be capable of working to a degree of accuracy/tolerance of one or a few hundredths of a millimetre (e.g. 0.01-0.09 mm). The resolution on scanning may in one embodiment (e.g. scanning by laser) be appreciably greater, e.g. one or a few thousandths of a millimetre.

SOLUTION

One object of the present invention is int. al. to solve the above-outlined problem structure and that which may then substantially be considered as characterizing the novel apparatus according to the present invention is that the representation may be entered into computer equipment which generates a signal array that effectuates or is included in the control of the tool equipment, and that the sensing and/or a

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selection function effectuated by the computer equipment of the representation is or are selected so as to ensure an order of magnitude of the signal array which, from the sufficiency viewpoint, satisfies the degree of accuracy with which it is expected that the tool equipment will perform.

In one embodiment, the sensing function operates with a first member co-operating with the contour, e.g. a needle. In its portion co-operating with the contour, the member displays a first form which substantially corresponds to a second form of a second member which is included in the tool equipment and which interacts, with a portion carrying the second form, with a blank in the production process. The said portion may consist of a milling cutter. In one embodiment, said first and second forms are substantially spherical. In addition, the sensing function and the processing function of the tool equipment are mutually co-ordinated so that a linear transmission function arises. The sensing function and the processing function may then operate at different speeds. It is thus of interest in this art that the speed of the processing function may exceed the sensing function.

The computer equipment is preferably designed with memory means in which the representation or information of significance for the representation is stored. The memory may, for instance, consist of a magnetic internal or primary memory of the RAM type. In that case when information is to be stored, a secondary memory may also be employed. As example of a secondary memory, mention may be made of a memory of the permanent magnet type. The read-in function of the information is then preferably separated from its read-out function so that, for example, control signal generation may be carried out more rapidly than the read-in of the representation.

In one embodiment, the sensing function takes place on models of soft or brittle material, for example plaster. With the aid of the tool equipment, bodies or tool parts may be made completely or partly of hard, soft or brittle material.

In one embodiment, compression takes place in the computer equipment of first information referable to the representation on the formation of second information referable to control of the tool equipment. The first and/or second information may be stored in storage devices on delayed transmission of the control information, e.g. via a telecommunications medium (for example the public telephone network). The storage devices may then be designed with a capacity which entails storage of the information from sensing of one or more contours. In one embodiment, the storage devices have a capacity of at least 2-3 megabyte.

In one embodiment, the sensing function is carried out during rotation of the model with simultaneous mutual relative displacement between the model and a sensing device. The sensing function is executed a large number of times per revolution, e.g. 360 times per revolution. The relative displacement may be selected to be approx. 0.1 mm/revolution. Only characteristic parts of the representation and/or control can, in one embodiment, be transmitted on the employed telecommunications medium. A replica of the control/control signals is generated at a reception point with the aid of the characteristic parts.

The present invention also utilizes known mathematical principles in the compression function.

ADVANTAGES

As a result of the proposals disclosed in the foregoing, a considerable reduction may be achieved in the quantity of information which is obtained in the sensing function. The capacity and space on the computer equipment may then be kept to a minimum, at the same time as transmission via the relevant link is simplified/shortened in terms of time. The sensing and control signal-generating functions may be kept separated and processed independently of each other. A plurality of sensing stations may be connected to the same computer equipment and similarly a plurality of sensing and computer equipment units may be connected to one and the same tool equipment via the same or different connections. The information quantities may be reduced substantially, which gives short processing times in the computer equipment and transmission of a relatively small quantity of control information. The proposed principles also afford the possibility of so-called contact-free sensing in which the sensing function more exactly and in greater detail senses the contour in question. The representation obtained from the sensing function can be reduced/compressed in the computer equipment with the aid of the above-mentioned selection function. As a result of the proposed spherical shape of the abutment portion of the sensing device against the contour, sensing of soft and/or brittle models can be carried out. In that the shapes of the sensing and processing device are designed to be substantially identical, complicated calculated functions referable to the actual and sensed contour of the model in question are eliminated. As a result of the proposed structure, the processing capacity in the computer equipment may be reduced by one third and savings of the space/volume of the computer equipment may be reduced by up to one fifth.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

One currently proposed embodiment of an apparatus which displays the characteristics significative of the present invention will be described in greater detail hereinbelow, with particular reference to the accompanying Drawings. In the accompanying Draw-

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ings:

Fig. 1 shows in block diagram form the structure of the sensing device with computer equipment (PC), programmable input and output circuits, control unit for signal emission and signal sensing units in which the signal emitting unit controls a model carrying unit so that this moves in relation to a sensing unit that emits signals to the above-mentioned signal sensing unit;

Fig. 2 shows, on a larger scale and from the side, how a sensing portion in a sensing unit interacts with the contour of a model;

Fig. 3 shows from the side how a blank is processed by means of a tool equipment part, by means of which the contour in Fig. 2 is produced from the blank on reduced, equal or enlarged form;

Fig. 4 shows on a larger scale the interaction between the sensing portion and the contour of the model; and

Fig. 5 shows in table form how the sensing proceeds in the embodiment according to Fig. 4.

DETAILED DESCRIPTION OF EMBODIMENT

Referring to the Drawings, in Fig. 1 a read-off device is given reference No. 1 and comprises int. al. a mechanical unit 2 on which a model 3 may be secured on a rotatable device 4. In addition to being rotatable in the direction of the arrows of rotation 5 (counter-clockwise and clockwise) about an axis of rotation 6 by means of a motor 7, the device 4 and the drive motor 7 are longitudinally displaceably disposed in the directions 8 of the axis 6. By this means, the model 3 will also be longitudinally displaceably disposed in said directions 8. The longitudinal displacements are realized by means of a motor 9. A sensing unit 10 which is fixedly disposed in relation to the model is provided with a device 11 which may be resiliently brought into contact against the contour 3a of the model 3. When the model is turned and displaced in relation to the unit 10 and the device 11 in connection with the activations of the motors 7 and 9, there will be received from the output of the unit 10 a representation in response to sensing by the device 11 of the contour 3a, the representation being in the form of one or more electric signals i1. The latter signal or signals are processed in a signal processing unit 12. Processing in the unit 12 entails that the representation i1 is sampled and that digital signals i2 are obtained from the output 12a of the unit 12 in response to the samplings. The digital signals can be transmitted on a bus connection for parallel transmission of 16 bits. The unit 12 is, via the bus connection, connected to a control unit 14. The above-mentioned motors 7, 9 are controlled by means of a combined unit 15 for driving, speed adjustment and positioning of the motors. The control functions for the motors operate with feedback function and the control and feedback conductors are indicated by reference numerals 16, 17; and 18, 19, respectively, and the set and actual value signals are indicated by i3, i4; and i5, i6, respectively. The unit 15 is connected via inputs and outputs 15a to the control unit 14. The connection is designed as an additional bus connection 20 for 16-bits parallel transmission. The control unit comprises first and second units 14a and 14b which serve units 12 and 15 respectively. Control of the motors 7 and 9 is related to the sensing and the representation i1 for this.

The sensing device includes a programmable interface 21 with read-in and read-out devices which are connected to the control unit 14 via a bus connection 22 for 24-bits parallel transmission. A data processing equipment, e.g. a PC 23, is connected to the read-in and read-out devices 21 via a bus connection, e.g. an AT bus connection. The PC may be of type AT-286 which includes one or more magnetic internal memories 25 or primary memories of the RAM type. The computer 23 is also fitted with a secondary memory 26, 27 of the permanent magnet type. A memory 26 may consist of a hard disk and a memory 27 of a floppy disk.

The signals on the bus connection 20 are shown with reference numeral i7, on the bus connection 22 with i8 and on the bus connection with i9. The computer 23 is connected to or provided with a data communication port 28 via which the control/representation information may be entered into and retrieved from the read-off device via an input and output 28a to and from another data processing equipment or data communication (not shown). Moreover, the computer 23 is connected to a modem 29 via which the computer may be connected to a telecommunication connection 30 in a telecommunications network, for example the public telephone network. Information to and from the connection 30 via the modem 29 is indicated by reference numerals i12 and i13 respectively.

The software which is employed in the computer may be of per se known type. In the present case, the following are employed:

User program
Program for text and calibration
Program for file handling
Program for data compression
Program for data communication
Program for automatic call up/transmission via the modem on the telecommunications network, single/multiple file program.

Fig. 2 shows the device 11′ sensing the contour 3a′ of the model magnified in relation to Fig. 1. The resilient abutment of the device 11′ against the contour is effectuated by spring means 31. The unit 10′ is securely disposed in relation to the device 11′. The latter is designed with an abutment portion 32 which is preferably substantially spherical in the illustrated

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case. The spherical shape is indicated by reference numeral 33.

In Fig. 3, a blank is indicated by reference numeral 34. The blank, which may be of titanium, cemented carbide, alloy, graphite, etc., must be provided with a contour 3a and 3a' in Figs. 1 and 2 corresponding to contour 3a'. The blank 34 is processed or treated with a tool 35 which, in the present embodiment, consists of a milling cutter. The forward portion 36 of the tool has a shape 37 which substantially, preferably exactly, agrees with the shape 33 of the read-off device 32 according to Fig. 2. The tool/milling cutter is disposed in a per se known manner in a spindle and the tool includes a tool adjustment control portion 38 which receives control signals i14 via the telecommunication connection 39 (cf. 30 in Fig. 1) and a modem 40 which interacts with the modem 29 according to Fig. 1. Via the modem 40, control signals i14' are fed to the control portion 38.

Figs. 4 and 5 show the read-off principle, read-in and read-out into and from, respectively, the memory of a computer of sensed values and entered values V, respectively. The model 3''' is rotated about its axis 6' and sensing takes place in different angles φ. In the example, sensing takes place for each degree, i.e. 360 times per revolution and the read-off angles are indicated by 0-360 . The read-off points are symbolized by reference numeral 41. For each revolution (360), the model moves in a Z direction in relation to the read-off portion 33', 33'', these positions each representing their location in relation to the model 3'''. For every revolution that the model rotates, a relative movement S (= pitch) between the model and the sensing portion in the present embodiment is 0.1 mm. In the table according to Fig. 5, the pitch Z for each degree φ is 0.1 mm/360. Other pitches S and number of sensing points may be employed within broad limits.

In the table IS indicates a read-in sequence in the memory of the computer and US a read-out sequence from the memory. V represents read-in/readable value for each degree. The values V occur in binary form or other suitable form. The sequences IS and US can be executed in a per se known manner at different speeds. The sequence US is preferably higher than the sequence IS.

The sensing surface 33 of the sensing portion 32 displays a radius R which may lie within the range of between 0.5 and 2.0 mm and is preferably 1.0 mm. This size of the radius is suitable on production from models which represent a dental implant, bridge, etc. The sensing surface 33 is thus selected so as to give a reduced sensing degree/resolution in relation to the true detailed shape of the contour.

One method of compressing the entered data quantity is to approximate a number of points by means of a function, e.g. a polynomer of the third degree ($c_1 + c_2x + c_3x^2 + c_4x^3$). The total computer quantity is divided into groups. Each such group is approximated by a function. So instead of transmitting pure measurement data from the read-off unit to a relevant factory computer, the coefficients of the function are transmitted for each group (c_2, c_2, c_3 and c_4 in the case employing a polynomer of each degree).

Since both functional value (indicator signal) and the distance between each read-in is known, i.e. f (x) and x in each group when the function is a function of a variable, the function may be approximated by the least square method. The solution in the sense of the least square method to the above equation system $\underline{A}\underline{c} = \underline{f}$ is given by the solution to the equation system $\underline{A}^T\underline{A}\underline{c} = \underline{A}^T\underline{f}$. If Q(x) is the indicator signal at a given position and f(x) is the approximated value at the same point, the error can be calculated with error(x) = f(x) · Q(x). The number of values included in each group to be approximated by a function must be adapted such that the error (error(x)) is less than the largest permitted error for all values in the group. The above mathematical processing is carried out in the computer in a per se known manner.

The present invention should not be considered as restricted to that described above and shown on the drawings, many modifications being conceivable without departing from the spirit and scope of the appended Claims.

Claims

1. An apparatus for generating, by means of a sensing function applied to a contour (3a) of a model (3) which may be sensed, preferably a three-dimensional model, a representation (i1) usable for controlling tool equipment (35) working with a high degree of precision for producing a body usable in a human being, e.g. a dental implant, support member, etc., or a tool part for said body **characterized in that** the representation (i1) may be applied to computer equipment (23) which generates a signal array (i13) which effectuates or is included in the control of the tool equipment (36); **and that** the sensing and/or selection function effectuated by the computer equipment of the representation is/are selected so as to ensure an order of magnitude of the signal array (i13) which satisfies, from the sufficiency viewpoint, the degree of accuracy with which the tool equipment is expected to perform.

2. The apparatus as claimed in Claim 1, **characterized in that** the sensing function operates with a first device interactable with the contour; and that the device displays, at its part interactable with the contour, a first form which substantially corresponds to a second form of a second device included in the tool equipment and which interacts

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with a part carrying said second form with a blank in the production process for the body and the tool part respectively, said first and said second forms preferably being substantially spherical.

3. The apparatus as claimed in Claim 1 or 2, **characterized in that** the sensing function and the processing function of the tool equipment are mutually substantially co-ordinated.

4. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the sensing function and the processing function of the tool equipment operate at different speeds, preferably such that the speed of the processing function exceeds, for example significantly, the speed of the sensing function.

5. The apparatus as claimed in any of the preceding Claims, **characterized in that** information significative of the representation is storable in the computer equipment, in a memory associated therewith, for example in a magnetic internal (primary) memory of the RAM type and/or a secondary memory of the permanent magnet type; **and that** the read-in function of such information is separated from its read-out function.

6. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the sensing function is carried out on a model of soft or brittle material, e.g. plaster; **and that** bodies are produced by means of the tool equipment completely or partly of cemented carbide or ceramics, or a tool part for whole or partial production of bodies (tool parts) of hard, soft or brittle material.

7. The apparatus as claimed in any one of the preceding Claims, **characterized in that** compression takes place in the computer equipment of first information referable to the representation on formation of second information referable to the control of the tool equipment, and/or that the first and/or the second information may be storable in storage means, e.g. buffert means, memory means, etc., in order to realize a time lag between the sensing and/or control functions in relation to a transmission function, e.g. effectuated on a telecommunications medium, of the control to the tool equipment.

8. The apparatus as claimed in Claim 9, **characterized in that** the storage devices store the representations for one or more contours for transmission via a telecommunications medium at off-peak hours thereon, and that said storage devices have a capacity of at least 2-3 megabit.

9. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the sensing function is of the type which senses the contour during rotation of the model with simultaneous mutual relative displacement between the model and the sensing device, and/or that the sensing takes place a large number of times per revolution, e.g. approx 360 times per revolution, and that the relative displacement is approx. 0.1 mm/revolution.

10. The apparatus as claimed in any one of the preceding Claims, **characterized in that** characteristic parts of the representation and/or the control are selected prior to the transmission on a telecommunications medium; and that a replica of the control is generated at a reception site with the aid of the characteristic parts.

11. The apparatus as claimed in any one of the preceding Claims, **characterized in that** to the computer equipment (23) are connected via an interface (21) comprising programmable input and output circuits, which are connectable to a control unit (14) which in turn is connected to a signal generation unit (15) for model movement actuating means (7, 9) and to a unit (10, 11) converting the shape of the contour (3a) into electrical signals (i1).

12. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the sensing surface (33) of the sensing portion (32) displays a radius (R) in the range of between 0.5 and 2.0 mm in connection with a model (3) which represents a dental implant, bridge; etc.

13. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the sensing surface (33) of the sensing portion (32) is selected so that it gives a reduced sensing degree/resolution in relation to the true detailed form of the contour (3a).

14. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the read-in or read-off data quantity will be compressed by means of an approximation of a quantity of read-in or read-off points with a function, e.g. a polynomer of the third degree.

15. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the read-in or read-off data quantity will be divided into groups; that each respective group is approximated with a function; **and that** the coefficients of each respective function are transmitted between relevant communication parts, e.g. from

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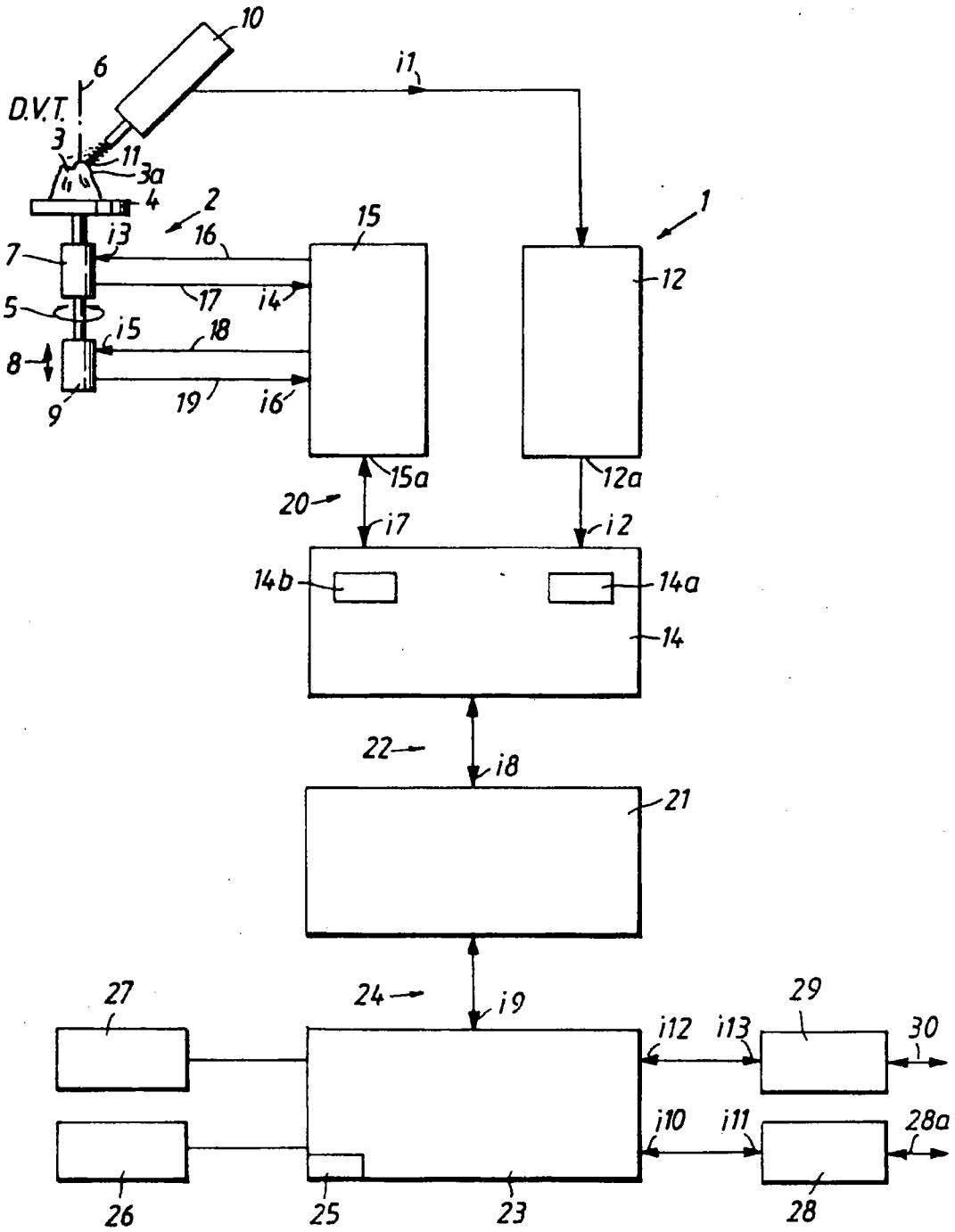
the read-off unit to a factory computer, as representation of the pure/total quantity of read-in or read-off data.

16. The apparatus as claimed in any one of the preceding Claims, **characterized in that** by utilizing the knowledge that the value of each respective function, i.e. the indicator signal or sensing, and each respective distance between each respective read-in, is known, each respective function will be approximated using the least square method.

17. The apparatus as claimed in any one of the preceding Claims, **characterized in that** the error between the actual indicator signal and each respective approximated value is calculated, and also the number of included values in each respective group of said groups which is to be approximated with a function will be adapted such that the absolute value error is less than the largest permitted error for all values in the group.

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Fig.1



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Fig. 2

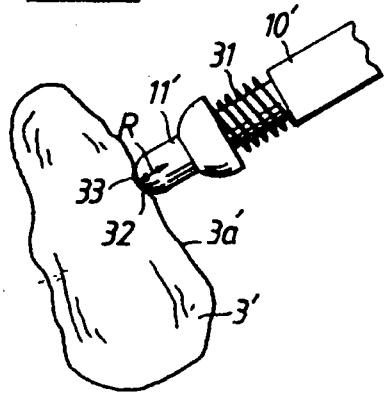


Fig. 3

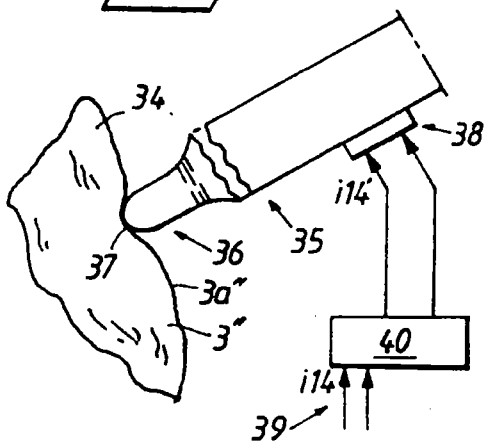


Fig. 4

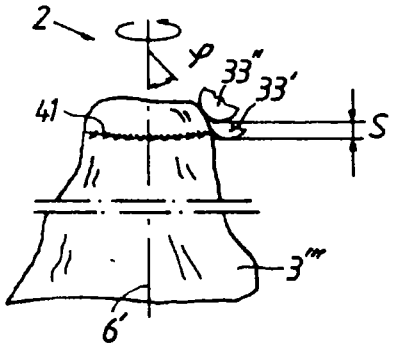


Fig. 5

IS	Z	φ°	V	US
→	S0/360°	0°	100110010111	←
→	S1/360°	1°	110101010101	←
→	S2/360°	2°	111011101111	←
→	S3/360°	3°	110100010110	←
→	S4/360°	4°	111101001001	←
→	-"-	-"-	-"-	←
→	-"-	-"-	-"-	←
→	S360/360°	360°	11011011101101	←

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 92 85 0249

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X Y A	US-A-4 997 369 (AARON SHAFIR) * column 3, line 35 - line 67; figures 1,2 * * column 5, line 31 - column 9, line 64; figures 8-13 *	1,4-6,9 7,8,11, 14 12,13	G05B19/42 A61C13/00 G01B5/20
Y A	ASSOCIATION FOR INTEGRATED MANUFACTURING TECHNOLOGY - 22ND ANNUAL MEETING & TECHNICAL CONFERENCE PROCEEDINGS 14 May 1985, ST. LOUIS, MO. HIDEMASA IIDA ET AL. 'Cam Station and Part Drawing Reader with 32-Bit Microprocessors' * page 17 - page 26 *	7,8,11, 14 12,13	
X,P A,P	EP-A-0 455 855 (SIEMENS AKTIENGESELLSCHAFT) * the whole document *	1-6,9 7,8	
Y	ROBOTICS AND COMPUTER-INTEGRATED MANUFACTURING vol. 5, no. 2-3, 1989, pages 173 - 181 G. PRITSCHOW, G. GRUHLER 'AUTOMATIC PROGRAMMING OF INDUSTRIAL ROBOTS BY SENSOR GUIDANCE'	1-3,6, 15-17	TECHNICAL FIELDS SEARCHED (Int. Cl.5) G05B A61C G01B
Y	EP-A-0 420 990 (FANUC LTD) * column 3, line 10 - column 4, line 40 *	1-3,6, 15-17	

3

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 FEBRUARY 1993	PANDOLFI C.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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Orthodontic treating device and method of manufacturing same

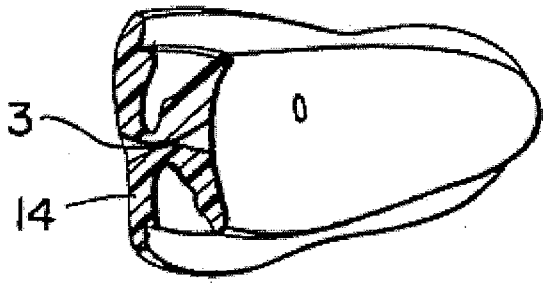
Patent number: ES463897
Publication date: 1980-01-01
Inventor:
Applicant: HITO SUYEHIRO D (US)
Classification:
- international: A61C
- european: A61C7/08; A61K6/093
Application number: ES19770463897 19771105
Priority number(s): JP19760132323 19761105

Also published as:
US4505673 (A1)
US4504225 (A1)
JP53058191 (A)
GB1550777 (A)
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Original models of plaster are obtained from impressions of the dentition of the upper and lower jaws of a patient with malocclusion. The teeth are then separated from the base of the models and reset in wax to a normal occlusion. The realigned teeth are fixed in place with wax, and impressions of the upper and lower models are taken to duplicate the rearranged models, forming working models made of plaster. The working models are mounted on an anatomic dental articulator and a wax occluding model is constructed of the new occlusion to cover both upper and lower arches. The working upper and lower models, together with the wax occluding model are buried in plaster in a split cast. The wax occluding model in the split cast is heated and the wax is melted and discharged out of the cast. Silicone resin is then placed into the impression of the occluding model and cured.



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MINISTERIO DE INDUSTRIA Y ENERGIA
Registro de la Propiedad Industrial

ESPAÑA

(19) ES (11) (21) NUMERO 463897 (10) A1

(23) FECHA DE PRESENTACION

PATENTE DE INVENCION

Concedido el Registro de acuerdo con los datos que figuran en la presente descripción y según el contenido de la Memoria adjunta.

(30) PRIORIDADES: (31) NUMERO	(32) FECHA	(33) PAIS
51-132323	5 Noviembre 1.976	JAPON

(47) FECHA DE PUBLICIDAD	(51) CLASIFICACION INTERNACIONAL	(62) PATENTE DE LA QUE ES DIVISIONARIA
	A61C	

(54) TITULO DE LA INVENCION

"PROCEDIMIENTO PARA EL TRATAMIENTO COMPLETO DE LA MALOCLUSION DENTAL Y DISPOSITIVO ORTODONCICO DE RESINA DE SILICONA PARA EFECTUAR DICHO PROCEDIMIENTO".

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UNE A-4 MOD. 3106

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El tratamiento ortodóncico convencional es realizado con ayuda de bandas métalicas provistas de un enganche realizado para adaptarse a los dientes y se fija a los dientes - con ayuda de cemento, y se hace pasar un alambre metálico a - través de las mismas para desplazar los dientes. En este caso la fuerza correctora (esfuerzo para desplazar los dientes) — utiliza principalmente las fuerzas elásticas del alambre metálico mismo, y es usado en general ampliamente como dispositivo de tratamiento ortodóncico.

No obstante, en el tratamiento ortodóncico usando - esta técnica de bandas múltiples con el curvado del alambre - metálico en formas complicadas, se ha reconocido que se precisan enormes cantidades de energía y habilidad así como largos períodos de educación. Igualmente, tal tratamiento no sólo ocasiona molestias al paciente, sino que además presenta otros - problemas tales como los dientes cariados o descalcificados o la enfermedad periodontal resultante de la adherencia de partículas de los alimentos a los dientes durante el tratamiento ortodóncico y, además, los gastos suben enormemente.

La presente invención ha sido concebida con vistas a fabricar un dispositivo de tratamiento ortodóncico por el - que pueda tratarse de manera simple una maloclusión utilizando la fuerza elástica de las resinas de silicona como fuerza funcional en vez de alambre metálico empleado en la actualidad, y dado que es fácilmente separable, no produce molestia alguna al paciente, haciendo posible la realización del tratamiento ortodóncico mediante su uso en la hora de acostarse y en las horas en que se permanece despierto según sea necesario.

Primeramente, es necesario seleccionar un material

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elástico de alto peso molecular que satisfaga suficientemente las especiales y severas condiciones del tratamiento intraoral. Los solicitantes han descubierto que las resinas de silicona son un material elástico apropiado para el tratamiento ortodóncico que alcanzan los mejoras resultados desde el punto de vista del estudio científico, de ingeniería y clínico. A saber, el material ha sido reconocido estar provisto de calidad científica y de ingeniería de manera que no se deteriora su elasticidad mientras permanece en la boca, tiene un esfuerzo de rotura suficiente, y no se deforma durante largos períodos de tiempo debido a la fuerza ejercida durante el tratamiento. Debido a estas importantes propiedades, el dispositivo de tratamiento de la presente invención puede ser usado para tratar pacientes desde las etapas iniciales hasta la terminación del tratamiento.

Igualmente, cambiando la porción endurecedora de las resinas de silicona y catalizadores y la mezcla de los mismos, se puede modificar libremente la dureza de la resina de silicona moldeada. Se pueden proporcionar fuerzas comprendidas entre una fuerza ligera y una fuerza fuerte lo que resulta ventajoso desde el punto de vista clínico. El dispositivo mantiene un alto grado de transparencia sin tener sabor ni olor, y es preparado a partir de una composición que no causa daño al cuerpo humano. Estas propiedades no pueden ser halladas en otros materiales de caucho.

Además de la resina de silicona, las resinas de poliuretano tienen unas propiedades sensiblemente similares a las mencionadas más arriba, pero las resinas de silicona presentan ventajas adicionales tales como un tiempo de elaboración de endurecido más corto en comparación con la resi

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na de poliuretano, y el proceso de fabricación puede ser realizado fácilmente, y por consiguiente se reconoce una marcada diferencia entre las dos resinas. Además, cuando se usa resinas de poliuretano para preparar dispositivos similares, tales resinas se destruyen en la boca del paciente y no son transparentes. Por consiguiente, tales dispositivos sólo son usados durante las etapas finales del tratamiento y no pueden ser empleados desde la fase inicial.

En consecuencia, los solicitantes han descubierto que el dispositivo de tratamiento de la presente invención fabricado con resinas de silicona desde la primera vez, proporciona un medio de tratamiento de un paciente desde el comienzo hasta la terminación. Hasta la presente, ello sólo ha sido posible mediante el procedimiento conocido que utiliza bandas metálicas.

La presente invención está destinada a proporcionar un dispositivo de tratamiento ortodóncido y un método de fabricación, que utiliza por fin las características de la resina de silicona mencionada más arriba.

La figura 1 es una vista oclusal de un modelo original con maloclusión.

La figura 2 es un alzado de varios dientes separados del modelo de la figura 1.

La figura 3 es una vista oclusal de un modelo obtenido por reordenación en cera de los dientes del modelo original para una oclusión normal.

La figura 4 es una vista oclusal del dispositivo de tratamiento ortodóncico completo.

La figura 5 es un alzado frontal del dispositivo de tratamiento ortodóncico.

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La figura 6 es una vista en sección transversal - tomada a lo largo de la línea VI-VI de la figura 5.

La figura 7 es una vista en sección transversal - de frente de la sección transversal tomada a lo largo de — una línea VII-VII de la figura 4.

La figura 8 es una vista de comparación relativa a antes y después del tratamiento ortodóncico, correspon— diendo la figura 8A a antes del tratamiento y la figura 8B a después del mismo.

La figura 9 muestra la primera realización de la presente invención, mostrando 9A una vista de frente de la condición en que se separa un vaciado partido (9), mien— tras que 9B representa una vista en sección transversal de frente de la condición en que se llena con resina de silico na el vaciado partido, y 9C muestra una vista en sección — transversal de frente de la condición en que son unidas las proporciones separadas del vaciado partido.

La figura 10 muestra una segunda realización de - la presente invención, mostrando 10A una vista superior de un articulador anatómico, mientras que 10B muestra una vis— ta de costado de la condición en que es fundido y descarga— do el material de placa de cera necesario para fijar los mo delos de yeso superior e inferior, y 10C muestra una vista de costado de la condición en que la resina de silicona es puesta en contacto a presión sobre la superficie de modelo de trabajo para producir el dispositivo de tratamiento orto dóncico, y 10D muestra una vista en sección transversal to— mada a lo largo de la línea X-X de la figura 10A.

La presente invención es relativa a un primer méto do de fabricación de un dispositivo de tratamiento ortodónci

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co de resina de silicona que consiste en (a) preparar modelos de yeso de las mandíbulas superior e inferior de un paciente incluyendo los dientes que presentan malocusión, (b) determinar la relación céntrica entre los dientes superiores e inferiores del paciente mediante la toma de una impresión en cera, (c) tomar una transferencia del arco de la cara de los dientes superiores del paciente para establecer la relación de la mandíbula superior con la cabeza y la cara, (d) colocar el arco de la cara en un articulador anatómico, (e) disponer los modelos superior e inferior del paso (a) en el articulador anatómico usando el arco de la cara y la impresión en cera del paso (b) para reproducir la relación existente entre las mándibulas superior e inferior del paciente y fijar los modelos en yeso de tal modo que se unan los modelos al articulador, (f) retirar los dientes de los modelos y realinear los dientes en cera para la oclusión normal, (g) duplicar la oclusión normal de los modelos con un material duplicador para formar impresiones negativas, (h) formar modelos de yeso positivos a partir de las impresiones negativas, (i) abrir el articulador para formar un espacio de 3 a 5 mm entre el borde incisor superior e inferior, (j) echar cera en el espacio para obtener una impresión de los dientes superiores e inferiores en oclusión normal, (k) poner los dientes de los modelos de yeso superiores e inferiores del paso (h) dentro de la impresión de cera del paso (j), (l) cubrir la combinación resultante del paso (k) con cera de tal modo que la cara tenga sustancialmente la misma forma y espesor que el dispositivo de tratamiento de resina de silicona, (m) moldear la combinación del modelo cubierto de cera del paso (l) en un vaciado partido, (n) so

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meter el vaciado partido que contiene el modelo cubierto de cera al calor en cantidad suficiente para fundir la cera y producir un vacío, (o) retirar la cera, (p) llenar el vacío con resina de silicona y curar la resina, y (q) retirar el dispositivo de tratamiento de resina de silicona.

La invención es también relativa a un segundo método para producir el dispositivo de tratamiento ortodóncico de resina de silicona repitiendo sustancialmente los pasos (a)-(h) expuestos anteriormente incluyendo los pasos adicionales consistentes en: (i) retirar los modelos de cera del articulador y sustituirlos por los modelos de yeso del paso (h) a la vez que se mantiene la misma relación entre las mandíbulas superior e inferior, (j) abrir el articulador para formar un espacio de 3 a 5 mm entre el borde incisor superior e inferior, (k) formar resina de silicona termocurable alrededor de los dientes superiores e inferiores y curar la resina y (l) retirar el dispositivo de tratamiento resultante.

Si bien puede usarse cualquiera de los procedimientos anteriormente identificados para fabricar el dispositivo de tratamiento ortodóncico de la presente invención, se prefiere el primer método ya que proporciona el medio de utilización de la presión adecuada para empujar la resina de silicona dentro de cada hendidura que rodea a los dientes y el dispositivo de tratamiento resultante facilita una duplicación adecuada de los dientes del paciente en oclusión normal.

La presente invención es realizada en un proceso que emplea los pasos siguientes:

(a) preparar modelos de yeso de las mandíbulas su

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perior e inferior de un paciente incluyendo los dientes que presentan maloclusión.

Se toma una impresión de los dientes superiores e inferiores del paciente así como del tejido circundante usando un material duplicador para obtener una impresión negativa. Se retira el material duplicador de los dientes y se forma un vacío en el material. Se vierte yeso dentro del vacío de la impresión negativa para obtener un molde de yeso positivo de los dientes superiores e inferiores del paciente.

(b) Determinar la relación céntrica entre los dientes superiores e inferiores del paciente mediante la toma de una impresión de cera.

Se dispone cera entre los dientes superiores e inferiores del paciente para obtener una impresión del bocado para determinar la relación céntrica de los dientes superiores e inferiores. Esta impresión de cera es usada posteriormente en el proceso para alinear correctamente los modelos de yeso superior e inferior preparados en el paso (a).

(c) Tomar una transferencia del arco de la cara de los dientes superiores del paciente para establecer y reproducir la relación existente entre la mandíbula superior con la cabeza y la cara.

Se usa un arco de la cara para tomar una impresión en cera de los dientes superiores del paciente para reproducir la relación existente entre la mandíbula superior con la cabeza y la cara. Este paso resulta vital para el proceso de la invención, ya que proporciona el único medio para reproducir correctamente la relación final de las mandíbulas superior e inferior del paciente y este procedimiento sirve de base para alinear correctamente los modelos de ye-

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so a partir de los cuales hay que preparar el dispositivo - de tratamiento ortodóncico. El dispositivo debe tener la — misma relación entre la mandíbula superior e inferior que - las del paciente de tal modo que, cuando se usa el dispositivo, la relación de los dientes se ajuste adecuadamente en el dispositivo para hacer que se muevan los dientes hacia - la oclusión normal.

(d) Colocar el arco de la cara en un articulador anatómico.

El arco de la cara con la impresión en cera de — los dientes superiores del paciente se acopla con un articulador anatómico para alinear correctamente los modelos de - yeso superior e inferior.

(e) Colocar los modelos superior e inferior del - paso (a) en el articulador anatómico usando el arco de la - cara y el bocado de cera del paso (b) para reproducir la relación existente entre las mandíbulas superior e inferior - del paciente y fijar los modelos en yeso de tal modo que se unan los mismos con el articulador.

Este procedimiento es realizado colocando los — dientes del modelo de yeso superior preparado en el paso — (a) en la impresión de cera del arco de la cara que se ha - unido al articulador anatómico. Se pone yeso encima del modelo superior y se le empuja contra la parte superior del - articulador permitiéndole secarse, haciendo así que el modelo superior se una a la parte superior del articulador. Una vez que se ha secado el yeso, se retira del articulador el arco de la cara. El modelo superior ha sido colocado ahora en el articulador en la misma relación que la posición natural de los dientes y mandíbulas superiores del paciente.

La impresión del bocado en cera preparada en el paso (b) se coloca sobre los dientes del modelo superior y se pega o une. El modelo de yeso inferior del paso (a) se inserta dentro de la porción inferior de la impresión de cera que está unida con el modelo superior. Se vierte yeso sobre la superficie del modelo inferior y se cierra el articulador y se deja secar el yeso de tal modo que el modelo inferior quede unido con el articulador.

Hasta este punto del proceso de la invención, los modelos de yeso superior e inferior han sido unidos con el articulador de tal modo que se establezca una reproducción exacta de la relación existente entre las mandíbulas y dientes del paciente.

(f) Retirar los dientes de los modelos y realinear los dientes en cera para la oclusión normal.

Los dientes de yeso son retirados individualmente del modelo de yeso por medio de una sierra de cuchilla delgada. Después se echa material de cera sobre la base de los modelos de yeso de los que se han retirado los dientes individuales y se colocan los dientes en la cera ordenándolos en oclusión normal. En este punto, los modelos superior e inferior tienen los dientes colocados de tal modo que el dispositivo de tratamiento ortodóncico de resina de silicona a fabricar mediante el proceso de la invención desplace los dientes a la posición formada por los modelos de cera.

(g) Duplicar la oclusión normal de los modelos con un material duplicador para formar impresiones negativas.

Se forma un material duplicador alrededor de los modelos de cera para formar impresiones negativas en oclusión normal. Se retira el material de los modelos y las im-

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presiones muestran los vacíos de los dientes en oclusión — normal.

(h) Formar modelos de yeso positivos a partir de la impresión negativa.

Se vierte yeso en los vacíos de la impresión negativa para preparar modelos de yeso positivos que muestran la posición de los dientes del paciente después del tratamiento con el dispositivo de tratamiento ortodóncico fabricado por el proceso de la invención.

(i) Abrir el articulador para formar un espacio de 3 a 5 mm entre el borde incisor superior e inferior.

Se abre el articulador de tal modo que se forme un espacio de 3 a 5 mm, preferiblemente de 4 mm, entre el borde incisor superior e inferior. Este espacio es necesario para formar correctamente el dispositivo de tratamiento ortodóncico en el que la resina de silicona llenará el espacio comprendido entre los dientes y cuando el paciente muerde la resina durante el tratamiento ortodóncico, la fuerza de mordedura y la resiliencia de la resina ayudarán a desplazar los dientes.

(j) Echar cera en el espacio para obtener una impresión de los dientes superiores e inferiores en oclusión normal.

Este paso es necesario para obtener la relación correcta entre los dientes superiores e inferiores. Esta impresión será usada posteriormente para reemplazar a los modelos de cera por los modelos de yeso del paso (h) en el articulador.

(k) Poner los dientes de los modelos de yeso superior e inferior del paso (h) en las impresiones de cera del

paso (j).

Los modelos de yeso en oclusión normal tal como son preparados en el paso (h) son colocados en la impresión de cera obtenida en el paso (j). La impresión de cera es empleada para alinear correctamente los modelos de yeso superior e inferior. Esta combinación o montaje es realizada por separado y fuera del articulador.

(l) Cubrir la combinación resultante del paso (k) con cera de tal modo que la cera tenta prácticamente la misma forma y espesor que el dispositivo de tratamiento de resina de silicona.

Se dispone cera sobre todas las áreas superficiales de los dientes y la porción representativa del tejido de los modelos superior e inferior que incluye el material de cera colocado entre los dientes del paso (k). El material de cera debería tener prácticamente la misma forma y espesor que el dispositivo de tratamiento de resina de silicona que hay que preparar durante el proceso como se explicará mas adelante.

(m) Moldear la combinación del modelo cubierto de cera del paso (l) en un vaciado partido.

La combinación preparada en el paso (l) es colocada en la mitad inferior de un vaciado partido y se vierte yeso en el vaciado para cubrir toda la mitad inferior del modelo de combinación. Se deja secar y endurecer al yeso y se aplica un medio de separación sobre la capa de yeso endurecido.

Se da la vuelta al vaciado partido y se vierte yeso en el vaciado y se cierra este último de tal modo que la porción superior expuesta de la combinación quede empotrada

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totalmente en el yeso blando. Debe usarse suficiente cantidad de yeso de manera que el mismo cubra toda la superficie del modelo de combinación lo que es puesto de manifiesto — cuando fluye el yeso por fuera del vaciado. Se mantiene entonces el vaciado apretado y se deja secar el yeso.

(n) Someter el vaciado partido que contiene el modelo cubierto de cera a un calor suficiente para fundir la cera y producir un vacío.

Todo el vaciado partido que contiene el modelo — preparado en el paso (m) es calentado disponiéndolo por — ejemplo en agua hirviendo durante un tiempo suficiente para fundir la cera.

(o) Retirar la cera.

Se abre el vaciado partido y se retira la cera — fundida dejando un vacío alrededor de los dientes y el tejido del modelo de yeso incluyendo el espacio comprendido entre los dientes superiores e inferiores.

(p) Llenar el vacío con resina de silicona termocurable y curar la resina.

Se echa un material de resina de silicona blando dentro del vacío en cantidades suficientes para llenar completamente el mismo. Se cierra el vaciado fuertemente de — tal modo que el material de resina llene completamente cualquier espacio y hendidura y el material en exceso fluirá — por fuera del vacío. El vaciado partido es sometido entonces al calor por ejemplo en agua hirviendo durante un período de aproximadamente 40 minutos para curar el material de resina de silicona.

(q) Retirar el dispositivo de tratamiento de resina de silicona.

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El vaciado partido es retirado, enfriado, abierto y el dispositivo de tratamiento ortodóncico de resina de silicona resultante es retirado.

Como paso final, el dispositivo de tratamiento resultante puede ser recubierto con una solución de resina de silicona que contenga dos resinas de silicona diferentes, - incluyendo un catalizador, para dar una superficie lisa, — clara e invisible. Se mezclan las dos soluciones en una relación de aproximadamente 10 a 1. El procedimiento descrito más arriba es el método preferido, ya que el dispositivo de tratamiento es fabricado como resultado de la utilización - de un vaciado partido para empujar la resina de silicona — dentro de cada espacio y hendidura del vacío del modelo de yeso.

En una segunda realización de la invención, se emplea un proceso similar, con la excepción de que sólo se repite los pasos (a) a (h) del proceso anterior. Se ejecuta la segunda realización mediante los pasos siguientes:

(a) Preparar modelos de yeso de la mándíbula superior e inferior del paciente incluyendo los dientes que presentan maloclusión.

Se toma una impresión de los dientes superiores e inferiores delpaciente así como del tejido circundante usando un material duplicador para obtener una impresión negativa. Se retira el material duplicador de los dientes y se forma un vacío en el material. Se vierte yeso dentro del vacío de la impresión negativa para obtener un molde de yeso positivo de los dientes superiores e inferiores del paciente.

(b) Determinar la relación céntrica entre los — dientes superiores e inferiores del paciente mediante la to

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ma de una impresión de cera.

Se dispone cera entre los dientes superiores e inferiores del paciente para obtener una impresión del bocado para determinar la relación céntrica de los dientes superiores e inferiores. Esta impresión de cera es usada posteriormente en el proceso para alinear correctamente los moldes de yeso superior e inferior preparados en el paso (b).

(c) Tomar una transferencia del arco de la cara de los dientes superiores del paciente para establecer y reproducir la relación existente entre la mandíbula superior con la cabeza y la cara.

Se usa un arco de la cara para tomar una impresión en cera de los dientes superiores del paciente para reproducir la relación existente entre la mandíbula superior con la cabeza y la cara. Este paso es vital para el proceso de la invención, ya que proporciona el único medio para reproducir correctamente la relación final de las mandíbulas superior e inferior del paciente y este procedimiento sirve de base para alinear correctamente los modelos de yeso a partir de los cuales hay que preparar el dispositivo de tratamiento ortodóncico. El dispositivo debe tener la misma relación entre la mandíbula superior e inferior que las del paciente de tal modo que, cuando se usa el dispositivo, la relación de los dientes se ajuste adecuadamente en el dispositivo para hacer que se muevan los dientes hacia la oclusión normal.

(d) Colocar el arco de la cara en un articulador anatómico.

El arco de la cara con la impresión en cera de los dientes superiores del paciente se acopla con un articu

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lador anatómico para alinear correctamente los modelos de - yeso superior e inferior.

(e) Colocar los modelos superior e inferior del - paso (a) en el articulador anatómico usando el arco de la - cara y el bocado de cera del paso (b) para reproducir la relación existente entre las mandíbulas superior e inferior - del paciente y fijar los modelos en yeso de tal modo que se unan los mismos con el articulador.

Este procedimiento es realizado colocando los - - dientes del modelo de yeso superior preparado en el paso — (a) en la impresión de cera del arco de la cara que se ha - unido al articulador anatómico. Se pone yeso encima del modelo superior y se le empuja contra la parte superior del - articulador permitiéndole secarse, haciendo así que el modelo superior se una a la parte superior del articulador. Una vez que se ha secado el yeso, se retira del articulador el arco de la cara. El modelo superior ha sido colocado ahora en el articulador en la misma relación que la posición natural de los dientes y mandíbulas superiores del paciente.

La impresión del bocado en cera preparada en el - paso (b) se coloca sobre los dientes del modelo superior y se pega o une. El modelo de yeso inferior del paso (a) se - inserta dentro de la porción inferior de la impresión de cera que está unida con el modelo superior. Se vierte yeso sobre la superficie del modelo inferior y se cierra el articulador y se deja secar el yeso de tal modo que el modelo inferior quede unido con el articulador.

Hasta este punto del proceso de la invención, los modelos de yeso superior e inferior han sido unidos con el articulador de tal modo que se haya establecido una repro—

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ducción exacta de la relación existente entre las mandíbulas y dientes del paciente.

(f) Retirar los dientes de los modelos y realinear los dientes en cera para la oclusión normal.

Los dientes de yeso son retirados individualmente del modelo de yeso por medio de una sierra de cuchilla delgada. Después se echa material de cera sobre la base de los modelos de yeso de los que se han retirado los dientes individuales y se colocan los dientes en la cera ordenándolos en oclusión normal. En este punto, los modelos superior e inferior tienen los dientes colocados de tal modo que el dispositivo de tratamiento ortodóncico de resina de silicona a fabricar mediante el proceso de la invención desplace los dientes a la posición formada por los modelos de cera.

(g) Duplicar la oclusión normal de los modelos con un material duplicador para formar impresiones negativas.

Se forma un material duplicador alrededor de los modelos de cera para formar impresiones negativas en oclusión normal. Se retira el material de los modelos y las impresiones muestran los vacíos de los dientes en oclusión normal.

(h) Formar modelos de yeso positivos a partir de la impresión negativa.

Se vierte yeso en los vacíos de la impresión negativa para preparar modelos de yeso positivos que muestran la posición de los dientes del paciente después del tratamiento con el dispositivo de tratamiento ortodóncico fabricado por el proceso de la invención.

(i) Retirar los modelos de cera del articulador y

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sustituirlos por los modelos de yeso del paso (h) a la — vez que se mantiene la misma relación entre las mandíbulas superior e inferior.

Los modelos de yeso duplicados que han sido preparados en el paso (h) se montan sobre el articulador de — acuerdo con los siguiente pasos:

(i) Se retira el modelo de cera superior del articulador y se coloca y dispone el modelo de yeso superior sobre el modelo de cera inferior de tal modo que el modelo de yeso mantenga exactamente la misma relación con el modelo — de cera inferior que el modelo de cera superior que se ha — retirado. En este punto, el Modelo superior se fabrica en — yeso y el modelo inferior tiene los dientes colocados de cera.

(2) Se vierte yeso sobre la parte superior del modelo superior de yeso y se cierra el articulador de tal modo que, cuando se seca el yeso, el modelo de yeso superior, quede unido al articulador.

(3) Se retira el modelo de cera inferior del articulador y se sustituye por el modelo de yeso inferior del — paso (h) colocando y posicionando el modelo de yeso inferior en alineamiento con el modelo superior unido ahora al articulador del modo que ha sido descrito más arriba. Se vierte — entonces yeso sobre la superficie del modelo de yeso inferior, se cierra el articulador y una vez secado el yeso, el modelo inferior queda unido al articulador.

(j) Abrir el articulador para formar un espacio — de 3 a 5 mm entre el borde incisor superior y el inferior.

De nuevo, este espacio es necesario para formar — correctamente el dispositivo de tratamiento de resina de si

licona que ha sido descrito previamente en el paso (i) del primer procedimiento.

(k) Formar resina de silicona termocurable alrededor de los dientes superiores e inferiores y curar la resina.

La resina de silicona blanda es prensada a mano sobre toda las áreas superficiales de los dientes, anteriores y posteriores, y entre los dientes superiores e inferiores para llenar el espacio creado en el paso anterior. La resina es modelada a la forma final del dispositivo de tratamiento recortando todo el exceso de material. El conjunto completo es sometido entonces al calor disponiéndolo por ejemplo en agua hirviendo durante aproximadamente 40 minutos para curar la resina. Se comprenderá que en cualquier procedimiento de la presente invención, la resina puede ser curada por calentamiento a una temperatura de 100 a 130ºC por medio, por ejemplo, de agua hirviendo o aire caliente.

(l) Retirar el dispositivo de tratamiento resultante.

Después de curar la resina, se enfría todo el conjunto del modelo de yeso al que está aplicado el material de resina de silicona, se abre el articulador y se retira del vaciado de yeso el dispositivo de tratamiento resultante.

El dispositivo puede ser recubierto entonces con la resina de silicona de dos componentes que ha sido descrita más arriba para dar un producto final que tiene un acabado suave.

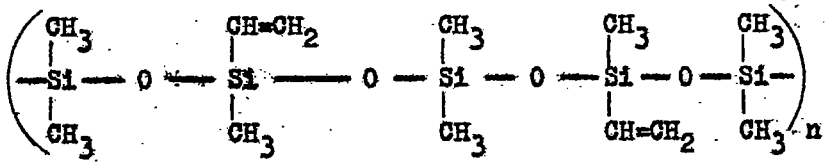
Puede emplearse varios tipos de materiales de resina de silicona en la presente invención, siempre que los

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mismos tengan las propiedades físicas correctas para desplazar los dientes de un paciente desde la posición de maloclusión a la oclusión normal. Las propiedades proporcionadas por los materiales de resina de silicona empleados en la presente invención incluyen las resinas que son fácilmente curables sometiendolas a la acción del calor a una temperatura ra de 100 a 130ºC, no tienen olor, sabor así como ningún tipo de ingredientes químicos que fuesen nocivos para el cuerpo. Además, las resinas de la presente invención son transparentes por lo que puede observarse los dientes y las encías del paciente a través del dispositivo de tratamiento durante el tratamiento.

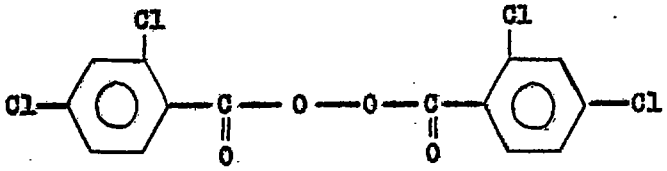
Los materiales de resina de silicona empleados en la presente invención son preparados en una composición que contiene (a) un material a base de resina de silicona y (b) un catalizador que incluye un aceite tal como aceite de silicona. Aunque puede emplearse varios tipos de materiales de resina de silicona que tengan las propiedades citadas anteriormente, los ejemplos de los mismos incluyen los materiales que tiene la fórmula:

(a)



El catalizador empleado en la composición de resina de silicona incluye los representados por la siguiente fórmula:

(b)



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La composición de catalizador comprende un aceite tal como aceite de silicona. La composición de catalizador contiene aproximadamente de 40 a 50% del catalizador y del 50 al 60% aproximadamente del aceite. La relación del material de resina de silicona a la composición de catalizador puede ser aproximadamente 100 gr. de (a) a 1-2 gr aproximadamente de (b), respectivamente.

La composición de resina de silicona puede ser preparada mezclando entre sí (a) y (b) en una mezcladora durante un tiempo suficiente para obtener una mezcla física completa de los materiales. La composición resultante puede ser entonces almacenada en un área fría tal como un refrigerador.

Las propiedades del material de resina de silicona a emplear en la presente invención son las siguientes:

1) Dureza (JIS)	aproximadamente	de 40 a 60
2) Resistencia a la tracción	"	de 85 a 130 kg/cm^2
3) Deformación plástica	"	de 400 a 560%
4) Peso molecular	"	6×10^5 (silicona base)
5) 200% módulo	"	de 35 a 45 kg/cm^2

La figura 1 muestra el modelo de yeso original después de tomar una impresión de la maloclusión de un paciente a tratar que incluye dientes 1 fabricados también en yeso.

La figura 2 muestra los respectivos dientes retirados del modelo original de la figura 1, y la figura 3 muestra la condición en que los dientes estan reordenados en la oclusión normal usando cera 2 empleada para montar y fijar los dientes. La figura 4 muestra el dispositivo de tratamiento ortodóncico completo usando resina de silicona 14 co

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mo material de partida, y la figura 5 muestra el dispositivo que tiene agujeros de ventilación 3 para la respiración y los dientes mostrados por líneas de puntos son impresiones negativas de los dientes que están reordenados a la oclusión normal. Los dientes mal alineados del paciente a tratar se insertan en el dispositivo que tiene las impresiones negativas al cerrar el paciente sus mándíbulas uniéndolas entre sí. Cuando es deformado por los dientes el dispositivo de resina de silicona, se genera la fuerza compensadora de la resina y la fuerza correctora hace que los dientes se desplacen a la oclusión normal del dispositivo.

La figura 6 es una vista en sección transversal, tomada a lo largo de una línea VI-VI del dibujo precedente, y la figura 7 es una vista en sección de frente tomada a lo largo de una línea VII-VII de la figura 4 que muestra un molde cóncavo 4 del dispositivo para la inserción de un molar de la mandíbula superior, y un molde cóncavo 5 para un molar de la mandíbula inferior. La figura 8 es un dibujo de comparación que muestra las condiciones existentes antes y después del tratamiento ortodóncico con el dispositivo de la invención, correspondiendo la figura 8A a antes del tratamiento ortodóncico, mientras que la figura 8B corresponde a después del tratamiento ortodóncico y mostrando también un diente anterior 6 de la mandíbula superior, y un diente anterior 7 de la mandíbula inferior. La figura 8A muestra huecos en el lado del labio del diente anterior superior y en el lado de la lengua del diente anterior inferior. La figura 8B no muestra el hueco debido al movimiento del diente con la fuerza ortodóncica generada por la fuerza compensadora de la resina durante el tratamiento.

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La figura 9 muestra la primera realización de la presente invención, y la figura 9A muestra la condición en la que el vaciado partido 9 está separado y contiene los modelos de yeso con los dientes en oclusión normal empotrados en yeso 12, y 9B muestra la condición en la que la resina de silicona 8 es llenada o vertida en la mitad inferior del vaciado partido, y 9C muestra la condición en la que los vaciados partidos separados están unidos y la resina de silicona 8 rodea completamente los dientes, y 10 designa un miembro de conexión para el vaciado partido.

La figura 10 muestra la segunda realización de la presente invención y 10A es una vista superior del articulador anatómico 11, y 10B es la vista lateral del mismo, mostrando la condición en la que la placa de cera es fundida y descargada, y en esta posición condicional, la resina de silicona se aplica a presión y se moldea sobre los modelos de yeso para formar el dispositivo de tratamiento ortodóncico. El dibujo 10C es una vista lateral del dispositivo de tratamiento ortodóncico formado con la resina de silicona, y cuando es curado este dispositivo por medio de agua caliente y aire caliente, se obtiene un producto final. La figura 10D es una vista en sección transversal tomada a lo largo de una línea X-X de la figura 10A. El número 12 designa un modelo de trabajo, y el número 14 designa el dispositivo de tratamiento ortodóncico.

El dispositivo de tratamiento de resina de silicona preparado más arriba tiene impresiones o vacíos negativos que son un duplicado de los dientes del paciente y desplazan los dientes del mismo a una posición deseada tal como la oclusión normal durante el tratamiento. El tratamien-

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to ortodóncico completo es realizado (a) abriendo la boca - del paciente para descubrir las mandíbulas y dientes superiores e inferiores, (b) adaptando el dispositivo usando la presión de los dedos para apretar el dispositivo sobre los dientes superiores, y (c) cerrando la mandíbula inferior para apretar el dispositivo sobre los dientes inferiores. El movimiento real de los dientes es realizado (d) apretando - los dientes superiores e inferiores entre sí durante breves períodos de tiempo, preferiblemente entre 10 y 20 segundos aproximadamente para hacer que el dispositivo aplique presión o fuerza contra los dientes, relajando las mandíbulas para aliviar la presión y repitiendo el apriete y la relajación durante las horas en que el paciente permanece despierto, (e) manteniendo el dispositivo sobre los dientes del paciente durante las horas de sueño, y (f) repitiendo los pasos (d) y (e) durante un período de tiempo suficiente para desplazar los dientes a la posición deseada.

Se comprenderá que cuando la maloclusión es grave tal que los dientes deban ser desplazados a distancias considerables, puede ser necesario usar varios dispositivos de tratamiento de la invención de modo que los dientes puedan ser desplazados a cortas distancias con cada tratamiento de acuerdo con los procedimientos de tratamiento anteriormente expuestos. Igualmente, cuando son necesarios varios dispositivos para el tratamiento, cada dispositivo puede ser preparado de acuerdo con los procedimientos anteriormente descritos.

El dispositivo de tratamiento ortodóncico obtenido de acuerdo con la presente invención produce una oclusión - normal sobre la base de los dientes reordenados del paciente.

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Al ser corregidos gradualmente los dientes después de colocarlo en la boca, no imprime esfuerzos indebidos a los dientes ni a la estructura periodontal, haciendo actuar a la fuerza correctora del dispositivo y, en consecuencia, se realiza el tratamiento ortodóncico.

Debido a sus propiedades, el dispositivo de tratamiento ortodóncico moldeado en resina de silicona no puede ser deformado permanentemente y está libre de cambios debidos a los esfuerzos. Su dureza puede ser modificada libremente y puede hacerse transparente sin sabor ni olor, por lo que resulta muy ventajoso no sólo por constituir un excelente tratamiento ortodóncico sino además por su facilidad de utilización por parte del paciente.

Particularmente, la presente invención resulta ventajosa en comparación con las resinas de poliuretano conocidas, dado que el tiempo de polimerización del poliureta no es de aproximadamente 20 minutos, y por consiguiente la presente invención acorta enormemente el tiempo de fabricación. Igualmente, la resina de poliuretano produce espuma de gas de ácido carbónico en grandes cantidades cuando reacciona con el agua en el yeso y, por consiguiente, el modelo de trabajo tiene que ser fabricado usando resinas especiales, y tiene la desventaja de producir deformaciones debido a la gran contracción resultante del termocurado de la resina. Por consiguiente, en caso de usar la resina de silicona de la presente invención, puede utilizarse yeso para fabricar el modelo de trabajo y no se produce deformación alguna y, en consecuencia, el dispositivo de tratamiento ortocónci co puede ser producido con una precisión incrementada.

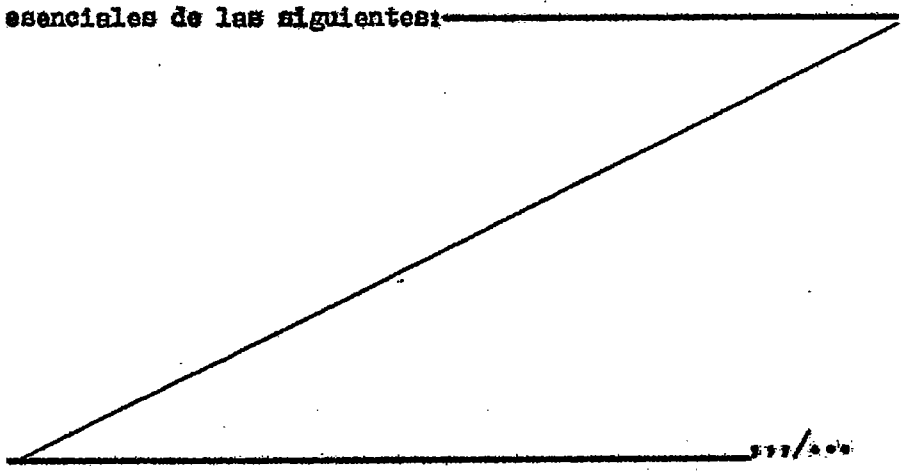
Igualmente, al usar resinas de poliuretano, la ma

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nipulación del líquido no diluido va acompañada de peligro, y es necesaria igualmente la desespumación durante el proceso de agitación con una bomba de vacío para impedir la espumación del poliuretano. Por otra parte, debe usarse un compresor y autoclave de alta presión y, adicionalmente, en el moldeo se precisa una trituradora de gran tamaño, por lo que se complica el proceso de funcionamiento y se tiene los inconvenientes de usar máquinas especiales. Por el contrario, la presente invención es extremadamente segura, ya que emplea la resina de silicona, eliminando la desespumación durante el proceso de agitación y los procedimientos de pulido y acabado, y, en consecuencia, tiene muchos efectos — excelentes.

N O T A

La Patente de Invención que se solicita por veinte años para España, de acuerdo con la vigente Legislación, deberá recaer sobre: "PROCEDIMIENTO PARA EL TRATAMIENTO COMPLETO DE LA MALOCLUSION DENTAL, Y DISPOSITIVO ORTODONCICO DE RESINA DE SILICONA PARA EFECTUAR DICHO PROCEDIMIENTO", con Prioridad de la demanda de Patente en Japón nº 51-132323, de fecha 5 de Noviembre de 1.976, según las características esenciales de las siguientes:



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R E I V I N D I C A C I O N E S

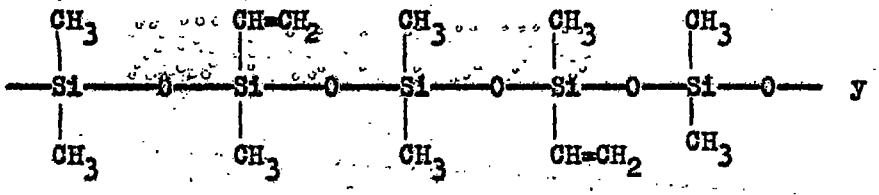
1ª.- Procedimiento para el tratamiento completo de la maloclusión dental, y dispositivo ortodoncico de resina de silicona para efectuar dicho procedimiento, comprendiendo dicho procedimiento de tratamiento las fases de: (a) la - - abertura de la boca del paciente para ver las mandíbulas superior e inferior y los dientes, (b) el ajuste del dispositivo mediante presión del dedo para forzar el dispositivo sobre los dientes superiores, (c) el cierre de la mandíbula inferior para formar el dispositivo sobre los dientes inferiores, (d) el apriete de los dientes superiores e inferiores entre si durante breves periodos de tiempo para hacer que el dispositivo ejerza presión contra los dientes, relajando las mandíbulas para aliviar la presión y repitiendo el apriete y la relajación durante las horas en que permanece despierto el paciente, (e) el mantenimiento del dispositivo sobre los dientes del paciente durante las horas de sueño, y (f) la reiteración de las fases (d) y (e) durante un periodo de tiempo suficiente para desplazar los dientes a la posición deseada.

2ª.- Dispositivo ortodoncico de resina de silicona para el tratamiento de la maloclusión dental según el procedimiento de tratamiento de la reivindicación 1ª, comprendiendo dicho dispositivo impresiones negativas superiores e inferiores que duplican los dientes superiores e inferiores y los mueven a la posición deseada durante el tratamiento.

3ª.- Dispositivo ortodóncico de resina de silicona para el tratamiento de la maloclusión dental, según la reivindicación 2, en el que la resina de silicona es una composición que contiene:

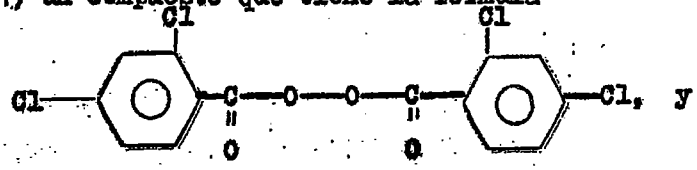
(a) una resina de silicona que tiene la siguiente fórmula:

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(b) una composición catalizadora que contiene:

(1) un compuesto que tiene la fórmula



(2) un aceite de silicona.

4ª.- Dispositivo ortodoncico de resina de silicona para el tratamiento de la maloclusión dental, según las reivindicaciones 2 y 3, cuyo dispositivo se fabrica según las fases de: (a) la preparación de modelos de yeso de las mandíbulas superior e inferior de un paciente incluyendo los dientes que presentan maloclusión, (b) la determinación de la relación céntrica entre los dientes superiores e inferiores del paciente mediante la toma de una impresión en cera, (c) la toma de una transferencia del arco de la cara de los dientes superiores del paciente para establecer y reproducir la relación de la mandíbula superior con la cabeza y la cara, (d) la colocación del arco de la cara en un articulador anatómico, (e) la colocación de los modelos superior e inferior de la fase (a) en el articulador anatómico usando el arco de la cara y la impresión en cera de la fase (b) para reproducir la relación entre las mandíbulas superior e inferior del paciente y fijación de los modelos en yeso de tal modo que los modelos sean unidos al articulador, (f) la retirada de los dientes de los modelos y la realineación de -

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los dientes en cera para la oclusión normal, (g) la duplicidad de la oclusión normal de los modelos con un material duplicador para formar impresiones negativas, (h) la formación de modelos positivos en yeso a partir de las impresiones negativas, (i) el alineamiento de los modelos positivos en yeso en la oclusión normal con un espacio de 3 a 5 mm entre el borde incisor superior e inferior, (j) la formación de resina de silicona termo-curable para fijar los modelos alineados de la fase (i) y la curación de la resina, y (k) la retirada del dispositivo de tratamiento resultante.

5ª.- Dispositivo ortodoncico de resina de silicona para el tratamiento de la maloclusión dental, según reivindicado en las reivindicaciónes 2, 3 y 4, en el que dicha fase de alineamiento (i) incluye la retirada de los modelos en cera del articulador y reemplazándolos con los modelos en yeso de la fase (h) mientras que se mantiene la misma relación entre la mandíbula superior e inferior, y abriendo el articulador para formar un espacio de 3 a 5 mm entre el borde incisor superior e inferior, y en el que dicha fase de formación (j) incluye la formación de resina de silicona termo-curable alrededor de los modelos en yeso superior e inferior.

6ª.- Dispositivo ortodoncico de resina de silicona para el tratamiento de la maloclusión dental, según las reivindicaciones 2, 3 y 4, en el que dicha fase de alineamiento (i) incluye las fases de: (l) la abertura del articulador para formar un espacio de 3 a 5 mm entre el borde incisor superior e inferior, (m) la colocación de cera en el espacio para obtener una impresión de los dientes superiores e inferiores en oclusión normal, y (n) la colocación de los

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dientes de los modelos en yeso, superior e inferior de la -- fase (h) en la impresión en cera de la fase (m), y en el que dicha fase de formación (j) incluye las fases de : (o) la - protección de la combinación resultante de la fase (n) con cera de tal modo que la cera tendrá sustancialmente la misma configuración y espesor que el dispositivo de tratamiento de resina de silicona deseado, (p) el moldeado de la combinación del modelo cubierto de cera de la fase (o) en un - vaciado partido, (q) sometiendo el vaciado partido que contiene el modelo cubierto de cera a un calentamiento suficiente para derretir la cera y producir un vacio, (r) la retirada de la cera, y (s) el llenado del vacio con una resina de silicona termocurable y el curado de la resina.

7ª.- Dispositivo ortodoncico de resina de silicona para el tratamiento de la maloclusión dental, según las reivindicaciones 2, 3 y 4, en el que la resina es curada a una temperatura de 100ºC a 130ºC.

8ª.- "PROCEDIMIENTO PARA EL TRATAMIENTO COMPLETO DE LA MALOCLUSION DENTAL, Y DISPOSITIVO ORTODONCICO DE RESINA DE SILICONA PARA EFECTUAR DICHO PROCEDIMIENTO".

Según queda sustancialmente descrito en la presen

.../...

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te memoria que consta de treinta hojas escritas a máquina por una sola cara y acompañada de dibujos.

Madrid, 15 NOV. 1977

D. Hito SUYEHIRO.

5. P.P.

FRANCISCO GARCIA CABRERIZO
P. P.

Firmado: M.ª Dolores Jorquera

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FIG. 1

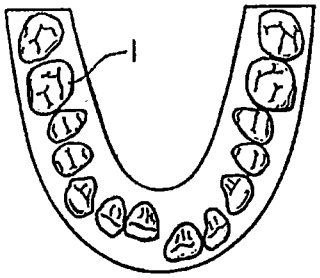


FIG. 2

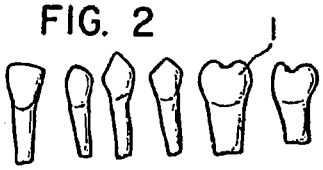


FIG. 3

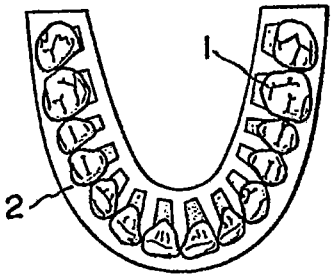


FIG. 4

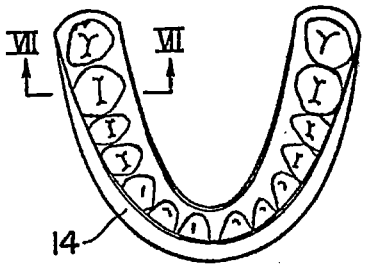


FIG. 5

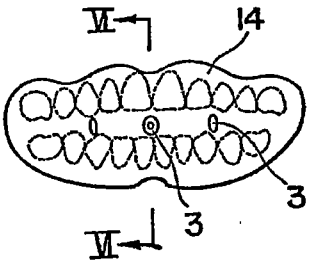


FIG. 6

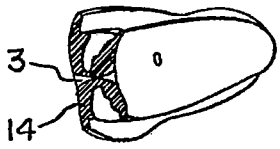


FIG. 7



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Madrid

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FRANCISCO GARCIA CABRERIZO

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FIG. 8A

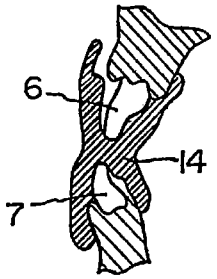


FIG. 8B

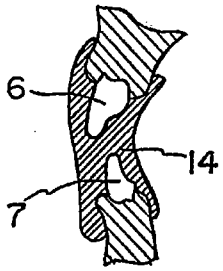


FIG. 9A

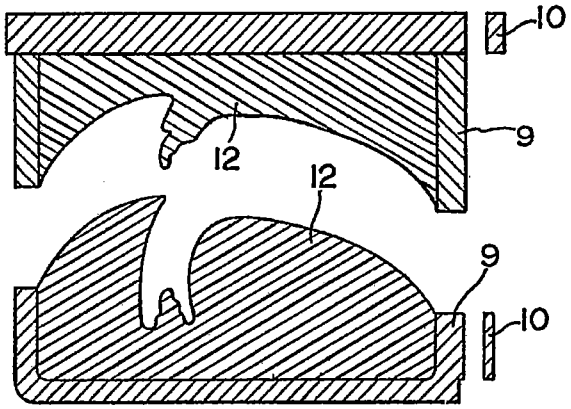
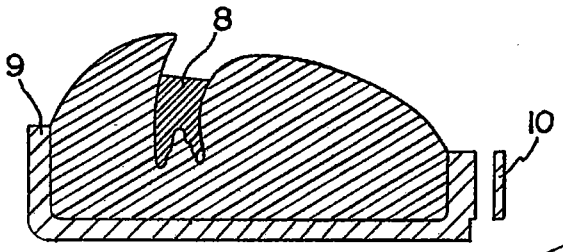


FIG. 9B



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FIG. 9C

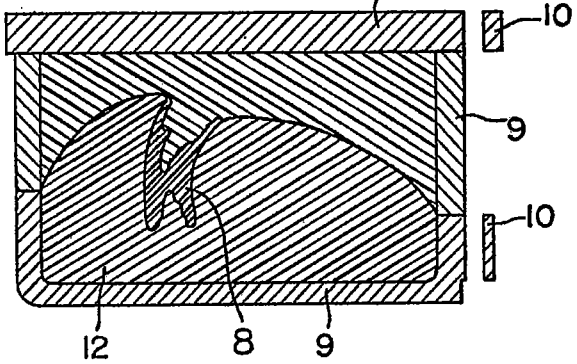


FIG. 10A

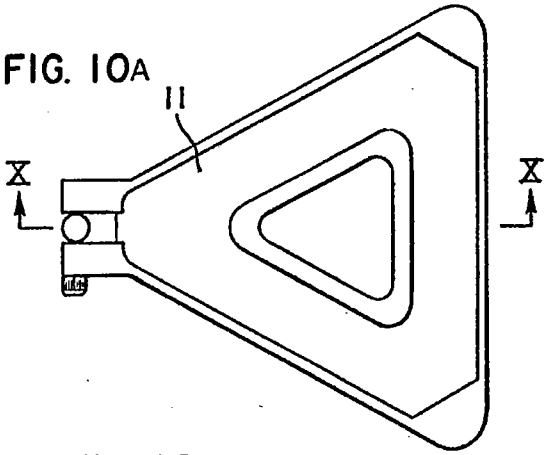
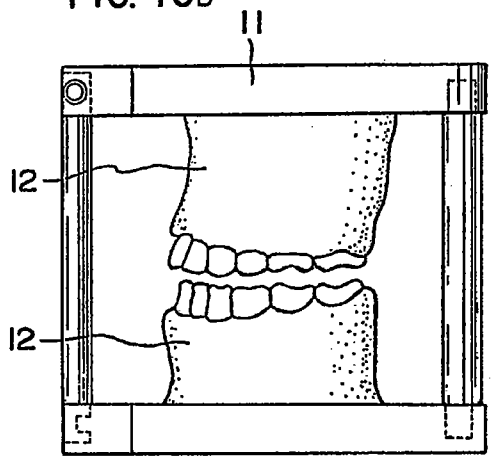


FIG. 10B



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FIG. 10C

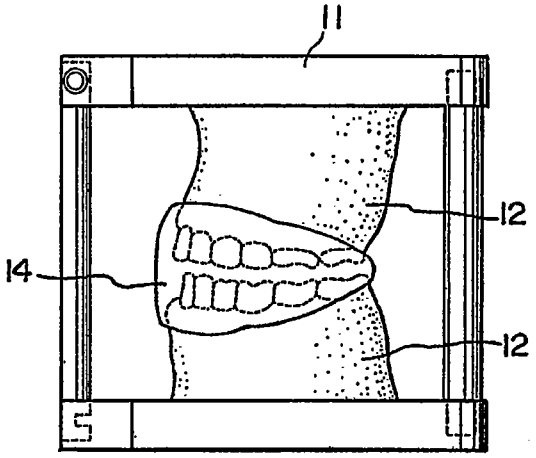
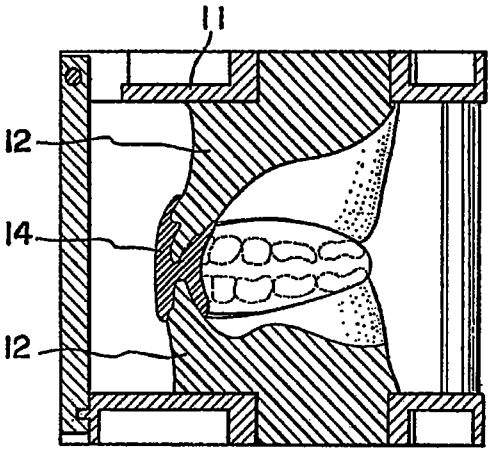


FIG. 10D



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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 667 753 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
19.01.2000 Bulletin 2000/03

(21) Application number: **94901388.2**

(22) Date of filing: **09.11.1993**

(51) Int. Cl.[7]: **A61C 7/00**, A61C 13/00

(86) International application number:
PCT/US93/10858

(87) International publication number:
WO 94/10935 (26.05.1994 Gazette 1994/12)

(54) CUSTOM ORTHODONTIC APPLIANCE FORMING METHOD AND APPARATUS

VERFAHREN UND VORRICHTUNG ZUM HERSTELLEN VON INDIVIDUELL ANGEPASSTENORTHODONTISCHEN EINRICHTUNGEN

PROCEDE ET APPAREIL DE FORMATION D'APPAREILS ORTHODONDIQUES PERSONNALISES

(84) Designated Contracting States:
DE FR

(30) Priority: **09.11.1992 US 973844**
09.11.1992 US 973947
09.11.1992 US 973965
09.11.1992 US 973973

(43) Date of publication of application:
23.08.1995 Bulletin 1995/34

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(56) References cited:
EP-A- 0 502 227
WO-A-90/08512

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Description

[0001] The present invention relates to the design, manufacture and use of orthodontic appliances for the straightening of teeth, and more particularly, to the automated design, manufacture and use of custom orthodontic appliances based on individual patient anatomy and to the diagnosis of patients therefor and the treatment of patients therewith.

[0002] The orthodontic treatment of patients has as its fundamental objective the repositioning or realignment of the teeth of a patient in the patient's mouth to positions where they function optimally together and occupy relative locations and orientations that define a pair of opposed and cooperating planar, or nearly planar, smooth arches. The teeth of the two arches, the maxillary arch of the teeth of the upper jaw and the mandibular arch of the teeth of the lower jaw, when in an optimal or ideal position, contact the teeth of the opposite arch along a surface that is usually flat or slightly upwardly concave and commonly referred to as the plane of occlusion.

[0003] The treatment applied to patients who have been diagnosed as having teeth insufficiently close to the ideal positions to require orthodontic correction includes an initial or rough procedure to overcome the more serious defects of tooth positioning followed by a finish treatment designed to bring the teeth as closely as possible or practical to their ideal positions. The rough treatment usually involves the movement of certain teeth through the use of any of a number of recognized techniques performed by an orthodontia, and sometimes procedures such as the extraction of certain teeth or surgery on the patient's jaw performed by an oral surgeon.

[0004] In the finish treatment, the orthodontia applies an appliance, or set of braces, to the teeth of the patient to exert continual forces on the teeth of the patient to gradually urge them toward their ideal positions. The application of the appliance usually involves the attachment of brackets to the teeth, either with the application of adhesive to the teeth or the securing of bands around the teeth. The brackets are usually each provided with a slot through which an archwire is extended. One archwire is provided for the upper teeth and one for the lower teeth. Typically, the slots in the brackets are of rectangular cross-section and the archwire is of rectangular cross-section. The archwire installed in the slots of the brackets interconnects the teeth, through the brackets, and exerts forces on the teeth to translate or rotate them toward a finish position envisioned by the orthodontist.

[0005] It has been recognized in the design and application of orthodontic appliances that an ideally designed and installed orthodontic appliance will present the slots of the brackets in a position to initially receive a preshaped archwire that will elastically deform to exert corrective forces on the teeth to urge them toward their finish positions. When in their finish positions, the archwire of the ideally designed appliance will no longer be elastically deformed, and will no longer exert forces upon the teeth. Achieving this objective has been inhibited by certain problems in the prior art.

[0006] One problem presented by the prior art is that current orthodontic products are designed and manufactured to average anatomy. As a result, orthodontists are faced with the need to select what they perceive to be the brackets and archwires of the closest design to those required by a particular patient, and to modify the designs for treatment of the patient. Some of this modification may be performed when the appliance is initially installed, but almost inevitably modification is required during the course of treatment of the patient. This modification may take the form of the replacement of brackets, but most commonly requires a periodic bending and reshaping of the archwire as the treatment progresses. Thus, the treatment of the patient has become a manual feedback system in which the orthodontist monitors the progress of the patient's treatment and then readjusts the appliance, usually by bending the archwires, to correct the forces being applied to the teeth to bring the teeth to their ultimate positions, which are less than ideal. As a result, the patient may be subjected to treatment over a period that is longer than would be necessary if the appliance were initially made to the optimum design. In addition, the time required of the orthodontist for implementation of the treatment may be several times greater than it would be if modification of the appliance were unnecessary. Thus, the orthodontist is able to treat fewer patients and the cost of the treatment to the patient or so the orthodontist is increased.

[0007] Location of the connection points for the appliance to the teeth also presents a problem in the prior art. Typically, brackets are bonded to the teeth and then interconnected by the installation of the archwires. This is done when the teeth are in their malocculded positions, with the orthodontist having only a mental vision of where the finish positions of the teeth will be and where the brackets are to be placed to move the teeth so those finish positions. For more effective use of the appliance and to promote ease in cleaning the teeth, the orthodontist prefers to locate the brackets and archwires away from the gums. If they are placed to close to the tips of the teeth, however, they may interfere with the teeth of the opposite arch as the teeth approach their finish positions.

[0008] Another problem of the prior art that has inhibited the selection or design of an ideal orthodontic appliance for the patient is the difficulty in arriving at an expression of the ideal finish position of the teeth. Orthodontists typically make models of the patient's mouth and, with the models and the aid of x-rays, determine a treatment so move the teeth so finish tooth positions. This process is time consuming and presents a source of error and inaccuracy. From the measurements and based on the judgment of the orthodontist, appliance components are selected so implement the prescribed treatment. In reality, the treatment of patients is in many eases more of an art than a science, with results ranging from poor to excellent, and generally variable.

[0009] The need for custom manufactured orthodontic appliances and the use of automatic design techniques has

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been recognized by some, while others have advocated adherence to standard components and manual techniques in view of a perceived lack of practical custom appliance manufacturing and automated appliance design systems of the art.

[0010] E-P-A 0502227 describes a method of forming an orthodontic brace in which a model of a patient's teeth is used to determine the contours thereof and from this, and desired teeth positionings provided by the orthodontist, an appropriate bracket geometry is determined. In determining it, mesio-distal profiles of the teeth are employed, these being two-dimensional representations of individual tooth shapes, the profiles being related to the position of the archwire. The geometry is computed such that the arch wire, when positioned on the brackets, has a substantially linear configuration in a vertical plane and a progressive curvature in a horizontal plane. The computed geometry is then employed automatically to form the brackets which, with the arch wire, are shipped to the orthodontist for fitting.

[0011] WO90/08512 also discloses a method of orthodontic appliance design involving digitization of teeth shape and calculation of desired bracket geometry. In this case the finish position is calculated with respect to the initial position in a mathematical model produced by a CAD system from the digitized information. The orthodontist provides a description of the desired results and account is taken of the patient's physical characteristics. A standard bracket is then modified to provide for the determined necessary tooth movements. As a CAD system is employed, it would seem that an operator calculates the final positions by manipulation of the model displayed as an image.

[0012] The development of automated custom appliance design systems has encountered several difficulties. These difficulties have included the task of developing an automated system that includes reliable and efficient decision making algorithms and techniques for automatically determining an ideal finish position of the teeth. Further, these difficulties have included arriving at an expression of appliance geometry in terms that can be efficiently produced by automated appliance manufacturing equipment. Furthermore, the prior art has not provided a way to accurately manufacture an appliance on an individualized basis in accordance with the appliance design. An additional problem in the automated design and manufacture of orthodontic appliances lies in the difficulty in designing the custom design system to take into account the professionally recognized parameters and criteria, derived over many years from the knowledge and experience of the practicing and clinical orthodontist, upon which diagnosis and treatment is based.

[0013] Accordingly, there is a great need in orthodontics for a practical, reliable and efficient custom appliance automated design and manufacturing system, and method of providing custom appliances and treating patients therewith.

[0014] A primary objective of the present invention is to provide a practical, reliable and efficient custom appliance automated design and manufacturing system and methods of automatically designing custom orthodontic appliances and treating patients therewith.

[0015] It is a particular objective of the present invention to provide an automated custom orthodontic appliance design and manufacturing system that can be easily and reliably used by practicing orthodontists and that will make best use of the skills, knowledge and experience that the orthodontist possesses. It is a further objective of the present invention to increase the accuracy of the orthodontist's treatment, to render the use of the orthodontist's time more efficient, to eliminate sources of error and guesswork from the orthodontist's treatment of patients, and to efficiently, repeatedly and reliably perform automatically the many of the routine steps in the diagnosis, prescription and implementation of orthodontic treatment and in the design and manufacture of orthodontic appliances.

[0016] It is a further objective of the present invention so improve the practice of orthodontics by aiding the practitioner in achieving optimal finish treatment of patients and in more accurately determining and precisely achieving the finish placement of a patient's teeth. An additional objective of the present invention is to provide for the accumulation of data from individual patients for the analysis of the data so advance the orthodontic art.

[0017] It is still another objective of the present invention so apportion the tasks involved in the design and manufacture of custom appliances most efficiently between orthodontist and appliance manufacturing facility in accordance with the scale and other particulars of the individual practitioner operation.

[0018] A method of fabricating a custom orthodontic appliance to position teeth of a patient to preferred finish positions in the mouth of the patient, in accordance with the invention, comprises the steps of measuring anatomical shapes from the mouth of the patient, and producing therefrom digitized anatomical shape data including three dimensional tooth shape data representing the shapes of individual teeth of the patient; deriving an ideal dental archform by processing the digitized anatomical shape data with a digital computer programmed to produce a digitized mathematical archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical shape data and the digitized mathematical archform model to mesio-distally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth; designing a custom orthodontic appliance with the computer from the digitized three dimensional tooth shape data, the established appliance connection points and the derived tooth finish positions, such that the custom orthodontic appliance has an appliance configuration dimensioned to interconnect the teeth at their respective connection points with the teeth in the derived tooth finish positions; producing machine readable control signals containing geometric

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information correlated to the results of the appliance designing step; and automatically fabricating a custom orthodontic appliance with a machine responsive to the machine readable control signals to shape the appliance according to the geometric information contained in the control signals so as to form the custom orthodontic appliance having the designed appliance configuration.

[0019] A custom orthodontic appliance fabricating apparatus, in accordance with the invention, comprises means for measuring anatomical shapes from the mouth of the patient and producing thereby digitized anatomical shape data including three dimensional tooth shape data representing the shapes of individual teeth of the patient, a digital computer including program means for deriving an ideal dental archform from the digitized data with a specially programmed digital computer to produce a digitized archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical data and the derived digitized ideal archform to mesio-distally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth designing, from the digitized tooth shape data, established appliance connection point and the derived tooth finish positions, an appliance configuration such that a custom appliance fabricated in accordance therewith is dimensioned to interconnect the teeth at the connection point with the teeth in the derived tooth finish positions, and producing machine code containing geometric information correlated to the designed appliance configuration; and a machine for automatically fabricating a custom orthodontic appliance in response to the machine code to shape the appliance, according to the geometric information so as to form the appliance with the designed appliance configuration.

[0020] The system and method depart from traditional design and manufacture by designing orthodontic appliances around the anatomy of the individual patient. Further, unlike current orthodontic products that are designed and manufactured to avenge anatomy, the orthodontic products of the present invention and the methods of manufacturing and using them are tailored to the individual anatomy of the patient.

[0021] These and other objectives and advantages of the present invention will be more readily apparent from the following detailed description of the drawings in which:

Figs. 1-1F are diagrams illustrating the preferred embodiments of the system of the present invention, of which:

Fig. 1 is a block diagram illustrating one preferred embodiment of an automated system for the design and manufacture of custom orthodontic appliances for the treatment of patients therewith according to the principles of the present invention.

Fig. 1A is an elevational diagram of a video graphics image forming embodiment of the data input portion of one embodiment of the scanner of the system of **Fig. 1**.

Fig. 1B is an elevational diagram of a laser scanner version of a three dimensional graphics imaging embodiment of a scanner of the system of **Fig. 1**.

Fig. 1C is an elevational diagram of a mechanical tooth profile probe scanner version of a two dimensional imaging portion of one embodiment of the scanner of the system of **Fig. 1**.

Fig. 1D is an isometric diagram of one embodiment of a bracket cutting device of the system of **Fig. 1**.

Fig. 1E is an isometric diagram of one embodiment of a wire forming device of the system of **Fig. 1**.

Fig. 1F is an isometric diagram of a bracket placement jig forming device of the system of **Fig. 1**.

Figs. 2-2D are flow chart diagrams of the preferred methods of carrying out the present invention, of which:

Fig. 2 is a flow chart of one preferred embodiment of the process of the present invention performed with the system of **Fig. 1**.

Fig. 2A is a more specific flow chart illustrating the steps of the input procedure of automated tooth positioning and appliance design and manufacturing operation of the process of **Fig. 2**.

Fig. 2B is a more specific flow chart illustrating the steps of the analysis and tooth finish position calculating procedure of the automated tooth positioning and appliance design and manufacturing operation of the process of **Fig. 2**.

Fig. 2C is a more specific flow chart illustrating the steps of the custom appliance design procedure of the automated appliance design and manufacturing operation of the process of **Fig. 2**.

Fig. 2D is a more specific flow chart illustrating the steps of the custom appliance manufacturing procedure of the automated tooth positioning and appliance design and manufacturing operation of the process of **Fig. 2**.

Figs. 3-3C are illustrations of graphics computer images produced in the input procedure, in which:

Fig. 3 is an example of a computer display of a video image generated by the scanner of the system of **Fig. 1** illustrating in a top plan view a mandibular model produced by the scanner of the type shown in **Fig. 1A**.

Fig. 3A is an example of a portion of a three dimensional digital image, illustrated in perspective, and produced by the scanner of the type shown in **Fig. 1B**.

Fig. 3B is an illustration similar to **Fig. 3A** of another portion of a three dimensional digital image produced by the scanner of **Fig. 1B**.

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Fig. 3C is an example of a set of vertical tooth profile images produced by the scanner of **Fig. 1C.**

Figs. 4-4E are plan views of the teeth of the patient on tooth placement archforms at various stages of the tooth position calculation procedure of **Fig. 2B**, of which:

Fig. 4 is a geometric diagram illustrating a horizontal plan view data input screen showing diagrammatically the video image of **Fig. 3** used as a template, with variables relevant to the digitization of data from the mandibular video image marked thereon.

Fig. 4A is a geometric diagram similar to **Fig. 4** for the maxillary teeth.

Fig. 4B is a geometric diagram plotting horizontal mandibular archforms calculated through the analysis procedure of **Fig. 2B.**

Fig. 4C is a geometric diagram plotting horizontal maxillary archforms calculated through the analysis procedure of **Fig. 2B.**

Fig. 4D is a horizontal plan diagram showing the maxillary teeth in their finish positions.

Fig. 4E is a horizontal plan diagram showing the mandibular teeth in their finish positions and with the custom appliance in place.

Figs. 5-5P are mathematical calculation diagrams for reference in connection with apline to circle conversion and tooth placement routines, in which:

Fig. 5 is a horizontal plan diagram illustrating the placement of a tooth on an archform equation described in circle segment form.

Figs. 5A-5J are detailed diagram of the spline to circle conversion and tooth placement subroutines.

Figs. 5K-5P are detailed diagrams of the tooth placement subroutine.

Figs. 6-6I are diagram of tooth profiles illustrating landmark determination, tooth inclination and vertical positioning, in which:

Fig. 6 is an isometric image of a three-dimensional computerized representation, similar to **Fig. 3A**, of a molar showing the locations of alternative vertical labial-lingual profile planes and tooth profiles.

Fig. 6A is a mathematical tooth profile plot as illustrated on the computer screen of the system of **Fig. 1** of a mandibular molar showing selected landmark parameters.

Fig. 6B is a mathematical tooth profile plot, similar to **Fig. 6A**, of a mandibular cuspid or incisor showing selected landmark parameters.

Fig. 6C is a mathematical tooth profile plot, similar to **Fig. 6A**, of a maxillary molar or bicuspid showing selected landmark parameters.

Fig. 6D is a mathematical tooth profile plot, similar to **Fig. 6A**, of a maxillary cuspid or incisor showing selected landmark parameters relevant thereto.

Fig. 6E is representation of a display, similar to **Fig. 3C**, of an array of mathematical tooth profile plots of all of the teeth, angularly oriented, with landmark parameters marked thereon.

Fig. 6F is representation of a display of an array of mathematical tooth profile plots, similar to a portion of **Fig. 6E**, of the mandibular teeth with working horizontal placement planes marked thereon.

Fig. 6G is mathematical tooth profile plot, similar to **Fig. 6A**, of a mandibular posterior tooth with relevant dimensional variables for placement of the tooth marked thereon.

Fig. 6H is mathematical tooth profile plot, similar to **Fig. 6B**, of a mandibular anterior tooth with relevant dimensional variables for the placement of the tooth marked thereon.

Fig. 6I is mathematical tooth profile plot, similar to **Fig. 6H**, of the tallest mandibular tooth.

Figs. 7-7D are diagrams for reference in connection with the finish tooth position calculation, of which:

Fig. 7 is an elevational diagram of the relationship of the jaws of a patient for illustration of cuspid rise occlusion calculation.

Fig. 7A is an enlarged view of a portion of **Fig. 7.**

Fig. 7B is a plan mathematical diagram illustrating certain of the mathematics of tooth placement on the mandibular offset arch.

Fig. 7C is a perspective diagram illustrating the relationship of the vertical tooth profile planes and relevant horizontal arch planes in the course of tooth finish position calculation.

Fig. 7D is a set of related elevational profiles of mandibular and maxillary teeth showing occlusal and overlap relationships in the course of tooth finish position calculations.

Figs. 8-8H are diagrams for reference in connection with the steps of the custom appliance design procedure, of which:

Fig. 8 is a diagram similar to **Fig. 7D** illustrating archwire plane and bracket slot design on positioned teeth.

Fig. 8A is an elevational diagram illustrating a bracket and slot configuration in connection with the diagram of **Fig. 8.**

Fig. 8B is a top view illustrating the relation of a tooth to an archform by placement routine.

Fig. 8C is a tooth profile diagram illustrating the slot in-out dimension calculation.

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Fig. 8D is a perspective diagram illustrating the placement of a custom bracket onto a tooth with the use of a custom placement jig.

Fig. 8E is a plan diagram of a custom archwire for the appliance required to move the mandibular teeth to the finish positions illustrated in **Fig. 4E**.

Fig. 8F is a plan diagram illustrating the labial installated appliance on the teeth of the patient in their initial positions.

Fig. 8G is a plan diagram, similar to **Fig. 8F**, illustrating a lingual appliance installed on the teeth of the patient.

Fig. 8H is an elevational diagram illustrating an orthodontic lingual bracket of the appliance of **Fig. 8G**.

Fig. 8I is a top view of a bracket having a base slot curvature conforming to that of an archwire supported therein.

Figs. 9-9W are diagrams relating to appliance manufacturing steps, of which:

Figs. 9-9H relate to substeps of the bracket slot cutting code generation and bracket manufacturing step.

Figs. 9I-9W relate to the substeps of the bracket placement jig manufacturing step.

[0022] The overall configuration of the system 10 is illustrated diagrammatically in **Fig. 1**. The overall operations of the preferred method of the invention are illustrated in the flowchart of **Fig. 2**, where examination of a patient is performed by an orthodontist at the orthodontist's office to assemble information to determine the patient's condition, prescribe the approrpriate treatment, and specify the type of orthodontic appliance to implement the treatment. The information is communicated to a remotely located appliance design and manufacturing facility where the design of a custom appliance for use in administering the treatment is carried out with the use of computer analysis. The appliance design, together with the information necessary for the orthodontist to install the appliance on the patient is then transmitted back to the orthodontist, who installs the appliance and administers the treatment in accordance with the appliance manufactures instructions and his own professional expertise.

SYSTEM CONFIGURATION

[0023] Referring to the system diagram of **Fig. 1**, an orthodontic appliance manufacturing and patient treatment system 10 is illustrated. The system components are distributed between two locations, a doctor's office 11, and an appliance design and manufacturing facility 13. At the doctor's office 11, a patient 12, who requires orthodontic treatment, is examined by an orthodontist 14, who makes a diagnosis 15 of the condition of the patient and of the treatment, if any, needed. The examination involves the traditional application of the skill, knowledge and expertise of the orthodontist 14, and results in the preparation of detailed records 16 of the anatomy and condition of the mouth 18 of the patient, of the treatment proposed, and of other information necessary to the preparation of an orthodontic appliance.

[0024] The records 16 prepared by the orthodontist include a physical modal 20 from a mold of the patient's mouth 18, which includes a mandibular model 21 of the patients lower jaw or mandible 22 and a maxillary model 23 of the patient's upper jaw or maxilla 24. The records 16 also include prescription 27 wherein the orthodontist sets forth a treatment to be applied to the patient and a result to be achieved by the treatment. The prescription 27 may also include a specification of techniques that are to be included in the treatment and a designation of an orthodontic appliance to be employed. The records 16 will further include identification information 17 and patient history information 19.

[0025] In the illustrated embodiment of the invention, the records 16 are transmitted to the appliance manufacturing facility 13, at which the finish position of the teeth are calculated and a custom appliance 25 is designed and manufactured. The facility 13 is provided with one or more trained operators 28. In some embodiments, the physical model 20 itself is transmitted in the information 16 to the facility 13. In such cases, one of the primary functions of the operators 28 is to input digital information 26 from the records 16 into a computer 30a. Another function is to operate the same or another computer 30b to design the custom appliance 25, and to operate NC equipment 38 controlled by one of the same or another computer 30c to manufacture the appliance 25. Where the inputing, design and manufacture are performed at the appliance facility 13, the computers 30a, 30b and 30c may be the same computer 30.

[0026] In other embodiments of the invention, the orthodontist 14 digitizes data from the model 20, in which case the inputing computer 30 is located at the orthodontist's office 11. In these embodiments, the digitized information 26, rather than the physical model 20, is transmitted to the appliance facility 13. The analyzing and appliance design computer is nonetheless preferably at the appliance facility 13.

[0027] The entry of the information into the input computer 30 involves a digitizing of the information 16 to produce the digitized anatomical information 26 in machine readable form for analysis by the analyzing computer 30b. The input computer 30 connected thereto by a scanner 33, which, in the alternative embodiments of the invention, includes equipment that employs one or more video cameras, mechanical probes, laser scanners, ultrasonic scanners, moire image scanners or other forms of imaging or measurement hardware that alone, or in combination with other such components, produce anatomical geometric information that describes the patient's teeth and jaw. The images may be three-dimensional or be made along a plurality of planes or other surfaces that can ultimately be combined to provide information in three dimensions.

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[0028] The combined information from the scanner 33 of the illustrated embodiment provides a basis for three dimensional analysis of the patient's teeth and from which calculations of finish tooth positions can be made. From the final positional calculations and tooth anatomy data, automatic design and manufacture of the custom orthodontic appliance 25 is carried out. In the illustrated embodiment, the data is imaged in a plurality of differently oriented two dimensional planes in the computer 30, then mathematically manipulated and combined in the computer 30b to construct a three dimensional solution to the tooth positioning and appliance design problems.

[0029] In a configuration in which the scanner 33 is connected to a separate dedicated inputing computer 30 is herein described, the functional equivalent of the inputing computer 30 may be included in circuitry within the scanner 33 itself.

[0030] Preferably, the digital input process utilizes interactive methods by which an operator 28 uses a pointing device and digitizer to select particularly useful orthodontic parameters from graphics images produced by the scanner 33 on a screen 35 of a display connected to the inputing computer 30.

[0031] In embodiments where some or all of the extraction of the digitized anatomical information 26 from the model 20, which my also be derived directly from the mouth 18 of the patient 12, is accomplished by the orthodontist 14 at the orthodontist's office 11, the information 26 is digitized by the orthodontist 14 then transmitted as part of the information 16 to the appliance design center 13. The transmitted information 16 is preferably transmitted from the orthodontist's office 11 to the appliance facility 13 by modem, but may be transmitted in any other available manner.

[0032] An analysis and design computer 30b, preferably at the appliance design facility 13, produces an archive diskette 34 that is formatted and written with all of the relevant information of the analysis and the history and prescribed treatment of the patient 14.

[0033] The computer 30b at the appliance facility 13 calculates, based on the digitized information 26, the final position of the patients teeth, and the configuration of the appliance 25 required to move the patient's teeth to this final or finish position. As a result, calculated information for the patient is stored in a patient data file 36. From the calculations the computer 30c produces CNC machine readable code 42 for operating NC manufacturing equipment 38 to produce the appliance 25. An instruction document or file 37 is also produced, either by the computer 30b or the computer 30c, of information to aid the orthodontist 14 in creating the patient 14 with the custom appliance 25.

[0034] The manufacturing equipment 38 includes an appliance bracket cutting or forming machine 39 which produces custom brackets for the appliance 25 by cutting slots calculated angles and to calculated depths in slotless generic brackets. The machine 39 may also or alternatively shape the surfaces of the bracket bases. This provides the bracket design option of torquing the teeth by either the bracket slot or base, as may be best for various bracket materials.

[0035] The equipment 38 also includes an appliance archwire bending or forming machine 40 which produces custom shaped archwires for the appliance 25 by feeding and bending wire of any one of several available materials and stiffnesses into the custom archwire shape. The equipment 38 may also include a machine for forming patient treatment components and hardware to aid in the manufacture or installation of the appliance 25. In the illustrated embodiment, this includes a machine 41 for the making of bracket placement jigs, which cuts each tooth crown portion of the tooth profile into a plastic form, along with a superimposed cutout of the positioned bracket, for use in accurately installing the custom brackets in their calculated positions on the teeth.

[0036] The appliance manufacturing machines 38 may be connected directly to the analyzing computer 30b or one or more my be connected to a separate manufacturing equipment controlling computer or machine controller 30c. The computer 30c may be located at the appliance facility 13 or, together with one or more of the appliance manufacturing machines 38, 40 or 41, be located at the orthodontist's office 11. In one preferred embodiment of the invention, one manufacturing computer 30c and the bracket cutting machine 40 arc located at the orthodontist's office, along with the scanner 33 and input computer 30, which may be the same computer as the manufacturing computer 30c, while another manufacturing central computer 30c, which may be the analyzing computer 30b, the wire beading machine 40 and the jig forming machine 41 are located at the appliance facility 13. The optimum distribution of the computers 30, 30b and 30c and the scanner 33 and appliance manufacturing machines 38, 40 and 41 will be determined by the scale of the orthodontist's practice and the orthodontist's preferences. In the illustrated embodiment, the computers 30-30c are IBM PC clones, with Intel 80386 or 80486 microprocessors and equipped with 80387 or 80487 math coprocessors, respectively.

[0037] Certain components of the system 10 of **Fig. 1** are described below in further detail.

Scanning Assembly 33

[0038] Three steps in the information input procedure (82), described below, involve the inputing into the computer 30, for analysis in digital form, of data concerning the shape of the mouth 18 of the patient 12 and of the shapes of the individual teeth therein. In these steps, digitized images and measurement data of the mouth 18 of the patient 12, preferably taken indirectly from the model 20, are digitized to form a three dimensional mathematical model of the patient's mouth 18. The mathematical model includes, in the preferred embodiment of the invention, the definition of certain parameters of the patient's lower jaw and individual teeth, and my include come information of the initial position and

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orientation of the teeth in the mouth 18 of the patient 12 for evaluating the magnitude of the treatment.

[0039] The input information 26 is, in some embodiments of the invention, input as a full three dimensional image, and then simplified by reducing it to a plurality of curves in a plurality of differently oriented planes or fairly flat curved surfaces, each defined in the independent *X-Y* coordinate system of the respective surface or plane. In subsequent analysis, these planes are oriented, translated and rescaled with respect to each other in arriving at a derivation of the ideal finish positions of the teeth and the design of the custom appliance 25. In accordance with the preferred embodiment of the invention, curves and points on the contours of the jaw and teeth of the patient 12 are expressed in terms of accepted or generally applicable orthodontic parameters so that manual and automated decision making can combine and coordinate the best of orthodontic knowledge and experience with the efficiency and precision of computer analysis to minimize the use of the orthodontist's time, shorten the patient's treatment period and optimize the final treatment result.

[0040] The various types of and components of the scanner 33 of various embodiments of the invention are described below.

Video Scanning Data Input Assembly 43:

[0041] One preferred form or component of the scanner 33 includes a video imaging assembly 43 as illustrated in **Fig. 1A**. The video imaging assembly 43 includes one or more video cameras 44 which each produce two dimensional images of the patient's mouth 18, preferably by forming an image of the model 20. When two or more are used together, the video assembly 43 produces stereo images capable of being resolved in three dimensions. In the illustrated embodiment of the invention, a single video camera 44 is employed to produce two dimensional video images of a plan view of the patient's lower or upper jaws 22 and 24, from the models 21 or 23, respectively, in generally horizontal *X-Y* planes. In accordance with this embodiment, other forms or components of the scanner 33 are preferably employed to produce information in a third dimension as described below.

[0042] Referring to **Fig. 1A**, the video imaging assembly 43 is shown diagrammatically in side elevation at the appliance manufacturer's facility 13. The video imaging assembly 43, in its preferred form, is an operator-computer graphical interface that includes the video camera 44 connected to a video interface board 44a in the input computer 30. The camera 44 is mounted on a stand 45 to face downwardly to form a top plan view of one of the halves 21 or 23 of the model 20, shown as the mandibular portion 21 in **Fig. 3**, on a horizontal support 46 attached to a base 45a of the stand 45. The model half 21 or 23 is positioned on the support 46 such that the teeth face upwardly toward the camera 44 and so that the tips thereof lie generally in a horizontal plane that is maintained at a known fixed distance from the camera 44, so that the scale of the image formed by the camera 44 is known. This may be accomplished by mounting the support 46 on springs 46a to urge the model half 21 or 23 upwardly against a transparent horizontal plate 45b.

[0043] The input computer 30 has connected thereto a pointing device which may be a mouse 47a or, as shown, a mouse equipped digitizer board 47. The camera 44 produces a graphics image display 48 on the screen 35 of the computer 30, which an operator 28 may align with the assistance of a positioning grid *G* (**Fig. 4A**). With the digitizer 47, the operator selects points by positioning a cursor 48a on the screen 35 with the mouse 47a. The selection results in the storage of *X,Y* coordinate data for each of the points selected. The points selected, in the description of the preferred process below, correspond to preselected boundary points of the teeth and, from the mandibular model 21, the lower jaw. From these top view boundary points. tooth and mandibular jaw dimensions are calculated. The calculated dimensions are used in analysis steps to calculate equations for the mandibular bone structure or mandibular trough *MT* and to calculate from the trough equation and the calculated horizontal dimensions and relative positions of features on individual teeth the finish positions of the teeth.

[0044] In the alternative to selecting points from the video image display 48, the same points may be selected in the same manner from a plan view video image of a digitized three-dimensional computerized image of the teeth and jaws, such as an image formed by a laser scanner, moire interference pattern scanner, ultrasonic scanner, stereo video cameras, or other three-dimensional imaging apparatus. Sectional displays 55a and 55b of such a three-dimensional computerized image made with a laser scanner are shown in perspective in **Figs. 3A and 3B**, respectively. Such a laser scanner is described in connection with **Fig. 1B** below.

Laser Three-dimensional Image Input Assembly 51:

[0045] One preferred form or component of the scanner 33 is the laser generated three-dimensional image forming assembly 50 illustrated in **Fig. 1B**. Referring to **Fig. 1B**, one of the halves 21 and 23 of the model 20 is mounted on a support 51 while laser 52 directs a laser beam 52a onto the model 21 or 22. The laser beam 52a is reflected and the reflected beam is detected by a sensor 53 composed of a photoelectric pixel array which uses a triangulation method to convert a change in position on the sensor into a change in distance between the assembly 50 and the model 21 or 23 mounted to translate parallel to the model 21 or 23 on a support 54 so as to scan the model with the laser beam.

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Equipment for producing images using laser technology in this manner is commercially available for forming computerized representations in three dimensions of manufactured and other objects. An example of equipment suitable for this purpose are the Cyber Scan™ Measurement System manufactured by Cyber Optics Corporation of Minneapolis, Minnesota. The images formed by such equipment would preferably include full detailed three-dimensional image data of the patient's lower and upper jaws 22 and 24, taken from the model 20, with the teeth in their original positions. The data is written in standard ASCII files by the equipment described and is readable by the input computer 30a into the digitized information files 26.

[0046] Illustrated In **Figs. 3A** and **3B** are two sections of the mandibular digitized model, and include a section 55a showing the front mandibular incisors T_{BR1} and T_{BL1} of the patient 12, and a section 55b showing the right mandibular second bicuspid T_{BR5} and first molar T_{BR6} of the patient 12. When such images are rotated to a horizontal plan view, a derivation of the same information that is available from the video imager 43 of **Fig. 1A** may be derived, and points may be selected therefrom for digitization automatically with software, or through an operator/computer interactive process as with the video scanner 43. The three-dimensional image 55 may be rotated into other orientations for the derivation of other information in various planes such as vertical tooth profile information that is derived with the mechanical scanner 57 described below. Additionally, other computerized procedures may be used to automatically derive information from the three dimensional image 55 with or without intervention or interaction by an operator.

Mechanical Probe Digital Scanner Assembly 57:

[0047] The scanner may also include, alternatively or in combination with other scanning equipment such as to video scanner assembly 43 of **Fig. 1A** or the laser scanning assembly of **Fig. 1B** above, a mechanical probe assembly 57 as illustrated in **Fig. 1C**. This entire assembly 57 is used in the illustrated embodiment of the invention in combination with the video scanner 43 to derive labial-lingual vertical profiles of the individual teeth of the patient from the model 20 to supplement jaw and horizontal tooth dimensional and shape information derived from a video image produced by the video scanner 43 from the model 20. Alternatively, portions of this assembly can be used to produce the same information from a three dimensional image 55 produced by equipment such an the laser scanning assembly 50.

[0048] Referring to **Fig. 1C**, the probe assembly 57 includes a measurement probe 60 which is moveable over the individual teeth of the model 21 to produce an electrical signal that is digitized for computer input of point locations or profiles of the surfaces of the teeth in separate *X-Y* for each tooth. In the illustrated embodiment of the process of the invention, to information 26 preferably derived from the model 21 includes the tooth profiles curves PF_j in a labial-lingual plane viewed in a mesial-to-distal direction.

[0049] The probe assembly 57 further includes a magnetic base 59 upon which is mounted the model 20, and from which extends an upstanding vertical support 58 on which to probe 60 is mounted. The probe tip 60a is freely rotatable about a vertical axis on which its tip lies, while the probe itself is hooked to allow the tip to track recesses in the surfaces of the teeth of the model 21. The probe 60 is mounted on the support 58 to move in *X* and *Y* directions in a vertical plane preferably that extends through the support 58 and the probe 60. In this manner, the probe tip 60a is positioned to scan the surface of a tooth of the model 21 along this plan. The probe 60 is linked to to support 58 through a pair of orthogonal measurement position transducers 61, which respectively generate electrical analog measurements of the positions of the tip of the probe 60 along respective ones of the *X-Y* orthogonal coordinates. The outputs of the transducers 61 are connected to circuitry that generates a sequence of periodic readings of the transducer measurements of the probe tip positions which are then digitized. These outputs are sent in along lines 61a connected to input computer 30, preferably to a serial port thereof.

[0050] In use, a half of the model 20, for example, to mandibular model 21, is mounted upon the magnetic base 59 on a steel surveyors mount 62 which slides on the base 59 when lightly urged, but which otherwise holds its place thereon for precise positioning. The mount can be raised, lowered or tilted for positioning and for leveling. In operation, the probe 60 is manually moved by an operator 28 or automatically to scan the surface of each selected tooth of the model 21 to produce profile curves *PF* of a section of each tooth as illustrated in **Fig. 3C**. The profile *PF* may be generated by any one of a number of commercially available off-the-shelf CAD/CAM or illustration software packages, such as VERSACAD™ available from Prime Computers. Inc. of Bedford, Massachusetts. The video images 63 of the profiles *PF* are displayed on the screen 35 and the digitized profiles are stored as part of the input information 26 in non-volatile memory of the computer 30.

[0051] With the curves such as the profile *PF* so formed, an operator can, with the use of the pointing device 47, select, by positioning the cursor on the formed profile on the screen 35, point parameters of the tooth, the coordinates of which can be thereby input digitally into the computer 30.

Appliance Manufacturing Equipment 38

[0052] The manufacturing equipment 38 of the preferred embodiment of the invention includes: an appliance bracket

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cutting or forming machine 39 that custom forms the bracket bases to mount to the teeth and cuts archwire slots in the brackets at precise calculated positions and angles; an appliance archwire bending or forming machine 40 that precisely bends archwires to a shape that will cooperate with the custom brackets to apply corrective forces to the teeth until they are in their calculated finish positions; and a bracket placement jig forming machine 41 that manufactures bracket placement jigs that conform to the contours of the patient's teeth, as recorded in the profiles *PF*. These jigs are used by the orthodontist to precisely place the custom brackets at calculated positions on the teeth.

[0053] The manufacturing equipment 38 is controlled by NC computer generated programs based on the data from the digitized input information files 26 and the calculated patient data riles 36.

Bracket Cutting Machine 39:

[0054] Referring to **Fig. 1D**, a bracket slot cutting machine 39 is illustrated. The machine 39 includes a stationary base 72 on which is fixed a pair of upwardly extending workpiece support brackets 72a to the top of which is pivotally mounted a workpiece or bracket support 73. On the support, a full set 80a of brackets 80 for the custom appliance 25 is mounted, prearranged in an assembly or cartridge of twenty or twenty-four brackets. The support 73 pivots about an axis 73a extending between the brackets 72a. Connected to the axis 73a is an angular positioning motor 74 which positions the support 73, and the brackets 80 mounted thereto, to any angular orientation with respect to the horizontal. The motor 74 has an input connected to the computer 30c to set the inclination to the slot inclination angle of the bracket design in response to NC command codes.

[0055] Also fixed to the base 72 and extending upwardly therefrom is a saw support bracket 72b. To the top of the support bracket 72b is a saw drive motor 75 and a set of three saw blade positioning linear drive actuator 76, including an X-drive actuator 76x. a Y drive actuator 76y, and a Z drive actuator 76z through which a saw support arm 77 is supported to move respectively in the X, Y and Z directions, that is, in an X direction horizontally perpendicular to the axis of rotation 73a of the bracket holder 73, in a Y direction horizontally parallel to the axis of rotation 73a of the workpiece holder 73, and in a vertical Z direction. The actuators 76 have inputs connected to the computer 30c to receive positioning signals from the computer 30c to cut arcuate slots in the X-Y plane of the machine 39 in response to NC commands generated in accordance with a custom appliance design.

[0056] At the remote end of the movable arm 77 is a slot cutter assembly 77a, drivably linked to the motor 75. The assembly 77a has extending downwardly therefrom a rotatable cutter blade drive shaft 77b, which has fixed to the lower end thereof a circular slot cutter blade 77c. The blade 77c lies in the horizontal X-Y plane and is of the thickness of the slot needed for the thickness of archwire selected. The archwires are typically rectangular in cross-section so that they are able to exert torque on the bracket, which accordingly will be provided by the saw blade 77c with a slot of rectangular cross-section. The base of the slot will be cut, in accordance with the command signals from the computer 30c, at an angle in the X-Y plane of the machine 39 that is tangent to the final curve of the archwire that it will receive. The base of the slot will be convex to accommodate the curve of the wire in the horizontal plane. The base of the slot will be convex to accommodate the curve of the wire in the horizontal plane. The inclination of the bracket slot is achieved by the angle of the support 73 in response to control signals from the computer 30c. The computer 30c is programmed to account for changes in elevation of the bracket 80 due to the offset of the brackets from the support axis of rotation 73a.

Wire Reading Machine 40:

[0057] The wire bending apparatus 40 is illustrated diagrammatically in **Fig. 1E**. Primary control of the apparatus 40 is preferably by an IBM PC clone, preferably with an 80386 or 80486 microprocessor with a math coprocessor, and with motion controller board 65 installed. The controller board 65 is, for example, an MC300 Motion controller 3-axis card manufactured by Motion Engineering, Inc. The MC300 is a dedicated motion control card which sends and received signals to and from MC-OLS stepper interfaces 66a and 66b. MC-OLS stepper motor interfaces 66a and 66b send control signal commands to the stepper motor power supplies 67a and 67b, such as Compumotor S-Drive stepper power supplies #88-011483D, regarding rate and direction of motion of the motors.

[0058] The power supply 67a has an output connected to wire feed rollers 68, positioned on opposite sides of a wire guide 68a, which guides archwire 69 to feed it from a continuous coil supply. The power supply 67b has an output connected to a wire bending roller assembly or wire anvil 70.

[0059] The controller 66b additionally is adapted to receive feedback signals regarding position from a disc encoder 70a, such as a Dynapar/Veeder Root #E1000A76500, which monitors the position of wire forming roller 70b, providing closed loop control of a wire bending roller 70b. The roller is driven by a wire anvil motor 70c, such as a Compumotor #S/SX 57-102, through a drive screw 70d, such as an Industrial Devices Corp. Electric cylinder #X995A-2-M56-MT1-200-PS. The screw 70d converts the angular position of the motor 70c into linear motion of the roller 70b to deflect and bend the wire 69 as it is fed through the guide 68a by the rollers 68.

[0060] By coordinating the anvil 70 and the wire feed 68, formed archwires 64 of any planar shape are fabricated. The

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rollers 68 pinch the wire, forcing it to advance into the anvil 70. The roller 70b of the anvil 70 moves up and down varying the radius and thus controlling the radius to which the wire is permanently deformed. If the formation of archwires with inflection points, that is that have bends in opposite directions, a second anvil would be provided opposite the wire 69 from the anvil 70 and controlled in synchronism therewith.

[0061] A wire position sensor 71 is provided that inspects the finished archwire by comparing the width of the formed wire 64 to the desired width. The sensor 71 is mounted with respect to the anvil 70 and feed rollers 68 to detect the position of the formed archwire 64 when it is at the end of its forming cycle. This measurement provides a feedback signal that provides compensation for material property variations that effect the formed shape and the amount of overbending required. The sensor 71 sends information back to the computer 30c as to whether the wire 64 is acceptable or over-bent or under-bent. If the wire is either over or under-bent, the computer 30c calculates the correction required and incrementally modifies the signals through the interfaces 66a and 66b to provide compensation to progressively correct successive archwires 64 until the result of the signal from the sensor 71 is deemed acceptable by the computer 30c.

Bracket Placement Jig Forming Machine 41:

[0062] The bracket jig forming equipment 41 is preferably a standard NC mill configured as illustrated in **Fig. 1F**. The machine 41 includes the standard mill 81, having a downwardly projecting rotary tool head 81a on which is mounted an endmill tool 81b of, for example, 0.5 mm (0.020 inches) in diameter, where 0.55 mm (0.022 inch) archwire is used, and, for example 0.4 mm (0.016 inches) in diameter where 0.45 mm (0.018 inch) archwire is used.

[0063] The mill 81 is either connected to a controller which will have been loaded with CNC program code 42 prepared by the computer 30c or will be directly connected to the computer 30c. The mill 81 is provided with a tool support 81c to which a set of circular ABS plastic jig blanks 83, usually twenty or twenty-four in number, are fed by a feeding mechanism 81d, equipped with a magazine 81e of the sets 83a of jig blanks 83. The tool head 81a is moveable vertically to bring the tool 81b into contact with the blanks 83 and horizontally in the *X-Y* directions in accordance with the tool path instructions from the code 42.

GENERAL OPERATIONS AND PROCEDURES

[0064] One preferred method of the invention is represented by the operations and procedures illustrated in the flowchart of **Figs. 2**.

[0065] The method preferably includes three general operations: (85) a patient evaluation operation performed by the orthodontist 14 at the doctor's office 11 on the patient 12; (87) a computer aided analysis and appliance design and manufacturing operation performed, preferably at least in part, at the appliance facility 13 to produce the custom appliance 25, and (89) a patient treatment operation that includes treatment of the patient 12 by the orthodontist 14 at the doctor's office 11 to install and use the appliance 25.

(85) Patient Evaluation Operation

[0066] Referring to the system diagram of **Fig. 1** and the flow chart of **Fig. 2**, the orthodontic evaluation operation (85) is performed at a doctor's office 11. The operation (85) includes the procedures (90) of the examination of a patient 12, (91) the preparation of the model 20 of the patient's mouth and teeth, (92) the prescription by the orthodontist 14 of treatment, (93) and communication to the appliance facility 13.

[0067] The examination procedure (90) the patient 12, who requires orthodontic treatment, is examined by an orthodontist 14, who makes a diagnosis 15 of the condition of the patient and of the treatment, if any, needed. Based on the diagnosis 15, the orthodontist or doctor 14 assembles the information 16 that is necessary to implement the prescribed treatment.

[0068] In assembling the information 16, the orthodontist 14 (91) prepares a model of the patient's mouth 18, usually a physical model 20 from a mold of the patient's mouth, in its initial condition at the time of the diagnosis 15. The model 20 includes the mandibular model 21 of the patient's lower jaw or mandible 22 and the maxillary model 23 of the patient's upper jaw or maxilla 24.

[0069] Then, further based on the diagnosis 15, the orthodontist 14 (92) prescribes a particular treatment and generates a prescription 27 in a tangible record form.

[0070] The orthodontist 14 then (93) communicates the information 16, for example, by transmitting the model 20, the prescription for treatment 27, a record of information 17 identifying the doctor 14 and the patient 12, together with information 19 containing statistical and historic data of the patient 12, to an appliance design facility 13, at some remote location. At the appliance design facility 13, the information 16 is digitized and input into the computer 30 for analysis.

[0071] Alternatively, the orthodontist 14 may convert the information 16 to digital computer readable form and transmit

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the digitized information to the appliance design facility 13. In this alternative, the system 10 would be configured with the input computer 30 located at the orthodontist's office 11, and the orthodontist 14 or assisting personnel would perform portions of a data input procedure (94) described below.

(87) Analysis, Design and Manufacture Operation

[0072] When the information 16, which includes, for example, the model 20, the prescription 27 and the information 17 and 19, are received either at the appliance system manufacturer 13 or is ready to be digitized at the orthodontist's office 11, (87) an analysis, finish tooth position calculation, and orthodontic appliance design and manufacturing operation is begun. In the operation (87), the information 16 is processed and the custom appliance 25 for moving the patient's teeth to an optimum final or finish position in accordance with treatment prescribed by the orthodontist 14 is produced.

(94) Input Procedure:

[0073] In the input procedure (94) is illustrated in the flowchart of **Fig. 2A.** In the procedure (94), the received information 16 is input, in the illustrated embodiment by operator 28 at the design facility 13, into a computer 30 in digital form. Even where the inputing is performed by operator at the design facility 13, some information 16, such as the information 17 and 19, may be supplied by the orthodontist 14 in machine readable form and input directly into the computer 30. The input procedure (94) includes five steps (100)-(500). The steps of the input procedure (90), in the illustrated embodiment, also include certain substeps that are part of the function of the analysis step (92) but are more conveniently performed at the time of the information is entered into the computer.

[0074] The input steps (100) and (200) involve the entry of background information assembled by the orthodontist 14. In the input steps (300), (400) and (500), tooth and jaw positions and profiles are defined in terms of orthodontic parameters and landmarks that can be later analyzed by computer to best implement the orthodontic knowledge, skill and experience embodied in the prescription 27 and of the orthodontic profession while efficiently automatically producing a optimum result.

(95) Analysis and Tooth Positioning Procedure:

[0075] The computer analysis procedure is illustrated in the flowchart of **Fig. 2B.** In the computer analysis procedure (95), the digitized information input by the input procedure (94) is analyzed to calculate the finish position of the teeth, so that the custom appliance 25 can be designed in computerized design procedure (96) and manufactured in computer controlled manufacturing procedure (97). The analysis procedure (95) includes six steps and subroutines (600)-(1100). These steps include the following:

(600) The dental analysis step in which the orthodontic landmarks of the teeth are identified:
A minimum number of points on the tooth profiles are selected that are sufficient for determining the contact points between teeth that are relevant to finish tooth position calculation and appliance design.

(700) The cuspid rise determination step in which the occlusion of the upper and lower teeth is defined.

(800) The mandibular tooth placement step in which the plane of the mandibular teeth is defined and the teeth are positioned with respect to the mandibular trough, including the steps of placing the teeth with their crown long axes CLAs intersecting the plane of the mandibular trough on the mandibular trough equation MTE, adjusting the teeth vertically so the tips (except the cuspides) are in the same plane, calculating trigonometrically a horizontal OFFSET for each tooth from its crown height and long axis inclination angle LAI to define a mandibular trough offset equation MO, placing the teeth on the offset equation MO and moving the remaining teeth with their mesial contact points MCP in contact with the distal contact point DCP of the previous tooth.

(900) The best fit cusp step in which the best fit equation is derived for mandibular arch.

(1000) The mandibular teeth placement step in which the positions of the mandibular teeth are calculated for placement on the best fit arch equation.

(1100) The maxillary placement step in which the maxillary arch is derived for occlusion with the placed mandibular teeth.

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[0076] Since the anterior teeth do not occlude incisal edge, to incisal edge, the best fit buccal cusp equation *BFBCE* is modified to take into account the distance from the *BFBCE* to the labial contact points of the mandibular incisors and laterals, plus a horizontal or labial clearance, with the maxillary teeth. This defines the points of occlusion with the maxillary anteriors, at the intersection of their lingual surfaces with the plane of occlusion *MOC*.

[0077] The vertical positioning of the maxillary anteriors and cuspids is then performed based on the vertical occlusion methods that have been prescribed, establishing an overlap for the incisors and cuspid rise as determined in step (700). This defines the incisal overlap or overbite.

[0078] Placement of the maxillary posterior teeth places the intersections of the marginal ridges and the central grooves from steps (400) to (600) the cusps of the mandibular teeth with which they will occlude. The archforms for the maxillary tooth placement are illustrated in **Fig. 4B**.

[0079] The vertical positioning of the remaining teeth takes into account the occlusion and other prescription information input in step (200). The remaining calculations are at forth in detail below.

(96) Appliance Design Procedure:

[0080] The appliance design procedure (96), as illustrated in the flowchart of **Fig. 2C**, calculates the dimensions of the appliance components in a form capable of being translated into NC codes for operating NC machinery for production of the appliance components, such as the brackets and archwires and also placement jigs for installing the brackets in the proper positions on the teeth of the patient. In the appliance design procedure (96) includes the following steps (1200) through (1800). These include :

(1200) The mandibular archwire plane step in which the plane of the archwire for the mandibular teeth is defined in relation to the teeth of the mandible.

The archwire should preferably lie in a literally flat plane and be symmetrical about the midline of the arch. As such, the archwire will be properly shaped for installation with either side facing upward. (1300) The mandibular slot inclination step in which the angles of the slots of the mandibular tooth brackets of the appliance are calculated.

(1400) The maxillary archwire plane step in which the plane of the archwire for the maxillary teeth is defined in relation to the teeth of the maxilla.

(1500) The maxillary slot inclination step in which the angles of the slots of the maxillary tooth brackets of the appliance are calculated.

(1600) The mandibular archwire and bracket in-out dimension calculation step in which the slot depth and bracket geometry is calculated for the mandibular tooth brackets.

(1700) The maxillary archwire and bracket in-out dimension calculation step in which the slot depth and bracket geometry is calculated for the maxillary tooth brackets. In determining the in-out dimensions, the deepest and shallowest slot depths are determined, and the smoothest archwire curve, namely that with least variation in radius change along the curve, and preferably with no inflection points, which passes between the depth limits is determined.

(1800) The bracket placement jig designing step in which placement jigs are designed for use in property positioning the custom designed brackets on the patient's teeth.

[0081] In **Fig. 8D**. a plastic jig 82 is shown which engages the walls and bottom of the bracket slot fully. Additionally, the portion of the jig 82 contacting the tooth designed to be formed to precisely fit the known contour of the tooth, as determined by the profiles input in step (500). This assures that the bracket slot and hence the bracket is placed at precisely the correct height when bonded to the tooth.

(97) Appliance Manufacturing Procedure:

[0082] The appliance manufacturing procedure (97), as illustrated in the flowchart of **Fig. 2D**, entails the generation of controller codes for NC machinery to produce the brackets, archwires and bracket placement jigs designed in the appliance design procedure (96), and the manufacture of the appliance components with the use of the machinery controlled by the codes. The procedure (97) includes the steps of:

(3000) Controlling and operating the bracket forming machinery 39 to produce the custom brackets.

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(3200) Controlling and operating the Wire-bending machinery 40 to produce the custom archwires:

(3500) Controlling and operating the jig forming machinery 41 to make custom placement jigs for the location of the brackets on the patient's teeth:

(98) Appliance Transmission Procedure:

[0083] One of the ultimate objectives is to place the custom orthodontic appliance 25 into the hands of the orthodontist 14, along with the tools and information necessary for the proper installation of the appliance 25 in the mouth of the patient 12 to treat the patient by moving the patient's teeth to the calculated finish positions. This is best understood by reference to **Fig. 1**.

[0084] Referring to **Fig. 1**, as set forth above, the configuration of the preferred system 10 will vary depending on the nature and scale of the orthodontist's practice. Preferably, all or much of the appliance design portion of the procedure (87) takes place at an appliance design facility 13, although in a large scale orthodontic clinic, the entire process could be carried out at the patient treatment location. Usually, however, the functions performed in the design computer 30b, or design portion of the computer 30, are carried out at the appliance facility 13, together with some of the manufacturing functions performed by manufacturing control computer 30c and the appliance manufacturing equipment 38.

[0085] In the configuration where, as illustrated, some or all of the appliance 25 is made at the appliance facility 13, the custom appliance 25 is transmitted to the orthodontist 14. Along with the appliance 25 is communicated documentation in the form of a hard copy printout of information 37 generated by the design computer 30b, which could also include documentation of the input data that made up the data 26 and the prescription information 27, and a printout of parameters recorded by the manufacturing computer 30c.

[0086] The transmitted appliance 25 includes a set of archwires 64, as illustrated in **Figs. 8E** and **8F**, a complete set of custom brackets 80, as illustrated in **Figs. 8D** and **8F**, and the placement jigs as illustrated in **Figs. 8D** and **9T** through **9W**. Along with the jigs 82 are included a set of adapters 84 that are used to align the slots 80b of the brackets 80 with coplaner slots 84a of the jigs 82. The appliance and the bracket placement jigs therefor are similar in the case of lingual appliances, a bracket for which is illustrated on a tooth in **Fig. 8G** while the lingual appliance is shown positioned on the mandibular teeth in **Fig. 8H**.

[0087] In addition, custom archwires 64 are transmitted so the orthodontist 14. These archwires include archwires in the exact form, as illustrated in **Fig. 8E**, to move the teeth to their finish calculated positions, as illustrated, for example for the lower teeth, in **Fig. 4D**. In **Fig. 4D**, the archwire 64 is shown in the unstressed state (or having nominal residual stress sometimes motivating some orthodontists to prescribe overcorrection) that it will attain when the appliance 25 has moved the patient's teeth to the calculated finish positions. This is the same shape as the archwire of **Fig. 8E** shipped to the orthodontist 14. This finish arch wire will be of a material and stiffness determined to be appropriate for the final positioning of the teeth. Depending on the severity of the initial malpositioning of the patients teeth, however, less stiff archwires, or temporary archwires may be desired for beginning the orthodontic treatment. Thus, additional archwires 64 of various properties but in the shape shown in **Fig. 8E** will be provided to the orthodontist 14. In addition or in the alternative to the provision of these additional archwires, an actual size drawing or template having thereon the shape shown in **Fig. 8E** will be provide to the orthodontist 14 to enable him so form archwires for preliminary treatment and rough positioning.

[0088] In alternative configurations, information may be sent from the design computer 30b in machine readable form, for example by diskette 34 or modem, to a manufacturing computer 30c to which is attached one or more of the appliance component manufacturing machines 38.

(89) Patent Treatment Operation

[0089] The patient treatment involves, first, the assembly of the respective bracket 80, jig 82 and adapter 84 combinations, as illustrated in **Fig. 8D**, and the application of the brackets 80 thereby to the patient's teeth. This involves the application of adhesive to the area generally in the enter of the face of the tooth, either labial or lingual, to which the brackets 80 are to be applied. This illustrated in **Fig. 8D**, for example, with the application of a bracket 80 to the labial face of a maxillary incisor $T_{U,1}$. The assembly is positioned on the tooth with the blade of the jig 82 positioned on a generally vertical labial lingual cross section through the approximate center of the tooth, in the plane that may be said to contain the crown long axis *CLA* of the tooth.

[0090] When the bracket adhesive has set, the bracket placement jig 82 is removed by first sliding out adapter 84 mesiodistally and then sliding the jig 82 off of the incisal edge of the tooth, leaving the bracket in the calculated position.

[0091] Then, with the brackets 80 set on the teeth the archwire 64 is installed. Often, the first archwire installed will be one of lower stiffness than the final archwire. In the example of **Fig. 8F**, the mandibular teeth in their initial position as illustrated in **Figs. 4** and **4A** are shown. The brackets 80 are positioned on the teeth in the exact same positions as

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shown in the calculated finish position diagram of **Fig. 4D**. Because the teeth are not yet in this ideal finish position, the archwire 64, when inserted into the archwire slots and tied to the brackets 80, will be stressed into the elastically deformed condition shown in **Fig. 8F**. This stressed condition of the archwire 64 operates, without the need of the orthodontist to artfully bend the wire, to apply the forces to the teeth to urge them toward the ideal positions of **Fig. 4D**. This force will continue to be applied until the teeth have moved to the finish positions. In some prescribed forms of treatment the, wire and brackets are designed to move the teeth to a slightly overcorrected position to allow for a relaxation movement of the teeth when the appliance 25 is removed.

DETAILS OF STEPS OF APPLIANCE ANALYSIS, TOOTH POSITION CALCULATION, AND APPLIANCE DESIGN AND MANUFACTURING OPERATION (87)

[0092] The analysis, design and manufacturing operation (87), as stated above, includes the (94) input, (95) analysis, (96) design, (97) manufacturing, and (98) transmission procedures of a computerized custom designed appliance manufacturing operation.

Digitized Input Procedure (94)

[0093] The input of digitized information includes the (100) input of patient and doctor identifying information, (200) the input of patient background information, (300) the input of digitized information of the horizontal dimensions of the mandibular teeth and the mandibular bone, (400) the input of horizontal dimensions of the maxillary teeth, and (500) the input of vertical labial-lingual profile information of each of the individual teeth.

(100) Identification Information Input Step:

[0094] The input of the doctor-patient identification information 17 includes the substeps, performed by an operator 28 in response to prompts for text input at a terminal of the computer 30, of doctor's name, doctor's identification number, and patient's name. Then, the computer 30 (120) assigns a patient identification number. With this information, (125) a patient-specific floppy disk or diskette 34 is automatically formatted.

(200) Patient Background Input Step:

[0095] Entry of patient background information 19, and the prescribed treatment information 27 from the doctor involves entering, from the background information 19, the patient's age sex and race and selecting from multiple choice prompts, such as

Whether treatment is to include an extraction, and if so, which teeth,
Whether the occlusion type is a group function or a cuspid rise, and if a cuspid rise, whether averages or individual head film is to be used,
Whether to preserve lower intercuspid distance or allow expansion, and if expansion is to be allowed, how much expansion,
Whether or not the occlusion is mutilated,
Whether a Steiner compromise is to be allowed,
Whether a Roth or Ricketts inset is to be used on upper laterals, and if so which,
Whether a Roth or Andrews upper lateral overbite is indicated, and if so, which,
the preferred slot size,
Whether the case is to be treated with labial or lingual appliances,
Whether the case is to be diagnosed using symmetry or not, or
How inter-incisal angle is to be determined, using the Andrews Norms, the Parallel Upper Central to Facial Axis Norm, or Ricketts Norm.

(300) Mandible Digitized Video Input Step:

[0096] The (300) inputing of video or other graphics top view image of the patient's lower jaw, including the teeth, is illustrated in Fig. 3, and includes the digitizing and processing of the data of the widths of the mandibular teeth and size and shape of the mandibular bone or bone of the lower jaw 22 of the patient 12 from the horizontal plan view of the lower jaw as in **Fig. 4**.

[0097] The roots of the lower teeth of the patient are contained within the mandibular trough *MT*, which is defined as the space between boundaries B_L and B_B of **Fig. 4**. The outer, or buccal, and inner, or lingual, boundaries B_B and B_L,

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respectively, are preferably digitized by interactive selection by the operator 28 from an image 48 of the cortical bone of the mandible 22 on the screen 35. Furthermore, the mandibular teeth must lie in the arch in contact with one another. They each occupy a portion of the arch equal to the distances between their mesial and distal contact points with the adjacent teeth.

[0098] A grid *G* is overlaid to define *X,Y* coordinates with a *Y* axis on a midline *ML* of the lower jaw 22 and an *X* axis perpendicular to the *Y* axis through a selected intersection point or origin *0,0*, preferably set at the mesial contact points of the lower central incisors.

[0099] The operator sequentially selects each point, first for the individual tooth contact points, then the jaw bone boundaries. From the *X,Y* coordinates of $M_{X,Y}$, M_X and M_Y. and of $D_{X,Y}$, D_X and D_Y, the mesio-distal width MDW_I of each tooth *I*, on each side of the mandible 22, is calculated using Pythagorean theorem:

$$MDW = \sqrt{(M_X + D_X)^2 + (M_Y + D_Y)^2}$$

where:

M_X is mandibular *X* coordinate;
M_Y is mandibular *Y* coordinate;
D_X is distal *X* coordinate; and
D_Y is distal *Y* coordinate.

[0100] The total length is *MAL*

[0101] From the selected intersections of the lines of the grid *G* with the mandible boundaries B_B and B_L, cartesian coordinates $La_{X,Y}$ and $Li_{X,Y}$ labial and lingual limits, respectively, of cortical bone on both sides of mandibular jaw are generated, and midpoint coordinates MP_{XY} are calculated as are the bone width distances between each of the respective labio-lingual pair *DLL*, as follows:

$$MP_X = La_X + \frac{Li_X - La_X}{2}\,;\; MP_Y = La_Y + \frac{Li_Y - La_Y}{2}$$

$$DLL = \sqrt{(La_X + Li_X)^2 + (La_Y + Li_Y)^2}$$

[0102] The sum of the individual mandibular tooth widths *MDW* equals the total dental length or mandibular arch length *MAL* contained in the mandibular trough equation *MTE* that will be constructed through the points $MP_{X,Y}$. *MAL* is referred to as the arch perimeter.

[0103] At this stage, the midpoints are typically averaged right to left to eliminate any asymmetry that may be present due to alight measurement errors unless the patient has been diagnosed to be of any asymmetrical anatomy.

[0104] The midline *ML* shown in **Fig. 4** is the axis of such symmetry corrections. These corrections for each point $MP_{X,Y}$ are calculated as follows:

$$S_X = MP_X + \frac{PR_X - PL_X}{2}\,;\; S_Y = MP_Y + \frac{PR_Y - PL_Y}{2}$$

where:

$S_{X,Y}$ is the symmetricalized point $MP_{X,Y}$;
$PR_{X,Y}$ is a point $MP_{X,Y}$ on the right side and
$PL_{X,Y}$ is the corresponding point on left side of the trough

[0105] With the completion of this symmetricali-zation process, a mathematical equation *MTE*, which describes the size and shape of the mandibular trough is derived by fitting a curve to the points $MP_{X,Y}$. Preferably, this curve is derived by fitting a series of cubic equations, such as a cubic spline equation, to pass smoothly through the points, for example, through the averaged midpoints $S_{X,Y}$.

[0106] The cubic equations are then preferably converted in form to a series of segments of tangent circle equations with slopes equal to the slopes of the cubic splice at the midpoints, and equal to the slopes of the adjacent circle seg-

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ments at the segment end points, or their points of intersection, along the curve. To fit a cubic equation with quadratics, two circles *CS* and *CL* are used to describe each segment of the *MTE* between midpoints, as illustrated in **Fig. 5**. This allows a smooth curve consisting of tangential circles to represent the mandibular trough.

[0107] The spline-to-circle conversion routine is described in further detail under routine (2100) below.

[0108] Cartesian coordinates are input for right and left mandibular cuspid cusp tips *CR* and *CL*, respectively, as illustrated in **Fig. 4**. A distance *DCT* between the cusp tips *CR* and *CL* of the two mandibular cuspids is then calculated:

$$DCT = \sqrt{(CR_X + CL_X)^2 + (CR_Y + CL_Y)^2}$$

[0109] This information is used to calculate if and how much the mandibular intercuspid distance is to be altered, and to evaluate whether the calculated final position is acceptable. Similarly, cartesian coordinates or right and left mesiobuccal cusp tips, *MR* and *ML*, respectively, of mandibular first molars are calculated, and the distance between these points *DMT* is calculated:

$$DMT = \sqrt{(MR_X + ML_X)^2 + (MR_Y + ML_Y)^2}$$

[0110] This information is used to determine if and how much the mandibular intermolar distance is to be altered.

(400) Maxilla Digitized Video Input Step:

[0111] As with the mandibular jaw information described in connection with **Fig. 4**, a computer image is made in the same manner from the upper modal 23 of the maxillary jaw 24 from the image 48a illustrated in **Fig. 4A**.

[0112] Coordinates $R_{x,y}$, $L_{x,y}$ of the central fossae of right and left maxillary first molars are input. Then, the distance between central fossae *DCF* is calculated as follows:

$$DCF = \sqrt{(R_X + L_X)^2 + (R_Y + L_Y)^2}$$

[0113] This information is recalculated after the tooth finish positions are calculated to coincide with the *DMT* spacing of the mandibular first molars, and compared with this initial measurement as an indicator of whether the intermolar width will be changed by treatment and the amount of such change, if any.

(500) Digitized Probe Tooth Profile Input Step:

[0114] In this step, selected profiles of each of the teeth are generated from either the model 20, or from a digitized three dimensional representation of the patient's teeth or the model 20 as illustrated in **Figs. 3A** and **3B**. In the illustrated embodiment, the use of the probe assembly 57 of **Fig. 1C** is used in this step.

[0115] The selection of the profile plane is illustrated in **Fig. 6** where a first profile PF_A through the center of the tooth is shown as missing the buccal cusp tip which is the maximum crown highpoint of the tooth. Profile PF_B is then selected to include the buccal cusp, and the ridge of the profile is found to generally align with the low point of PF_A. Alternatively, the profile may be non-planar to pick the important features of both planes. As such, the profile produced will be comparable to a projection onto a plane of the relevant tooth extremities.

[0116] The resulting profiles PF_I are illustrated in **Fig. 3C**.

(95) Analysis and Finish Tooth Position Calculation Procedure

[0117] The calculation of the finish positions of the teeth, as illustrated in the flowchart of **Fig. 2B**, includes (600) determining the relative positions of geometric landmarks on the surfaces of the teeth and establishing the axis inclinations of the teeth, (700) calculating cuspid rise, (800) initially positioning the mandibular teeth vertically and in relation to the mandibular trough, (900) calculating a best fit cusp tip equation for the mandibular teeth, (1000) calculating the finish positions of the mandibular teeth on the best fit equation, and (1100) calculating the finish positions of the maxillary teeth on three arches related to the best fit equation.

(600) Tooth Landmark Identification Analysis Step:

[0118] The input data 26 is analyzed to develop or derive further parameters for calculating the final positions of the

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teeth and for (96) the design of the appliance 25. In the tooth positioning analysis (95), as illustrated in the flowchart of **Fig. 2B**, (600) a tooth profile analysis is made in which, for example, certain anatomical landmarks are chosen, depending on the tooth to be analyzed.

[0119] In the tooth profile analysis step, individual images 63 of the profile curves PF_I of each tooth (**Fig. 3C**) are recalled separately to the screen of the computer 30b for selection of the landmarks. Using the displayed images 63 of the profile curves PF_I, specific landmark points are chosen, first on the mandibular molars and bicuspids. The selected points are digitized as illustrated in **Fig. 6**. The selected points are:

Point P_1: The Lingual (tongue side) gum/tooth intersection.
Point P_2: The prominence of the lingual cusp.
Point P_3: The prominence of the buccal (cheek side) cusp.
Point P_4: The buccal gum/tooth intersection.

[0120] From these landmarks, (615) the crown long axis *CLA* of each molar and bicuspid profiled is determined. The determination is made by constructing a first line L_1 between points P_2 and P_3 and a second line L_2 between points P_1 and P_4. The crown long axis *CLA* of a tooth is the line between the midpoints of L_1 and L_2.

[0121] A point $P_{2\text{-}3x,y}$ equidistant between points P_2 and P_3 along line L_1 is then calculated, and a point equidistant between points P_1 and P_4 along line L_2 is also calculated and defined as the Gingival Center Point *GCP*.

[0122] The line defining the crown long axis *CLA* is constructed using the following equation: where:

$X_{2\text{-}3}$, $Y_{2\text{-}3}$ = X and Y coordinates of the center point $P_{2\text{-}3}$.

$$\frac{Y - Y_{2\text{-}3}}{X - X_{2\text{-}3}} = \frac{Y_{GCP} - Y_{2\text{-}3}}{X_{GCP} - X_{2\text{-}3}}$$

X_{GCP} Y_{GCP} = X and Y coordinates of gingival center point $GCP_{X,Y}$.

[0123] For molars and bicuspids, point P_3, the buccal cusp tip, is defined as the Incisal Center Point *ICP*.

[0124] Similarly, the anatomical landmarks and crown long axis *CLA* for the mandibular cuspids, laterals and central teeth are determined, as illustrated in **Fig. 6B**. The point P_1 through P_4, as labeled in **Fig. 6B**, are selected as follows:

Point P_1: The lingual gum/tooth intersection.
Point P_2: The lingual aspect of the incisal edge.
Point P_3: The buccal aspect of the incisal edge.
Point P_4: The facial gum/tooth intersection.

[0125] As with the bicuspids and molars, lines L_1 and L_2 are constructed. The landmarks in the cases of the teeth as illustrated in **Fig. 6B**, are chosen because they are relatively tolerant to operator error in selection. This can be seen by the set of broken lines that are possible alternatives to L_2 in **Fig. 6B**. From these landmarks the crown long axis *CLA* is determined as defined above, by connection of the midpoints of L_1 and L_2.

[0126] For maxillary dentition for each upper molar and bicuspid, antomical landmarks are identified and chosen as illustrated in **Fig. 6C**, which requires the selection of a fifth point. P_5, the mesial marginal ridge of the tooth at central groove.

[0127] Next, as further illustrated in **Fig. 6D**, seed values for setting the crown long axis inclinations *LAI* of the teeth. Initially, such seed values may be derived from analyses that identified the facial axis plane *FAP* through the facial axis point *FA* of the tooth (the midpoints of the height of the clinical crowns along the facial axes of the clinical crowns).

[0128] The computer images as summarized in **Fig. 3C** for each tooth are then rotated so that the *CLA* is oriented at the desired angle *LAI*, the long axis inclination angle, to the mandibular trough plane *MT*. This computes the final inclinations of the teeth that will be preserved in the calculations below. This produces the oriented profiles *PF* summarized in **Fig. 6E**.

[0129] Once the tooth profiles have been rotated to the inclination angles *LAI*, certain precise vertical dimensions and extremities can be determined. From the digitized profile curves, which are stored in memory in the form of a series of closely spaced points, the precise incisal tip *IC*, as illustrated in **Figs. 6F, 6H and 6I**, are identified on the cuspids, laterals and centrals.

[0130] Additionally the elevation of the marginal ridge P_5 is identified. The marginal ridge elevation *MRE*, which is the vertical distance from P_3 to P_5, is identified on the maxillary posterior teeth because they are the centric stops for the buccal cusps of the mandibular molars and bicuspids. as illustrated in phantom line PH_1, in **Fig. 6C**. The *MRE* is used

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as the buccal cusp height *BCH* in the calculation of cuspid rise and archwire plane placement as described below in the discussion of **Figs. 7A** and **8**, respectively.

(700) Cuspid Rise Determination Step:

[0131] The cuspids (*I=3*) are close to the front of the mouth and are therefore further from the condyle or pivot point PP of the jaw than are the posterior teeth (*I>3*), as illustrated by distances DJ_I in **Fig. 7**. This results in the teeth closer to the back of the mouth moving less than the cuspids on opening. This differential rate of movement must be included in the calculation of cuspid rise or the back teeth will remain in contact after the cuspids have cleared each other. Also, the distance *DPP* from the occlusal plane to the pivot point *PP* of the condyle of the jaws must be considered, as illustrated in **Fig. 7**.

[0132] Preferably, where cuspid rise is prescribed to control occlusion, the contribution of cuspid rise is distributed between the maxillary and mandibular cuspids, with two parts of the cuspid rise provided by the maxillary cuspids and one part by the mandibular cuspids.

[0133] The initial vertical distance or buccal cusp height *BCH* from P_3 to the marginal ridge for each of the right and left maxillary first bicuspids *T(U,4)*, second bicuspids *T(U,5)*, first molars *T(U,6)*, and second molars *T(U,7)*, as illustrated in **Fig. 6C**. Then, from anatomical study, the cuspid rise vertical height *CR* required to clear each respective pair of teeth is determined by first computing the values in Table 1, which are derived from the jaw dimensions *DPP* and DJ_I in **Fig. 7**. required to clear each respective pair of teeth is determined by first computing the values in Table 1.

TABLE 1

1.67 x BCH of T(U,7)

1.50 x BCH of T(U,6)

1.36 x BCH of T(U,5) and

1.20 x BCH of T(U,4).

[0134] Then, from the products of the buccal cusp height *BCH* for each such tooth multiplied by the rise factor listed above, the largest value is selected. This selected product is the cuspid rise required to clear the most prominent cusp and provide group function occlusion. This is illustrated as BCH_4 in **Fig. 7A** for the case where the first molars are the last to clear.

(800) Mandibular Tooth Placement Step:

[0135] The first calculation places the tips of the mandibular teeth on an occlusal plane pending final refinement of the placement, as diagrammatically illustrated in **Fig. 6E**. In this step, the pending final refinement of the placement, as diagrammatically illustrated in **Fig. 6E**. In this step, the inclinations of the mandibular tooth crown long axes *CLA* are preserved, and the teeth are moved upward along their *CLA's* until their tips are in alignment with the plane of the top of the tallest tooth. The *CLA's* are placed to intersect the *MTE* below the tooth *GCP*. Because the teeth are inclined at different *LA/s*, or long axis inclination angles, the tooth tips will each be differently offset from the *MTE*, and thus not in smooth arch.

[0136] The tallest mandibular tooth, with the exception of the cuspids, is identified. In **Fig. 6F** this is illustrated as the left mandibular central. The tallest tooth is the tooth with the greatest crown height *CH*. The crown height *CH* is the distance, in the *Y* direction (with the teeth profiles oriented a described in step (600), from the a *GCP*, the point of intersection of line L_2 and crown long axis *CLA*, to highest point on buccal cusp, e.g. P_5 (for posterior teeth) as illustrated in **Fig. 6F** and (for the anterior teeth) to either the incisal center point *ICP* or, preferably to the incisal tip *IC*, as illustrated in **Fig. 6G**. The crown height *CH* of the tallest tooth, shown as the left mandibular central incisor in **Fig. 6F**, is the maximum crown height *MCH* of the mandibular teeth.

[0137] Three parallel planes are established:

an *MCH* reference plane *MCHP* parallel to the X-axis, and passing through an origin *0,0*, set at the *GCP* of the tallest tooth (**Figs. 6F** and **6I**);

a Buccal Cusp Plane *BCP* parallel to X-axis and passing through coordinates *0*, *MCH* on the tallest tooth (**Figs. 6F** and **6I**); and

a Cuspid Rise Plane *CRP* parallel to *X*-axis and passing through coordinates *0*, *CR* where *CR* is the cuspid rise calculated in step (700), where the cuspid rise option has been selected.

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[0138] With the planes defined, the oriented mandibular teach are placed such that the highest point on buccal cusp tip P_3 or incisal tip *IC* of each contacts the buccal cusp plane *BCP*, for all teach except the cuspids, as illustrated further in **Fig. 6F**. The *BCP* thereby is established as the occlusal plane *MOC*. The reference plane *MCHP* is set equal to the plane of the mandibular trough *MT*. This sets the *GCP* of the tallest tooth on the *MT*, with the *GCP's* of the remaining mandibular teeth above it. It also sets the occlusal plane *MOC* a distance *MCH* from the mandibular trough *MT*. The absolute highest point on a tooth crown is preferably used to align the teeth with the *BCP*. Such a point can be determined by additional point selection in step (500), such as by the direct selecting of the point *IC* for the precise incisal tip, or preferably by calculating the highest point directly from the profiles of Fig. 3C or from three dimensional images as in Figs. 3A, 3B after rotation of the teeth to their final inclination angles *LAI*, at the end of step (600).

[0139] At this stage, the vertical positions of the mandibular teeth relative to each other as illustrated in **Figs 6F** and **7C** are calculated.

[0140] The teeth are then horizontally set at temporary positions with respect to the *MTE*, which lies in the plane of the mandibular trough *MT* (*MHCP*).

[0141] The preferred goal, is to position the tips of the teeth in the smoothest arch in an occlusal plane *MOC* rather than their gingival aspects in a smooth arch at the mandibular trough *MT* so a horizontal distance *OFFSET* for each tooth is calculated, based on the tooth and the crown long axis inclination *LAI* determined in step (600). This offset is the horizontal distance from the *MTE* to the tooth tips when their *GCP's* are placed on the *MTE*.

[0142] For mandibular centrals and laterals and cuspids, the *OFFSET* is calculated by dividing, by the tangent of *LAI*, the vertical distance from (1) the intersection of crown long axis *CLA* and the incisal tip *IC* to (2) the intersection of *CLA* and maximum cusp height reference plane *MCHP*. The vertical distance may be calculated from the *IC* to the *MCHP* (equal to the *Y* coordinate of point *IC*, producing the incisal center vertical distance *ICD*.) For mandibular laterals and centrals, *ICD* equals *MCH*. For mandibular cuspids, *ICD* equals the mandibular cuspid rise component, which is *MCH + (Total CR)/3* when cuspid rise function occlusion has been selected. The calculation of the *OFFSET* for centrals, laterals and cuspids would thus be as follows for the incisors and laterals:

$$OFFSET = ICD/\tan(LAI).$$

[0143] For mandibular bicuspids and molars, referring to **Fig. 6F**, the *OFFSET* is calculated as the horizontal distance from point P_3 to the intersection of the *CLA* and the *MCHP* as follows:

$$OFFSET = [MCH/\tan(LAI)] + HD,$$

where *HD* equals the horizontal distance from point P_3 to incisal center point *ICP*.

[0144] Then, the mandibular trough placement point *MTPP* is defined as the intersection of *MCHP* and *CLA*, as illustrated in **Figs. 6G** and **6H**. For the tallest tooth, *MTPP* is its *GCP*, as illustrated in **Fig. 6I**. The *MCHP* is at the level of the mandibular trough and contains the *MTE*. The *MTPP* is the point on the tooth that is initially placed on the *MTE*.

[0145] Next, referring to **Fig. 7B** and **7C**, the teeth are placed with their *MTPP's* on the mandibular trough, one side at a time. To achieve this, a tooth placement routine is called, in which the mandibular trough equation *MTE* is first adjusted for the mandibular entrain to increase the radii by the amount of the central *OFFSET* for that particular tooth, as defined above, to form a mandibular trough offset curve *MO(1)* of **Fig. 4B**. The radii of the *MTE* referred to are those of the *MTE* defined in the circle segment form of the equation generated in step (300) with the spline to circle conversion routine

[0146] Since the *OFFSETs* of the teeth differ, the *MO* may be viewed as a discontinuous equation when constructed in this manner, made up of segments, each containing the tip of one tooth and spaced labial-lingually from the *MTE* by the amount of the individual tooth's *OFFSET*.

[0147] Beginning with the left side, the central is placed, as illustrated in **Fig. 7B**, by placing its mesial contact point *MCP* at the intersection of the midline *ML* with the offset curve *MO* for the tooth. This has the effect of the placing *MTPP* of the tooth, which is the intersection of the *CLA* with the *MCHP* or *MT*, on the *MTE* and the incisal tip *IC* of the tooth on MO_1 The tooth placement on the circle segment form of an equation is explained in detail in the description of the tooth placement routine. In the placement of the central, a circle C_1 is constructed with a radius equal to the mesiodistal width MDW_1 of the central tooth and with the center of the circle C_1 at the mesial contact point *MCP* of the tooth at intersection of the midline *ML* with the offset curve MO_1. Then, circle C_2 is constructed with a radius equal to *MDW/2* and with its center coincident with the center of circle C_1. Then, the intersections of trough offset curve *MO* with the circles C_1 and C_2 are found, its intersection with the circle C_1 being the distal contact point *DCP* of the tooth and its intersection with the circle C_2 being the tooth midpoint *TMP* of the central tooth. The tooth midpoint *TMP* is here defined as the midpoint of the mesiodistal width of the tooth placed on an archform, which is the intersection of the archform with a vertical labial-lingual plane that contains the *CLA*. This mid-point *TMP* of the central tooth on the *MO* is the approximate position of the incisal tip *IC*.

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[0148] Determining the intersections of the circles with the offset trough *MO*, or expanded mandibular trough, requires identification of which circle sector lines (**Fig, 5-5P**) the circles C_1 and C_2 intersect. These are identified by comparison of the *X* coordinates of the intersections with the *X* coordinates of the distal contact points *DCP* of each of the central teeth to determine which segments of the trough equation will be used, as explained more fully in the description of the tooth placement routine.

[0149] Finally, a distal contact point line *DCPL* is constructed for the central tooth through the *DCP*, at the intersection of circle C_1 with the *MO*, and through the center of the identified circle segment of the *MO*, the expanded *MTE*, on which the *DCP* of the tooth lies. This line lies along a radius of the circle segment of the *MO* curve through the distal contact point of the central tooth. Similar lines *DTMP* are constructed for the center of the tooth *TMP*.

[0150] For each of the remaining mandibular teeth on the same side of the arch, in distal sequence, a new mandibular trough offset MO_l is calculated, by expanding the *MTE* with radii of curvature increased by the amount of the next tooth's *OFFSET* and with center of the circles C_1 and C_2 moved labially or outwardly from the *MTE* along the prior tooth's distal contact point line *DCPL* by the amount of the current tooth's *OFFSET*. This is the *MCP* for the next tooth. Circle C_1 for the tooth is constructed with a radius equal to the mesiodistal width of the tooth and with its center at their center point *MCP*. Circle C_2 is constructed with a radius equal to *MDW/2* and with centers coincident with circle. *C1*.

[0151] For bicuspids and molars, the tooth midpoints *TMP* can be considered a their points P_3. Then, as with the central, the intersections of *MO* and circle. C_1 and C_2 are calculated for these teeth. The dial contact points *DCT* of these teeth are at the intersections of *MO* for the tooth and the respective C_1s. The centers of the teeth *TMP* are at the intersections of *MO* for the tooth and the respective circles C_2. The *MO* sector segments which the circles intersect are identified. Selection of the segments is made by comparing the *X* and *Y* coordinates of intersections to *X* and *Y* coordinates of distal contact points *DCPs*. Finally, a distal contact point line *DCPL* is constructed from selected segment center to the plane *DCP*. The same is done for the centers of the teeth *TMP*. When tooth placement is referred to below, this is the sequence that is preferably followed.

(900) Best Fit Mandibular Arch Equation Step:

[0152] The discontinuous offset equation *MO* contains the approximate tips of the teeth in the occlusal plane *MOC*, with the teeth irregularly offset as represented by the discontinuous *MO* lines in **Fig. 4B**. To place the tips of the teeth into an ideal arch, (900) a final equation for better placement of the buccal cusp tips and incisal edge of the mandibular teeth in continuous arch is developed.

[0153] The equation is statistically developed that best fits the cusp tips and incisal edges of the individual teeth; a Best Fit Buccal Cusp Equation *BFBCE*. In the formulation of the equation, the coordinates of the right and left tooth midpoints *TMP*, the *ICPs* or *ICs* in **Fig. 7B**, are preferably averaged. The equation *BFBCE* may be obtained by use of polynomial or other bezier or least square statistical techniques to arrive at a best fit equation. These are available in any of a number of off-the-shelf software packages.

[0154] Such a *BFBCE* equation is plotted in **Fig. 4B**. Once the *BFBCE* is determined, it my be converted to a circle segment equation in a manner such as with the spline to circle conversion routine above.

(1000) Mandibular Best Arch Placement Step:

[0155] After statistically deriving a best fit equation *BFBCE*, (1000) positions of the individual mandibular teeth are calculated to translate them facially, either labially or lingually, so that their tips fall on the best fit curve.

[0156] To achieve this, the mesiodistal contact point of the mandibular central, the point *MCP*, as in **Fig. 7B**, is first placed on the intersection of the midline *ML* with the BFBCE in the same manner as it was placed on the *MO* in step (800). Then circles *C1* and *C2*, as defined above, for the tooth are constructed and their intersections with the *BFBCE* curve are found. As with the placement in step (800) above, the intersection of C_1 with *BFBCE* is the distal contact point *DCP* of the tooth, and the intersection of C_2 with the *BFBCE* curve, is the center point *TMP* (which aligns with *IC*) of the tooth. This, in effect, moves the tooth normal to the circle segment of the *BFBCE* associated with the *TMP*. Then, new circles C_1 and C_2 are constructed with centers at the distal center points *DCP* and substeps are repeated for all teeth on the same side and then the opposite side of the mandibular arch.

[0157] The finish positions of the mandibular teeth are illustrated in **Fig. 7C** in which the *X-Y* coordinates are those of the horizontal arch planes. A vertical *Z* coordinate, perpendicular to the horizontal X-Y plane, is aligned with the *Y* axes of the individual tooth profile planes. The *X* coordinates of the profile planes are aligned with the labial-lingual directions *La-Li* in **Fig. 7B**.

(1100) Maxillary Tooth Placement Step:

[0158] The construction of occlusion requires the fitting of the maxillary teeth to the already positioned mandibular

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teeth. This is accomplished by deriving a modified best fit buccal cusp equation *BFBCE* for the maxillary teeth. With the maxillary teeth, the cusp tips of the posterior teeth and incisal edges of the anterior teeth are not set in a single arch, but rather place (1) the central groove-marginal ridge points of the maxillary bicuspids and molars on the *BFBCE*, (2) the maxillary anteriors spaced labially off the *BFBCE* to allow for incisal overlap and a clearance between the lingual surfaces thereof and the labial surfaces of the mandibular teeth, and (3) the cuspid tips in the arch generally between the first maxillary bicuspid and the lateral incisor. The arches on which the maxillary teeth are placed as illustrated in **Fig. 4C**, as explained above.

[0159] For the maxillary incisors, the modification of the *BFBCE* first involves an averaging the distances from point P_2 to point P_3 on the mandibular incisor incisal edge, and dividing by two, to locate the arch that will contain the labial surface of the tooth adjacent the incisal center point *ICP* of the tooth, which is generally the point P_3. This produces a uniform distance from the best fit equation to the contact point of the facial surface on the labial side of the mandibular anterior teeth with the facial point on the lingual side of the maxillary anterior teeth. An additional distance, of typically one-quarter millimeter, is added to the averaged distance to provide a slight *Clearance* between the upper and lower anterior teeth. This is illustrated in **Fig. 7D**.

[0160] The maxillary anterior denitition is set for vertical position relative to the occlusal plane *MOC* according to occlusion criteria selected to provide a predetermined overlap. From the cuspid rise calculation of step (700), the vertical positions of the maxillary cuspids are known relative to the mandibular occlusal plane *MOC*. For maxillary laterals and centrals, the vertical positions provide the overlaps according to the prescribed criteria, putting their lingual facial contact points with their mandibular counterparts on the *MOC* plane. All teeth are inclined at the prescribed crown long axis *CLA* inclination values *LAI* from step (600).

[0161] In the (1100) placement of the teeth of the maxilla, or upper jaw 24, with respect to those of the mandibular, or lower jaw 22, the maxillary anterior arch form *MAAF*, the central groove marginal ridge arch form *CGMRAF*, and the maxillary cuspid arch form *MCAF*, are defined as illustrated in **Fig. 4B**.

[0162] The calculation of the amount of circle segment radius expansion of the *BFBCE* needed to define to *MAAF* is made at the midpoint of the mesiodistal width of either maxillary central, TMP_1 in **Fig. 4C**, which is the intersection with *BFBCE* of circle C_2 in **Fig. 7C**. The tooth is placed on the maxillary contact arch form equation *MAAF* such that the mesial contact point of the tooth is on intersection of the midline *ML* and the maxillary contact arch form *MAAF* (**Fig. 4C**). The *MAAF* is defined as follows with respect to upper laterals and centrals:

$$MAAF = BFBCE + \Sigma \frac{P_{3x} - P_{2x}}{\{t\}\{Avg\}} + Clearance$$

where:

t = number of teeth,
Avg = 2 (for midpoint).

[0163] The *CGMRAF* coincides with the *BCBFE* as shown in **Fig. 4B**.

[0164] For the maxillary cuspids, the cusp tips are placed on some smooth arch between the *MAAF* and the *CGMRAF*. Preferably, their tips are placed on the *BFBCE* expanded by the average of the distances therefrom to the incisal tip of the lateral and to the buccal cusp tips of the first maxillary bicuspids.

[0165] The information from the prescription 27 from the orthodontist 14 is retrieved to determine which maxillary anterior vertical occlusion method has been selected, such as Roth or, Rickets occlusion, or the preferred method wherein the maxillary cuspids will extend a distance CR_{U3} equal to 0.67 of the cuspid rise *CR* below the occlusal plane *MOC*, laterals extend a distance CR_{U2} equal to 0.33 of the cuspid rise *CR* below the plane *MOC*, and the centrals extend a distance CR_{U1} equal to 0.50 of the cuspid rise *CR* below the plane *MOC*.

[0166] The elected horizontal occlusion is selected, preferably, the horizontal tooth placement proceeds by calculating the positions of the teeth to provide the horizontal occlusion, a distance is calculated from *LIMOC* to *ICP* for the maxillary centrals and the laterals. This distance is referred to as the maxillary anterior offset *MAO*, thus:

$$ICP = \frac{X_2 + X_3}{2} ; \frac{Y_2 + Y_3}{2}$$

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$$MAO = LIMOC_2 - ICP_2$$

The maxillary first bicuspid offset *MOB* is calculated as

$$MBO = P_{2X} - P_{2X}$$

The maxillary tooth positions are then recalculated.

Appliance Design Procedure (96)

[0167] The appliance design procedure includes the steps of (1200) determining the location of the mandibular archwire plane relative to the calculated finish positions of the mandibular teeth, (1300) calculating the angle of each mandibular bracket slot relative to the mounting surface of the respective tooth, (1400) determining the location of the maxillary archwire plane relative to the calculated finish positions of the maxillary teeth, (1500) calculating the angle of each maxillary bracket slot relative to the mounting surface of the respective tooth, (1600) calculating the shape of the mandibular archwire and the slot in-out dimension of each mandibular bracket, (1700) calculating the shape of the maxillary archwire and the slot in-out dimension of each maxillary bracket, and (1800) calculating the contours of bracket placement jigs for each tooth.

(1200) *Mandibular Archwire Plane Step*:

[0168] The next step is (1200) to establish the position of the archwire plane for the mandibular teeth. The archwire plane can be located in an infinite number of vertical positions since the brackets and archwire will be designed to accommodate any chosen location. Since the overlap of the maxillary teeth is known, for labial bracket placement, the mandibular archwire plane is set to provide bracket clearance for the maxillary teeth in the finished occlusion. For lingual bracket placement, this consideration is given to the maxillary archwire plane instead, in step (1300) below.

[0169] Since the maxillary teeth do not pose a bracket interference dilemma with labial bracket placement. the brackets can be positioned for ease of placement, cosmetic considerations and gingival health. This applies to the mandibular bracket positioning where lingual bracket placement is used. Typically, these brackets are located more centrally than the brackets of the other arch.

[0170] More particularly, to establish the archwire plane, the selected vertical occlusion and respective vertical overlap from *MOC* for cuspids, laterals and centrals is recalled. Then, the buccal cusp height *BCH* is recalled for each bicuspid and molar. Next, the maximum *BCH* or anterior vertical overlap is chosen as the maximum vertical overlap *MVO*. Then, a distance equal to the *MVO* is measured downward from the *MOC*. Finally, half of the bracket height (typically 3.0 mm) plus an additional 0.75 mm is added for occlusal clearance. This defines the mandibular archwire plane *MAWP*. This places brackets as occlusal as possible with an 0.75 mm clearance from the worst case from the maxillary occlusion.

(1300) Mandibular Slot Inclination Step:

[0171] Once the archwire planes have been defined with respect to the teeth, (1300) the angle between the bracket mounting surface of the teeth and archwire plane is determined. This angle minus 90° is the facial torque or inclination angle to be formed into the brackets. This also defines the bracket slot placement height which is the distance from the top of the incisal edge to the archwire plane. This distance is calculated perpendicular to the archwire plane.

[0172] Slotless bracket bodies have now been positioned appropriately. A smooth archwire is then designed such that it will pass through the bodies of the brackets. The archwire must not cut too deeply into the bracket or pass even partially outside the face of the brackets. Brackets are chosen having different heights according to need. Without modifying buccal tube assemblies, standard bracket distances from the tooth surface to the center of the slot may be used as seed values. The archwire equation is then mathematically derived from cubic spline and tangential circle techniques as previously described. Both archwires are developed similarly.

[0173] Bracket angle determination (1300), more particularly, is achieved by taking the intersection of the *MAWP* and labial (buccal) surface of each mandibular tooth in the case of labial appliances, and the intersection of the *MAWP* with the lingual surface of each tooth in the case of lingual appliances. Then, circles are constructed with centers at the intersections and with diameters that represent the occluso-gingival (vertical) dimensions of the bracket bonding pad (typically 3.0mm). Then, *X,Y* coordinates of the circle intersections with labial (buccal) tooth surface are taken, and, with the

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equations:

$$R^2 = (X_1 - h)^2 + (Y_1 - K)^2$$

$$Y_2 = mX_2 + b_2$$

$$Y_3 = mX_3 + b_3$$

[0174] The slopes between the points of intersection are calculated to produce the facial inclination *angle FIA.*:

h,k = coordinates of circle center
X_1,Y_2,b_2 = definition of first line segment
X_3,Y_3,b_3 = definition of second line segment

[0175] Then, as illustrated in **Fig. 8A** for labial appliances. x/2 radians are then subtracted to produce the slot inclination angle *SIA*:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - x/2$$

(1400) Maxillary Archwire Plane Step:

[0176] The next step is (1400) locating the maxillary archwire plane as illustrated in diagram of **Fig. 8**. For the maxillary centrals, this involves finding the vertical distance from incisal edge to point P_4. The smallest value is selected and divided by two to produce the slot placement height for the maxillary centrals. For terminal maxillary bicuspids the vertical distance from buccal cusp to point P_4 is found. The smallest value is selected and divided by two. This produces the slot height *SPH* for the terminal maxillary bicuspids.

[0177] For maxillary centrals, the *Y* value of *FIMOC* is subtracted from the *Y* value for the slot placement height *SPH*. This is the distance from *MOC* to the slot centerline. For terminal maxillary bicuspids, the *Y* value of *MOC* is subtracted from the *Y* value for the slot placement height *SPH*. This is the distance from *MOC* to the slot centerline. Then, the *SPH* for the terminal bicuspid from *SPH* for the maxillary centrals. This is elevation change DH of the maxillary archwire relative to the *MOC* from the centrals to the terminal maxillary bicuspids. The elevation of the maxillary archwire *MXAWP* from the *MOC*, or archwire height *AHT* on each tooth, is calculated as

$$AHT = K + DH + SPH - MOC_Y$$

+ *Vertical overlap from* where *K* is the conversion factor from Table 2.

TABLE 2

Tooth Type	Non- Extraction	Extraction (e.g. 2nd Bicuspid)
Maxillary Central	0.0	0.0
Maxillary Lateral	-0.19	-0.23
Maxillary Cuspid	-0.42	-0.62
Maxillary First Bicuspid	-0.68	-1.00
Maxillary Second Bicuspid	-1.00	NA
Maxillary First Molar	-1.32	-1.46

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(1500) Maxillary Slot Inclination Step:

[0178] Once the archwire plane is determined, (1500) the slot inclination angle *SAI* for each of the maxillary tooth brackets is determined in a manner similar to the slot inclination determination step for the mandibular brackets (1300) by first finding the intersection of the maxillary archwire plane *MXAWP* with the labial or buccal surface of each maxillary tooth. Then, circles are described, for each maxillary tooth, having centers at this intersection point and having diameters equal to the occluso-gingival, or vertical, dimensions of the bracket bonding pad, which is typically 4.0 mm. From these circles, *X,Y* coordinates of the intersections of the circles with the labial or buccal tooth surface are found, as follows:

$R^2 = (X_1 - h)^2 + (Y_1 - k)^2$;
$Y_2 = mX_2 + b_2$;
$Y_3 = mX_3 + b_3$

Then, as illustrated in **Fig. 8A**, x/2 radians are them subtracted to produce the slot inclination angle *SIA*:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - x/2$$

(1600) Mandibular Archwire and Slot Depth Step:

[0179] The next step, is (1600) to determine the mandibular archwire and bracket in-out dimension. First, the circle segment of the *BFBCE* with which the *ICP* of the right central is associated is determined, as illustrated in **Fig. 8D**. Then, the incisal center point and circle segment center point plane *ICPCDCPP* is created normal to the arch planes. An incisal center point line *ICPL* is struck that will pass through the *ICP* and a particular circle segment center point *CSCP* associated with the tooth. Then the Pythagorean distance *PD* from *CSCP* to *ICP* is determined. Then, viewing the tooth in the *ICPCSCPP*, as illustrated in **Fig. 8C**, a line *NL* is struck normal to the *BFBCE* plane through the *ICP*, which is the intersection of *CLA* and *BFBCE*. Next, still viewing the tooth in this plane, the intersection point *XP* of *NL* and *MAWP* is determined.

[0180] Still viewing the tooth in the *ICPCSCPP*, the *X* distance *XD* to the labial surface of the tooth from the *XP* is determined, and *PD* is added to *XD* and the lower limit of the bracket slot *LLBS*. The *LLBS* is a distance associated with the particular bracket that will be placed on this tooth. It is the deepest slot allowable for that bracket. Then, the lower limit *LL* is calculated as

$$LL = PD + XD + LLBS$$

Similarly, *PD* is added to the *XD* and the upper limit of the bracket slot *ULBS*. The *ULBS* is also a distance associated with the particular bracket that will be placed on this tooth. It is the shallowest slot allowable for that bracket. The, the upper limit *UL* is calculated as

$$UL = PD + XD + ULBS$$

[0181] Then, viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *LL* distance, *X* and *Y* points, $AWLL_{X,Y}$, are determined relative to an origin at the intersection of *BFBCE* and the mandibular midline *ML*. Then, viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *UL* distance, *X* and *Y* points. $AWUL_{X,Y}$ are determined relative to the intersection of *BFBCE* and the mandibular midline *ML*. Then, the midpoint of $AWLL_{X,Y}$ and $AWUL_{X<Y}$ is found and steps through are then repeated for all mandibular teeth.

[0182] Then, the average mid-point and distance from right to left is calculated to force mandibular archwire symmetry:

$$S_X = MP_X + \frac{PR_X - PL_X}{2}$$

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$$S_Y = MP_Y + \frac{PR_Y + PL_Y}{2}$$

The smoothest curve *SC* that will pass between all $AWLL_{X,Y}$ and $AWUL_{X,Y}$ points is then determined, as illustrated in **Fig. 4E**.

[0183] Preferably, it has no inflection points. If there are one or more inflection points, a logical alternative bracket solution will be derived based upon where the inflection occurred.

(1700) Maxillary Archwire and Slot Depth Step:

[0184] The next step, is (1700) to determine the maxillary archwire and bracket in-out dimension. As with the mandibular determination step (1600), the circle segment of the *BFBCE* with which the *ICP* of the right central is associated is determined. The step is similar to that for the mandibular slot in-out dimension calculation of **Figs. 4E** and **8C**, except that the maxillary centrals and laterals are associated with the *MAAF* rather than the *BFBCE*, the maxillary cuspids are associated with *MCAF*, and teeth posterior to the cuspid are associated with the *BFBCE*.

[0185] The bracket slot cutting is described in the discussion of step (3000) below.

(1800) Placement Jig Design Step:

[0186] The information necessary for the design of bracket placement jigs to aid the orthodontist in positioning the brackets in their proper positions on the individual teeth is now available. The design of the placement jigs is carried out in the software associated with the jig manufacturing step (3500) described below, following a loading of the appropriate files with the necessary data from the calculations described above into the manufacturing control computer 30c.

(97) Appliance Manufacturing Procedure

[0187] The appliance manufacturing procedure (97) includes the steps of (3000) manufacture of the custom brackets, (3200) manufacture of the custom archwires and (3500) manufacture of custom placement jigs for placement of the custom brackets on the patient's teeth. These steps are described in detail below for the embodiment in which all of the manufacturing is carried out at the appliance design facility 13.

(3000) Bracket Manufacturing Step:

[0188] The bracket manufacturing step (3000) produces the custom brackets, preferably by selecting bracket blanks and cuttings a torque slot in the bracket for the archwire 64.

[0189] The computer 30c loads the data for each bracket from the patient data file 36.

[0190] For each tooth and bracket, as a default or initial selection, low profile brackets are assumed. Then, the slot angle *FAI* and the slot in-out dimension *IO* are read. Also, the radius of the archwire at the tooth midpoint is determined.

[0191] Then, a main CNC program is created and the program loops to generate the code for the cutting of each bracket, beginning with the calculation of the variables for the bracket, assigning the variables for each bracket to set the cutting of the slot at the appropriate angle by rotating the bracket support 73 and setting the cutter 77c to a cooperating height *Z* and horizontal *X* position. If the position of the slot lies outside of the area of the bracket, a bracket of the appropriate higher profile is called for by the program, and loaded, either automatically or by an operator. The code is then generated to control the path of the cutter in the *Y* direction to cut the archwire radius in the slot bottom.

[0192] The CNC code is preferably downloaded to an NC controller and the brackets are formed by the cutting of the slots in the series of bracket blanks, and (3080) a report is written.

(3200) Archwire Manufacturing Step:

[0193] The archwire manufacturing step (3200) produces the archwire 64, that is symmetrical about its archwire midline *AML*, having the appropriate terminal leg span *TLS*, formed of a series of circle segments.

[0194] The manufacturing control computer 30c generates a CNC code to operate the wire forming machine 40. The program begins by opening files from the calculated patient data 36 and reading the wire alloy and the wire cross-section prescribed, and an array of data that contains a series of *j* sets of data including the radius and sector length of each circle segment of which the archwire curve is formed, and the calculated total cumulative archwire length. To the archwire equation, a radii and sector lengths are added to produce a one half inch (12.5mm) of straight segment at each end of the wire to form parallel terminal leg extensions. Then, calculating the cumulative slopes and sector lengths of

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the wire along the equation, the terminal leg span *TLS* is calculated.

[0195] The slopes of the wire equation describing wire behavior are calculated by: (1) computing the coefficients of a parabola. (2) filling the first point of a slope array, (3) filling the intermediate points of the slope array, and (4) filling the last point of the slope array. Then, the vertical displacement of the bending lever arm *LA* between the contact points of the roller 70b with the wire 69 and the contact point of the rollers 68 with the wire 69 is determined for each circle segment of the archwire equation, and data added to the array.

[0196] Then, temporary variables are defined for the sector length, lever arm displacement, radius and terminal leg span across the straight segments of the archwire, the controller card 65 of the computer 30c is initialized, the controller base address is set, and default parameters are set. Then, a sequential series of sector lengths and lever arm displacements are sent respectively (1) through the circuits 66a and 67a to the drive of the feed rolls 68, and (2) through the circuits 66b and 67b to the anvil assembly 70.

[0197] Then the lever arm displacement is zeroed and the wire leg location is read by the sensor 71. This reading converted to a numerical value in the computer 30b and any difference in the actual measured terminal leg span and the desired terminal leg span *TLS* is calculated. If the difference is out of tolerance, a correction is made and another wire is formed.

(3500) Jig Manufacturing Step:

[0198] The jig manufacturing step (3500) produces bracket placement jigs custom designed for each tooth to aid in the placement of the custom designed brackets in the proper positions on the teeth so that the custom designed archwire will, when installed in the custom designed and custom placed brackets, move the teeth to their calculated finish positions.

[0199] The information necessary for the design of the custom placement jigs is contained in the patient data file and from the calculations made in the appliance design procedure (96) and in the tooth profile data rile of digitized information reed in step (500), in the illustrated embodiment of the invention. The design of the custom jigs involves, primarily, an assembly of the information already generated, and, in the preferred embodiment, takes place in the course of generating the code for control of the NC controlled manufacturing equipment 41 that produces the jigs.

[0200] In the preferred and illustrated embodiment, the jig manufacturing equipment 41 is a standard CNC mill equipped with a small carbide endmill tool of, for example, 0.5 mm (0.020 inches) in diameter (**Fig. 1F**). The jigs themselves 82 are made from circular ABS plastic wafers 83 of approximately 2.5 cm (one inch) in diameter and approximately 1.0 mm (0.040 inches) in thickness, though considerable variation in size is acceptable.

[0201] The jig manufacturing step (3500), begins with the execution of a program or routine in the manufacturing computer 30b and the input of parameters identifying the patient or case. Upon beginning of the execution of the program, the file of patient data 36 generated in the tooth position calculation and analysis procedure (95) and the appliance design procedure (96) is opened and information is read for each tooth, as illustrated in the diagram of Fig. 91, in relation to a tooth profile *PF*. The variables read are (a) the intersection of the archwire plane and the labial (or lingual, if prescribed) surface of the tooth *TS*, which is in the form of a pair of *X,Y* coordinates $TS_{X,Y}$ in the tooth profile vertical-labial/lingual plane, (b) the slot in-out dimension *Elan* or *10*, (c) the type of bracket, which provides access to the appropriate place in a lookup table of bracket dimensions, such as bracket base thickness *BRel* and bracket pad height *BPH*, and (d) the torque slot width, 0.018 or 0.022 from the prescription.

[0202] Then, the bracket data file is opened and the bracket base thickness read, as illustrated in **Fig. 9J**.

[0203] A CAD program file containing the tooth profiles PF_I is loaded. The profiles *PF*, as illustrated in **Fig. 3C**, are made up of a series of closely spaced points in the profile plane, each represented by *X,Y* coordinates, connected by straight line segments to define the profile curve *PF*. The endmill tool diameter *Endmill* is also entered, which must be less than the archwire diameter or archwire slot width (0.018 or 0.022). Constants arc declared, including the diameter of the jig blank 83, the cut clearance on the outside of the jig, the number of loops, set at 23, and the counter initial settings.

[0204] Then, the CNC P-code is generated for each tooth.

[0205] This is followed by creating the profile and bracket clearance compensation tool paths *ITP* and *BCTP*, respectively. This involves the creation of an initial inside tool path line *IITP* made up of a series of straight line segments, one parallel to each of the line segments of the tooth profile curve, spaced a distance equal to the tool radius on the inside of the profile curve, as illustrated in **Fig. 9K**. the creation of an initial bracket base compensation tool path line *IBCTP* made up of a series of straight line segments, one parallel to each of the line segments of the tooth profile curve, spaced a distance equal to the bracket base dimension minus the tool radius outside of the profile curve, and (3600) creation of the final bracket base compensation tool path *(d)* to cut from the inside tool path line to the base compensation line at the top of the bracket base pad to cut off the jig at the bottom of the pad, as illustrated in **Fig. 9M** ("top" and "bottom" being used as an example for the lower teeth, and being opposite for the upper teeth).

[0206] Next, the archwire slot tool path *ASTP* is created, which can be understood from the sequence set forth in the

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flowchart with reference to the diagrams of **Figs. 9N, 9O** and **9P**. Then, a reference tool path *RefP* is created on an image of a jig blank 83, as illustrated in **Fig. 9Q**, and with reference to it. the outside jig boundary cutout *CTP* is added as illustrated in **Fig. 2R**, and (3620) the actual tool path *TP* is then generated as illustrated in **Fig. 9S**.

[0207] Then, (3625) the CNC machine code is generated, as illustrated in the detailed flowchart of **Fig. 2Z-6**, and written to the output file. Then, (3630) the variables are reset. (3635) the final results are displayed, and (3640) the program loops back to substep (3560) until all of the bracket jig code have been generated. Then, (3645) the completed CNC file is sent to the controller of the CNC mill and a pallet of wafers 83a (**Fig. 1F**) is cut into a set of bracket placement jigs 82. An example of one of the jigs is illustrated in **Figs. 9T** through **9W**.

Claims

1. A method of fabricating a custom orthodontic appliance to position teeth of a patient to preferred finish positions in the mouth of the patient, the method comprising the steps of measuring anatomical shapes from the mouth of the patient, and producing therefrom digitized anatomical shape data including three dimensional tooth shape data representing the shapes of individual teeth of the patient; deriving an ideal dental archform by processing the digitized anatomical shape data with a digital computer programmed to produce a digitized mathematical archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical shape data and the digitized mathematical archform model to mesiodistally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth; designing a custom orthodontic appliance with the computer from the digitized three dimensional tooth shape data, the established appliance connection points and the derived tooth finish positions, such that the custom orthodontic appliance has an appliance configuration dimensioned to interconnect the teeth at their respective connection points with the teeth in the derived tooth finish positions; producing machine readable control signals containing geometric information correlated to the results of the appliance designing step; and automatically fabricating a custom orthodontic appliance with a machine responsive to the machine readable control signals to shape the appliance according to the geometric information contained in the control signals so as to form the custom orthodontic appliance having the designed appliance configuration.

2. A method as claimed in claim 1 wherein the teeth include mandibular teeth and maxillary teeth and wherein: the anatomical shape measuring step includes the steps of measuring the lower jaw of a patient and producing thereby digitized data of lower jaw shape, and measuring mandibular and maxillary teeth of the patient and producing thereby digitized data of individual mandibular and maxillary tooth shape; the archform deriving step includes the step of deriving with the computer a mandibular skeletal archform from the digitized lower jaw shape data; and the tooth finish position deriving step includes the step of deriving tooth finish positions from the tooth shape data and the derived mandibular skeletal archform to arrange the teeth with respect to the mandibular skeletal archform.

3. A method as claimed in claim 2 wherein each tooth has a crown, a root and a long axis extending generally vertically through the centre of the crown, intersecting a gingival centre point where the crown meets the root, and wherein: the lower jaw measuring step includes the step of digitizing data points defining a mandibular trough in which mandibular tooth roots are to be confined; the mandibular skeletal archform deriving step includes the step of fitting a smooth continuous mandibular trough equation to the digitized mandibular trough data points and producing a digitized representation of the mandibular trough equation; the tooth finish position deriving step includes deriving positions which centre each mandibular tooth by placing the long axis thereof approximately on the mandibular trough equation near the gingival centre point of the tooth, and which place the tips of the mandibular teeth on a smooth continuous curve derived by adjusting the mandibular trough equation; and the appliance designing step includes defining the appliance configuration by a series of digital values derived from the smooth continuous curve.

4. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing data of the shape of the lower jaw of the patient by digitizing boundary points corresponding to boundaries of the patient's cortical bone and, the archform deriving step includes the step of deriving from the digitized data a skeletal archform mathematically representing the shape of the patient's cortical bone by a smooth continuous equation derived from the digitized boundary points.

5. A method as claimed in claim 4 wherein the smooth continuous equation is a cubic spline equation through points related to the digitized boundary points.

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6. A method as claimed in any preceding claim wherein the archform deriving step comprises the step of defining a curve based on the digitized anatomical shape data and smoothing the curve by a best fit statistical method to produce smooth continuous archform equation, the finish position deriving step and the appliance configuration designing step being based at least in part on the archform equation.

7. A method as claimed in any preceding claim further comprising the steps of digitally representing the derived archform by an archform equation in the computer; representing the archform equation by a series of successively tangent circle segments; wherein the appliance designing step includes the step of designing an arcuate appliance at least in part in accordance with a series of digital values representing circle segment lengths and radii derived from the circle segments of the archform equation and, the appliance fabricating step includes the step of converting the segment lengths and radii to a series of commands to produce the control signals and, in response to the signals, sequentially forming the appliance to a radius corresponding to each segment length thereof in response to the signals to conform to the designed appliance configuration.

8. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing the distances between mesial and distal contact points for each tooth to define mesial-distal widths for each tooth; the tooth finish position deriving step includes the step of deriving tooth finish positions to place adjacent mesial and distal contact points of adjacent teeth in mutual contact to form a tooth placement arch conforming in shape to the derived archform and approximately equal in length to the sum of the mesial-distal widths of the teeth placed thereon; and the appliance designing step includes the step of designing the appliance configuration in part from the mesial-distal widths and tooth placement arch.

9. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing, for each tooth, tooth profile data in the form of a series of digitized data points representing the shape of the surface of the tooth at least along a profile thereof extending generally vertically and labial-lingually; the connection point establishing step includes the step of locating an appliance connection point on the surface of each of the plurality of teeth along a profile thereof; and the appliance designing step includes the step of designing, from the series of digitized data points representing the shape of the surface of the teeth, the established connection points and the derived tooth positions.

10. A method as claimed in any preceding claim wherein the archform deriving step includes the steps of comparing corresponding contralateral points on opposite sides of the archform and, on the basis of the comparison, calculating a modified archform that is laterally symmetrical about its centre; and designing the appliance based at least in part on the modified archform.

11. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing data of points on labial and lingual surfaces of each of a plurality of the teeth of the patient, and the method further comprises deriving from the digitized labial and lingual surface data a digital representation of the orientation of a crown long axis of each tooth with respect to the points and calculating finish positions of the teeth from the digitized data and the digital representations of the crown long axes of the teeth, the calculated finish positions including preferred crown long axis orientations.

12. A method as claimed in claim 11 further comprising the steps of calculating the preferred crown long axis orientations for a plurality of patients and producing a record of the calculated preferred crown long axis orientations; recording personal data of each of the patient, correlating the personal data with the calculated preferred crown long asis orientations and classifying the patients in population groups on the basis of the correlation; and producing a statistical record of preferred crown long axis orientations for patients of the population groups.

13. A method as claimed in any preceding claim wherein the appliance designing step includes the step of designing appliance placement jig configurations from the tooth shape data, each having a jig surface that will conform to the surface of a respective tooth for facilitating the location of the connection point thereon and the connection of the appliance thereto; the control signal producing step includes the step of producing the control signals at least in part in accordance with the designed appliance placement jig configurations; and the appliance fabricating step includes the step of automatically fabricating appliance placement jigs with the machine in response to the control signals to conform to the designed placement jig configurations.

14. A method as claimed in claim 13 wherein the appliance placement jig configuration designing step comprises the steps of calculating, from the digitized tooth shape data and defined connection points, jig geometry defining a jig

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locating surface that conforms to a unique portion of the external surface of the crown of a tooth, and defining an appliance engaging surface having the same location relative to the jig locating surface as the unique portion of the external surface has to the connection point on the tooth, so that, the machine, when operated in response to the control signals, will form a jig that, when fitted on the tooth, will position and orient an appliance engaged thereby at the connection point of the tooth for connection thereto.

15. A method as claimed in claim 14 wherein the connection point defining step includes the step of calculating the connection points from the digitized tooth shape data; and the jig geometry calculating step includes the step of defining the appliance engaging surface such that the location relative to the jig locating surface is the same as that of the unique portion of the external surface to the calculated connection point on the tooth.

16. A method as claimed in either claim 14 or claim 15 wherein the appliance includes a plurality of brackets, one for connection at each connection point to a tooth, each bracket having an archwire receiving slot therein; the appliance configuration design includes bracket shape data including a digital representation of the position and inclination of the slot in the bracket; and the jig geometry calculating step includes the step of defining the appliance engaging surface to include a part thereof that will align with the slot of the bracket when the bracket is engaged thereby.

17. A method as claimed in claim 16 wherein the appliance designing step includes the step of calculating bracket design to accommodate an archwire of arcuate shape.

18. A method as claimed in either claim 16 or 17 wherein the appliance designing step includes the step of selecting, from a plurality of bracket blanks, an optimum blank for the manufacture of the bracket in accordance with slot digital representation.

19. A method as claimed in any preceding claim wherein the measuring step includes the step of measuring the shapes of individual upper and lower teeth and the shape of the lower jaw of the patient and producing thereby digitized upper and lower tooth data and lower jaw shape data, the tooth shape data including data of the incisal tips of the lower anterior teeth and buccal cusp tips of lower posterior teeth and central ridge or marginal ridge locations of upper posterior teeth; the tooth finish position deriving step includes the steps of deriving a tooth-bearing lower jaw configuration based on assembly of the lower teeth along the lower arch configuration with adjacent teeth in contact with each other and the lower arch configuration; vertically adjusting each lower tooth such that the incisal tips of the lower anterior teeth and buccal cusp tips of the lower posterior teeth are in substantially the same occlusal plane and are inclined at controlled angles of inclination; adjusting the tooth-bearing lower arch configuration to provide a finished tooth bearing lower jaw configuration by labially-lingually positioning the lower teeth to place the incisal and buccal cusp tips thereof in a smooth arch in the occlusal plane with adjacent teeth in contact with each other; and deriving a tooth-bearing finished upper tooth configuration in which the posterior teeth have their central grooves or marginal ridges lying horizontally on the finished tooth bearing lower jaw configuration and vertically on the occlusal plane; the anterior teeth have their incisal tips positioned below the occlusal plane to achieve predetermined overlaps and are horizontally labially offset from the finished tooth bearing lower jaw configuration so as to establish a predetermined clearance between the lower anterior teeth lingual faces and the labial faces of the lower anterior teeth; the appliance designing step includes the step of calculating a bracket configuration for individual upper and lower tooth brackets including the angle and depth of a slot in each bracket, and calculating and archwire shape for upper and lower archwire, based upon the calculated finished tooth positions, predetermined upper and lower archwire planes, the tooth shapes, and the connection positions and, the appliance fabricating step includes the steps of fabricating upper and lower archwires to conform to the calculated archwire shapes; and fabricating brackets to conform to the calculated bracket configurations.

20. A method as claimed in any preceding claim further comprising the steps of providing criteria describing the distances of the individual teeth from the pivot axis of the lower jaw; wherein the tooth finish position deriving step includes the steps of calculating from the criteria and the tooth shape data a component of cuspid rise; and vertically adjusting the upper and lower cuspids such that their cusp tips are respectively below and above the occlusal plane a distance that has a predetermined relationship to the calculated cuspid rise.

21. A method as claimed in claim 20 when dependent on claim 19 wherein the tooth-bearing finished upper tooth configuration deriving step includes deriving the configuration in which the upper anterior teeth have incisal tips positioned below the occlusal plane so as to achieve predetermined overlaps that have a predetermined relationship to the calculated cuspid rise.

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22. A method as claimed in either claim 20 or claim 21 wherein the cuspid rise component calculating step includes the steps of identifying occluding pairs of respective upper and lower posterior teeth of the patient, and determining for each pair from the digitized tooth shape data a vertical distance from the highest extent of the lower tooth of the pair to the lowest extent of the upper tooth of the pair when the jaws are in a closed position; adjusting each determined vertical distance by a factor proportionally related to a distance of each pair from the pivot axis, and selecting the largest adjusted vertical distance calculating, from the digitized data, finish positions of the mandibular teeth of the patient at which highest points thereon are at vertical positions on an approximately flat occlusal surface; and calculating finish positions of the upper and lower cuspids of the patient extend respectively below and above the occlusal surface.

23. A method as claimed in any preceding claim further comprising the steps of providing an orthodontic appliance designing and manufacturing system including a data input sub-system for the digitizing input data of measured anatomical shapes and generating input signals carrying the digitized input data, a data processing sub-system for processing the digitized input signals and generating, in response thereto, output signals carrying the control signals and an appliance hardware manufacturing sub-system, including the fabricating machine, for fabricating, in response to the output signals, a custom orthodontic appliance for the treatment of the patient by moving the teeth of the patient to the preferred finish positions; generating, with the data processing sub-system, from the derived archform, output signals for operating the appliance hardware manufacturing sub-system to fabricate the custom orthodontic appliance; and fabricating, with the appliance hardware manufacturing sub-system, in response to the output signal and in accordance with the control signals the custom orthodontic appliance of the custom configuration.

24. A method as claimed in claim 23 wherein the custom orthodontic appliance includes an archwire having an arcuate shape that is mathematically related to the mandibular trough skeletal archform; the appliance hardware manufacturing sub-system includes a wire bending apparatus responsive to signals carried by the output signal; and the output signal includes a series of control signals for operating the wire bending apparatus to feed a wire and to bend the fed wire into the custom archwire configuration for connection of the archwire to the teeth of a jaw at a respective connection points.

25. A method as claimed in claim 24 wherein the digitized input data contains information from which the connection point of the appliance and slope of the surface at the connection point can be derived; the custom orthodontic appliance includes a plurality of brackets, one for each tooth connection point, each having a base securable to the respective connection point, and each having an archwire slot connectable to the archwire; the appliance hardware manufacturing sub-system includes a bracket fabricating apparatus responsive to control signals carried by the output signal; and, the output signal includes a series of control signals for operating the bracket fabricating apparatus to fabricate each bracket with the archwire slot positioned with respect to the base to support and orient a point on the archwire with respect to the connection point of the respective tooth to transfer force therebetween to urge the tooth toward its finish position.

26. A method as claimed in claim 25 wherein the digitized input data contains information of a contour on the surface of the tooth; the custom orthodontic appliance includes a bracket placement jig for each bracket having a surface for uniquely positioning the jig with respect to the surface of the tooth and for positioning the bracket thereon at the connection point thereof; the appliance hardware manufacturing sub-system includes a bracket placement jig fabricating apparatus responsive to control signals carried by the output signal; and, the output signal includes a series of control signals for operating the bracket placement jig fabricating apparatus to fabricate the bracket placement jig.

27. A method as claimed in either claim 25 or claim 26 wherein the appliance fabricating step includes the steps of providing a plurality of bracket blanks; and forming a bracket from the bracket blank by forming an archwire slot in each of the bracket blank such that each slot will lie in an archwire plane when the bracket is mounted on the connection point of a tooth with the tooth in its derived finish position.

28. A method as claimed in claim 27 wherein the archform deriving step includes the step of deriving from the digitized data a skeletal archform mathematically representing the shape of the patient's cortical bone by a smooth continuous equation derived from digitized boundary points corresponding to the boundaries of the patient's cortical bone and representing the archform equation by a series of successively tangent circle segments the bracket slot cutting step includes the step of forming the slot to a depth defined by the intersection of the archform equation with the bracket, when the bracket is mounted on the connection point of a tooth with the tooth in its derived finish position;

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and the bracket slot cutting step includes the step of forming the slot to a slot bottom curvature of the radius of the intersecting circle segment of the archform equation.

29. A method as claimed in any preceding claim wherein to provide optimal spacing thereof from the gums of a patient and clearance with teeth of the opposite jaw of the patient, the connection position establishing step includes the steps of digitizing the geometry of parts of the appliance; calculating from the digitized tooth shape data, the relationships of points on the surfaces of teeth of the opposite jaws of the patient; calculating from the digitized data, locations on the surfaces of the teeth of one jaw of the patient at which the appliance is to be connected to provide optimal spacing thereof from the gums of a patient and clearance with teeth of the opposite jaw of the patient; and designing the appliance configuration in accordance with the calculated locations for connection of the appliance to the teeth of the patient.

30. A method as claimed in any one of claims 1 to 23 wherein the custom orthodontic appliance includes an archwire; the appliance designing step includes the step of deriving digital archwire shape data based at least in part on the derived archform; the control signal producing step includes the step of generating a wire shape control signal in response to the digital archwire shape data, such that, when communicated to an archwire former, the former will produce a custom orthodontic archwire based on the anatomical shapes from the individual patient's mouth; and forming a length of orthodontic archwire material into a controlled shape in response to the wire shape control signal to produce the custom archwire.

31. A method as claimed in claim 30 wherein the control signal producing step includes the steps of providing archwire material property data of the archwire material; and generating the wire bending control signal in response to the material property data of the archwire material.

32. A method as claimed in either claim 30 or claim 31 further comprising the steps of measuring an archwire span between two points on the produced custom archwire; calculating a design archwire span from the derived archwire shape data; comparing the measured archwire span with the design archwire span and signalling a result of the comparison; and generating the wire bending control signal in response to the signalled result of the comparison.

33. A custom orthodontic appliance fabricating apparatus comprising means (30,30a,33,43,50,57) for measuring anatomical shapes (20-24) from the mouth (18) of the patient (12) and producing thereby digitized anatomical shape data (26) including three dimensional tooth shape data representing the shapes of individual teeth of the patient, a digital computer (30b,30c) including program means for deriving an ideal dental archform from the digitized data (26) with a specially programmed digital computer (30b) to produce a digitized archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical data (26) and the derived digitized ideal archform to mesio-distally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth; designing, from the digitized tooth shape data, established appliance connection point and the derived tooth finish positions, an appliance configuration such that a custom appliance fabricated in accordance therewith is dimensioned to interconnect the teeth at the connection point with the teeth in the derived tooth finish positions, and producing machine code (42) containing geometric information correlated to the designed appliance configuration; and a machine (38,39,40,41) for automatically fabricating a custom orthodontic appliance (25) in response to the machine code (42) to shape the appliance (25), according to the geometric information so as to form the appliance (25) with the designed appliance configuration.

34. Apparatus as claimed in claim 33 wherein the fabricating machine (38) comprises an archwire former (40) including means (66-71) for forming a length of orthodontic archwire material (69) into a controlled shape in response to a wire shape control signal communicated thereto; and the program means including means for generating a wire shape control signal in response to the digital archwire shape data, such that, when the signal is communicated to the archwire former, the former will produce a custom orthodontic archwire (64) conforming to the anatomical shape of the individual patient's mouth (18).

35. Apparatus as claimed in claim 34 wherein the derived digital archwire shape data includes wire length data correlated to a length component of the derived digital archwire shape data and wire curvature data correlated to a curvature component of the derived digital archwire shape data that is a function of the length component; the wire

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shape control signal includes a wire feed control signal carrying the wire length data and a wire bending control signal carrying the wire curvature data; the program means includes means for generating the wire feed control signal and means for generating a wire bending control signal and communicating the control signals to the archwire former; and the archwire former (40) includes means (68) for longitudinally feeding the orthodontic archwire material (69) in response to the wire feed control signal and means (70) for transversely bending the archwire material (69) fed by the wire feeding means (68) in response to the wire bending control signal and in synchronism with the feeding of the archwire material (69).

36. Apparatus as claimed in claim 34 wherein the digital archwire shape data is a digital representation of a connected series of wire segments, each having a length component and a curvature component; and the archwire former includes means for longitudinally feeding a series of lengths of the orthodontic archwire material corresponding to the respective wire length components in accordance with the wire length data and means (70) for bending each fed length of archwire material (69) to a curvature corresponding to the respective wire curvature component in accordance with the wire curvature data.

37. Apparatus as claimed in claim 36 wherein each wire segment is in the form of a circle segment with the length component thereof representing a tangential length of archwire material and with the curvature component thereof representing a constant radius of curvature of the material over the tangential length of the segment; and the feeding means (68) includes means for longitudinally feeding a series of tangential lengths of the orthodontic archwire material (69) and the bending means (70) includes means for bending each fed length of archwire segment to a constant radius in accordance with the wire curvature data.

38. Apparatus as claimed in claim 37 wherein the feeding means (68) is operative to sequentially feed a series of lengths of the archwire material equal to the length components of the circle segments, in response to the wire feed signal, along a longitudinal path; the bending means (70) includes a bending element (70b) moveable in response to the wire bending signal transverse to the path to impart a transverse bending deflection to the segment and a transverse position sensor for producing a feedback signal responsive to the deflection; and the computer (30b, 30c) includes means for modifying the wire bending control signal in response to the feedback signal to provide closed loop control of the bending element.

39. Apparatus as claimed in any one of claims 36 to 38 further comprising means for measuring an archwire span between points on first and last segments of the series of the produced custom orthodontic archwire (64); the program means including means for calculating a design archwire span from the derived archwire shape data; means for comparing the measured archwire span with the design archwire span and for storing the results of the comparison; and the program means being operative to generate the wire shape control signal in response to a stored result of the comparison.

40. Apparatus as claimed in any one of claims 36 to 39 wherein the program means includes means in communication with the wire shape control signal generating means for receiving material property data of the archwire material and for modifying the wire bending control signal in accordance with the property data to compensate for elastic properties of the material.

41. Apparatus as claimed in any one of claims 33-40 wherein the fabricating machine (38) comprises a bracket forming apparatus (39) including a holder (73) having means thereon for mounting a bracket blank (80) thereon for fabrication; means (75-77) for forming at least one surface of a bracket blank (80) mounted on the holder (73) in response to a machine control signal communicated thereto in response to the control signal including means (77) for shaping the bracket blank (80) mounted on the holder (73) to produce a bracket having a slot of a calculated geometric relationship to the mounting surface of the bracket base thereof.

42. Apparatus as claimed in claim 41 wherein each slot includes generally parallel upper and lower sides defining a slot inclination and includes a slot base at an end thereof nearest the bracket base defining a slot position; each calculated geometric relationship of a slot to the mounting surface of a bracket includes the slot inclination and a slot position relative to the mounting surface; the generated machine control signal carries machine control instructions for causing the forming means (75-77) to shape the bracket blank (80) to produce a bracket having a slot (80b) of the calculated slot inclination and slot position with respect to the mounting surface; the slot (80b) of each bracket is adapted to receive an archwire (64) having a custom curvature adjacent the tooth on which the bracket is to be secured; each calculated geometric relationship of a slot to the mounting surface of a bracket includes a slot bottom curvature conforming to the custom curvature of the archwire (64) adjacent thereto; and the generated machine

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control signal carries machine control instructions for causing the forming means to shape the bracket blank (80) to produce a bracket having a slot of the calculated slot bottom curvature.

43. Apparatus as claimed in either claim 41 or claim 42 wherein the forming means (75-77) includes means (77) for cutting a slot (80b) in response to the control signal.

44. Apparatus as claimed in any one of claims 41 to 43 wherein the holder (73) and the forming means (75-77) are mounted on a stand (72); and the apparatus further comprises means (74) for angularly orienting the holder (73) with respect to the stand (72) and to the forming means (75-77), and means (75,76) for translating the shaping means (77) with respect to the stand (72) and to the holder (73), in response to the control signal.

45. Apparatus as claimed in any of claims 33 to 44 wherein the fabricating machine (38) comprises a jig former (41) including means (81) for forming a jig for positioning a custom orthodontic appliance on a tooth of a patient, including means (81) for shaping the contours of a surface of a blank of jig forming material (83) in response to a control signal communicated thereto; the measuring means (30,30a,33,43,50,57) includes means for providing a digitized record of the shapes of the teeth of a patient (12) and of the locations relative to the tooth shape record of appliance connection points on surfaces of the teeth; the program means includes means for calculating, from the digitized tooth shape and connection point record, jig geometry defining a jig locating surface that conforms to a unique portion of the external surface of the crown of a tooth, and defining an appliance engaging surface having the same location relative to the jig locating surface as the unique portion of the external surface has to the connection point on the tooth; and the generating means includes means for generating a machine control signal carrying machine control instructions for producing a jig (82) in accordance with the calculated jig geometry.

46. Apparatus as claimed in claim 45 wherein the appliance includes a plurality of brackets (80) one for connection at each connection point to a tooth; the apparatus further comprises means for providing digitized bracket shape data of an external surface of each bracket to be connected to a connection point; and wherein the jig geometry calculating means includes means for defining the appliance engaging surface of the jig to conform, in response to the digitized bracket shape data, to the established appliance geometry.

Patentansprüche

1. Verfahren zur Herstellung eines individuellen kieferorthopädischen Apparats für die Bewegung der Zähne eines Patienten in gewünschte Endpositionen im Mund des Patienten, das folgende Schritte umfaßt: Vermessen der anatomischen Formen im Mund des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den anatomischen Formen, einschließlich der die Formen der einzelnen Zähne des Patienten darstellenden dreidimensionalen Zahnformdaten; Ableiten einer idealen Zahnbogenform durch Verarbeiten der digitalisierten Daten zu den anatomischen Formen mit Hilfe eines Computers, der für die Erstellung eines zumindest teilweise von den digitalisierten Daten zu den anatomischen Formen abhängigen digitalisierten mathematischen Bogenform-Modells programmiert ist; Ableiten der Zahnendpositionen aus den digitalisierten Daten zu den anatomischen Formen sowie des digitalisierten mathematischen Bogenform-Modells mit Hilfe des Computers zur mesiodistalen Anordnung der Zähne auf dem abgeleiteten idealen Zahnbogen und zur Bewegung der Zähne in bezug auf den abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; Konstruktion eines individuellen kieferorthopädischen Apparats anhand der dreidimensionalen Zahnformdaten, der vorgegebenen Apparatfixierpunkte und der abgeleiteten Zahnendpositionen mit Hilfe des Computers, so daß der individuelle kieferorthopädische Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihren entsprechenden Fixierpunkten und den Zähnen in den abgeleiteten Zahnendpositionen besteht; Erzeugen maschinenlesbarer Steuersignale, die mit den Ergebnissen des Apparatkonstruktionsschritts korrelierende geometrische Informationen enthalten; und automatisches Fertigen eines individuellen kieferorthopädischen Apparats mit Hilfe einer Fertigungsanlage, die mittels maschinenlesbarer Steuersignale steuerbar ist und den Apparat entsprechend den in den Steuersignalen enthaltenen geometrischen Informationen formt, so daß der individuelle kieferorthopädische Apparat mit der zuvor konstruierten Konfiguration ensteht.

2. Verfahren nach Anspruch 1, bei dem unter dem Begriff Zähne sowohl die Unterkieferals auch Oberkieferzähne zu verstehen sind und bei dem der Schritt Vermessen der anatomischen Form die Schritte Vermessen des Unterkiefers eines Patienten und auf dieser Grundlage Gewinnen digitalisierter Daten zur Form des Unterkiefers sowie Vermessen der Unterkiefer- und Oberkieferzähne des Patienten und auf dieser Grundlage Gewinnen digitalisierter Daten zur Form der jeweiligen Unterkiefer- und Oberkieferzähne umfaßt; der Schritt Ableiten der Bogenform den

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Schritt Ableiten einer Mandibularskelettbogenform aus den digitalisierten Daten zur Unterkieferform mit Hilfe des Computers umfaßt; und der Schritt Ableiten der Zahnendposition den Schritt Ableiten der Zahnendpositionen aus den Zahnformdaten und der abgeleiteten Mandibularskelettbogenform umfaßt, so daß die Zähne unter Berücksichtigung der Mandibularskelettbogenform angeordnet werden.

3. Verfahren nach Anspruch 2, bei dem jeder Zahn eine Krone, eine Wurzel und eine Längsachse aufweist, die im allgemeinen senkrecht durch den Mittelpunkt der Krone verläuft und sich mit einem Gingivamittelpunkt schneidet, in dem die Krone an die Wurzel angrenzt, und bei dem der Schritt Vermessen des Unterkiefers den Schritt Digitalisieren von Punkten von Daten umfaßt, die eine die Wurzeln der Unterkieferzähne einschließende Mandibularalveolenmulde definieren; der Schritt Ableiten der Mandibularskelettbogenform den Schritt Anpassen einer glatten stetigen Mandibularalveolenmuldengleichung an die digitalisierten Punkte der Mandibularalveolenmuldendaten und Gewinnen einer digitalisierten Darstellung der Mandibularalveolenmuldengleichung umfaßt; der Schritt Ableiten der Zahnendposition das Ableiten von Positionen umfaßt, durch die jeder Unterkieferzahn mittig ausgerichtet wird, indem dessen Längsachse approximativ auf die Mandibularalveolenmuldengleichung nahe dem Gingivamittelpunkt des Zahns angeordnet wird, und durch die die obersten Zahnpartien der Unterkieferzähne auf eine glatte stetige Kurve gebracht werden, die durch Anpassen der Mandibularalveolenmuldengleichung abgeleitet wurde; und bei dem der Schritt der Apparatkonstrution die Festlegung der Apparatkonfiguration mit Hilfe einer Reihe aus der glatten stetigen Kurve abgeleiteter digitaler Werte umfaßt.

4. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Daten zur Form des Unterkiefers des Patienten durch Digitalisieren den Grenzen der Kompakta des Patienten entsprechender Grenzpunkte und der Schritt Ableiten der Bogenform den Schritt Ableiten einer die Form der Kompakta des Patienten mathematisch darstellenden Skelettbogenform aus den digitalisierten Daten mit Hilfe einer aus den digitalisierten Grenzpunkten abgeleiteten glatten stetigen Gleichung umfaßt.

5. Verfahren nach Anspruch 4, bei dem die glatte stetige Gleichung eine kubische Spline-Funktion durch Punkte ist, die mit den digitalisierten Grenzpunkten in Beziehung stehen.

6. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Ableiten der Bogenform den Schritt Definieren einer Kurve auf der Grundlage der digitalisierten Daten zur anatomischen Form und Glätten der Kurve mit Hilfe eines statistischen Best-fit-Verfahrens zur Gewinnung einer glatten stetigen Bogenformgleichung umfaßt, wobei der Schritt Ableiten der Endposition und der Schritt Konstruktion der Apparatkonfiguration zumindest teilweise auf der Bogenformgleichung basieren.

7. Verfahren nach einem der vorstehenden Ansprüche, das zudem die Schritte digitale Darstellung der abgeleiteten Bogenform durch eine Bogenformgleichung mittels Computer; und Darstellung der Bogenformgleichung durch eine Reihe von einander berührenden Kreissegmenten beinhaltet; und bei dem der Schritt Konstruktion des Apparats den Schritt Konstruktion eines bogenförmigen Apparats zumindest teilweise in Übereinstimmung mit einer Reihe von digitalen Werten, die die Kreissegmentlängen und -radien darstellen, die ihrerseits aus den Kreissegmenten der Bogenformgleichung abgeleitet wurden, und der Schritt Fertigen des Apparats den Schritt Umwandeln der Segmentlängen und -radien in eine Reihe von Befehlen zur Gewinnung von Steuersignalen und, gesteuert durch diese Signale, schrittweises Formen des Apparats mit einem einer jeden Segmentlänge des Apparats entsprechenden Radius in Übereinstimmung mit der berechneten Apparatkonfiguration umfaßt.

8. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Entfernungen zwischen den mesialen und distalen Kontaktpunkten eines jeden Zahns zur Definition der mesial-distalen Breiten eines jeden Zahns; der Schritt Ableiten der Zahnendpositionen den Schritt Ableiten der Zahnendpositionen, wobei aneinander angrenzende mesiale und distale Kontaktpunkte benachbarter Zähne miteinander in Kontakt zu bringen sind, wodurch ein Zahnanordnungsbogen gebildet wird, der in bezug auf die Gestalt mit der abgeleiteten Bogenform übereinstimmt und etwa die gleiche Länge wie die Summe der mesial-distalen Breiten der darauf angeordneten Zähne aufweist; und der Schritt Konstruktion des Apparats den Schritt Konstruktion der Apparatkonfiguration teilweise anhand der mesial-distalen Breiten und des Zahnanordnungsbogens umfaßt.

9. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der für jeden Zahn gewonnenen Zahnprofildaten in Form einer Reihe digitalisierter Punkte von Daten, die die Gestalt der Zahnoberfläche zumindest entlang eines sich im allgemeinen senkrecht und labial-lingual erstreckenden Zahnprofils darstellen; der Schritt Vorgeben des Fixierpunktes den Schritt örtliches Zuweisen eines Apparatfixierpunktes auf der Oberfläche eines jeden einer Anzahl von Zähnen entlang dem Zahnprofil; und der Schritt Konstruktion

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des Apparats den Schritt Konstruktion der vorgegebenen Fixierpunkte und der abgeleiteten Zahnpositionen aus einer Reihe die Gestalt der Zahnoberfläche darstellender Punkte digitalisierter Daten umfaßt.

10. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Ableiten der Bogenform die Schritte Vergleichen entsprechender einander gegenüberliegender Punkte auf einander gegenüberliegenden Seiten der Bogenform und auf der Grundlage dieses Vergleichs Berechnen einer modifizierten Bogenform mit seitlicher Symmetrie gegenüber ihrer Mittellinie sowie Konstruktion des Apparats zumindest teilweise auf der Grundlage der modifizierten Bogenform umfaßt.

11. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Daten von Punkten an den labialen und lingualen Flächen eines jeden Zahns einer Anzahl von Zähnen des Patienten umfaßt, und das des weiteren beinhaltet: Ableiten einer digitalen Darstellung der Ausrichtung einer Kronenlängsachse eines jeden Zahns in bezug auf die Punkte aus den digitalisierten Daten der labialen und lingualen Fläche sowie Berechnen der Endpositionen der Zähne anhand der digitalisierten Daten und der digitalen Darstellungen der Kronenlängsachsen der Zähne, wobei die berechneten Endpositionen bevorzugte Kronenlängsachsenrichtungen einschließen.

12. Verfahren nach Anspruch 11, das ferner die Schritte Berechnen der bevorzugten Kronenlängsachsenrichtungen für eine Anzahl von Patienten und Dokumentieren der berechneten bevorzugten Kronenlängsachsenrichtungen; Dokumentieren der Personendaten eines jeden Patienten, Zuordnen der Personendaten zu den berechneten bevorzugten Kronenlängsachsenrichtungen und Klassifizieren der Patienten in Populationsgruppen auf der Basis dieser Zuordnung; sowie Erstellen einer Statistik zu den bevorzugten Kronenlängsachsenrichtungen bei den Patienten der Populationsgruppen umfaßt.

13. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Konstruktion des Apparats den Schritt Konstruktion der Apparateinsetzhalterkonfigurationen anhand der Zahnformdaten umfaßt, wobei für jede Konfiguration eine Halteroberfläche vorgesehen wird, die mit der jeweiligen Zahnoberfläche übereinstimmt, wodurch die Festlegung der Anordnung des Fixierpunktes und die Fixierung des Apparats an der Zahnoberfläche erleichtert werden; der Schritt Erzeugen der Steuersignale den Schritt Erzeugen von Steuersignalen umfaßt, die zumindest zu einem Teil mit den konstruierten Apparateinsetzhalterkonfigurationen übereinstimmen; und der Schritt Fertigen des Apparats den Schritt automatische Fertigung der Apparateinsetzhalter entsprechend den Steuersignalen zur Gewährleistung der Übereinstimmung mit den berechneten Einsetzhalterkonfigurationen umfaßt.

14. Verfahren nach Anspruch 13, bei dem der Schrift Konstruktion der Apparateinsetzhalterkonfigurationen die Schritte Berechnen der Haltergeometrie anhand der digitalisierten Zahnformdaten und der definierten Fixierpunkte umfaßt, wobei eine Halteranlagefläche, die mit dem individuellen Abschnitt der Kronenaußenfläche eines Zahns übereinstimmt, und eine Apparatangriffsfläche, die hinsichtlich der Lage mit der Halteranlagefläche genauso übereinstimmt, wie der individuelle Abschnitt der Außenfläche mit dem Fixierpunkt am Zahn, definiert werden, so daß die Fertigungsanlage bei Steuerung anhand der Steuersignale einen Halter fertigt, der bei Einsatz am Zahn einen Apparat, auf den er am Fixierpunkt des Zahns zum Befestigen daran aufgesetzt wird, am Ort fixiert und ausrichtet.

15. Verfahren nach Anspruch 14, bei dem der Schritt Festlegen des Fixierpunktes den Schritt Berechnen der Fixierpunkte anhand der digitalisierten Zahnformdaten; und der Schritt Berechnen der Haltergeometrie den Schritt Festlegen der Apparatangriffsfläche unter dem Aspekt umfaßt, daß diese hinsichtlich der örtlichen Zuordnung mit der Halteranlagefläche in gleicher Weise übereinstimmt, wie der individuelle Abschnitt der Außenfläche mit dem berechneten Fixierpunkt am Zahn übereinstimmt.

16. Verfahren nach Anspruch 14 oder 15, bei dem zum Apparat eine Anzahl von Brackets gehört, wobei je eines zum Befestigen an je einem Fixierpunkt an einem Zahn bestimmt ist und jedes Bracket einen Schlitz zur Aufnahme des Bogendrahts aufweist; der Schritt Konstruktion der Apparatkonfiguration Bracketformdaten, so auch eine digitale Darstellung der Position und Neigung des Schlitzes im Bracket, einschließt; und der Schritt Berechnen der Haltergeometrie den Schritt Festlegen der Apparatangriffsfläche umfaßt, so daß ein Teil des Apparats einbezogen ist, der fluchtend auf den Schlitz des Brackets ausgerichtet wird, wenn der Apparat in das Bracket eingesetzt wird.

17. Verfahren nach Anspruch 16, bei dem der Schritt Konstruktion des Apparats den Schritt Berechnen der Bracketauslegung für die Aufnahme eines bogenförmig gestalteten Bogendrahts umfaßt.

18. Verfahren nach Anspruch 16 oder 17, bei dem der Schritt Konstruktion des Apparats den Schrift Auswählen eines

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optimalen Rohlings für die Fertigung des Brackets entsprechend der digitalen Schlitzdarstellung unter einer Anzahl von Bracketrohlingen umfaßt.

19. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schrift Vermessen den Schritt Vermessen der Formen der einzelnen oberen und unteren Zähne und der Unterkieferform des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den Formen der oberen und unteren Zähne sowie zur Unterkieferform umfaßt, wobei die Zahnformdaten auch Daten der Schneidkanten der unteren vorderen Schneidezähne und der bukkalen Höcker der unteren hinteren Zähne sowie des zentralen Kamm- oder des Randleistenbereichs der oberen hinteren Zähne beinhalten; der Schritt Ableiten der Zahnendposition die Schritte Ableiten einer Konfiguration des mit Zähnen bestückten Unterkiefers unter Berücksichtigung der Anordnung der unteren Zähne entlang der unteren Bogenkonfiguration mit miteinander kontaktierenden benachbarten Zähnen, und der unteren Bogen-konfiguration; senkrechtes Ausrichten eines jeden unteren Zahns unter dem Aspekt, daß die Schneidkanten der unteren Vorderzähne und die bukkalen Höcker der unteren hinteren Zähne im wesentlichen die gleiche Okklusionsebene einnehmen und einen angestrebten Neigungswinkel aufweisen; Anpassen der mit Zähnen bestückten unteren Bogenkonfiguration zur Erzielung einer Endkonfiguration des mit Zähnen bestückten Unterkiefers durch labial-linguale Positionierung der unteren Zähne, um deren Schneidkanten und bukkalen Höcker auf einen glatten Bogen in der Okklusionsebene auszurichten, wobei benachbarte Zähne miteinander kontaktieren; und Ableiten einer Endkonfiguration des mit Zähnen bestückten Oberkiefers umfaßt, bei der die zentralen Höckerfurchen bzw. die Randleisten der hinteren Zähne horizontal mit der Endkonfiguration des mit Zähnen bestückten Unterkiefers und vertikal mit der Okklusionsebene übereinstimmen; die Vorderzähne mit ihren Schneidkanten unterhalb der Okklusionsebene angeordnet sind, so daß sie eine festgelegte Überdeckung und ein horizontales Offset in labialer Richtung gegenüber der Endkonfiguration des mit Zähnen bestückten Unterkiefers erhalten, damit ein bestimmter Abstand zwischen den lingualen Seiten der unteren Vorderzähne und den labialen Seiten der unteren Vorderzähne hergestellt wird; der Schritt Konstruktion des Apparats den Schrift Berechnen einer Bracketkonfiguration für die Brackets der einzelnen oberen und unteren Zähne einschließlich des Schlitzwinkels und der Schlitztiefe jedes Brackets und Berechnen der Bogendrahtform für den oberen und unteren Bogendraht, und zwar auf der Grundlage der berechneten Zahnendpositionen, der festgelegten Ebenen für den oberen und unteren Bogendraht, der Zahnformen und der Fixierpositionen; und der Schritt Fertigen des Apparats die Schritte Fertigen des oberen und unteren Bogendrahts in Übereinstimmung mit den berechneten Bogendrahtformen und Fertigen der Brackets entsprechend den berechneten Bracketkonfigurationen umfaßt.

20. Verfahren nach einem der vorstehenden Ansprüche, zu dem ferner die Schritte Bereitstellen von Kriterien für die Beschreibung der Abstände zwischen den einzelnen Zähnen und der Drehachse des Unterkiefers gehören, und bei dem der Schritt Ableiten der Zahnendstellung die Schritte Berechnen einer Molarenanhebungskomponente aus den Kriterien und den Zahnformdaten; und vertikales Ausrichten der oberen und unteren Molaren umfaßt, so daß ihre Höcker entsprechend unterhalb oder oberhalb in einem Abstand zur Okklusionsebene angeordnet werden, der mit der berechneten Molarenanhebung in einer bestimmten Beziehung steht.

21. Verfahren nach Anspruch 20, wenn dieser von Anspruch 19 abhängig ist, bei dem der Schritt Ableiten der Endkonfiguration des mit Zähnen bestückten Oberkiefers das Ableiten der Konfiguration umfaßt, bei der die Schneidkanten der oberen Vorderzähne so weit unterhalb der Okklusionsebene angeordnet sind, daß festgelegte Überdeckungen erreicht werden, die in einer bestimmten Beziehung zur berechneten Molarenanhebung stehen.

22. Verfahren nach Anspruch 20 oder 21, bei dem der Schrift Berechnen der Molarenanhebungskomponente die Schritte Bestimmen der Okklusionspaare der entsprechenden oberen und unteren hinteren Zähne des Patienten und Bestimmen eines senkrechten Abstands zwischen dem höchsten Punkt des unteren Zahns des Paars und dem tiefsten Punkt des oberen Zahns des Paars für ein jedes Paar aus den digitalisierten Zahnformdaten, wenn sich die Kiefer in geschlossener Stellung befinden; Ausgleichen eines jeden ermittelten vertikalen Abstands mittels eines Faktors, der einem Abstand eines jeden Paares zur Drehachse proportional ist, und Auswählen des größten ausgeglichenen vertikalen Abstands, indem aus den digitalisierten Daten die Endpositionen der Unterkieferzähne des Patienten berechnet werden, bei denen sich die höchsten Punkte dieser Zähne hinsichtlich der vertikalen Position an einer weitestgehend flachen Okklusionsfläche befinden; und Berechnen der Endpositionen der sich entsprechend bis unter und über die Okklusionsfläche erstreckenden oberen und unteren Molaren des Patienten umfaßt.

23. Verfahren nach einem der vorstehenden Ansprüche, zu dem des weiteren die Schritte Bereitstellen eines Systems für die Konstruktion und zum Fertigen kieferorthopädischer Apparate einschließlich eines Dateneingabe-Untersystems zur Digitalisierung der Eingabedaten von gemessenen anatomischen Formen und zur Erzeugung von Ein-

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gangssignalen als Träger der digitalisierten Eingabedaten, eines Datenverarbeitungs-Untersystems zur Verarbeitung der digitalisierten Eingangssignale und zur Erzeugung entsprechender Ausgangssignale als Träger der Steuersignale und eines Apparatfertigungs-Ausrüstungsuntersystems mit der dazugehörigen Fertigungsanlage zur durch die Ausgangssignale gesteuerten Herstellung eines individuellen kieferorthopädischen Apparats für die Behandlung des Patienten durch Bewegen der Zähne des Patienten in die bevorzugten Endpositionen; und Erzeugen von Ausgangssignalen für die Steuerung des Apparatfertigungs-Ausrüstungsuntersystems mit Hilfe des Datenverarbeitungs-Untersystems aus der abgeleiteten Bogenform zur Herstellung eines individuellen kieferorthopädischen Apparats; sowie Fertigen des individuellen kieferorthopädischen Apparats mit der individuellen Konfiguration mit Hilfe des Apparatfertigungs-Ausrüstungsuntersystems entsprechend dem Ausgangssignal und den Steuersignalen gehören.

24. Verfahren nach Anspruch 23, bei dem zum individuellen kieferorthopädischen Apparat ein Bogendraht in gebogener Form, die mathematisch in Beziehung steht zur Skelettbogenform der Mandibularalveolenmulde; zum Apparatfertigungs-Ausrüstungsuntersystem eine Drahtbiegevorrichtung, die durch Signale gesteuert wird, für die das Ausgangssignal als Träger dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Drahtbiegevorrichtung gehören, so daß sie mit einem Draht gespeist wird und das Biegen des zugeführten Drahts entsprechend der individuellen Bogendrahtkonfiguration erfolgt, um den Bogendraht an den Zähnen eines Kiefers an den entsprechenden Fixierpunkten fixieren zu können.

25. Verfahren nach Anspruch 24, bei dem die digitalisierten Eingabedaten Informationen enthalten, aus denen der Fixierpunkt des Apparats und die Neigung der Fläche am Fixierpunkt abgeleitet werden können; bei dem zum individuellen kierferorthopädischen Apparat eine Anzahl von Brackets, und zwar je Fixierpunkt des Zahns eines, gehört, wobei jedes eine Basis, die sich am entsprechenden Fixierpunkt fixieren läßt, und einen für die Aufnahme des Bogendrahts bestimmten Bogendrahtschlitz aufweist; zum Apparatfertigungs-Ausrüstungsuntersystem eine Bracketfertigungsvorrichtung gehört, die mittels Steuersignale gesteuert wird, für die das Ausgangssignal als Träger dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Bracketfertigungsvorrichtung gehört, die dazu dienen, jedes Bracket mit dem Bogendrahtschlitz in einer solchen Richtung zur Basis ausgerichtet zu fertigen, daß dieser einen Punkt am Bogendraht bezüglich des Fixierpunktes des entsprechenden Zahns stützt und orientiert und so eine Kraft zwischen diesen Punkten überträgt und schließlich den Zahn in Richtung seiner Endposition drückt.

26. Verfahren nach Anspruch 25, bei dem die digitalisierten Eingabedaten Informationen zum Zahnumriß enthalten; zum individuellen kieferorthopädischen Apparat ein Bracketeinsetzhalter für jedes Bracket mit einer Fläche zur individuell paßgerechten Positionierung des Halters an der Zahnfläche und zur Positionierung des Brackets am Zahn an dessen Fixierpunkt gehört; zum Apparatfertigungs-Ausrüstungsuntersystem eine Bracketeinsetzhalter-Fertigungsvorrichtung gehört, die mit Hilfe der Steuersignale gesteuert wird, für die als Träger das Ausgangssignal dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Vorrichtung für die Fertigung von Bracketeinsetzhaltern gehört.

27. Verfahren nach Anspruch 25 oder 26, bei dem der Schritt Apparatfertigung die Schritte Bereitstellen einer Anzahl von Bracketrohlingen; und Herstellen eines Brackets aus dem Bracketrohling durch Ausbilden eines Bogendrahtschlitzes in jedem der Bracketrohlinge in einer solchen Weise umfaßt, daß jeder Schlitz beim Befestigen des Brakkets am Fixierpunkt eines Zahns in einer Bogendrahtebene angeordnet ist, wobei sich der Zahn in seiner abgeleiteten Endposition befindet.

28. Verfahren nach Anspruch 27, bei dem der Schritt Ableiten der Bogenform den Schritt aus den digitalisierten Daten vorgenommenes Ableiten einer Skelettbogenform umfaßt, die mathematisch die Form der Kompakta des Patienten mittels einer glatten stetigen Gleichung darstellt, die ihrerseits von den digitalisierten Grenzpunkten abgeleitet wurde, die den Grenzen der Kompakta des Patienten entsprechen und die Bogenformgleichung mit Hilfe einer Reihe von einander berührenden Kreissegmenten darstellen; der Schritt Bracketschlitzfräsen den Schritt Ausführen des Schlitzes bis auf eine Tiefe, die durch das Sichschneiden der Bogenformgleichung mit dem Bracket bestimmt wird, wenn das Bracket am Fixierpunkt eines in seiner abgeleiteten Endposition befindlichen Zahns befestigt ist; und der Schritt Bracketschlitzfräsen den Schritt Ausführen des Schlitzes bis zu einer Schlitzgrundflächenkurve mit dem Radius des schneidenden Kreissegments der Bogenformgleichung umfaßt.

29. Verfahren nach einem der vorstehenden Ansprüche, bei dem zur Gewährleistung eines optimalen Zwischenraums zwischen dem Apparat und der Gingiva eines Patienten sowie eines optimalen Zwischenraums zu den Zähnen des anderen Kiefers des Patienten der Schritt Festlegen der Position des Fixierpunktes die Schritte Digitalisieren der

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Geometrie von Teilen des Apparats; anhand der digitalisierten Zahnformdaten erfolgendes Berechnen der Beziehungen zwischen Punkten auf den Zahnflächen der gegenüberliegenden Kiefer des Patienten; anhand der digitalisierten Daten erfolgendes Berechnen der Stellen an den Oberflächen der Zähne eines Kiefers des Patienten, an denen der Apparat zu fixieren ist, damit ein optimaler Zwischenraum zwischen dem Apparat und der Gingiva eines Patienten und ein optimaler Zwischenraum zu den Zähnen des anderen Kiefers des Patienten gewährleistet wird; sowie Konstruktion der Apparatkonfiguration entsprechend den berechneten Orten für die Fixierung des Apparats an den Zähnen des Patienten umfaßt.

30. Verfahren nach einem der Ansprüche 1 bis 23, bei dem zu dem individuellen kieferorthopädischen Apparat ein Bogendraht gehört; der Schritt Konstruktion des Apparats den Schritt Ableiten der digitalen Bogendrahtformdaten, die zumindest teilweise auf der abgeleiteten Bogenform basieren; und der Schritt Erzeugen des Steuersignals den Schritt anhand der digitalen Bogendrahtformdaten erfolgendenes Erzeugen eines Drahtform-Steuersignals, so daß von der Bogendrahtformvorrichtung, wenn dies an die Vorrichtung angelegt wird, ein individueller kieferorthopädischer Apparat entsprechend den anatomischen Formgegebenheiten des Mundes des Patienten hergestellt wird; und Formen einer Länge des kieferorthopädischen Bogendrahtmaterials in eine angestrebte Form entsprechend dem Drahtform-Steuersignal zwecks Herstellung eines individuellen Bogendrahts umfaßt.

31. Verfahren nach Anspruch 30, bei dem der Schritt Erzeugen eines Steuersignals die Schritte Bereitstellen von Materialeigenschaftsdaten des Bogendrahts; und Erzeugen des Drahtbiegesteuersignals anhand der Materialeigenschaftsdaten des Bogendrahts umfaßt.

32. Verfahren nach Anspruch 30 oder 31, das ferner die Schritte Messen der Bogendrahtspannweite zwischen zwei Punkten an dem hergestellten individuellen Bogendraht; Berechnen einer Konstruktions-Bogendrahtspannweite aus den abgeleiteten Bogendrahtformdaten; Vergleichen der gemessenen Bogendrahtspannweite mit der Konstruktions-Bogendrahtspannweite und Übermitteln eines Ergebnisses des Vergleichs; sowie Erzeugen des Drahtbiege-Steuersignals entsprechend dem übermittelten Vergleichsergebnis umfaßt.

33. Fertigungskomplex für die Herstellung eines individuellen kieferorthopädischen Apparats, zu dessen Bestandteilen zählen: technische Mittel (30, 30a, 33, 43, 50, 57) zum Vermessen der anatomischen Formen (20 bis 24) des Mundes (18) des Patienten (12) und darauf aufbauend zur Erzeugung digitalisierter Daten zur anatomischen Form (26) einschließlich dreidimensionaler Zahnformdaten, die die Formen der einzelnen Zähne des Patienten darstellen, und ein digitaler Computer (30b, 30c) einschließlich der Programme zur Ableitung einer idealen Zahnbogenform aus den digitalisierten Daten (26) mit Hilfe eines speziell programmierten Computers (30b) zur Gewinnung eines digitalisierten Bogenformmodells, das zumindest teilweise von den digitalisierten Daten zur anatomischen Form abhängt; zum Ableiten der Zahnendpostionen aus den digitalisierten anatomischen Daten (26) und der abgeleiteten digitalisierten idealen Bogenform mit Hilfe des Computers zur mesiodistalen Anordnung der Zähne auf der abgeleiteten idealen Zahnbogenform und zur Bewegung der Zähne in bezug auf den abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; zum Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; zur Konstruktion einer Apparatkonfiguration anhand der digitalisierten Zahnformdaten, der vorgegebenen Apparatfixierpunkten und der abgeleiteten Zahnendpositionen unter dem Aspekt, daß der entsprechend diesen Daten gefertigte individuelle Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihrem jeweiligen Fixierpunkt und den Zähnen in den abgeleiteten Zahnendpositionen besteht; zum Erzeugen eines Maschinencodes (42), der mit der konstruierten Apparatkonfiguration in einer bestimmten Beziehung stehende geometrische Informationen enthält; und eine Fertigungsanlage (38, 39, 40, 41) zum automatischen Fertigen eines individuellen kieferorthopädischen Apparats (25) durch Formen des Apparats (25) entsprechend dem Maschinenkode (42) in Übereinstimmung mit den geometrischen Informationen, so daß auf diese Weise der Apparat (25) mit der konstruierten Konfiguration entsteht.

34. Fertigungskomplex nach Anspruch 33, bei dem zur Fertigungsanlage (38) eine Bogendrahtformvorrichtung (40) mit technischen Mitteln (66 bis 71) zum Formen einer Länge von kieferorthopädischem Bogendrahtmaterial (69) in eine angestrebte Form entsprechend einem an diese technischen Mittel angelegten Drahtform-Steuersignal; sowie Programmeinheiten mit Einheiten zur Erzeugung eines Drahtform-Steuersignals in Übereinstimmung mit den digitalen Bogendrahtformdaten gehören, so daß bei Anliegen des Signals an der Bogendrahtformvorrichtung diese einen individuellen kieferorthopädischen Bogendraht (64) entsprechend der jeweiligen anatomischen Form des Mundes (18) des Patienten herstellt.

35. Fertigungskomplex nach Anspruch 34, bei dem die abgeleiteten digitalen Bogendrahtformdaten die mit einer Län-

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genkomponente der abgeleiteten digitalen Bogendrahtformdaten in einer Beziehung stehenden Drahtlängendaten und die mit einer Krümmungskomponente der abgeleiteten digitalen Bogendrahtformdaten in einer Beziehung stehenden Drahtkrümmungsdaten enthalten, die eine Funktion der Längenkomponente sind; bei dem zum Drahtform-Steuersignal ein als Träger der Drahtlängendaten dienendes Drahtzuführungssteuersignal und ein als Träger der Drahtkrümmungsdaten dienendes Drahtbiegesteuersignal gehören; bei dem zu den Programmeinheiten Einheiten zur Erzeugung des Drahtzuführungssteuersignals und Einheiten zur Erzeugung eines Drahtbiegesteuersignals und zur Übertragung der Steuersignale an die Bogendrahtformvorrichtung gehören; und bei dem zur Bogendrahtformvorrichtung (40) eine Zuführungsvorrichtung (68) zur Zuführung des kieferorthopädischen Bogendrahtmaterials (69) in Längsrichtung entsprechend dem Drahtzuführungssteuersignal und eine Vorrichtung (70) zum Biegen des mit Hilfe der Drahtzuführungsvorrichtung (68) zugeführten Bogendrahtmaterials (69) in Querrichtung entsprechend dem Drahtbiegesteuersignal und synchron mit der Zuführung des Bogendrahtmaterials (69) gehören.

36. Fertigungskomplex nach Anspruch 34, bei dem die digitalen Bogendrahtformdaten eine digitale Darstellung einer Reihe von zusammenhängenden Drahtsegmenten sind, von denen ein jedes eine Längenkomponente und eine Krümmungskomponente aufweist; und zur Bogendrahtformvorrichtung eine Vorrichtung zur Zuführung einer Reihe von Längen des kieferorthopädischen Bogendrahtmaterials in Längsrichtung entsprechend den jeweiligen Drahtlängenkomponenten in Übereinstimmung mit den Drahtlängendaten und eine Vorrichtung (70) zum Biegen einer jeden zugeführten Länge des Bogendrahtmaterials (69) in eine Form mit einer Krümmung entsprechend der jeweiligen Drahtkrümmungskomponente in Übereinstimmung mit den Drahtkrümmungsdaten gehören.

37. Fertigungskomplex nach Anspruch 36, bei dem jedes Drahtsegment die Form eines Kreissegments mit einer Segmentlängenkomponente als Ausdruck für eine tangentiale Länge des Bogendrahtmaterials und mit einer Segmentkrümmungskomponente als Ausdruck eines konstanten Krümmungsradius des Materials über die tangentiale Länge des Segments aufweist; und zur Zuführungsvorrichtung (68) eine Vorrichtung für die Zuführung einer Reihe von tangentialen Längen des kieferorthopädischen Bogendrahtmaterials (69) und zur Biegevorrichtung (70) eine Vorrichtung zum Biegen einer jeden zugeführten Länge des Bogendrahtsegments in einer Form mit gleichbleibendem Radius entsprechend den Drahtkrümmungsdaten gehören.

38. Fertigungskomplex nach Anspruch 37, bei dem die Zuführungsvorrichtung (68) für die fortlaufende Zuführung einer Reihe von Längen des Bogendrahtmaterials, die den Längenkomponenten der Kreissegmente gleich sind, entsprechend dem Drahtzuführungssignal auf einer längs ausgerichteten Bahn vorgesehen ist; bei dem zur Biegevorrichtung (70) ein Biegeelement (70b), das entsprechend dem Drahtbiegesignal quer zur Bahn bewegt werden kann, um so die Biegung in Querrichtung auf das Segment zu übertragen, und ein Querrichtungspositionssensor zur Erzeugung eines auf die Biegung ansprechenden Rückkopplungssignals gehören; und bei dem zum Computer (30b, 30c) eine Einheit zur Modifizierung des Drahtbiegesteuersignals entsprechend dem Rückkopplungssignal zur Gewährleistung der geschlossenen Steuerung des Biegeelements gehört.

39. Fertigungskomplex nach einem der Ansprüche 36 bis 38, zu dem des weiteren eine Vorrichtung zum Messen der Bogendrahtspannweite zwischen Punkten am ersten und letzten Segment der Reihe von hergestellten individuellen kieferorthopädischen Bogendrähten (64) gehört; bei dem zu den Programmeinheiten Einheiten zur Berechnung einer Bogendraht-Konstruktionsspannweite anhand der abgeleiteten Bogendrahtformdaten; sowie Einheiten zum Vergleich der gemessenen Bogendrahtspannweite mit der Bogendraht-Konstruktionsspannweite und zum Speichern der Vergleichsergebnisse gehören; und bei dem die Programmeinheiten für die Erzeugung des Drahtformsteuersignals entsprechend einem gespeicherten Vergleichsergebnis vorgesehen sind.

40. Fertigungskomplex nach einem der Ansprüche 36 bis 39, bei dem zu den Programmeinheiten mit den Einheiten zur Erzeugung der Drahtformsteuersignale im Datenaustausch stehende Einheiten für den Empfang der Materialeigenschaftsdaten des Bogendrahtmaterials und für die Modifizierung des Drahtbiegesteuersignals entsprechend den Eigenschaftsdaten gehören, wodurch ein Ausgleich der elastischen Eigenschaften des Materials ermöglicht wird.

41. Fertigungskomplex nach einem der Ansprüche 33 bis 40, bei dem zur Fertigungsanlage (38) eine Bracketfertigungsvorrichtung (39) mit einer Spannvorrichtung (73) einschließlich dazugehörender Elemente zur Aufnahme eines Bracketrohlings (80) für die Herstellung; und Elemente (75 bis 77) zur Bearbeitung mindestens einer Oberfläche eines in der Spannvorrichtung (73) eingespannten Bracketrohlings (80) entsprechend einem Fertigungsanlagensteuersignal, das in Übereinstimmung mit dem Steuersignal an diese angelegt wurde, einschließlich einem Element (77) zur Bearbeitung des in der Spannvorrichtung (73) eingespannten Bracketrohlings (80) zur Fertigung eines Brackets, das mit einem Schlitz mit einer berechneten geometrischen Beziehung zur Befestigungsfläche der

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Bracketbasis ausgeführt wird, gehören.

42. Fertigungskomplex nach Anspruch 41, bei dem jeder Schlitz durch eine im allgemeinen parallele Ober- und Unterseite, die eine Schlitzneigung definieren, und eine Schlitzgrundfläche an einem seiner Enden in größter Nähe zur Bracketbasis, die eine Schlitzposition definiert, gekennzeichnet ist; und jede berechnete geometrische Beziehung eines Schlitzes zur Befestigungsfläche eines Brackets durch die Schlitzneigung und eine Schlitzanordnung in bezug auf die Befestigungsfläche gekennzeichnet ist; bei dem das erzeugte Fertigungsanlagensteuersignal als Träger der Fertigungsanlageristeuerbefehle zur Betätigung der Fertigungselemente (75 bis 77) für die Bearbeitung des Bracketrohlings (80) zwecks Herstellung eines Brackets mit einem Schlitz (80b) mit der berechneten Schlitzneigung und -anordnung bezüglich der Befestigungsfläche dient; bei dem der Schlitz (80b) jedes Brackets so ausgeführt ist, daß ein Bogendraht (64) mit einer individuellen Krümmung unmittelbar am Zahn, an dem das Bracket befestigt werden soll, aufgenommen wird; bei dem jede berechnete geometrische Beziehung eines Schlitzes zur Befestigungsfläche eines Brackets durch eine mit der individuellen Krümmung des unmittelbar daran anliegenden Bogendrahts (64) übereinstimmende Schlitzgrundflächenkrümmung gekennzeichnet ist; und das erzeugte Fertigungsanlagensteuersignal als Träger von Fertigungsanlagensteuerbefehlen zur Betätigung der Fertigungselemente für die Bearbeitung des Bracketrohlings zwecks Herstellung eines mit einem Schlitz mit der berechneten Schlitzgrundflächenkrümmung ausgeführten Brackets dient.

43. Fertigungskomplex nach Anspruch 41 oder 42, bei dem zu den Fertigungselementen (75 bis 77) Elemente (77) zum Fräsen eines Schlitzes (80b) entsprechend dem Steuersignal gehören.

44. Fertigungskomplex nach einem der Ansprüche 41 bis 43, bei dem die Spannvorrichtung (73) und die Fertigungselemente (75 bis 77) an einem Ständer (72) montiert sind; und zu dem technische Mittel (74) zum Ausrichten der Spannvorrichtung (73) auf einen bestimmten Winkel bezüglich des Ständers (72) und der Fertigungselemenete (75 bis 77) sowie technische Mittel (75, 76) zum Bewegen der Fertigungselemente (77) relativ zum Ständer (72) und zur Spannvorrichtung (73) entsprechend dem Steuersignal gehören.

45. Fertigungskomplex nach einem der Ansprüche 33 bis 44, bei dem zur Fertigungsanlage (38) eine Halterfertigungsvorrichtung einschließlich der technischen Mittel (81) zur Fertigung eines Halters für das Einsetzen eines individuellen kieferorthopädischen Apparats am Zahn eines Patienten, einschließlich der dazugehörenden technischen Mittel (81) zum Bearbeiten der Konturen einer Fläche eines Halterrohlingsmaterials (83) entsprechend einem dieser Vorrichtung zugeführten Steuersignal gehört; zu den technischen Mitteln zur Vermessung (30, 30a, 33, 43, 50, 57) Einheiten zur Bereitstellung einer digitalisierten Aufzeichnung der Zahnformen eines Patienten (12) und der mit dieser Zahnformaufzeichnung verknüpften Stellen der Apparatfixierpunkte auf den Zahnoberflächen gehören; zu den Programmeinheiten Einheiten zur anhand der Aufzeichnung der digitalisierten Zahnformen und der Fixierpunkte erfolgenden Berechnung der Haltergeometrie, die eine Halteranlagefläche definiert, die einem individuellen Abschnitt der Kronenaußenfläche eines Zahns entspricht, und eine Apparatangriffsfläche definiert, die die gleiche örtliche Zuordnung gegenüber der Halteranlagefläche hat wie der individuelle Abschnitt der Außenfläche gegenüber dem Fixierpunkt am Zahn, gehören; und zu den Einheiten für die Erzeugung von Signalen Einheiten für die Erzeugung eines Fertigungsanlagensteuersignals als Träger der Fertigungsanlagensteuerbefehle für die Fertigung eines Halters (82) entsprechend der berechneten Haltergeometrie gehören.

46. Fertigungskomplex nach Anspruch 45, bei dem zum Apparat eine Anzahl von Brackets (80), und zwar je eines zum Fixieren an jedem Fixierpunkt an einem Zahn gehören; und zu dem des weiteren Einheiten zur Bereitstellung digitalisierter Bracketformdaten einer Außenfläche eines jeden an einem Fixierpunkt zu befestigenden Brackets gehören; und bei dem zur Haltergeometrieberechnungseinheit eine Einheit zur Festlegung der Halteranlagefläche am Apparat gehört, damit, auch gemäß den digitalisierten Bracketformdaten, eine Übereinstimmung mit der vorgegebenen Apparatgeometrie gewährleistet wird.

Revendications

1. Procédé de fabrication sur mesure d'un appareil orthodontique pour replacer les dents d'un patient dans une position finale choisie, ce procédé comprenant les étapes consistant à mesurer l'anatomie de la bouche du patient et produire à partir de ces mesures, des données numérisées de ladite anatomie comprenant des données numérisées représentant en trois dimensions la forme de chacune de ses dents ; définir une arcade dentaire idéale en traitant les données numérisées de celle anatomie avec un ordinateur numérique programmé pour produire un modèle mathématique d'arcade dentaire dépendant au moins en partie des données numérisées de l'anatomie ; définir avec l'ordinateur les positions finales des dents à partir des données numérisées de l'anatomie et du modèle

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mathématique numérisé d'arcade dentaire pour espacer dans le sens mesio-distal les dents le long de l'arcade dentaire idéale choisie et placer les dents par rapport à celle arcade dentaire idéale en positions et orientations reposant au moins en partie sur les données des formes des dents en trois dimensions pour chacune des dents respectives prises individuellement; concevoir sur mesure avec l'ordinateur un appareil orthodontique à partir des données numérisées des formes de dents en trois dimensions, des points de connexion de l'appareil établi et de la position finale choisie des dents, de telle sorte que cet appareil orthodontique sur mesure possède une configuration dont les dimensions sont établies de manière à faire coïncider les dents et leurs points de connexion respectifs, les dents étant dans leur positions finales choisies ; générer des signaux de commande assimilables par une machine contenant des informations géométriques corrélées avec les résultats de l'étape de conception de l'appareil ; et fabriquer sur mesure de manière automatisée un appareil orthodontique avec une machine sensible aux signaux de commande assimilables par celle machine pour façonner cet appareil selon les informations géométriques contenues dans les signaux de commande afin de former un appareil orthodontique sur mesure ayant la configuration dessinée.

2. Procédé selon la revendication 1, dans lequel les dents comprennent les dents mandibulaires et les dents maxillaires et dans lequel la mesure de leur anatomie comprend les étapes consistant à mesurer la mâchoire inférieure d'un patient et produire ainsi des données numérisées de la forme de cette mâchoire et à mesurer ses dents mandibulaires et maxillaires et produire ainsi des données numérisées de la forme de chaque dent; l'extraction de l'arcade comprend l'étape consistant à extraire avec l'ordinateur l'arcade squelettique d'un mandibule à partir des données numérisées de la forme de la mâchoire inférieure ; et l'extraction de la position finale des dents comprend l'étape consistant à extraire ces positions des données de leur forme et de celle de l'arcade squelettique du mandibule extraite pour y disposer les dents.

3. Procédé selon la revendication 2, dans lequel chaque dent a une couronne, une racine et un axe longitudinal généralement vertical passant par le centre de la couronne, faisant intersection avec un point central de la gencive où la couronne rencontre la racine et dans lequel la mesure de la mâchoire inférieure comprend l'étape consistant à numériser les points de mesure définissant un sillon mandibulaire dans lequel les racines des dents mandibulaires doivent se loger ; l'extraction de l'arcade squelettique du mandibule comprend l'étape consistant à faire correspondre la courbe lissée continue de l'équation du sillon mandibulaire aux points de mesure numérisés de ce sillon mandibulaire et à produire une représentation numérisée de l'équation de cette courbe; l'extraction de la position finale des dents comprend l'étape consistant à extraire les positions centrant chaque dent mandibulaire en plaçant leur axe longitudinal approximativement sur la courbe de l'équation du sillon mandibulaire à proximité du point central de la gencive de la dent et plaçant les pointes des dents mandibulaires sur une courbe lissée continue extraite par ajustement de l'équation du sillon mandibulaire ; et la conception de l'appareil comprend l'étape consistant à définir la configuration de cet appareil par une série de valeurs numériques extraites de la courbe lissée continue.

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel la mesure comprend l'étape consistant à numériser des données de la forme de la mâchoire inférieure du patient en numérisant les points correspondant aux contours de son os cortical et l'étape d'extraction de l'arcade consistant à extraire à partir des données numérisées une arcade squelettique représentant mathématiquement la forme de l'os cortical du patient par la courbe d'équation lissée continue tirée des points de contour numérisés.

5. Procédé selon la revendication 4, dans lequel l'équation lissée continue est une équation de la fonction spline cubique des points se rapportant aux points de contour numérisés.

6. Procédé selon l'une quelconque des revendications précédentes dans lequel l'extraction de l'arcade comprend l'étape consistant à définir une courbe basée sur les données numérisées de la forme anatomique et lisser cette courbe par la méthode statistique de l'ajustement optimal pour générer une équation lissée continue de cette arcade, l'étape d'extraction de la position finale et celle de conception de la configuration de l'appareil étant basées au moins en partie sur cette équation de l'arcade.

7. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre les étapes consistant à représenter numériquement, dans l'ordinateur, l'arcade extraite par une équation représenter cette équation de l'arcade par une série d'arcs de cercle tangentiels successifs ; dans lequel la conception de l'appareil comprend l'étape consistant à concevoir un appareil au moins en partie arqué sur la base d'une série de valeurs numériques représentant des longueurs d'arcs de cercle et des rayons tirés des arcs de cercle de l'équation de la forme d'arcade et, la fabrication de l'appareil comprend l'étape consistant à convertir les longueurs des arcs et des rayons en une série de commandes produisant des signaux de commande et, en réponse aux signaux, à former séquen-

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tiellement l'appareil selon un rayon correspondant à chaque longueur d'arc en réponse aux signaux pour se conformer à la configuration conçue dudit appareil.

8. Procédé selon l'une quelconque des revendications précédentes dans lequel la mesure comprend l'étape consistant à numériser les distances entre le point de contact mésial et le point de contact distal de chaque dent pour définir la largeur mésio-distale de chacune ; l'extraction des positions finales des dents comprend l'étape consistant à extraire les positions finales des dents pour mettre au contact l'un de l'autre les points de contact mésial et distal voisins de deux dents adjacentes pour former un arc de placement des dents dont la forme épouse celle de l'arcade extraite et approximativement en longueur égale à la somme des largeurs mésio-distales des dents placées sur cette arcade ; et la conception de l'appareil comprend l'étape consistant à concevoir la configuration de l'appareil en partie à partir des largeurs mésio-distales et de l'arcade de placement des dents.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel la mesure comprend l'étape consistant à numériser, pour chaque dent, des données relatives au profil de celle dent sous forme d'une série de points de données numérisées représentant la configuration de la surface de la dent au moins le long d'un de ces profils généralement vertical et cohérent avec la morphologie lèvres-langue ; l'établissement du point de connexion comprend l'étape consistant à situer un point de connexion de l'appareil à la surface de chacune des dents le long du profil de celles-ci ; et la conception de l'appareil comprend l'étape consistant à concevoir, à partir des séries de point de données numérisées représentant la configuration de la surface des dents, les points de connexion établis et les positions des dents extraites.

10. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'extraction de l'arcade comprend les étapes consistant à comparer les points controlatéraux correspondants sur les côtés opposés de l'arcade et, sur la base de cette comparaison, calculer une arcade modifiée présentant sur ces côtés une symétrie par rapport à son centre ; et concevoir l'appareil sur la base au moins en partie de l'arcade modifiée.

11. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape de mesure comprend l'étape consistant à numériser les données des points des surfaces labiales et linguales de chacune des dents du patient, ce procédé comprenant en outre l'extraction à partir de ces données numérisées d'une représentation numérique de l'orientation de l'axe longitudinal de la couronne de chaque dent par rapport aux points et le calcul, à partir des données numérisées, des positions finales des dents et des représentations numériques des axes longitudinaux des couronnes des dents, les positions finales calculées incluant les orientations préférées des axes longitudinaux des couronnes.

12. Procédé selon la revendication 11, comprenant en outre les étapes consistant à calculer les orientations préférées des axes longitudinaux des couronnes pour une pluralité de patients et à produire un enregistrement de ces orientations préférées calculées ; enregistrer les données personnelles de chacun des patients, corréler les données personnelles avec les orientations préférées calculées des axes longitudinaux des couronnes et placer les patients en groupe de population selon la corrélation ; et produire un enregistrement statistique des orientations préférées des axes longitudinaux des couronnes pour les patients des groupes de population.

13. Procédé selon l'une quelconque des revendications précédentes, dans lequel la conception de l'appareil comprend l'étape consistant à concevoir, à partir des données de la forme des dents, des configurations de gabarit pour la mise en place de l'appareil, chaque configuration ayant une surface de gabarit épousant la surface d'une dent respective pour faciliter la mise en place du point de connexion avec celle-ci et la connexion effective de l'appareil à celle-ci ; la production d'un signal de commande comprend l'étape consistant à produire les signaux de commande au moins en partie selon les configurations de gabarit de mise en place de l'appareil ; et la fabrication de l'appareil comprend l'étape de fabrication automatique avec la machine des gabarits de mise en place de l'appareil en réponse aux signaux de commande pour correspondre aux configurations conçues des gabarit de mise en place.

14. Procédé selon la revendication 13, dans lequel la conception des configurations des gabarits de mise en place de l'appareil comprend les étapes consistant à calculer, à partir des données numérisées des formes des dents et des points de connexion définis, la géométrie des gabarits présentant une surface de mise en place du gabarit épousant la partie unique de la surface externe de la couronne d'une dent et définir une surface engageant l'appareil ayant vis à vis de la surface de mise en place du gabarit le même emplacement que la partie unique de la surface externe vis à vis du point de connexion avec la dent, de telle manière que la machine, quand elle est actionnée en réponse aux signaux de commande, façonne un gabarit qui, lorsqu'il est ajusté sur la dent, positionne et oriente un appareil avec lequel il est en prise au point de connexion.

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15. Procédé selon la revendication 14, dans lequel la définition du point de connexion comprend l'étape consistant à calculer les points de connexion à partir des données numérisées de la forme des dents et le calcul de la géométrie du gabarit comprend l'étape consistant à définir la surface de prise de l'appareil de telle manière que l'emplacement vis à vis de la surface de mise en place du gabarit soit le même que celui de la partie unique de la surface externe vis à vis du point calculé de connexion sur la dent.

16. Procédé selon soit la revendication 14, soit la revendication 15, dans lequel l'appareil comprend une pluralité de crochets, un par connexion à chaque point de connexion d'une dent, chaque crochet ayant une fente recevant un arc dentaire ; la conception de la configuration de l'appareil comprend des données des formes des crochets incluant une représentation numérique de la position et de l'inclinaison de la fente dans le crochet ; et le calcul de la géométrie du gabarit comprend l'étape consistant à définir la surface de prise de l'appareil pour inclure une partie de ce dernier s'alignant sur la fente du crochet quand ce dernier est en prise avec cette surface.

17. Procédé selon la revendication 16, dans lequel la conception de l'appareil comprend l'étape consistant à calculer le dessin des crochets pour y adapter un arc dentaire de forme précise.

18. Procédé selon soit la revendication 16, soit la revendication 17, dans lequel la conception de l'appareil comprend l'étape consistant à sélectionner, à partir d'une pluralité d'ébauches de crochet, une ébauche optimale pour la fabrication du crochet selon la représentation numérique de l'encoche.

19. Procédé selon l'une quelconque des revendications précédentes, dans la mesure comprend l'étape consistant à mesurer les formes individuelles des dents supérieures et inférieures et la forme de la mâchoire inférieure du patient et à produire ainsi des données numérisées des dents supérieures et inférieures et des données de la forme de la mâchoire inférieure, les données de la forme des dents comprenant celles des pointes incisives des dents antérieures inférieures et des pointes cuspides buccales des dents postérieures inférieures et les emplacements des crêtes centrales ou marginales des dents postérieures supérieures ; l'extraction de la position finale des dents comprend les étapes consistant à extraire une configuration de la mâchoire inférieure portant des dents sur la base d'un assemblage de dents inférieures sur la configuration de l'arcade inférieure, les dents adjacentes étant au contact les unes des autres de l'arcade inférieure ; l'ajustement vertical de chacune des dents inférieures de telle manière que les pointes incisives des dents antérieures inférieures et les pointes cuspides buccales des dents postérieures inférieures se trouvent sensiblement dans le même plan occlusal et sont inclinées selon des angles définis ; l'ajustement de la configuration de l'arcade inférieure portant des dents pour fournir une configuration finale de la mâchoire inférieure en positionnant dans le sens lèvre/langue les dents inférieures pour placer les pointes incisives et les pointes cuspides buccales de ces dents sur un arc lisse dans le plan occlusal, les dents adjacentes étant au contact les unes des autres ; et extraire une configuration finale des dents supérieures dans laquelle les dents postérieures ont leur sillon central ou leur crête marginale placées horizontalement sur la configuration finale de la mâchoire inférieure portant des dents et verticalement sur le plan occlusal ; les dents antérieures ont leur pointes incisives placées sous le plan occlusal pour obtenir des chevauchements prédéterminés et sont horizontalement décalés vers les lèvres par rapport à la configuration finale de la mâchoire inférieure portant des dents de manière à établir un espace prédéterminé entre les faces linguales des dents antérieures inférieures et leur face labiale ; la conception de l'appareil comprend l'étape consistant à calculer une configuration de crochet pour les crochets individuels des dents supérieures et inférieures comprenant l'angle et la profondeur d'une fente dans chaque crochet, et à calculer une forme pour l'arc dentaire inférieur et supérieur, sur la base des positions finales calculées des dents, des plans prédéterminés des arcs dentaires supérieurs et inférieurs, des formes des dents et des positions de connexion et la fabrication de l'appareil comprend les étapes consistant à fabriquer des arcs dentaires supérieur et inférieur correspondant aux formes d'arc dentaires calculées ; et fabriquer des crochets correspondant aux configurations calculées de crochets.

20. Procédé selon l'une quelconque des revendications précédentes, comprenant les étapes consistant à fournir les critères décrivant les distances séparant les dents prises individuellement de l'axe de pivotement de la mâchoire inférieure ; dans lequel l'extraction de la position finale des dents comprend les étapes consistant à calculer à partir des critères et des données de la forme des dents une composante de la ligne cuspide ; et ajuster verticalement les cuspides supérieures et inférieures de telle manière que leurs pointes se retrouvent respectivement en dessous et au-dessus du plan occlusal à une distance ayant une relation prédéterminée avec la ligne cuspide calculée.

21. Procédé selon la revendication 20 quand elle dépend de la revendication 19, dans lequel l'extraction de la configuration finale des dents supérieures comprend l'extraction de la configuration dans laquelle les dents antérieures supérieures présentent des pointes incisives positionnées sous le plan occlusal de manière à obtenir un chevau-

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chement ayant une relation prédéterminée avec la ligne cuspide calculée.

22. Procédé selon soit la revendication 20 soit la revendication 21, dans lequel l'étape de calcul de la composante de la ligne cuspide comprend les étapes consistant à identifier les paires occlusales des dents postérieures supérieures et inférieures respectives du patient, et à déterminer pour chaque paire à partir des données numérisées de la forme des dents la distance verticale séparant le point le plus haut du point le plus bas de la dent supérieure de la paire quand les mâchoires sont serrées ; ajuster chaque distance verticale déterminée selon un facteur se rapportant proportionnellement à la distance séparant chaque paire de l'axe de pivotement et sélectionner la distance verticale ajustée la plus grande, calculer, à partir des données numérisées, les positions finales des dents mandibulaires du patient auxquelles les points les plus hauts de ces dents se trouvent en position verticale sur une surface occlusale approximativement plate ; et calculer les positions finales des cuspides supérieures et inférieures du patient passant respectivement en dessous et au-dessus de la surface occlusale.

23. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre les étapes consistant à concevoir un appareil orthodontique et à fabriquer un système comprenant un sous-système d'introduction de données destiné aux données d'entrée numérisées des formes anatomiques mesurées et générer des signaux d'entrée acheminant les données d'entrée numérisées, un sous-système de traitement de données pour traiter les signaux d'entrée numérisés et générer, en réponse à ceux-ci, des signaux de sortie acheminant les signaux de commande et un sous-système de fabrication des pièces de l'appareil, comprenant la machine de fabrication, pour fabriquer, en réponse aux signaux de sortie, un appareil orthodontique sur mesure pour le traitement du patient en mettant ses dents en positions finales préférées ; générer, avec le sous-système de traitement de données, à partir de l'arcade extraite, des signaux de sortie pour commander le sous-système de fabrication des pièces de l'appareil pour fabriquer l'appareil orthodontique sur mesure ; et fabriquer avec le sous-système de fabrication des pièces de l'appareil, en réponse au signal de sortie et selon les signaux de commande, l'appareil orthodontique sur mesure présentant la configuration sur mesure.

24. Procédé selon la revendication 23, dans lequel l'appareil orthodontique sur mesure comprend un arc dentaire ayant une forme précise se rapportant mathématiquement à l'arcade squelettique du sillon mandibulaire ; le sous-système de fabrication des pièces de l'appareil comprend un appareil à plier le fil sensible aux signaux acheminés par le signal de sortie ; et le signal de sortie comprend une série de signaux de commande pour actionner l'appareil à plier le fil pour assurer l'alimentation en fil et plier ce dernier selon la configuration d'arcade sur mesure afin d'assurer la connexion de l'arc dentaire avec les dents au niveau des points respectifs de connexion.

25. Procédé selon la revendication 24, dans lequel les données d'entrée numérisées contiennent une information à partir de laquelle le point de connexion de l'appareil et la pente de la surface au niveau de ce point de connexion peuvent être extraits ; l'appareil orthodontique sur mesure comprend une pluralité de crochets, un par point de connexion à la dent, chacun ayant une base susceptible d'être fixée sur le point de connexion respectif et une fente susceptible d'être reliée à l'arc dentaire ; le sous-système de fabrication des pièces de l'appareil comprend un appareil de fabrication de crochets sensible aux signaux de commande acheminés par le signal de sortie ; et le signal de sortie comprend une série de signaux de commande pour actionner l'appareil de fabrication de crochets afin de fabriquer chaque crochet doté d'une fente pour l'arc dentaire positionnée par rapport à la base de manière porter et orienter un point de l'arc dentaire par rapport au point de connexion de la dent respective pour transférer la force entre l'un à l'autre pour contraindre la dent à prendre sa position finale.

26. Procédé selon la revendication 25, dans lequel les données d'entrée numérisées contiennent une information concernant le contour de la surface de la dent ; l'appareil orthodontique sur mesure comprend, pour chaque crochet, un gabarit pour la mise en place du crochet, ce gabarit ayant une surface servant à positionner de manière unique le gabarit sur la surface de la dent et à positionner le crochet sur celle-ci au niveau de son point de connexion ; le sous-système de fabrication des pièces de l'appareil comprend un appareil pour fabriquer les gabarits pour assurer la mise en place des crochets, cet appareil étant sensible aux signaux de commande acheminés par le signal de sortie ; et le signal de sortie comprend une série de signaux de commande pour actionner cet appareil de fabrication des gabarits pour la mise en place des crochets.

27. Procédé selon soit la revendication 25 soit la revendication 26, dans lequel la fabrication de l'appareil comprend les étapes consistant à utiliser une pluralité d'ébauches de crochet ; et à façonner un crochet à partir de ces ébauches en formant, dans chacun de ces crochets, une fente pour l'arc dentaire de telle sorte que chaque fente se trouve dans le plan de l'arc dentaire quand le crochet est monté sur le point de connexion d'une dent, celle-ci étant dans sa position finale calculée.

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28. Procédé selon la revendication 27, dans lequel l'extraction de l'arcade comprend l'étape consistant à extraire à partir des données numérisées une arcade squelettique représentant mathématiquement la forme de l'os cortical du patient par une équation continue lissée extraite des points numérisés correspondant aux contours de l'os cortical du patient et représenter l'équation de l'arcade par une série d'arcs de cercle tangentiels successifs ; la découpe de la fente du crochet comprend l'étape consistant à former la fente à une profondeur définie par l'intersection de l'équation de l'arcade avec le crochet, quand le crochet est monté sur le point de connexion d'une dent, celle-ci étant dans sa position finale calculée, cette découpe de la fente comprenant également à former le fond de cette fente selon la courbure du rayon de l'arc de cercle venant en intersection avec la courbe de l'équation de l'arcade.

29. Procédé selon l'une quelconque des revendications précédentes, dans lequel, pour maintenir un espacement optimal de l'appareil par rapport aux gencives d'un patient et un espace libre vis à vis des dents de la mâchoire opposée du patient, l'établissement de la position des connexions comprend les étapes consistant à numériser la géométrie des parties de l'appareil ; calculer à partir des données numérisées de la forme des dents les relations des points sur les surfaces des dents des mâchoires opposées du patient ; calculer à partir des données numérisées les emplacements des surfaces des dents d'une mâchoire de patient sur lesquels l'appareil doit être fixé pour maintenir un espacement optimal entre l'appareil et les gencives et un espace libre vis à vis des dents de la mâchoire opposée du patient ; et concevoir la configuration de l'appareil selon les emplacements calculés pour la connexion de l'appareil sur les dents du patient.

30. Procédé selon l'une quelconque des revendications 1 à 23, dans lequel l'appareil orthodontique sur mesure comprend un arc dentaire ; la conception de l'appareil comprend l'étape consistant à extraire des données numériques concernant la forme de l'arc dentaire sur la base au moins en partie de l'arcade extraite ; la production des signaux de commande comprenant l'étape consistant à générer des signaux définissant la forme de l'arc en réponse aux données numériques de cette forme, de telle sorte que, quand elles sont communiquées à un dispositif formant les arcs, ce dispositif produit un arc sur mesure sur la base de l'anatomie de la bouche du patient ; et donner au matériau pour arc dentaire une forme définie en réponse au signal de commande de cet arc dentaire sur mesure.

31. procédé selon la revendication 30, dans lequel la production du signal de commande comprend les étapes consistant à fournir des données sur les propriétés du matériau de l'arc dentaire ; et à générer le signal de commande de pliage de l'arc en réponse à ces données sur les propriétés du matériau.

32. Procédé selon soit la revendication 30 soit la revendication 31, comprenant en outre les étapes consistant à mesurer un intervalle entre deux points situés sur l'arc dentaire fabriqué sur mesure ; calculer un intervalle théorique à partir des données extraites concernant la forme de l'arc dentaire ; comparer l'intervalle mesuré à l'intervalle théorique et signaler le résultat de la comparaison ; et générer le signal de commande de pliage de l'arc en réponse au résultat de la comparaison.

33. Dispositif pour la fabrication sur mesure d'un appareil orthodontique comprenant des moyens (30, 30a, 33, 43, 50, 57) pour mesurer l'anatomie (20-24) de la bouche (18) d'un patient (12) et produire à partir de ces mesures des données numérisées de cette anatomie (26) comprenant des données de la forme de la bouche en trois dimensions représentant les formes de chaque dent du patient prise individuellement, un ordinateur numérique (30b, 30c) comprenant un programme pour extraire une arcade dentaire idéale à partir des données numérisées (26) à l'aide de l'ordinateur (30b) programmé spécialement pour produire un modèle numérisé d'arcade, ce modèle étant au moins en partie dépendant des données numérisées concernant l'anatomie ; extraire avec l'ordinateur, à partir de ces données numérisées (26) et l'arcade numérisée extraite idéale, les positions finales des dents pour espacer de manière mésio-distale les dents le long de l'arcade dentaire idéale extraite et placer les dents par rapport à celle arcade dans des positions et orientations basées au moins en partie sur les données relatives à la forme des dents en trois dimensions pour chaque dent prise individuellement; établir des points de connexion de l'appareil sur chacune des dents d'une pluralité ; établir, à partir des données numérisées de la forme des dents, des points de connexion de l'appareil et des positions finales extraites des dents, une configuration d'appareil telle que l'appareil fabriqué sur mesure selon ces données présente des dimensions permettant d'interconnecter les dents au niveau des points de connexion, ces dents étant en position finale extraite, et produire un code machine (42) contenant les informations géométriques corrélées à la configuration conçue de l'appareil ; et une machine (38, 39, 40, 41) pour fabriquer automatiquement un appareil orthodontique sur mesure (25) en réponse au code machine (42) pour façonner l'appareil (25) selon les informations géométriques de manière à ce qu'il présente la configuration choisie.

34. Dispositif selon la revendication 33, dans lequel la machine de fabrication (38) comprend un dispositif (40) pour former des arcs dentaires comprenant des moyens (66-71) pour donner à un matériau pour arc dentaire (69) une

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forme déterminée en réponse à un signal de commande de la forme de cet arc communiqué à ce dispositif ; et le programme comprenant un moyen pour générer un signal de commande de la forme de l'arc en réponse aux données numériques relatives à la forme de l'arc, de telle manière que, quand le signal est communiqué au dispositif pour former des arcs dentaires, ce dispositif produit un arc dentaire (64) correspondant à la forme anatomique de la bouche du patient (18).

35. Dispositif selon la revendication 34, dans lequel les données numériques de la forme de l'arc dentaire comprennent des données concernant la longueur de l'arc corrélées à une composante de la longueur relative aux données numériques extraites de la forme de l'arc dentaire et des données concernant la courbure de l'arc corrélées à une composante des données numériques extraites relatives à la forme de l'arc dentaire fonction de la composante de longueur ; le signal de commande de la forme de l'arc comprend un signal commandant l'alimentation en fil acheminant les données concernant la longueur de ce fil et un signal commandant le pliage du fil acheminant les données relatives à la courbure de celui-ci ; le programme comprend un moyen pour générer le signal commandant l'alimentation en fil et un moyen pour générer un signal commandant le pliage du fil et communiquer les signaux de commande au dispositif formant l'arc dentaire ; et le dispositif (40) formant l'arc dentaire comprend un moyen (68) pour l'alimenter longitudinalement en matériau (69) en réponse au signal de commande et un moyen (70) pour plier transversalement le matériau de l'arc dentaire (69) fourni par l'alimentation (68) en réponse au signal commandant le pliage du fil, celui-ci étant synchrone avec la fourniture du matériau de l'arc dentaire (69).

36. Dispositif selon la revendication 34, dans lequel les données numériques relatives à la forme de l'arc dentaire sont une représentation numérique d'une série de segments de fil reliés, chacun ayant une composante de longueur et une composante de courbure ; et le dispositif formant l'arc dentaire comprend un moyen pour alimenter longitudinalement une série de longueurs de matériau d'arc dentaire correspondant aux composantes respectives de longueur de fil selon les données de longueur de fil et un moyen (70) pour plier chaque longueur fournie de matériau d'arc dentaire (69) selon une courbure correspondant à la composante respective de courbure du fil correspondant aux données de courbure du fil.

37. Dispositif selon la revendication 36, dans lequel chaque segment de fil à la forme d'un arc de cercle, sa composante de longueur représentant un longueur tangentielle de matériau de l'arc dentaire et sa composante de courbure représentant un rayon constant de la courbure du matériau sur la longueur tangentielle de l'arc ; et le moyen d'alimentation (68) comprend un moyen pour fournir longitudinalement une série de longueurs tangentielles du matériau de l'arc dentaire (69) et le moyen de pliage (70) comprend un moyen pour plier chaque longueur fournie de segment d'arc dentaire selon un rayon constant correspondant aux données de courbure du fil.

38. Dispositif selon la revendication 37, dans lequel le moyen d'alimentation (68) sert à fournir de manière séquentielle une série de longueurs du matériau de l'arc dentaire égales aux composantes de longueur des arcs de cercle, en réponse au signal d'alimentation en fil, sur un trajet longitudinal ; le moyen de pliage (70) comprend un élément de pliage (70b) susceptible d'être déplacé en réponse à un signal de pliage du fil transversal par rapport au trajet pour imprimer une déflexion de pliage transversale par rapport au segment et un capteur en position transversale pou reproduire un signal de retour sensible à la déflexion ; et l'ordinateur (30b, 30c) comprend un moyen pour modifier le signal commandant le pliage du fil en réponse au signal de retour pour assurer une commande en boucle fermée de l'élément de pliage.

39. Dispositif selon l'une quelconque des revendications 36 à 38, comprenant en outre un moyen pour mesurer un intervalle de l'arc dentaire produit sur mesure (64) entre des points situés sut les premier et dernier segments de la série de cet arc ; le programme comprend un moyen pour calculer un intervalle de l'arc dentaire conçu à partir des données extraites de la forme de cet arc ; un moyen pour comparer l'intervalle de l'arc dentaire mesuré et celui de l'arc dentaire conçu et pour mettre en mémoire les résultats de la comparaison ; et le programme servant à générer le signal de commande de la forme de l'arc en réponse au résultat mémorisé de la comparaison.

40. Dispositif selon l'une quelconque des revendications 36 à 39, dans lequel le programme comprend un moyen en communication avec le moyen générant le signal commandant la forme du fil pour recevoir des données relatives aux propriétés du matériau de l'arc dentaire et modifier ce signal selon ces données pour compenser les propriétés élastiques du matériau.

41. Dispositif selon l'une quelconque des revendications 33-40, dans lequel la machine de fabrication (38) comprend un appareil (39) formant les crochets comprenant un support (73) sur lequel se trouve un moyen pour monter l'ébauche de crochet (80) pour fabrication ; un moyen (75-77) pour façonner au moins une surface de l'ébauche

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(80) montée sur le support (73) en réponse à un signal de commande de la machine communiqué à celle-ci en réponse au signal de commande, comprenant le moyen (77) pour façonner l'ébauche de crochet (80) monté sur le support (73) afin de produire un crochet ayant une fente présentant, avec la surface de montage de la base de son crochet, une relation géométrique calculée.

42. Dispositif selon la revendication 41, dans lequel chaque fente comprend des côtés supérieur et inférieur globalement parallèles définissant une inclinaison de cette fente et une base à son extrémité la plus proche de la base du crochet définissant la position de la fente ; chaque relation géométrique calculée d'une fente avec la surface de montage d'un crochet comprend l'inclinaison de la fente et la position de celle-ci par rapport à la surface de montage ; le signal de commande de la machine généré achemine des instructions commandant la machine pour que le moyen de façonnage (75-77) donne forme à l'ébauche de crochet (80) pour produire un crochet ayant une fente (80b) présentant l'inclinaison et la position calculées par rapport à la surface de montage ; la fente (80b) de chaque crochet est adaptée pour recevoir un arc dentaire (64) ayant une courbure sur mesure voisine de la dent sur laquelle le crochet doit être fixé ; chaque relation géométrique calculée de la fente avec la surface de montage d'un crochet comprend une courbure du fond de la fente se conformant à la courbure sur mesure de l'arc dentaire (64) voisin ; et le signal de commande de la machine généré achemine des instructions commandant la machine pour que le moyen de façonnage donne forme à l'ébauche de crochet (80) pour produire un crochet ayant une fente dont le fond présente la courbure calculée.

43. Dispositif selon soit la revendication 41 soit la revendication 42, dans lequel le moyen de façonnage (75-77) comprend un moyen (77) pour découper une fente (80b) en réponse au signal de commande.

44. Dispositif selon l'une quelconque des revendications 41 à 43, dans lequel le support (73) et le moyen de façonnage (75-77) sont montés sur une base (72) ; et le dispositif comprend en outre un moyen (74) pour orienter de manière angulaire le support (73) par rapport à la base (72) et au moyen de façonnage (75-77), et un moyen (75,76) pour déplacer par translation le moyen de mise en forme (77) par rapport à la base (72) et au support (73), en réponse au signal de commande.

45. Dispositif selon l'une quelconque des revendications 33 à 44, dans lequel la machine de fabrication (38) comprend un dispositif (41) pour façonner un gabarit incluant un moyen (81) pour former un gabarit de mise en place d'un appareil orthodontique sur mesure sur la dent d'un patient, ce moyen (81) formant les contours de la surface d'un matériau (83) d'une ébauche de gabarit en réponse à un signal de commande ; les moyens de mesure (30, 30a, 33, 43, 50, 57) comprennent un moyen pour fournir un enregistrement numérisé des formes des dents d'un patient (12) et, par rapport à l'enregistrement de la forme des dents, des emplacements de points de connexion de l'appareil sur les surfaces des dents ; le programme comprend un moyen pour calculer, à partir de l'enregistrement de la forme numérisée des dents et des points de connexion, la géométrie du gabarit définissant une surface pour la mise en place du gabarit épousant une partie unique de la surface externe de la couronne de la dent et définissant une surface de prise de l'appareil ayant le même emplacement par rapport à la surface d'engagement du gabarit que celui de la partie de la surface externe par rapport au point de connexion avec la dent ; et le moyen de production comprend un moyen pour générer un signal de commande de la machine acheminant des instructions commandant la machine pour produire un gabarit (82) selon la géométrie calculée.

46. Dispositif selon la revendication 45, dans lequel l'appareil comprend une pluralité de crochets (80), un par connexion sur chaque point de connexion avec la dent ; l'appareil comprend en outre un moyen pour fournir des données numérisées de forme d'une surface externe de chaque crochet devant être connecté au point de connexion ; et dans lequel le moyen de calcul de la géométrie du gabarit comprend un moyen pour définir la surface de prise du gabarit et de l'appareil pour correspondre, en réponse aux données numérisées de la forme des crochets, à la géométrie établie de l'appareil.

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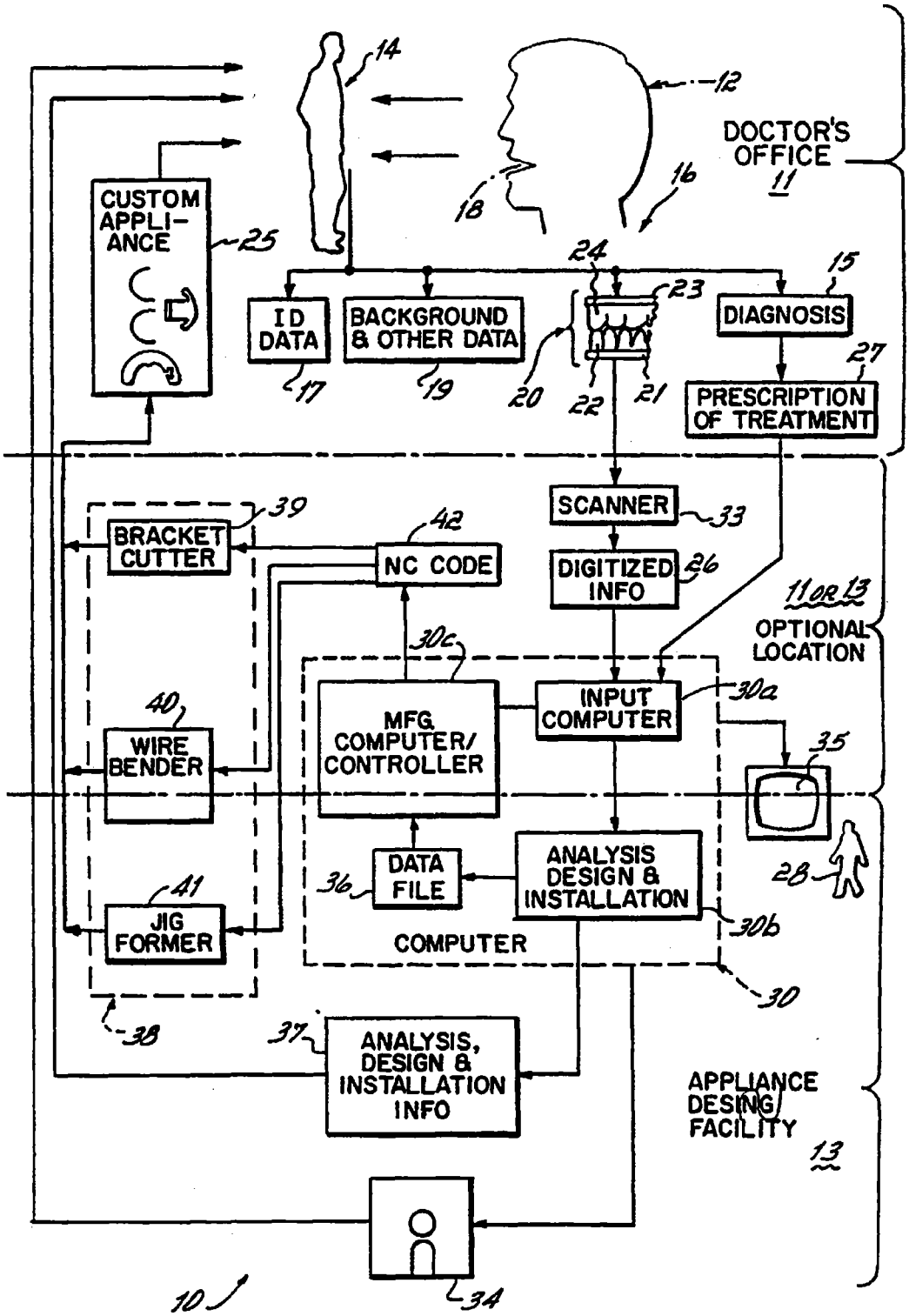


FIG. 1

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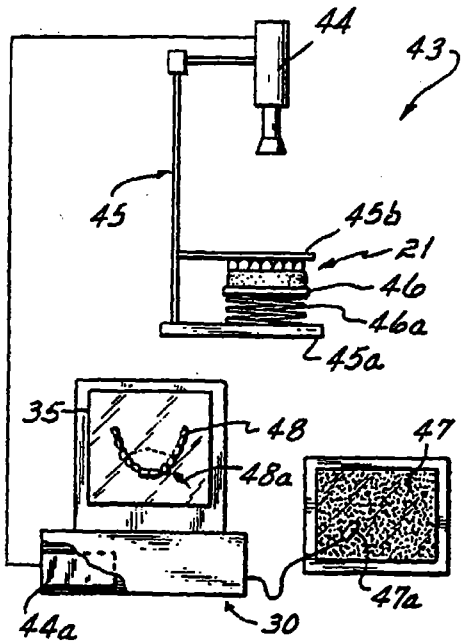


FIG. IA

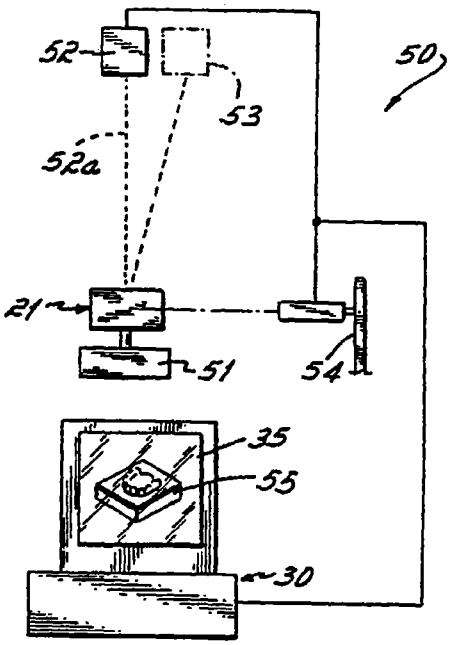


FIG. IB

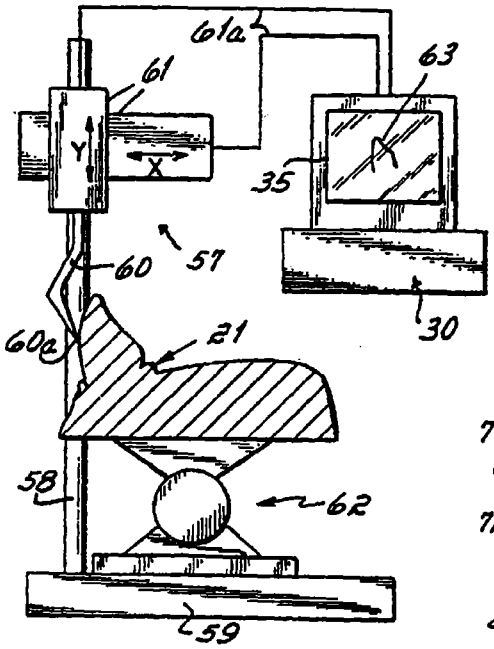


FIG. IC

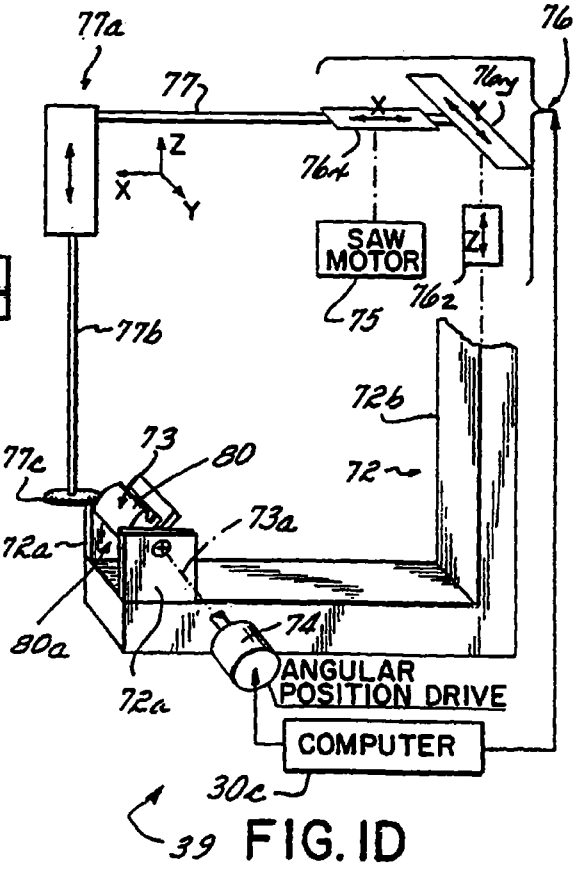


FIG. ID

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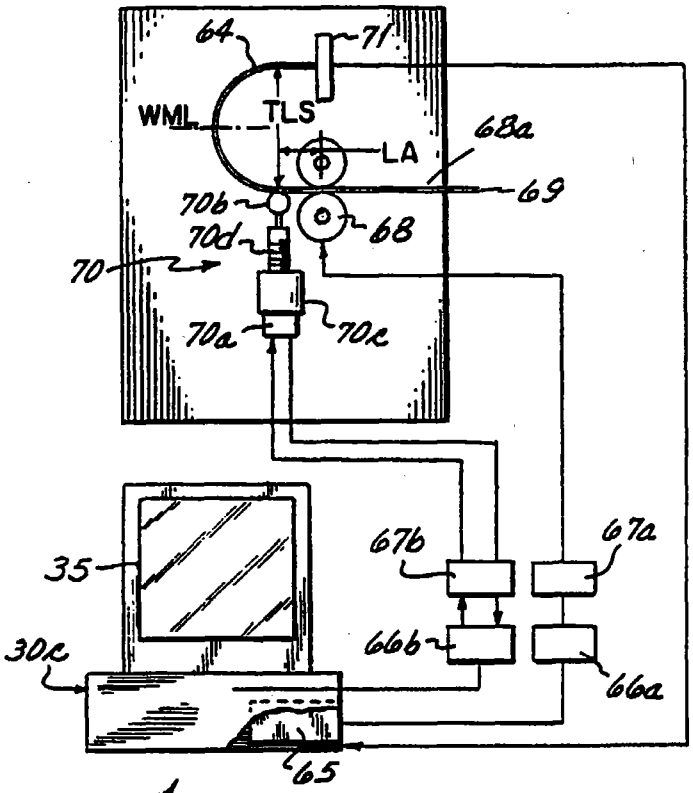


FIG. 1E

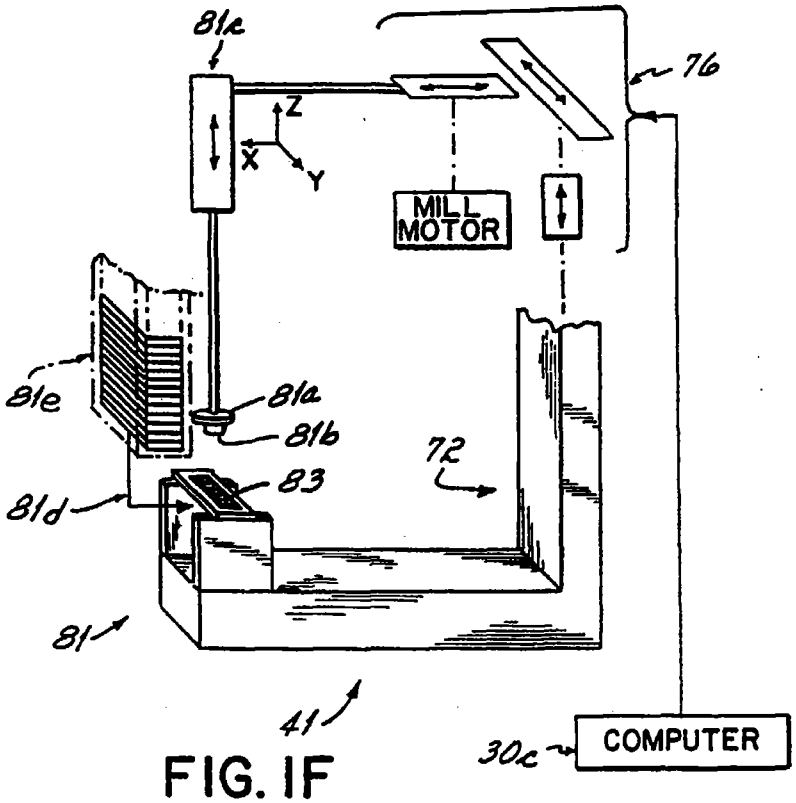


FIG. 1F

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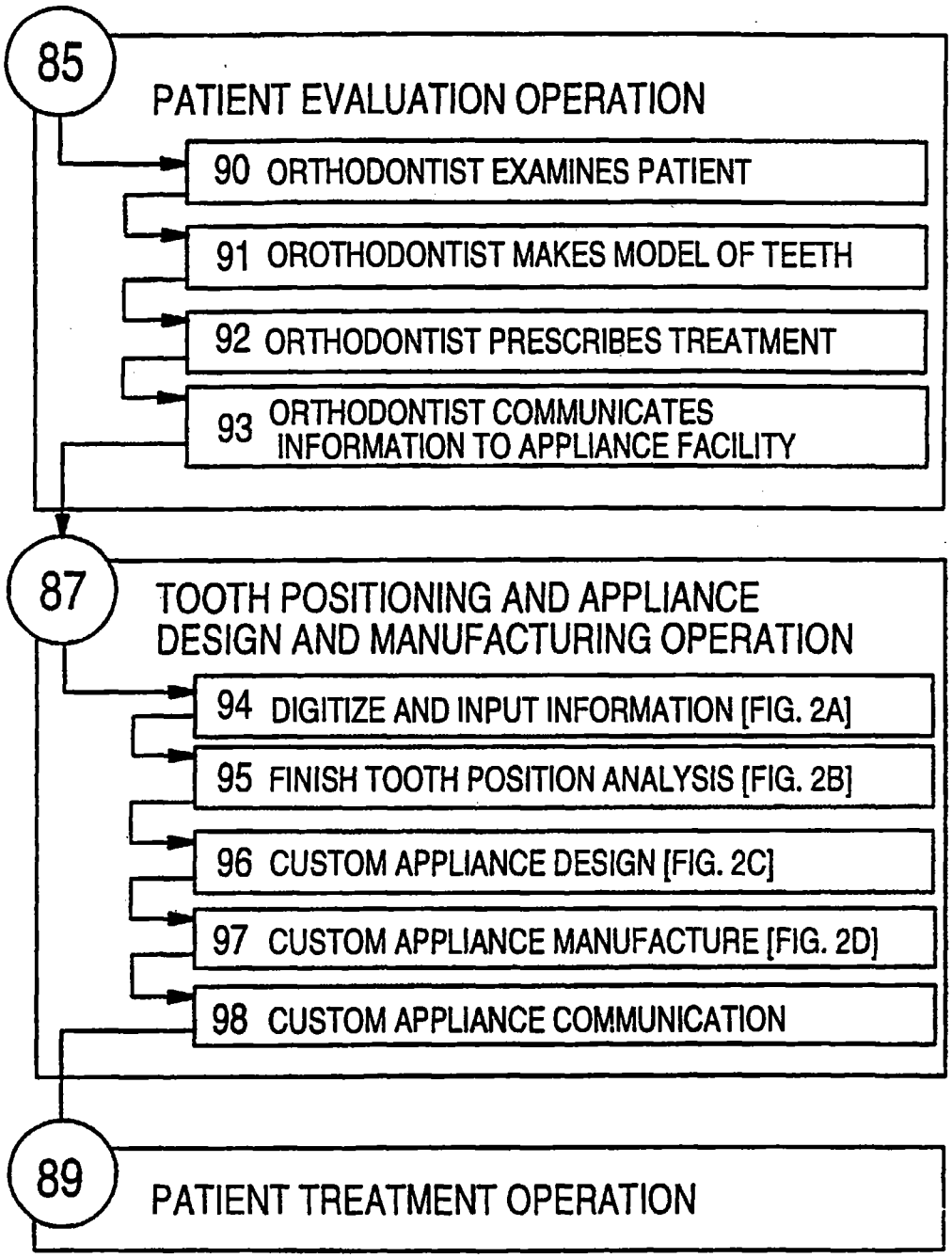


FIG. 2

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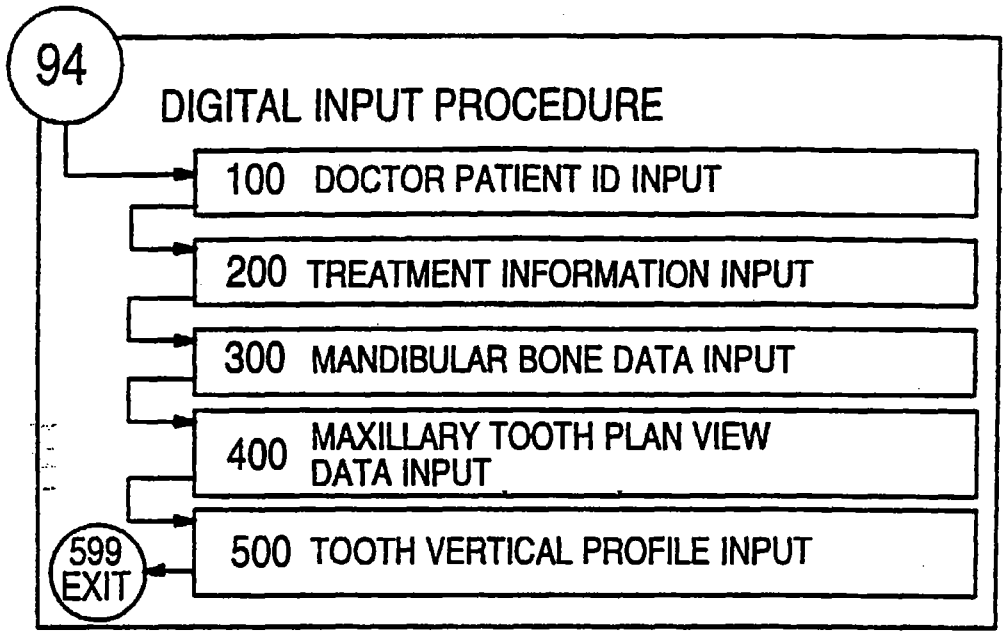


FIG. 2A

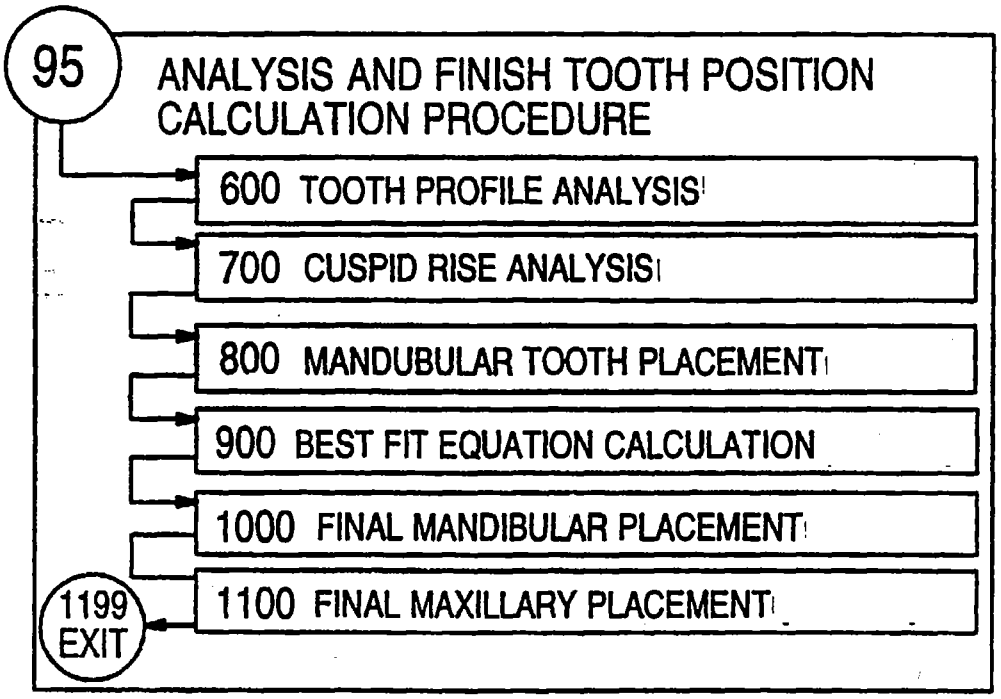


FIG. 2B

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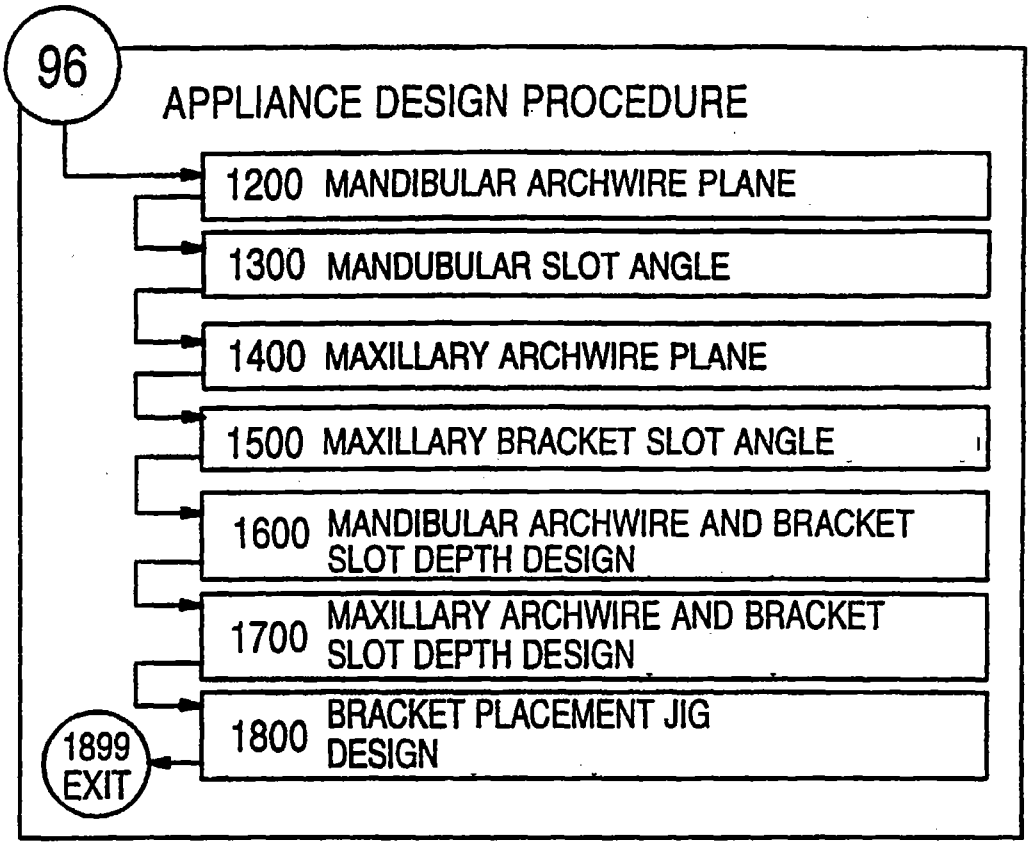


FIG. 2C

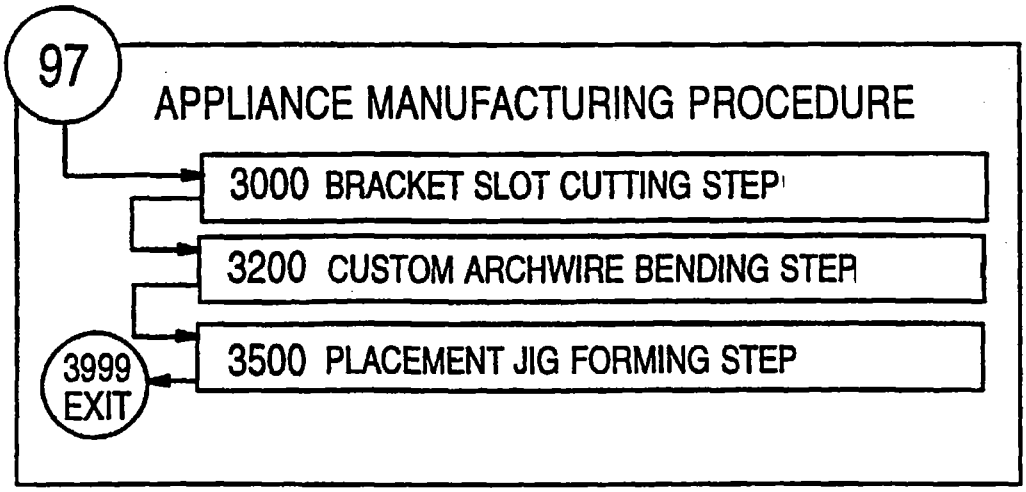


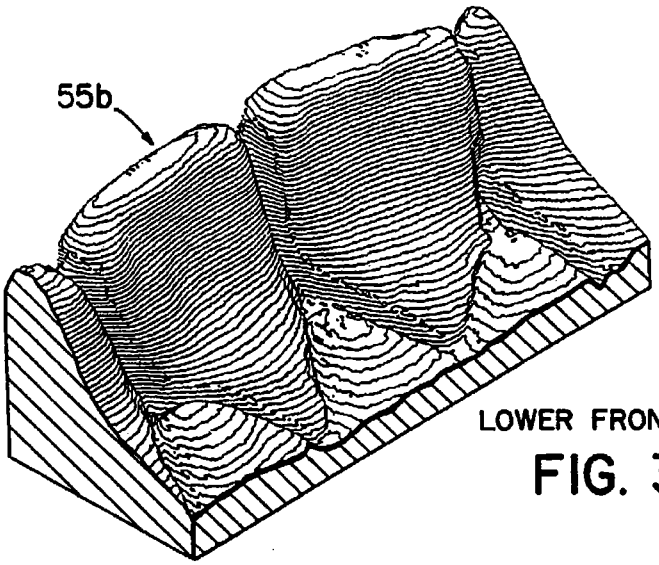
FIG. 2D

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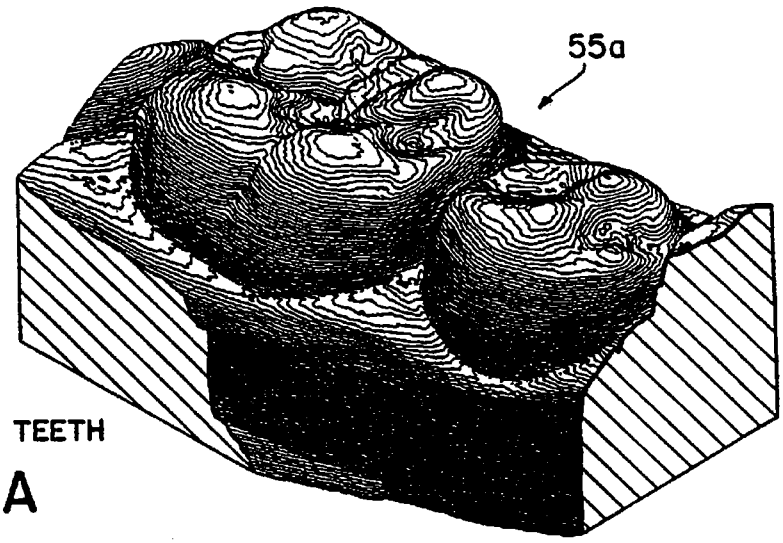
FIG. 3

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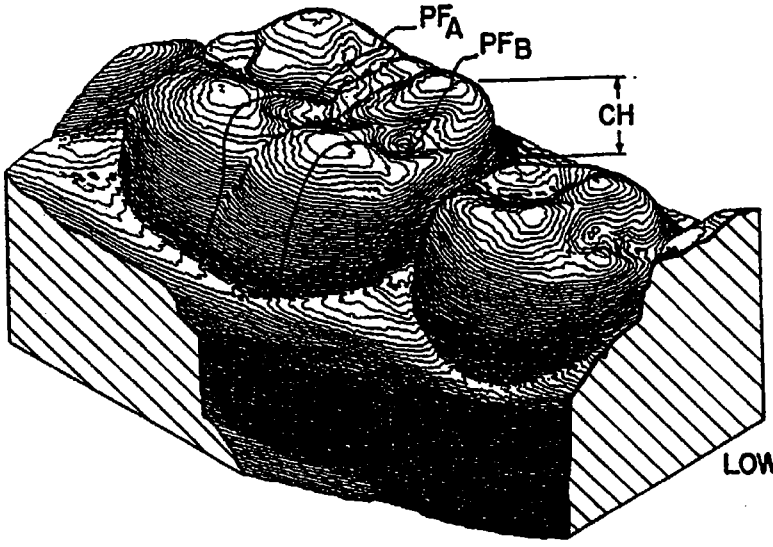
LOWER FRONT TEETH

FIG. 3B



LOWER RIGHT TEETH

FIG. 3A



LOWER RIGHT TEETH

FIG. 6

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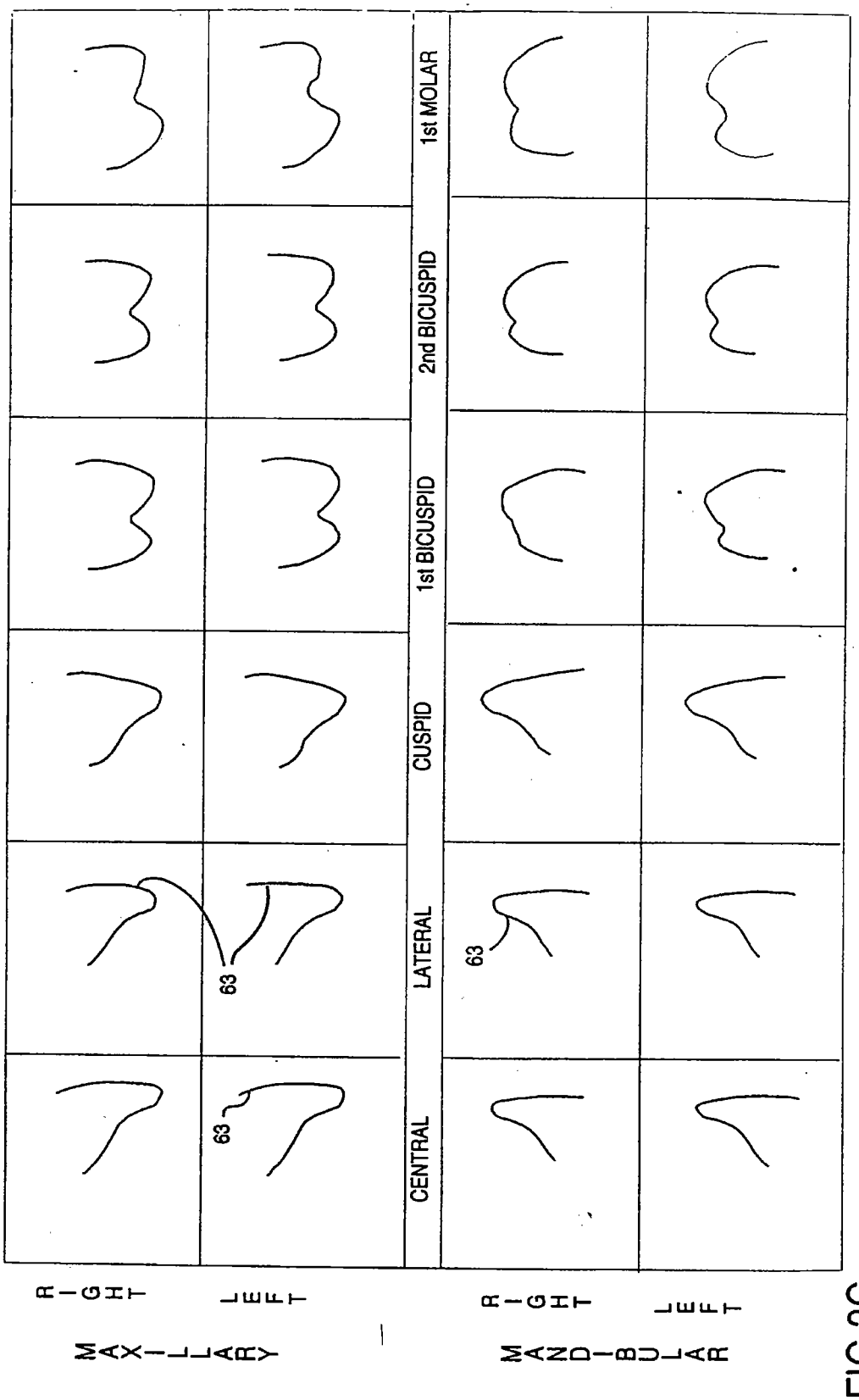


FIG.3C

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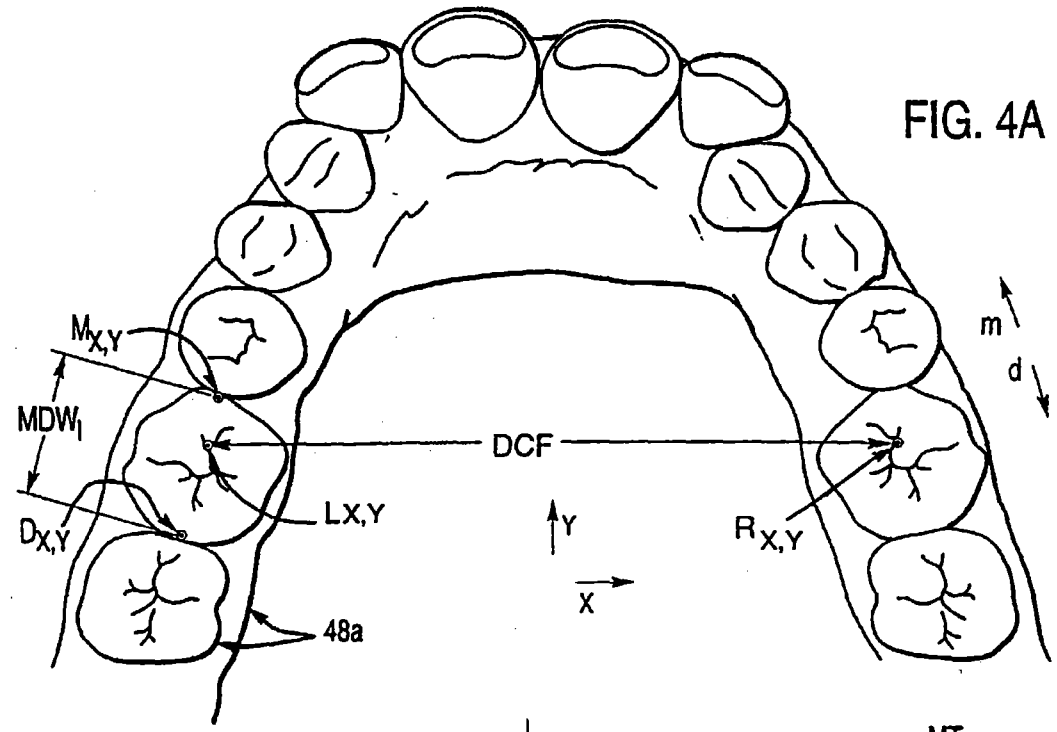


FIG. 4A

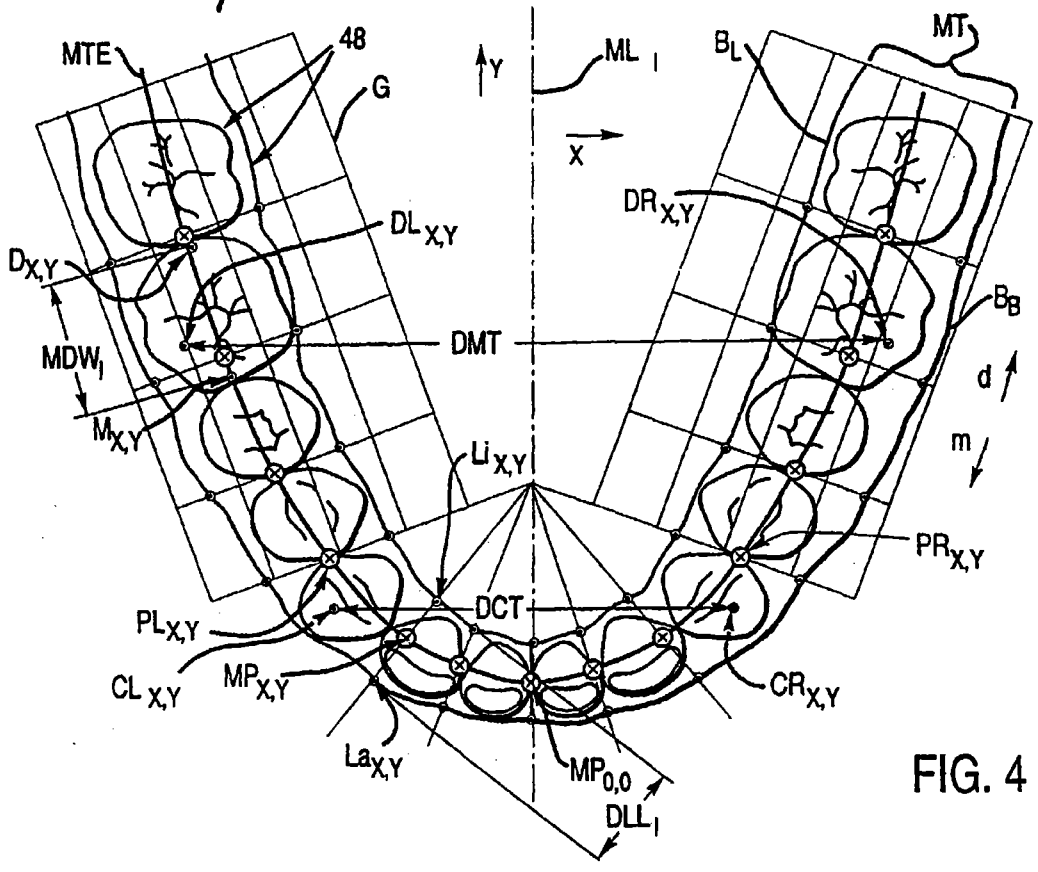
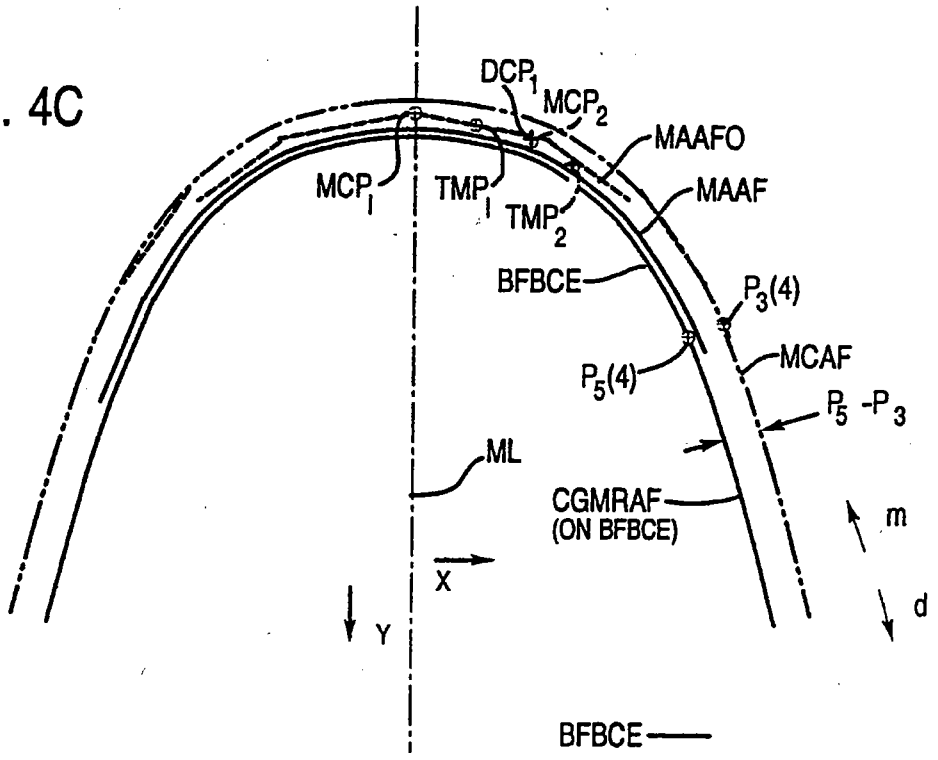


FIG. 4

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FIG. 4C



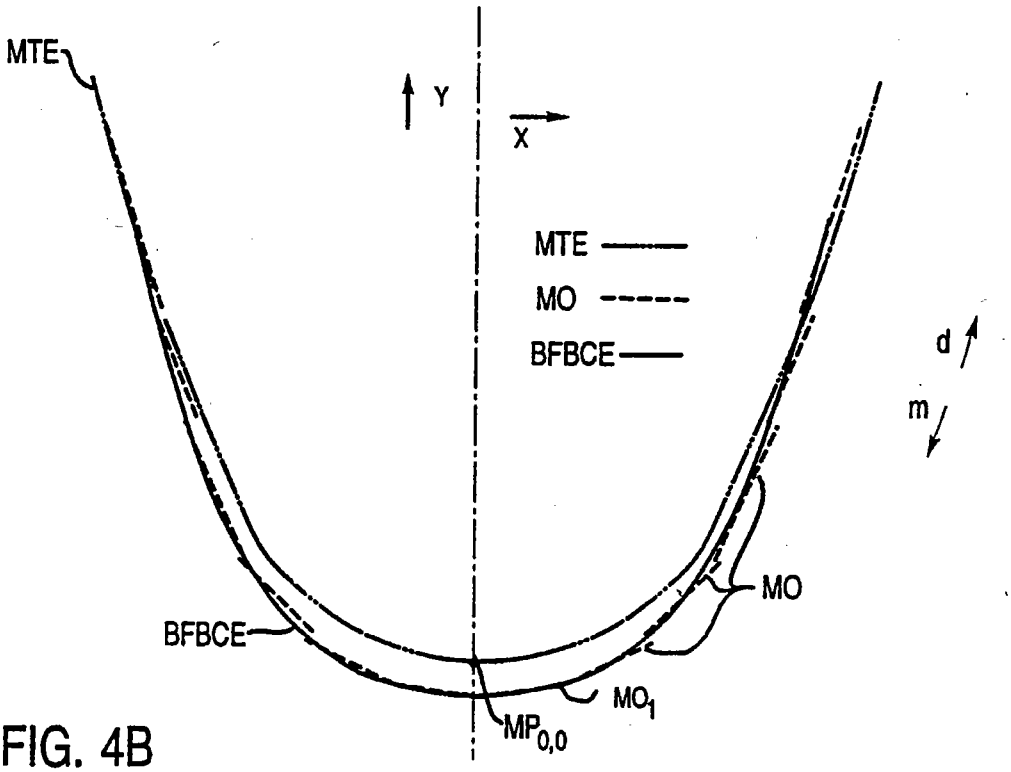
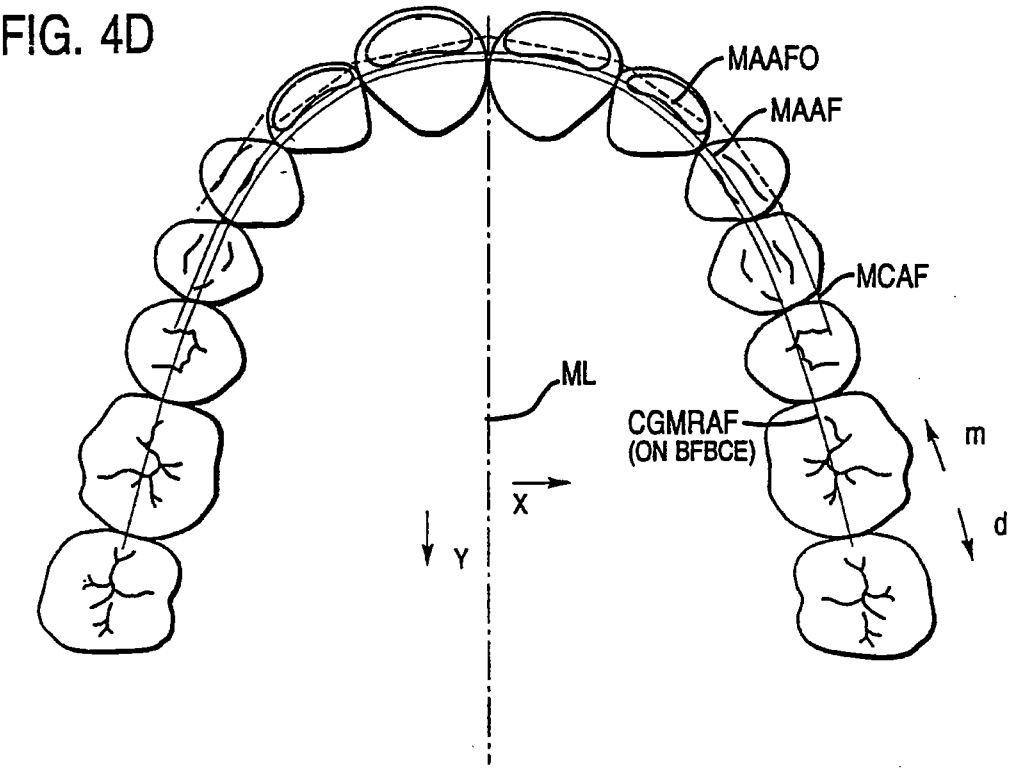


FIG. 4B

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FIG. 4D



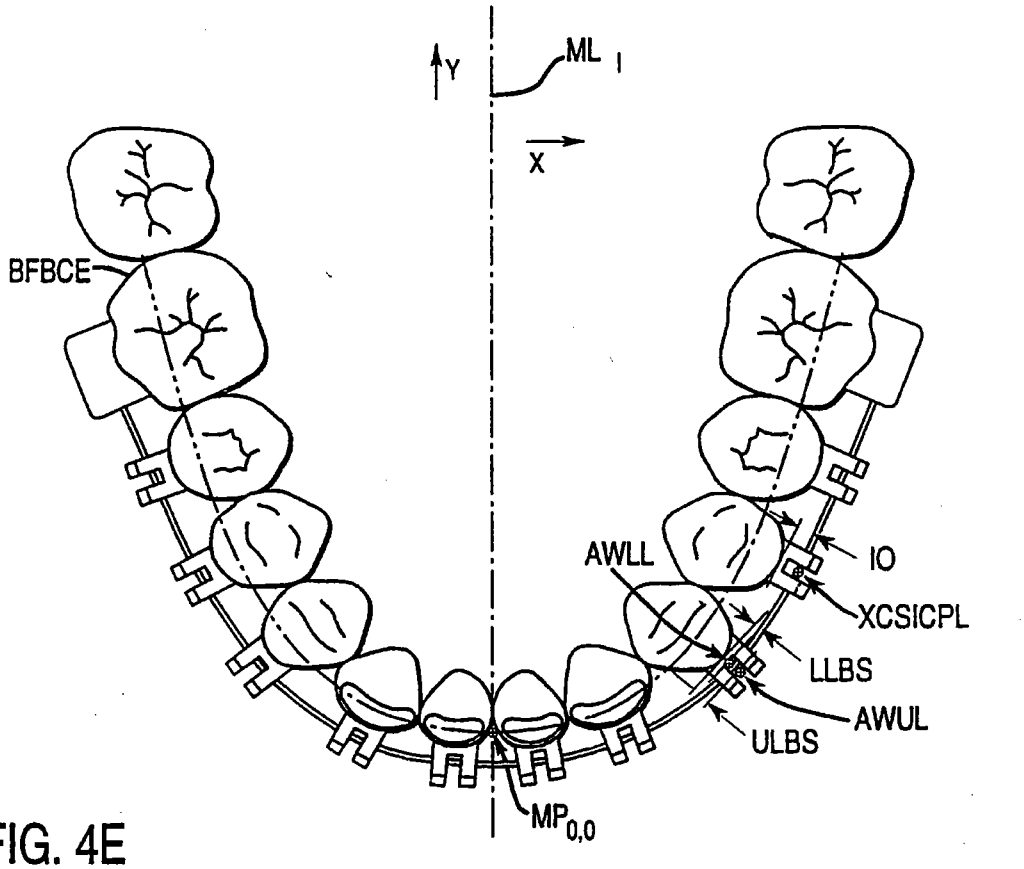


FIG. 4E

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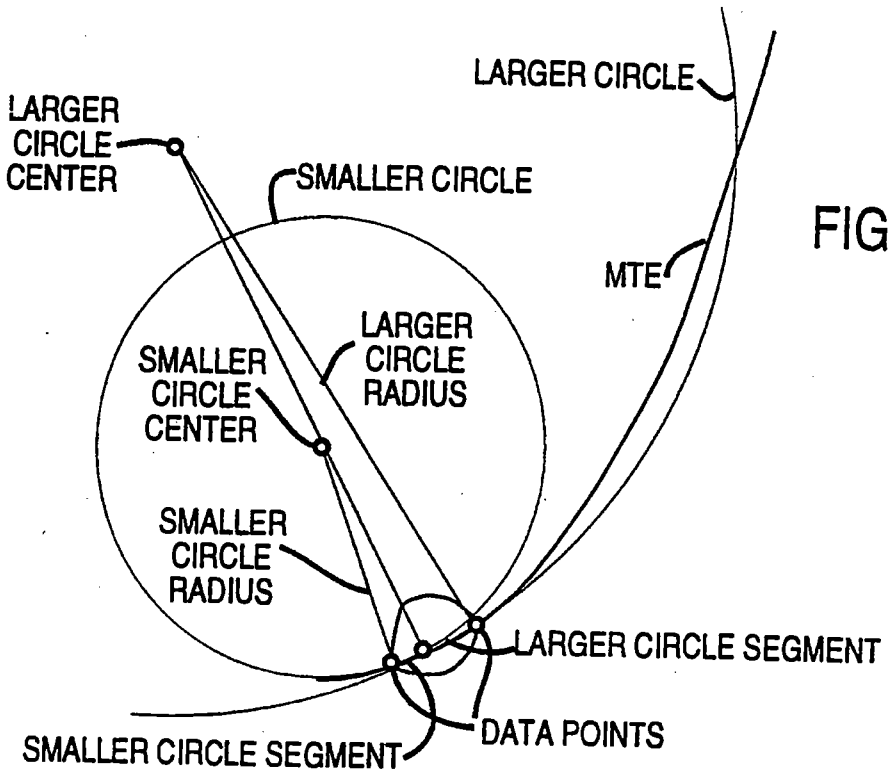


FIG. 5

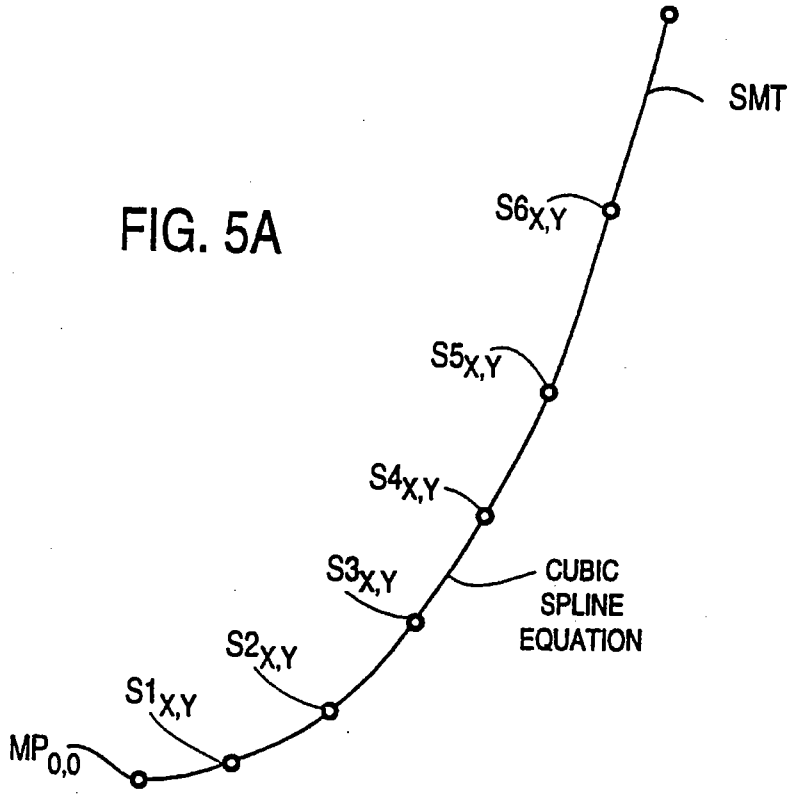


FIG. 5A

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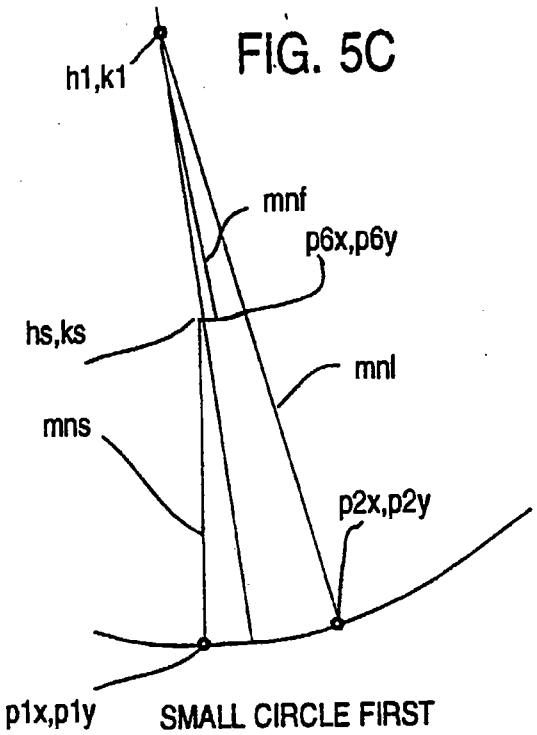


FIG. 5C

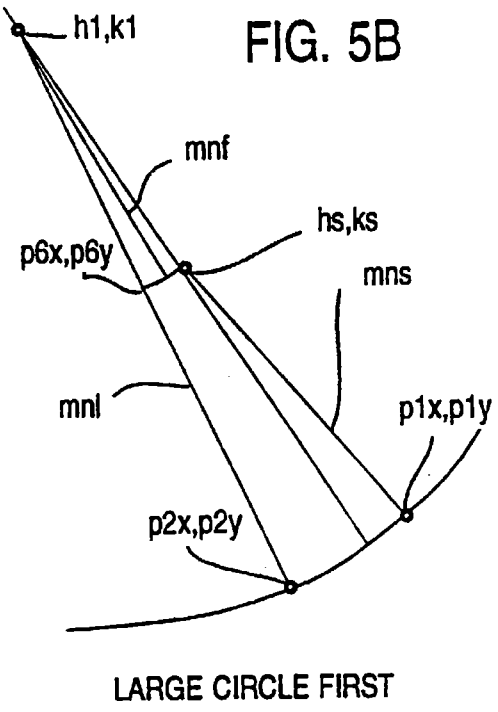


FIG. 5B

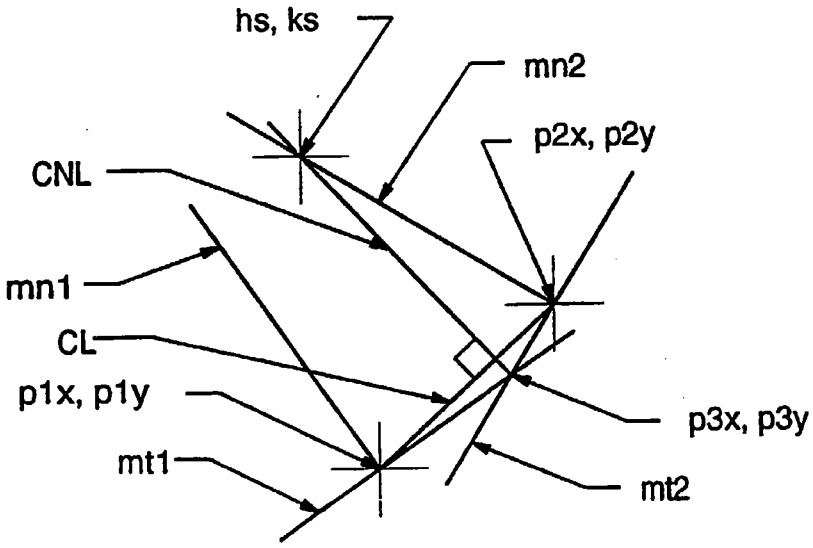
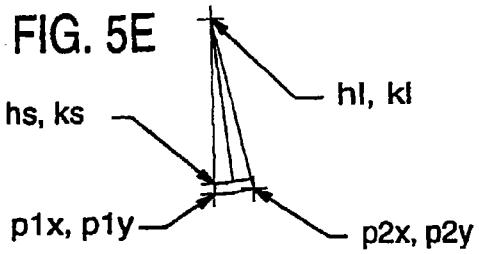


FIG. 5D

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FIG. 5E



Spline Seg. No. 1
Circle Seg. Nos. 1 and 2

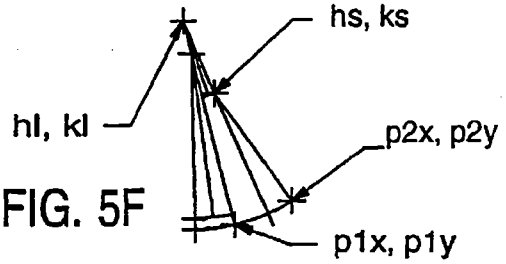
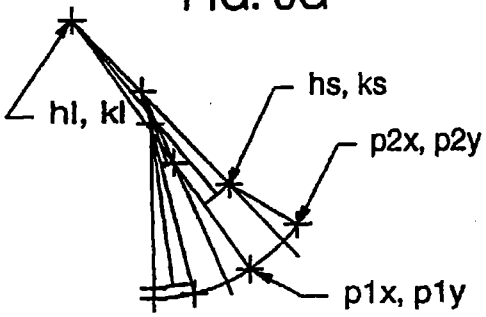


FIG. 5F

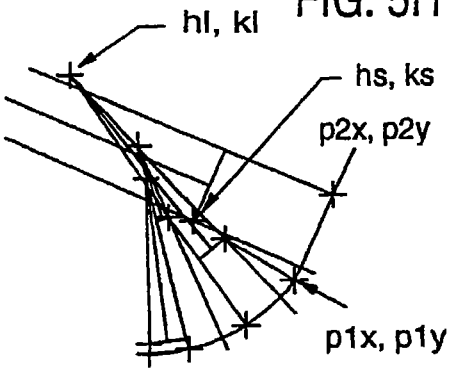
Spline Seg. No. 2
Circle Seg. Nos .3 and 4

FIG. 5G

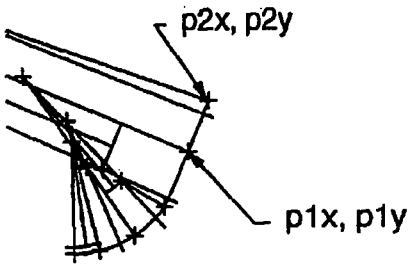


Spline Seg. No. 3
Circle Seg. Nos. 5 and 6

FIG. 5H

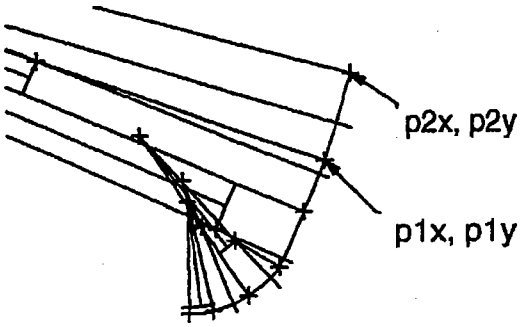


Spline Seg. No. 4
Circle Seg. Nos. 7 and 8



Spline Seg. No. 5
Circle Seg. Nos.9 and 10

FIG. 5I



Spline Seg. No. 6
Circle Seg. No.'s 11 and 12

FIG. 5J

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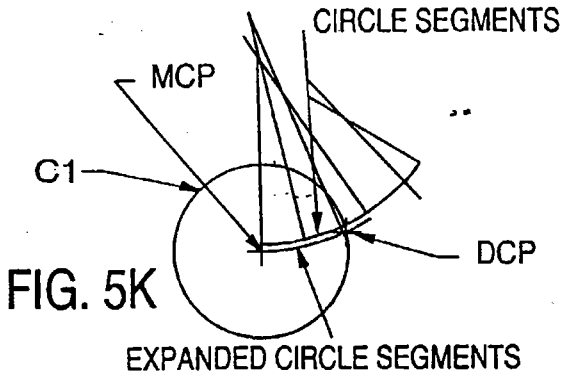


FIG. 5K

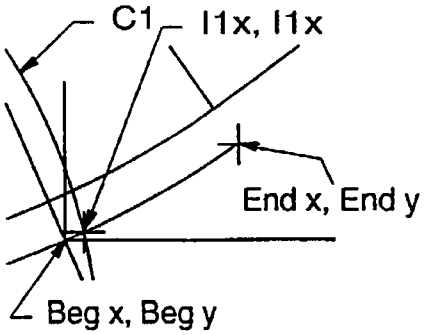


FIG. 5L

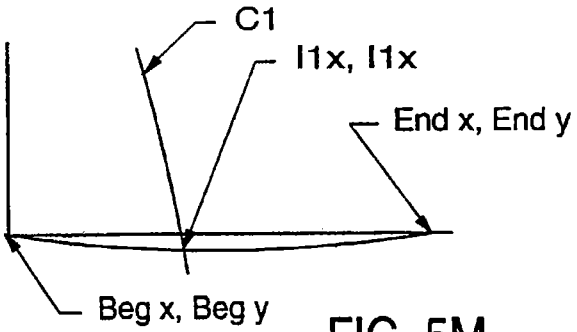


FIG. 5M

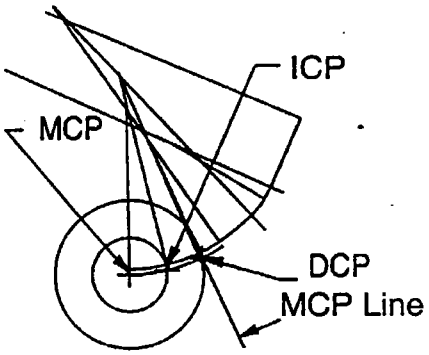


FIG. 5N

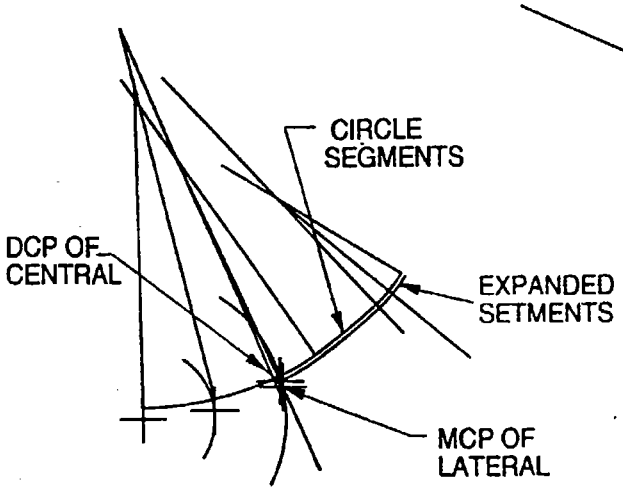


FIG. 5O

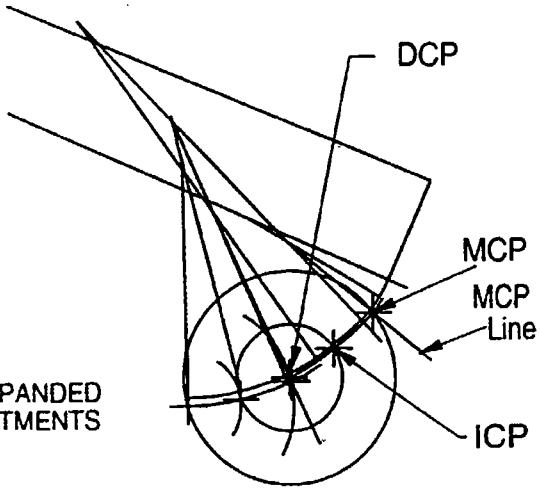


FIG. 5P

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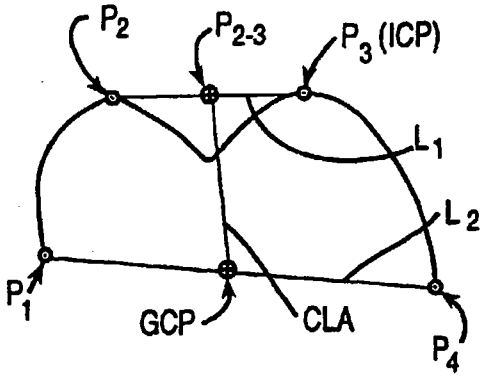


FIG. 6A

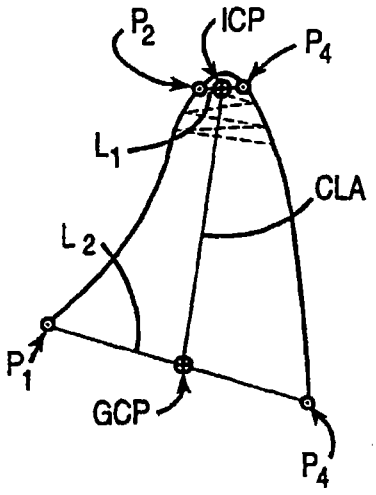


FIG. 6B

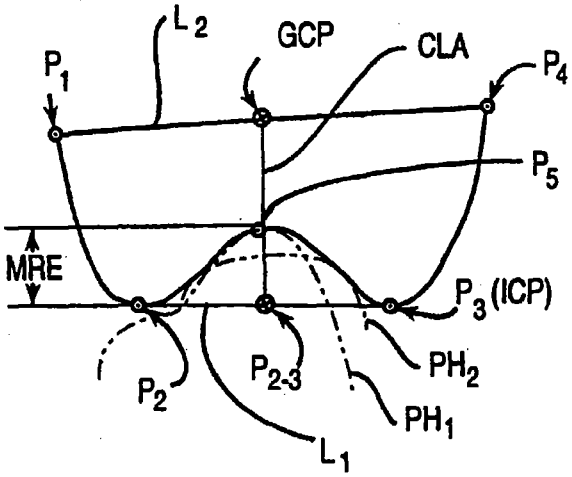


FIG. 6C

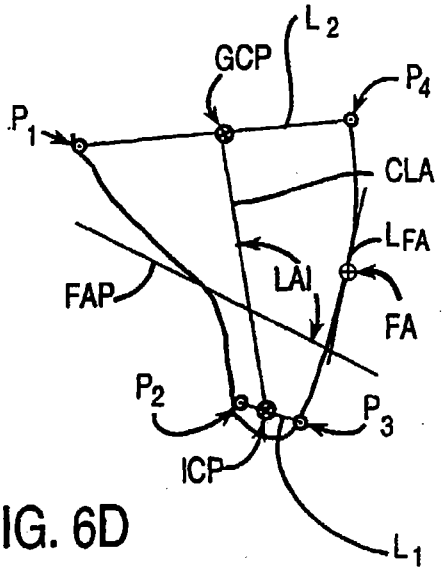


FIG. 6D

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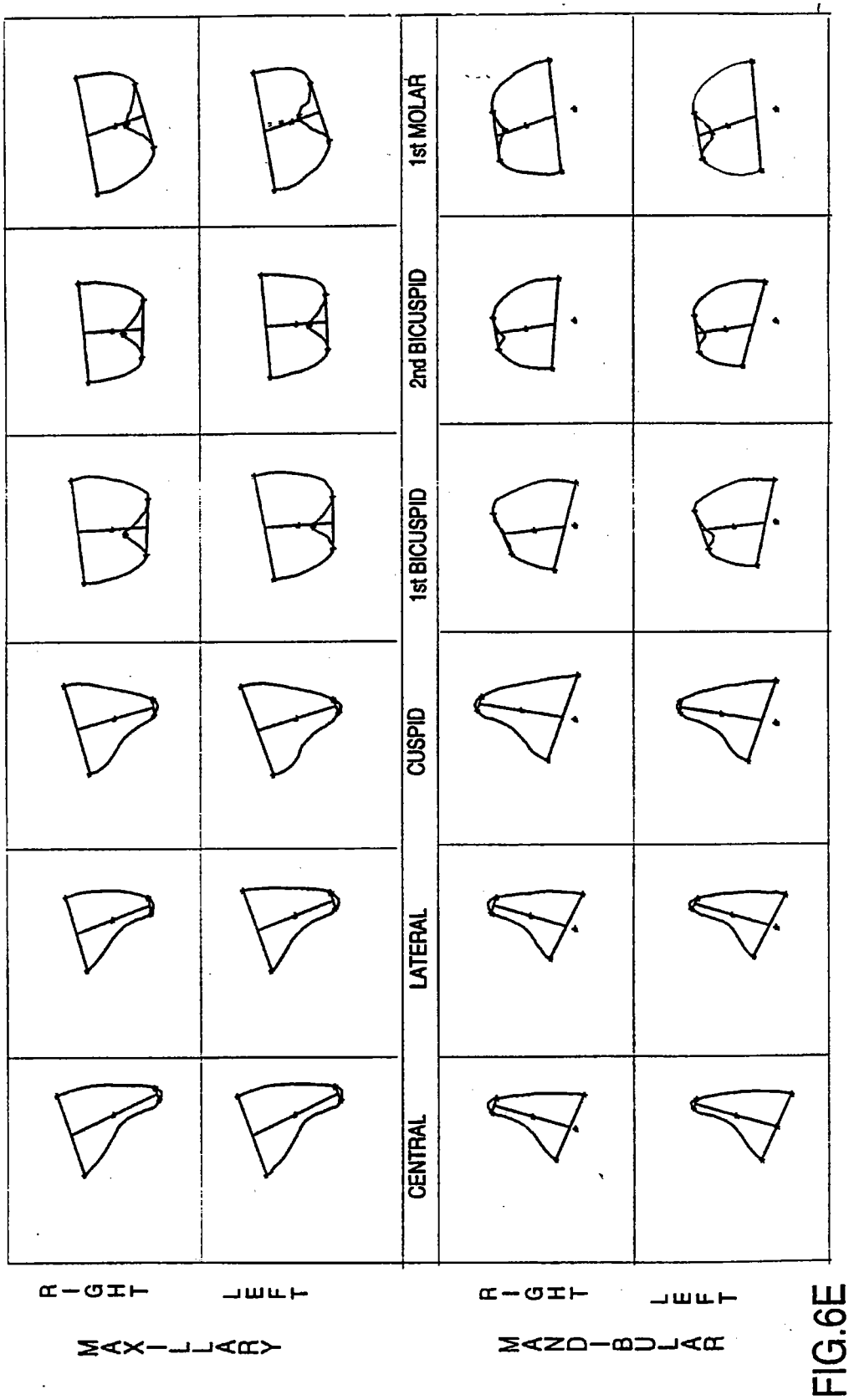


FIG.6E

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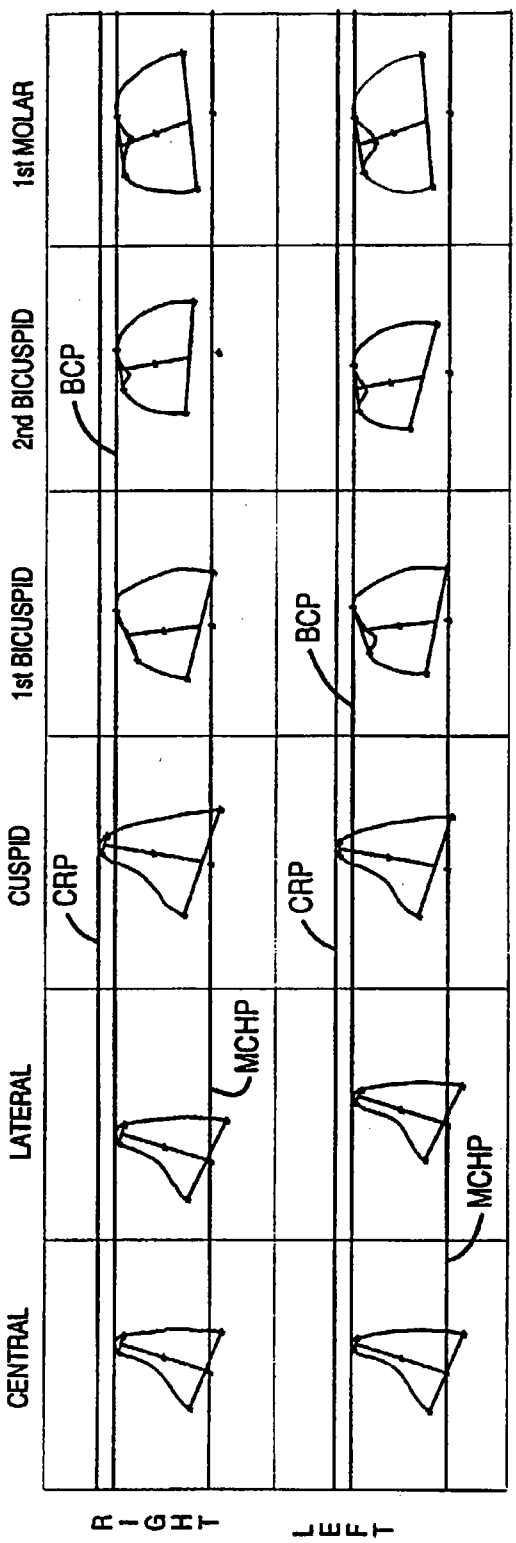


FIG. 6F

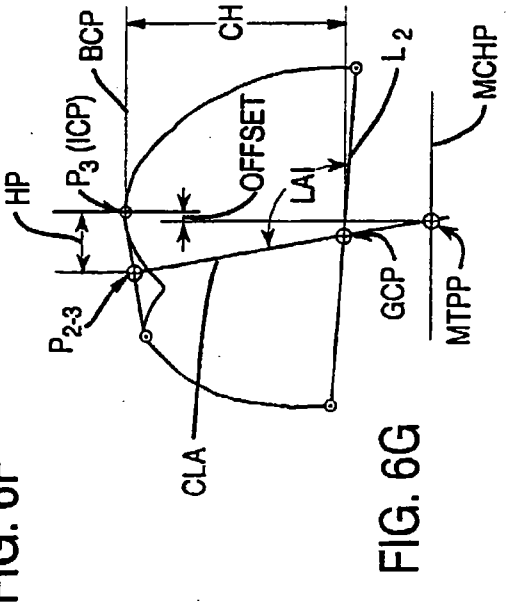


FIG. 6G

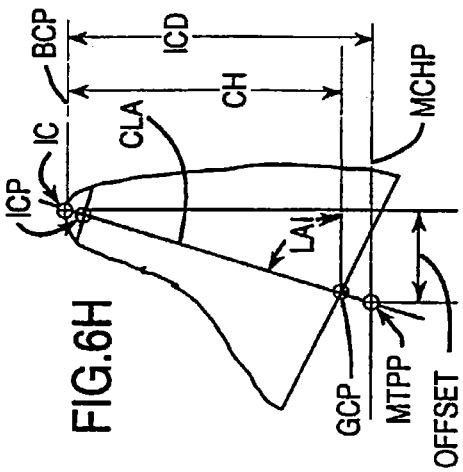


FIG.6H

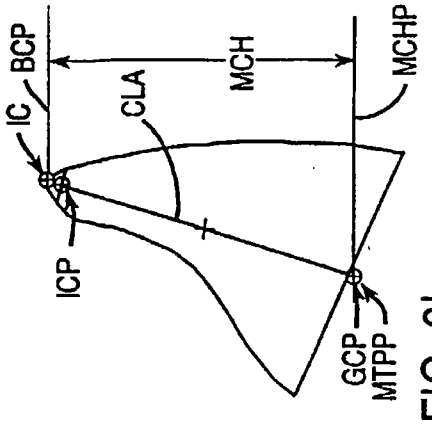


FIG. 6I

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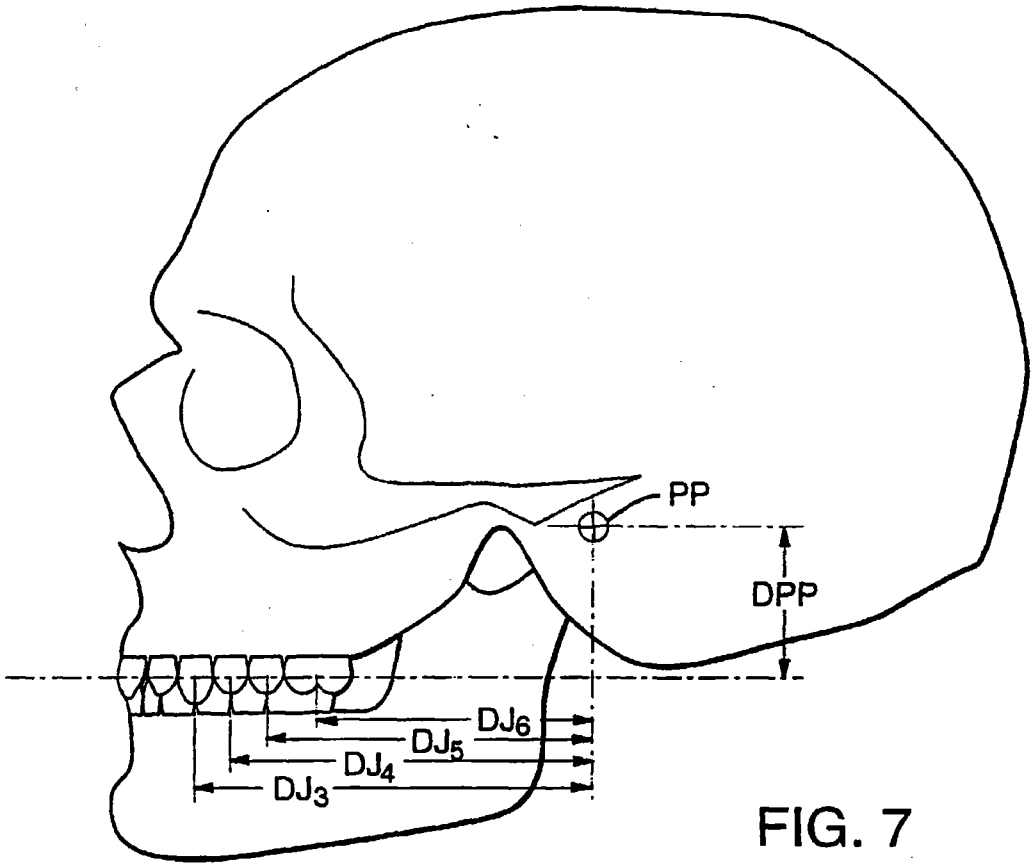


FIG. 7

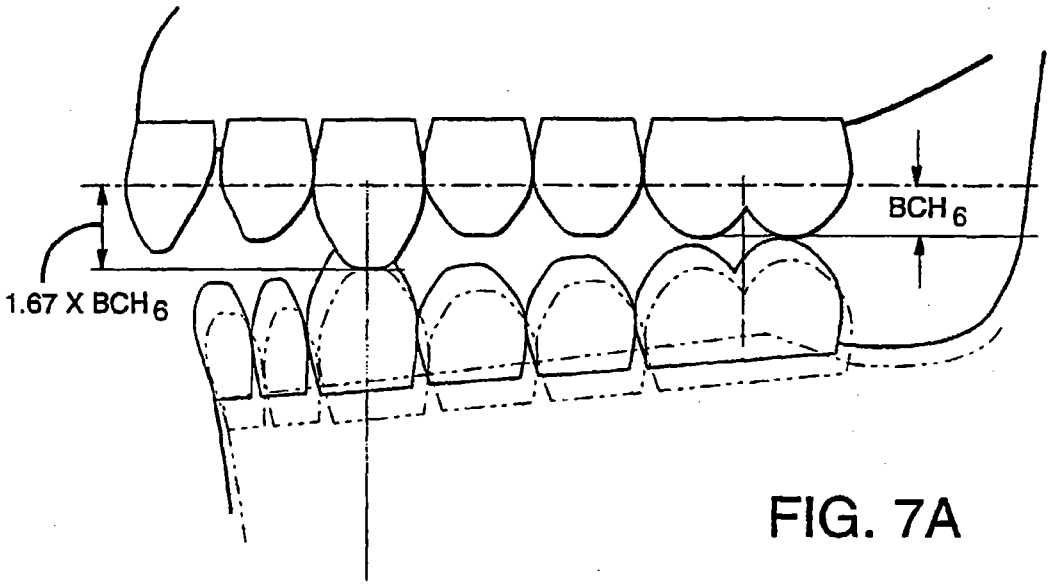


FIG. 7A

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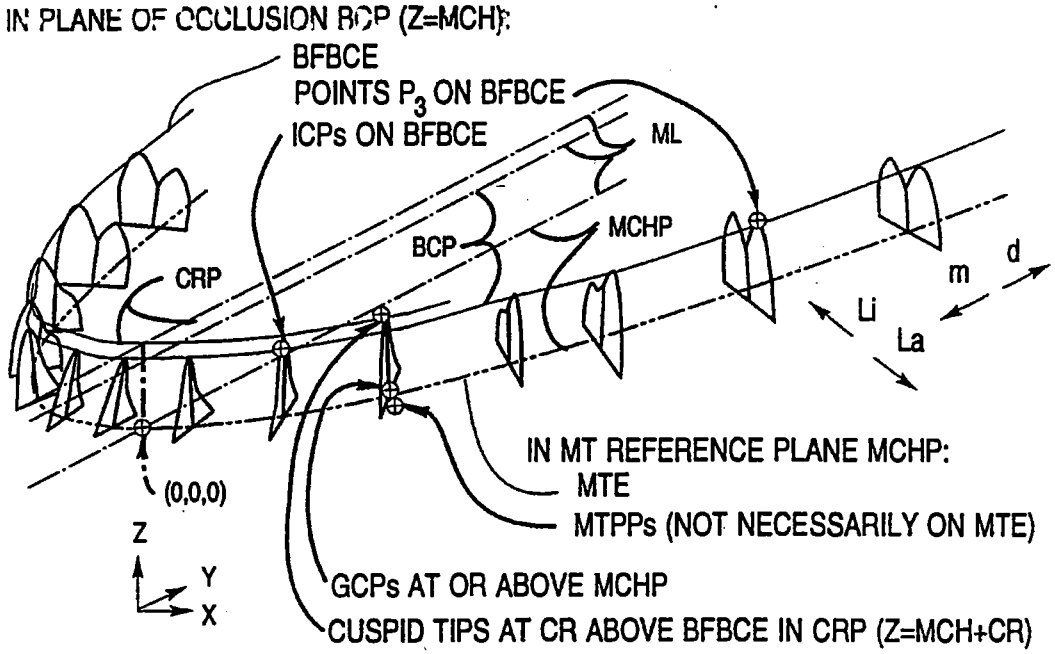


FIG. 7C

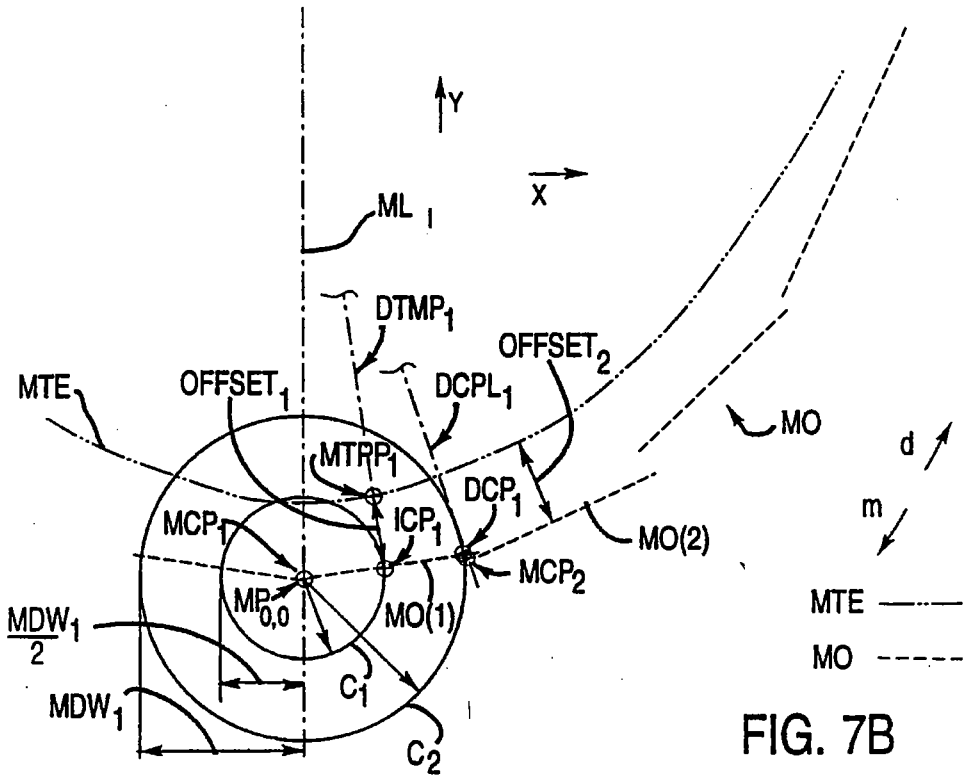


FIG. 7B

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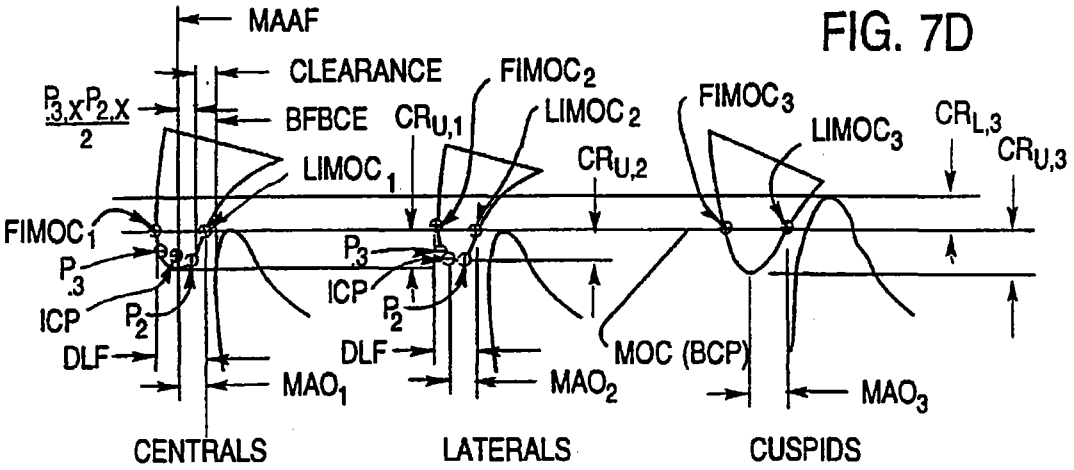


FIG. 7D

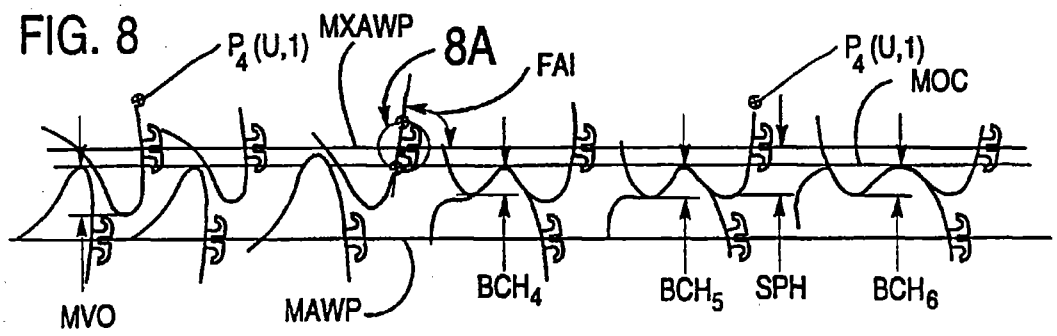


FIG. 8

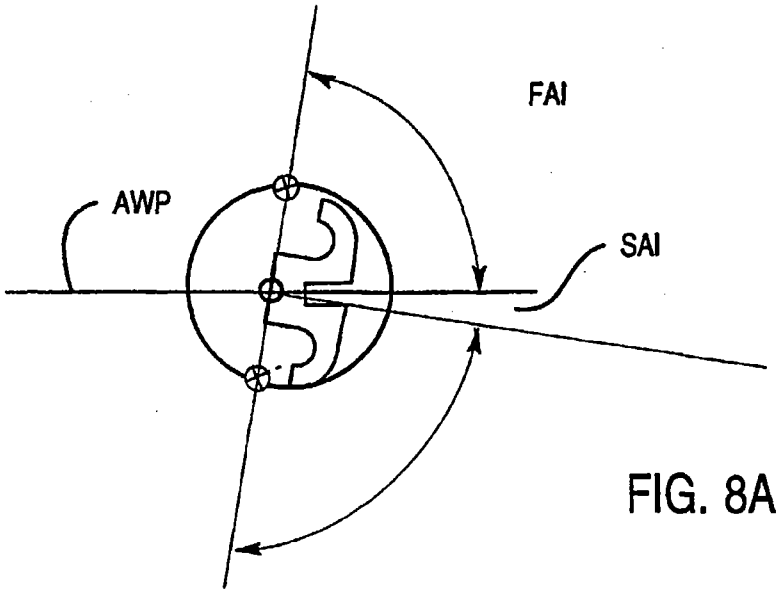


FIG. 8A

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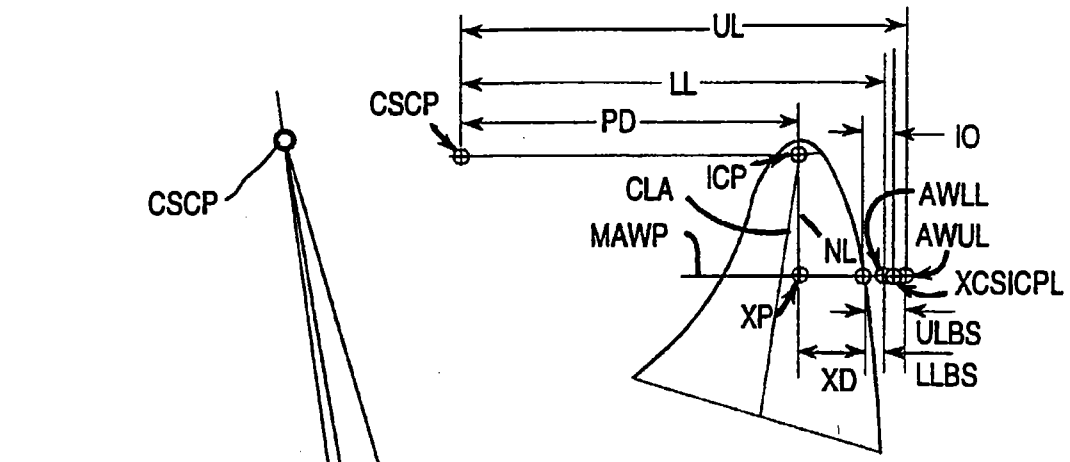


FIG. 8C

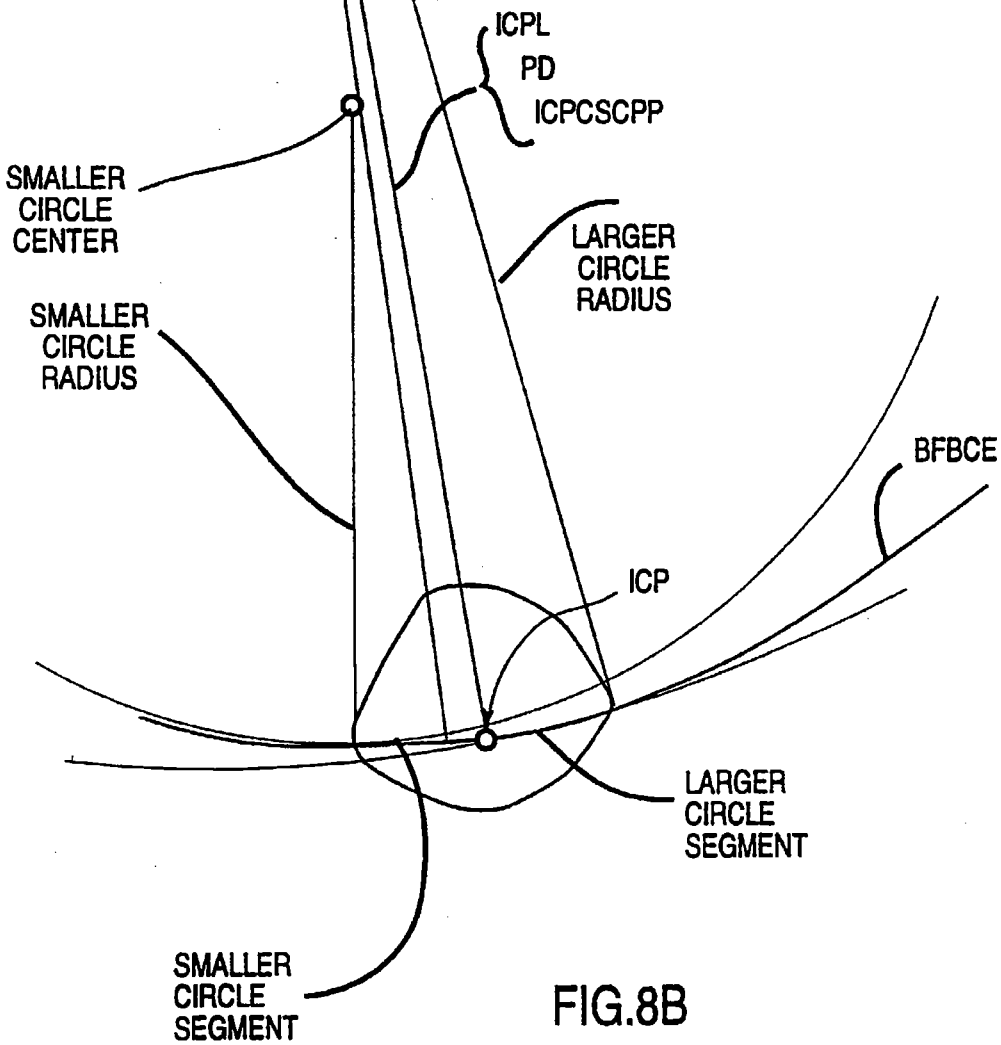


FIG.8B

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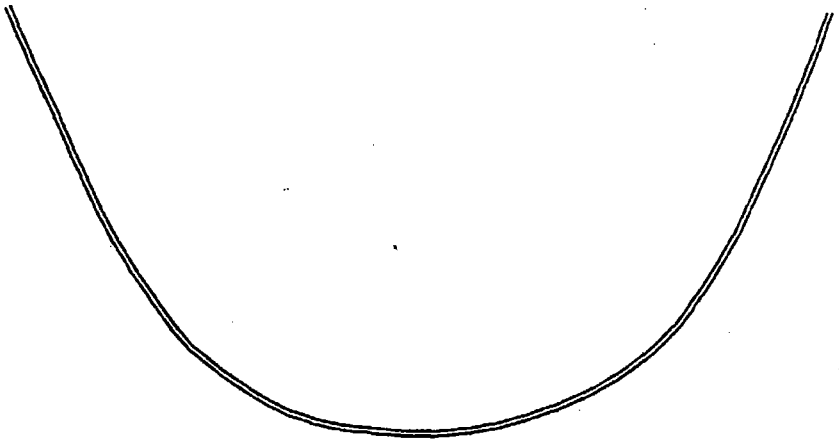


FIG. 8E

FIG. 8D

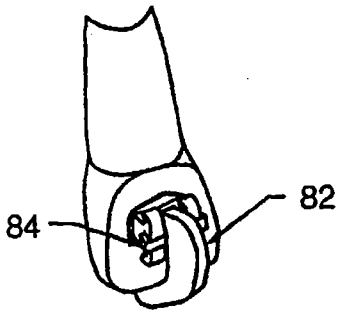
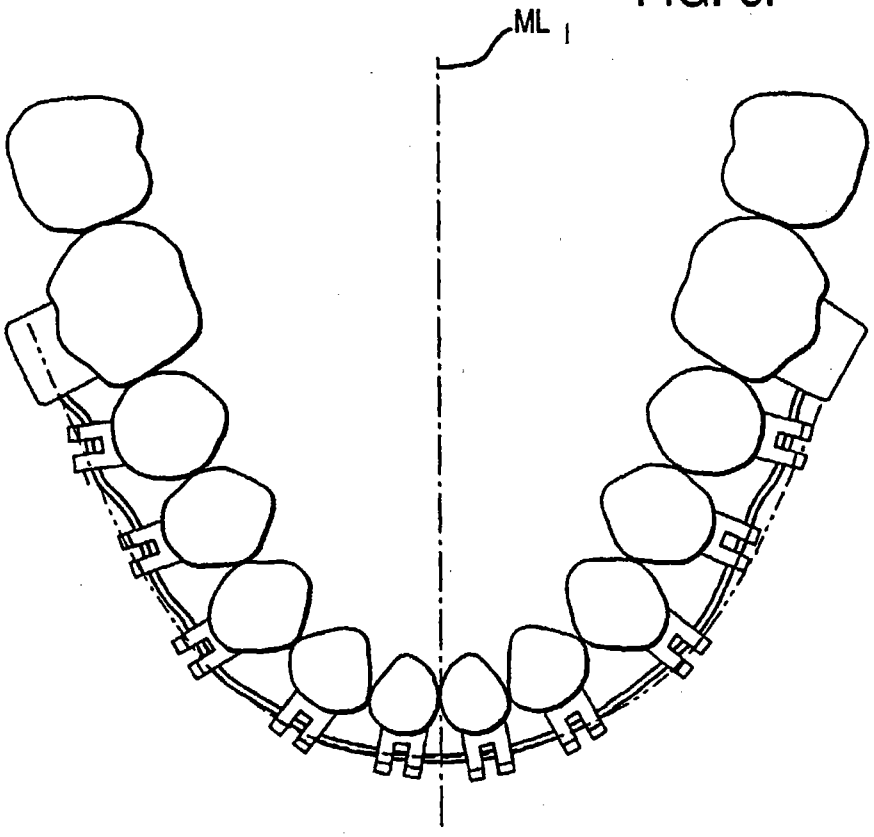
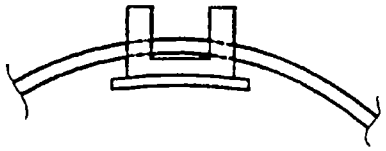


FIG. 8F



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FIG. 8I



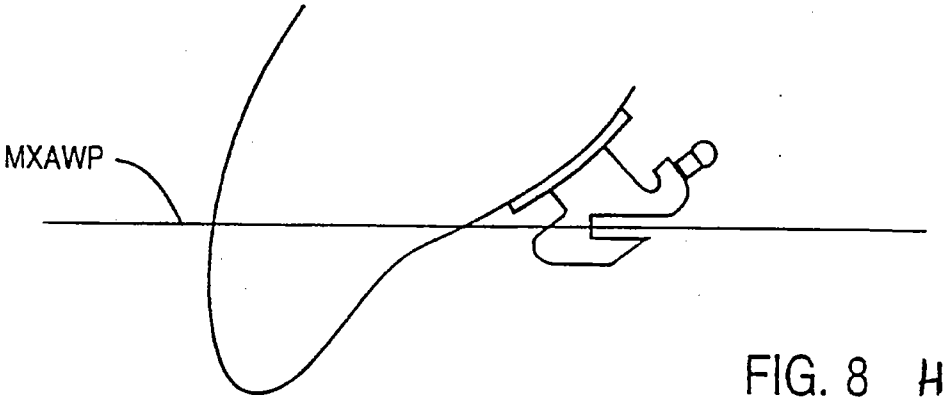
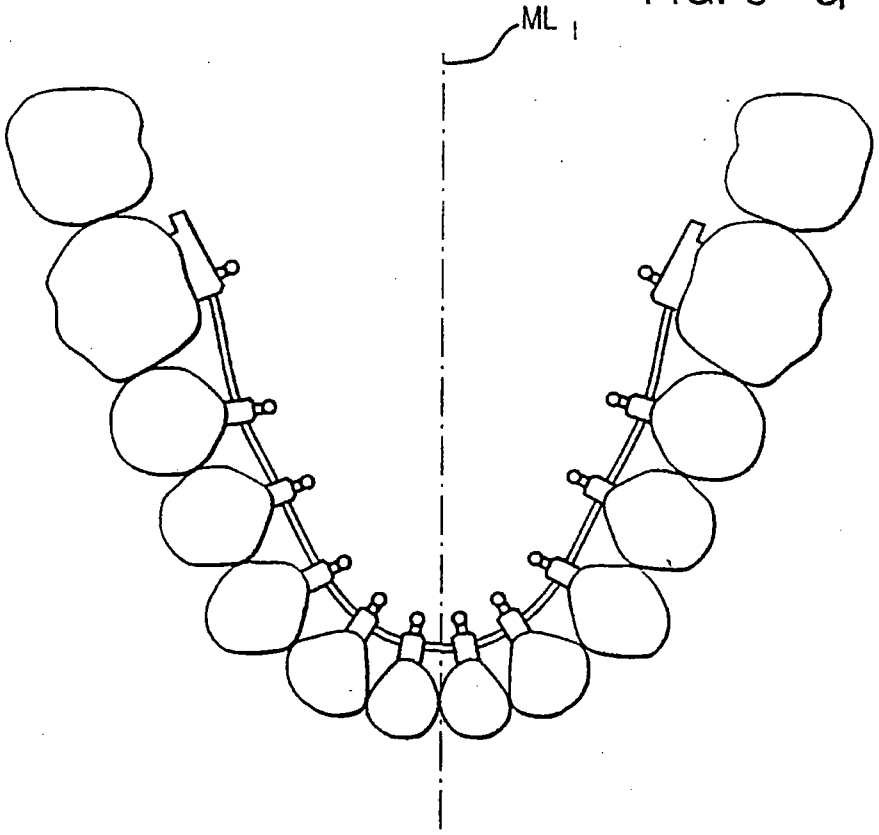


FIG. 8 H

FIG. 8 G



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FIG. 9

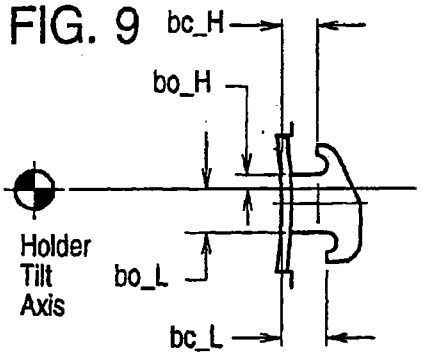


FIG. 9A

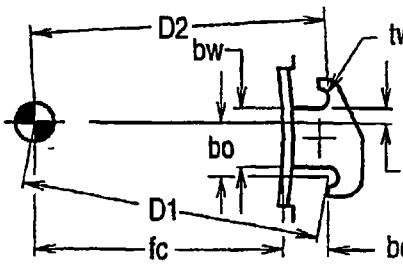


FIG. 9B

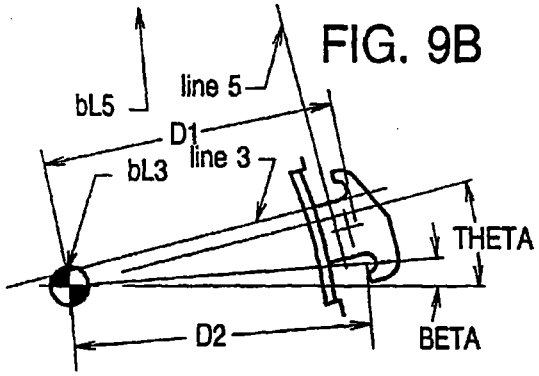


FIG. 9C

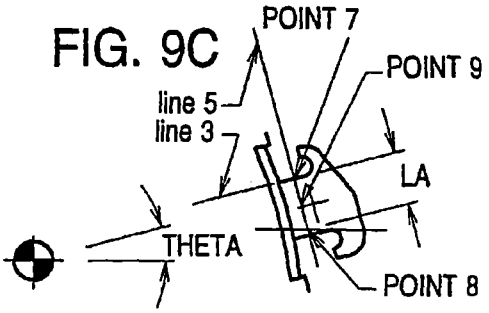


FIG. 9D

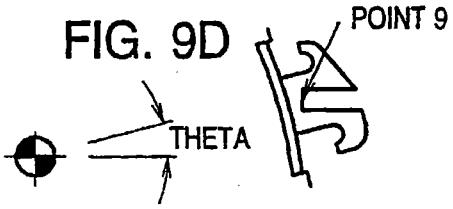


FIG. 9E

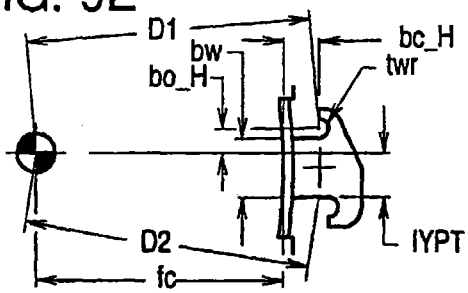
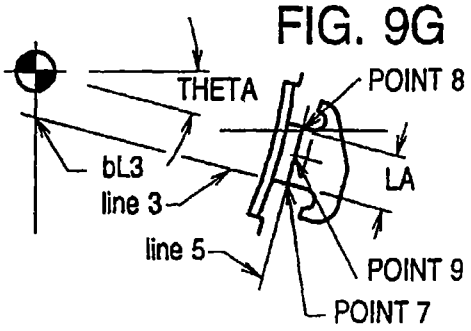


FIG. 9G



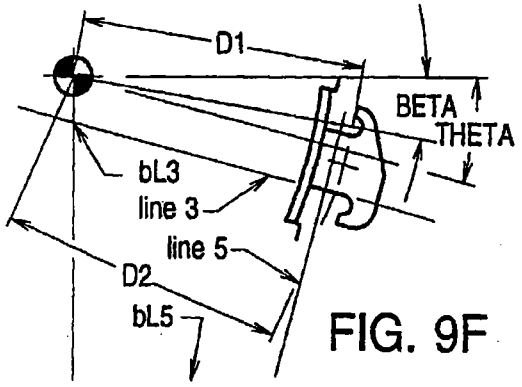


FIG. 9F

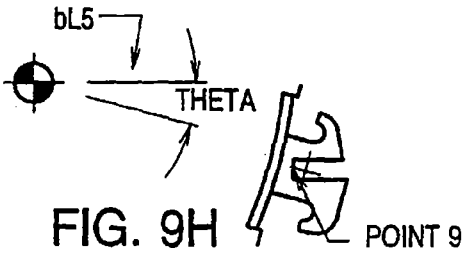


FIG. 9H

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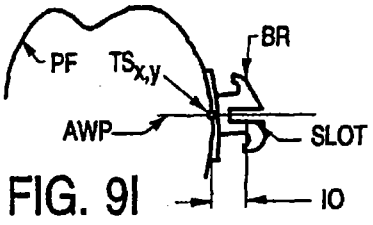


FIG. 9I

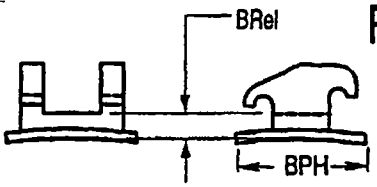


FIG. 9J

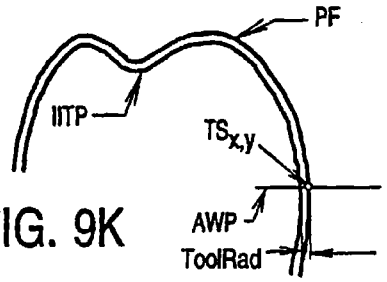


FIG. 9K

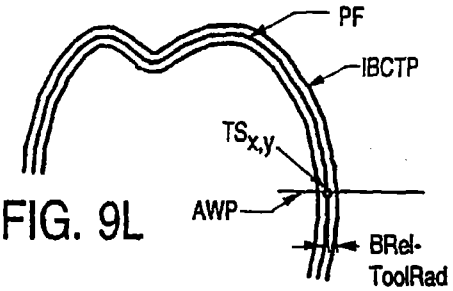


FIG. 9L

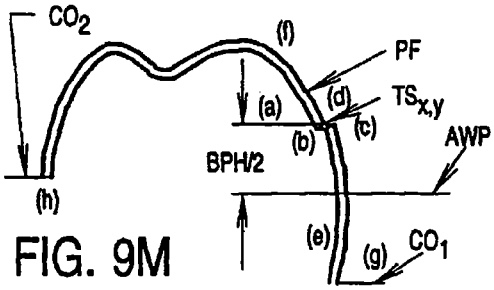


FIG. 9M

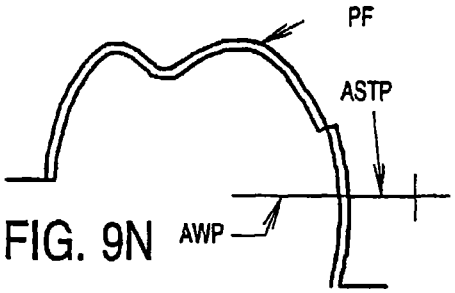


FIG. 9N

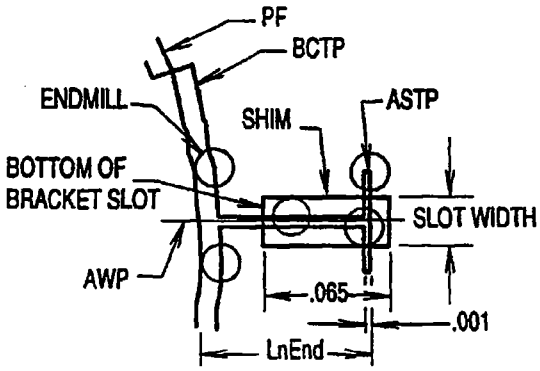
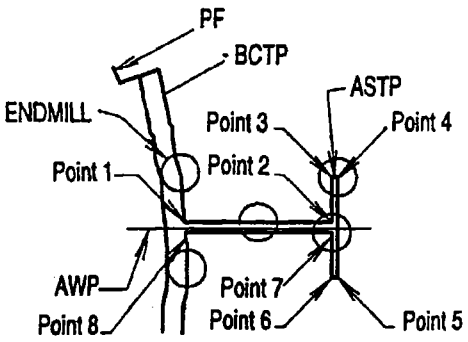


FIG. 9O

FIG. 9P



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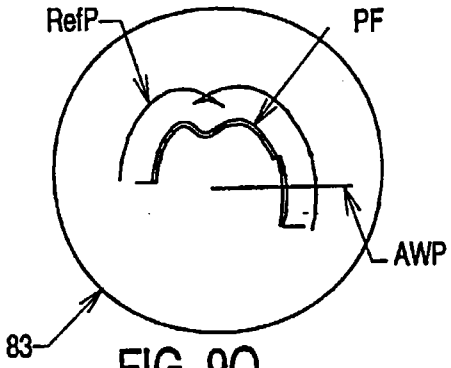
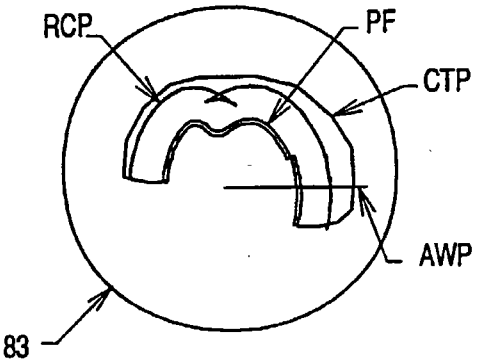


FIG. 9Q

FIG. 9R



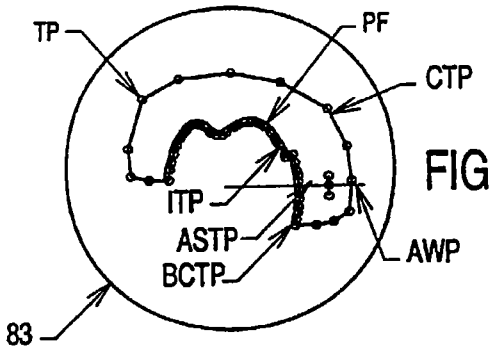
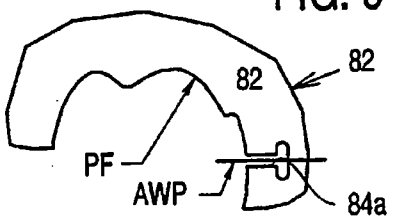


FIG. 9S

FIG. 9T



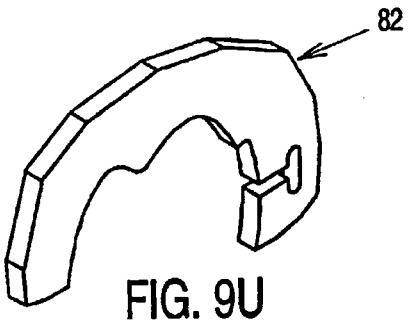


FIG. 9U

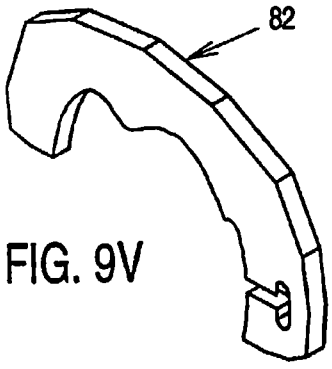


FIG. 9V

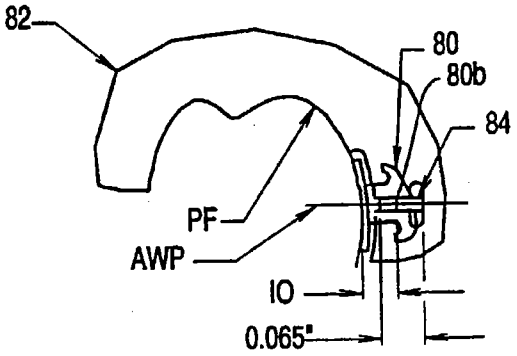


FIG. 9W

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DEMANDE INTERNATIONALE PUBLIEE EN VERTU DU TRAITE DE COOPERATION EN MATIERE DE BREVETS (PCT)

(51) Classification internationale des brevets 5 :		(11) Numéro de publication internationale:	WO 91/04713
A61C 9/00	A1	(43) Date de publication internationale:	18 avril 1991 (18.04.91)

(21) Numéro de la demande internationale: PCT/FR90/00690

(22) Date de dépôt international: 26 septembre 1990 (26.09.90)

(30) Données relatives à la priorité:
89/12814 26 septembre 1989 (26.09.89) FR

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(74) Mandataires: LAURENT, Michel etc. ; Cabinet Laurent et Charras, 20, rue Louis-Chirpaz, B.P. 32, F-69131 Ecully Cédex (FR).

(81) Etats désignés: AT (brevet européen), BE (brevet européen), CH (brevet européen), DE (brevet européen)*, DK (brevet européen), ES (brevet européen), FR (brevet européen), GB (brevet européen), IT (brevet européen), LU (brevet européen), NL (brevet européen), SE (brevet européen), US.

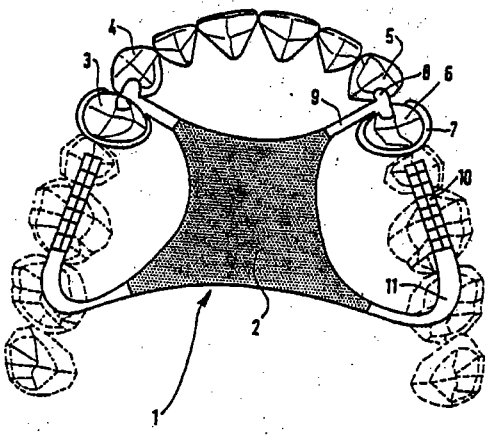
Publiée
Avec rapport de recherche internationale.

(54) Title: DEVICE FOR TRACING A REMOVABLE PARTIAL DENTAL PLATE

(54) Titre: DISPOSITIF POUR ETABLIR LE TRACE D'UNE PLAQUE DENTAIRE PARTIELLE AMOVIBLE

(57) Abstract

Device for tracing a removable partial dental plate *characterized* in that it is comprised of: means for displaying (15, 16, 19) the positioning of the teeth still in place in the mouth of the patient; calculation means (17) for the recurrent determination of the theoretical ideal tracing of the removable dental plate as a function, on the one hand, of the positioning of the teeth still in place, inputted during the preceding step, and on the other hand, brackets of physiological values previously inputted into said calculation means; input means (18) for introducing clinical particularisms proper to the mouth of the patient being treated; calculation means (17) for plotting the final theoretical tracing of the plate as a function, on the one hand, of the clinical particularisms and, on the other hand, of the physiological brackets of values.



(57) Abrégé

Dispositif pour établir le tracé d'une plaque dentaire partielle amovible caractérisé en ce qu'il comprend: des moyens pour afficher (15, 16, 19) le positionnement des dents encore en place dans la bouche du patient; un moyen de calcul (17) pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction, d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul; des moyens d'introduction (18) des particularismes cliniques propres à la bouche du patient en cours de traitement; un moyen de calcul (17) pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.

* Voir au verso

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DESIGNATIONS DE "DE"

Jusqu'à nouvel avis, toute désignation de "DE" dans toute demande internationale dont la date de dépôt international est antérieure au 3 octobre 1990 a effet dans le territoire de la République fédérale d'Allemagne à l'exception du territoire de l'ancienne République démocratique allemande.

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DISPOSITIF POUR ETABLIR LE TRACE D'UNE PLAQUE DENTAIRE PARTIELLE AMOVIBLE

La présente invention concerne un dispositif pour établir le tracé d'une plaque dentaire partielle amovible.

Par "plaque dentaire partielle", on entend au sens de l'invention et des revendications une plaque dentaire destinée à être fixée de manière amovible sur au moins deux dents encore présentes dans l'une des deux arcades de la bouche d'un patient.

A ce jour, les plaques dentaires partielles amovibles sont réalisées à partir d'un tracé obtenu à partir d'une empreinte de l'arcade de la bouche du patient. Le tracé de la plaque proprement dite est normalement réalisé par le praticien en fonction des données cliniques et physiologiques de l'arcade considérée. Toutefois, les praticiens sont de moins en moins capables d'effectuer ce tracé et laissent généralement ce soin aux prothésistes. Cela suppose l'emploi d'un personnel très qualifié compte tenu des objectifs visés pour le tracé de la plaque. Ces objectifs se résument principalement à une parfaite adaptation morphologique à la bouche du patient d'une part et d'autre part à un maintien efficacec de ladite plaque dentaire sur les dents restant en place dans la bouche du patient, ce maintien laissant toutefois possible l'amovibilité de ladite plaque dentaire, notamment en vue de son nettoyage.

La présente invention vise à proposer un dispositif apte à permettre à tout praticien non spécialiste de réaliser des tracés de plaques dentaires amovibles, plus économiques dans leur réalisation d'une part et d'autre part mieux adaptés du point de vue morphologique.

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Le dispositif pour établir le tracé d'une plaque dentaire partielle amovible conforme à l'invention se caractérise en ce qu'il comprend :

- des moyens pour afficher le positionnement des dents encore en place dans la bouche du patient ;
- un moyen de calcul pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul ;
- des moyens d'introduction de particularismes cliniques propres à la bouche du patient en cours de traitement ;
- un moyen de calcul pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.

En d'autres termes, la présente invention se caractérise en ce que l'on munit une installation de saisie de données, en l'occurence les dents restant encore dans la bouche du patient, d'un organe de calcul apte en fonction de critères pré-établis à délivrer de façon instantanée un tracé théorique de plaque dentaire, qui ne demande plus qu'à être adapté en fonction des particularismes cliniques d'un patient.

Dans une forme de réalisation avantageuse, le moyen pour afficher le positionnement des dents encore en place dans la bouche du patient est constitué par un écran sur lequel est susceptible de se déplacer un curseur, écran associé à un micro-ordinateur et à un organe de validation, validant les données en fonction de la position du curseur.

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Dans une autre forme de réalisation, le moyen de calcul destiné à déterminer le tracé idéal théorique et le tracé théorique final de la plaque dentaire est constitué par un micro-ordinateur dont les étapes de fonctionnement sont dictées par un logiciel adapté.

Selon l'invention, le moyen d'introduction des particularismes cliniques d'un patient est constitué par un clavier associé audit micro-ordinateur.

Les fourchettes de valeurs physiologiques introduites dans le moyen de calcul destiné à déterminer le tracé idéal théorique de la plaque concernent respectivement les crochets de fixation de la plaque, les épingles à cheveux destinées à solidariser la plaque à la selle de positionnement des dents, les caractéristiques dimensionnelles de la selle elle-même et la courbure de la plaque.

La manière dont l'invention peut être réalisée, et les avantages qui en découlent ressortiront mieux de l'exemple de réalisation qui suit donné à titre indicatif et non limitatif à l'appui des figures annexées.

La figure 1 est une vue schématique d'une plaque dentaire en place, réalisée selon la technique dite du "chassis amorti".

La figure 2 est également une vue schématique d'une plaque dentaire en place, réalisée selon la technique dite de KENNEDY, APPLEGATE.

La figure 3 est un schéma simplifié du dispositif conforme à l'invention.

Selon l'invention, et conformément à la représentation de la figure 1, la plaque dentaire portant la référence générale (1) est constituée de plusieurs éléments.

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Outre la plaque dentaire proprement dite portant la référence générale (2) et destinée à épouser la morphologie du palais, qu'il s'agisse de l'arcade inférieure ou de l'arcade supérieure, la plaque dentaire est maintenue sur les dents restant encore dans la bouche du patient, et portant les références (3) à (6) par des crochets (7) et des appuis (8) par l'intermédiaire de potences (9). Ces différents éléments à savoir crochets, appuis et potences sont réalisés en alliage à base de cobalt, nickel et chrome, bien entendu non toxiques.

Les dents artificielles, donc manquantes, sont positionnées sur une selle (10) reliée à la plaque dentaire (2) par l'intermédiaire d'une épingle à cheveux (11) également réalisée dans le même alliage cobalt, nickel, chrome.

Selon l'invention, la manière dont sont reliées les potences (9) et l'épingle à cheveux (11) à la plaque dentaire (2), ainsi que le positionnement des points d'appui des crochets font l'objet de fourchettes physiologiques particulières, destinées d'une part à permettre une meilleure adaptation morphologique de la plaque dentaire à la morphologie de la bouche du patient et d'autre part à un meilleur maintien réversible de ladite plaque sur les dents restantes.

Selon la présente invention, lorsqu'un praticien désire procéder à la réalisation d'un tracé de plaque dentaire d'un patient déterminé, il procède tout d'abord au relevé des différentes dents restant en place dans l'arcade considérée de la bouche du patient. Il est muni d'un micro-ordinateur (17) auquel est associé un écran (15) visualisant une arcade complète, c'est-à-dire seize dents. Cet écran est associé à un organe de validation

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(16), dans le cas d'espèces une souris associée à un curseur (19) se déplaçant sur l'écran selon le souhait du praticien. Le praticien peut déplacer le curseur (19) sur les dents manquantes et procède à la validation (16), par exemple par simple pression du bouton dudit organe de validation, afin d'introduire dans la mémoire du micro-ordinateur (17) le positionnement des dents restantes.

Ce micro-ordinateur comprend un micro-processeur géré par un logiciel spécialisé et adapté au tracé de plaque dentaire. Ce logiciel permet la restitution notamment à l'écran du tracé d'une plaque dentaire en fonction d'une part des données introduites par le praticien concernant les différentes dents restantes dans la bouche du patient, et d'autre part en fonction des fourchettes physiologiques sus-mentionnées, faisant partie intégrante des données du logiciel. Il est à noter que outre les fourchettes physiologiques déjà mentionnées, celles-ci concernent également les caractéristiques dimensionnelles de la selle et la courbure de la plaque dentaire elle-même.

Une fois ce tracé théorique restitué par le micro-ordinateur, notamment sur l'écran (15), le praticien introduit certains particularismes cliniques propres à chaque patient. Ces particularismes cliniques peuvent être de natures différentes, telles que des dents restant en mauvais état .

Ces particularismes cliniques étant introduits, et le tracé théorique précédent ayant été stocké en mémoire, le micro-ordinateur (17) restitue un nouveau tracé théorique, final cette fois, de la plaque dentaire destinée à être ensuite acheminée chez un prothésiste apte à réaliser effectivement cette plaque dentaire. Cette restitution est matérialisée soit sur l'écran (15) soit par l'imprimante (20).

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L'introduction des particularismes cliniques par le praticien s'effectue par exemple par un clavier (18) associé au micro-ordinateur au moyen de codes pré-établis ou suivant un langage propre au logiciel.

Il va de soi qu'afin d'optimiser le rendu du tracé théorique de la plaque dentaire, un travail clinique préalable peut être effectué par le praticien en vue de consolider ou de supprimer certaines dents.

De plus, en fonction des différentes données introduites par le praticien d'une part et d'autre part des fourchettes physiologiques stockées par les mémoires du micro-ordinateur, le microprocesseur de ce dernier effectue de manière récurrente un calcul précis des différentes caractéristiques de la plaque dentaire et de ses différents éléments associés, notamment crochets, appuis, potences, épingles à cheveux et selles. De la sorte, il ne reste plus au prothésiste qu'à respecter scrupuleusement les différentes indications fournies par le micro-ordinateur pour réaliser une plaque dentaire s'adaptant parfaitement à la bouche du patient.

Le dispositif conforme à la présente invention permet indifféremment de réaliser des plaques dentaires amovibles, selon la technique dite du chassis amorti, ou selon celle dite de KENNEDY - APPLEGATE. Le choix de l'une ou de l'autre de ces techniques appartient au praticien. On a représenté en figure 2 une plaque dentaire amovible, réalisée selon la technique KENNEDY-APPLEGATE, avec le dispositif conforme à l'invention.

Il ressort de la présente invention des avantages fondamentaux par rapport à ce qui était connu de faire jusqu'alors. On peut notamment citer la possibilité pour

tout praticien non spécialiste de prothèses de réaliser des tracés de plaques dentaires tout à fait exploitables par un prothésiste afin de réaliser les plaques dentaires proprement dites. Il ressort donc de ce dispositif le moyen d'effectuer d'importantes économies et surtout de réaliser des gains de temps appréciables.

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REVENDICATIONS

1/ Dispositif pour établir le tracé d'une plaque dentaire partielle amovible caractérisé en ce qu'il comprend :

- des moyens pour afficher (15, 16, 19) le positionnement des dents encore en place dans la bouche du patient ;
- un moyen de calcul (17) pour déterminer de manière récurrente le tracé idéal théorique de la plaque dentaire amovible en fonction d'une part du positionnement des dents encore en place, introduit au cours de l'étape précédente, et d'autre part de fourchettes de valeurs physiologiques introduites préalablement dans ledit moyen de calcul ;
- des moyens d'introduction (18) des particularismes cliniques propres à la bouche du patient en cours de traitement ;
- un moyen de calcul (17) pour restituer le tracé théorique final de la plaque en fonction d'une part de ces particularismes cliniques et d'autre part des fourchettes physiologiques.

2/ Dispositif selon la revendication 1, caractérisé en ce que le moyen pour afficher le positionnement des dents encore en place dans la bouche du patient est constitué par un écran (15) sur lequel se déplace un curseur (19) associé à un micro-ordinateur (17) et à un organe de validation (16) de données en fonction de la position dudit curseur (19).

3/ Dispositif selon la revendication 1, caractérisé en ce que le moyen de calcul (17) pour déterminer le tracé idéal théorique et le tracé théorique final de la plaque est constitué par un micro-ordinateur dont les étapes de fonctionnement sont dictées par un logiciel adapté.

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4/ Dispositif selon l'une des revendications 1 à 3, caractérisé en ce que le moyen d'introduction des particularismes cliniques du patient est constitué par un clavier (18) associé à un micro-ordinateur.

5/ Dispositif selon l'une des revendications précédentes caractérisé en ce que les fourchettes de valeurs physiologiques introduites dans le moyen de calcul destiné à déterminer le tracé idéal théorique de la plaque dentaire concerne les crochets de fixation de la plaque, les épingles à cheveux destinées à solidariser la plaque à la selle de positionnement des dents artificielles, les caractéristiques dimensionnelles de la selle et la courbure de la plaque dentaire elle-même.

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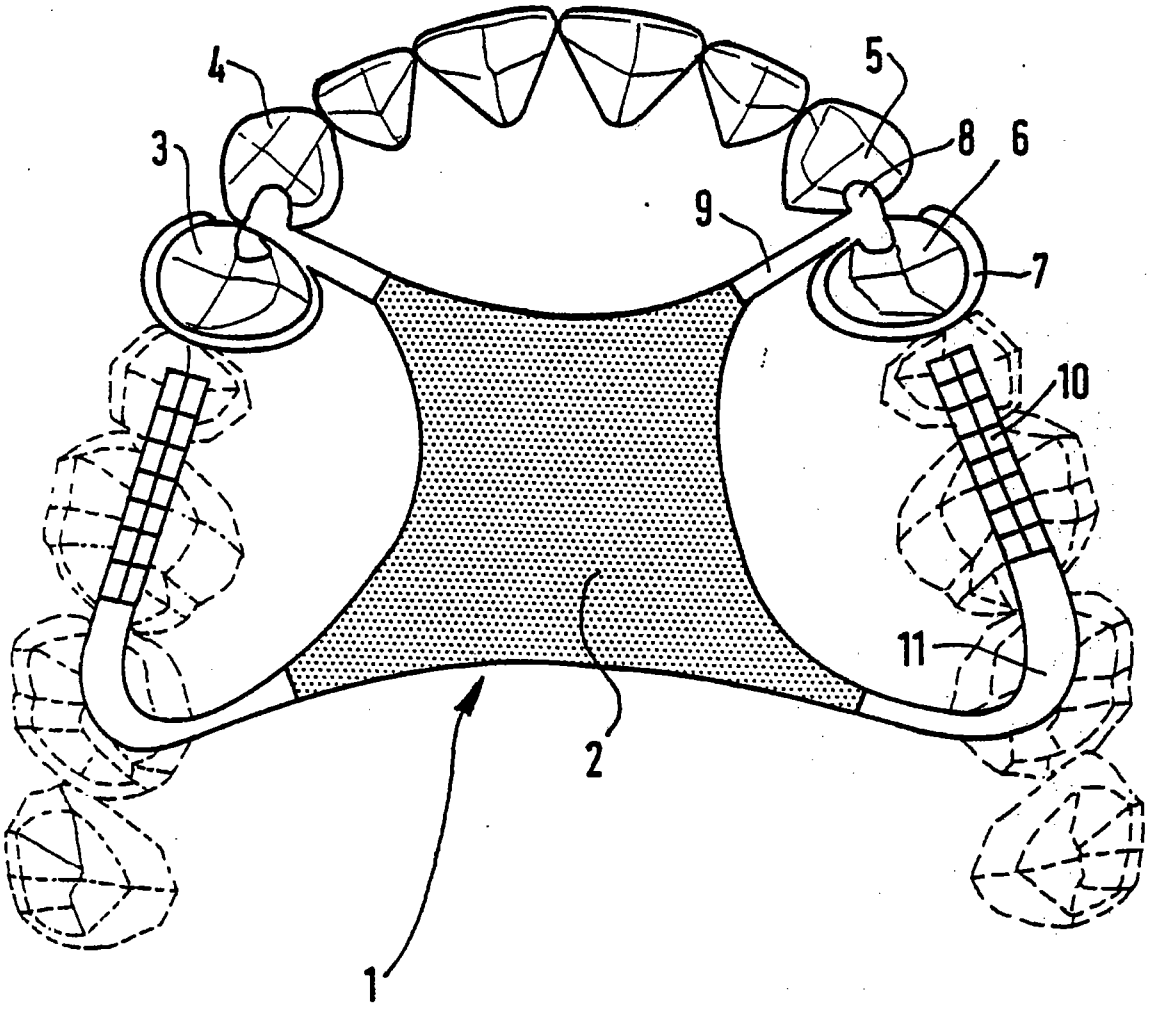


FIG.1

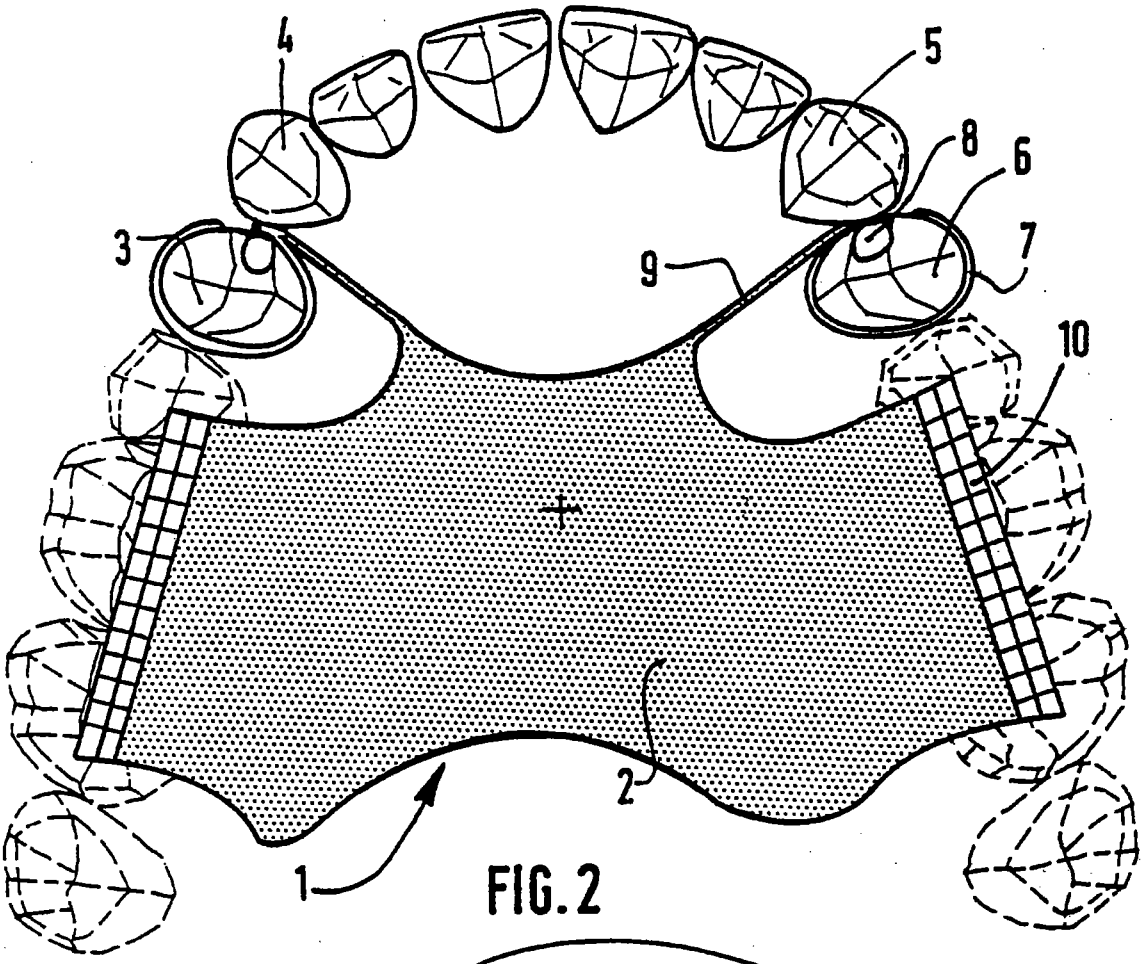


FIG. 2

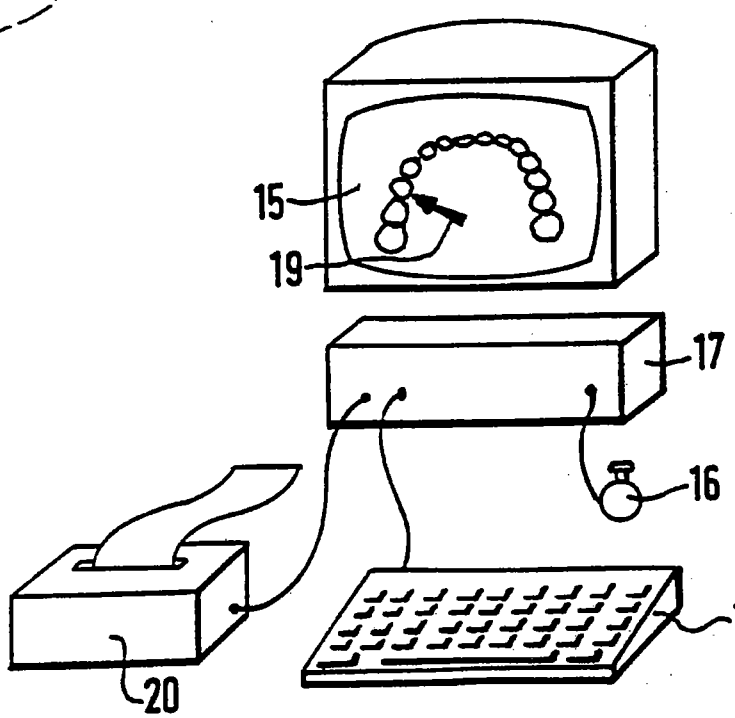


FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No PCT/FR 90/00690

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl.[5] A61C 9/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
Int.Cl.[5]	A61C

Documentation Searched other than Minimum Documentation to the Extent that such Documents are included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	DE, A, 3320395 (AICHER) 6 December 1984 see the whole document --	1-4
A	FR, A, 2594321 (INGLESE) 21 August 1987 see page 4,line 20 - page 5,line 5;figure 1 --	1,2,4
A	EP, A, 0040165 (MICHALLET) 18 November 1981 see claims --	1,3
A	US, A, 4663720 (DURET) 5 May 1987 see column 1,lines 23-27;column 2,line 48 - column 4,line 53;figure 7	1-4

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* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
21 December 1990 (21.12.90)	01 February 1991 (01.02.91)
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	

Form PCT/ISA/210 (second sheet) (January 1985)

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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. FR 9000690 SA 40866

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 23/01/91
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A- 3320395	06-12-84	None	
FR-A- 2594321	21-08-87	None	
EP-A- 0040165	18-11-81	FR-A,B 2481923	13-11-81
US-A- 4663720	05-05-87	US-A- 4742464	03-05-88

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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RAPPORT DE RECHERCHE INTERNATIONALE

Demande internationale N° PCT/FR 90/00690

I. CLASSEMENT DE L'INVENTION (si plusieurs symboles de classification sont applicables, les indiquer tous) [7]

Selon la classification internationale des brevets (CIB) ou à la fois selon la classification nationale et la CIB

CIB[5]: A 61 C 9/00

II. DOMAINES SUR LESQUELS LA RECHERCHE A PORTÉ

Documentation minimale consultée [8]

Système de classification	Symboles de classification
CIB[5]	A 61 C

Documentation consultée autre que la documentation minimale dans la mesure où de tels documents font partie des domaines sur lesquels la recherche a porté [9]

III. DOCUMENTS CONSIDÉRÉS COMME PERTINENTS [10]

Catégorie *	Identification des documents cités, [11] avec indication, si nécessaire, des passages pertinents [12]	N° des revendications visées [13]
A	DE, A, 3320395 (AICHER) 6 décembre 1984 voir le document en entier	1-4

A	FR, A, 2594321 (INGLESE) 21 août 1987 voir page 4, ligne 20 - page 5, ligne 5; figure 1	1,2,4

A	EP, A, 0040165 (MICHALLET) 18 novembre 1981 voir revendications	1,3

A	US, A, 4663720 (DURET) 5 mai 1987 voir colonne 1, lignes 23-27; colonne 2, ligne 48 - colonne 4, ligne 53; figure 7	1-4
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* Catégories spéciales de documents cités: [11]

«A» document définissant l'état général de la technique, non considéré comme particulièrement pertinent

«E» document antérieur, mais publié à la date de dépôt international ou après cette date

«L» document pouvant jeter un doute sur une revendication de priorité ou cité pour déterminer la date de publication d'une autre citation ou pour une raison spéciale (telle qu'indiquée)

«O» document se référant à une divulgation orale, à un usage, à une exposition ou tous autres moyens

«P» document publié avant la date de dépôt international, mais postérieurement à la date de priorité revendiquée

«T» document ultérieur publié postérieurement à la date de dépôt international ou à la date de priorité et n'appartenant pas à l'état de la technique pertinent, mais cité pour comprendre le principe ou la théorie constituant la base de l'invention

«X» document particulièrement pertinent: l'invention revendiquée ne peut être considérée comme nouvelle ou comme impliquant une activité inventive

«Y» document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme impliquant une activité inventive lorsque le document est associé à un ou plusieurs autres documents de même nature, cette combinaison étant évidente pour une personne du métier.

«&» document qui fait partie de la même famille de brevets

IV. CERTIFICATION

Date à laquelle la recherche internationale a été effectivement achevée	Date d'expédition du présent rapport de recherche internationale
21 décembre 1990	01. 02. 91
Administration chargée de la recherche internationale	**Signature du fonctionnaire autorisé**
OFFICE EUROPEEN DES BREVETS	F.W. HECK

Formulaire PCT/ISA/210 (deuxième feuille) (Janvier 1985)

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ANNEXE AU RAPPORT DE RECHERCHE INTERNATIONALE RELATIF A LA DEMANDE INTERNATIONALE NO.

FR 9000690
SA 40866

La présente annexe indique les membres de la famille de brevets relatifs aux documents brevets cités dans le rapport de recherche internationale visé ci-dessus.
Lesdits membres sont contenus au fichier informatique de l'Office européen des brevets à la date du 23/01/91
Les renseignements fournis sont donnés à titre indicatif et n'engagent pas la responsabilité de l'Office européen des brevets.

Document brevet cité au rapport de recherche	Date de publication	Membre(s) de la famille de brevet(s)	Date de publication
DE-A- 3320395	06-12-84	Aucun	
FR-A- 2594321	21-08-87	Aucun	
EP-A- 0040165	18-11-81	FR-A,B 2481923	13-11-81
US-A- 4663720	05-05-87	US-A- 4742464	03-05-88

EPO FORM P0472

Pour tout renseignement concernant cette annexe : voir Journal Officiel de l'Office européen des brevets, No.12/82

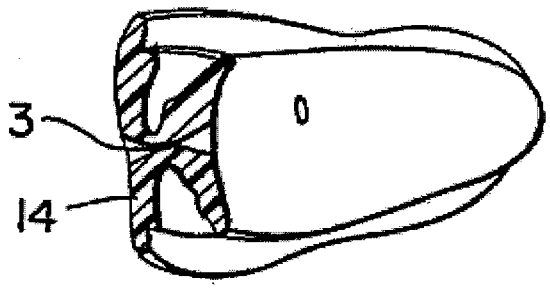
Orthodontic treating device and method of manufacturing same

Patent number: FR2369828
Publication date: 1978-06-02
Inventor:
Applicant: SUYEHIRO HITO (US)
Classification:
- international: A61C7/00; A61K5/06
- european: A61C7/08; A61K6/093
Application number: FR19770033235 19771104
Priority number(s): JP19760132323 19761105

Also published as:
US4505673 (A1)
US4504225 (A1)
JP53058191 (A)
GB1550777 (A)
ES463897 (A)
more >>

Abstract not available for FR2369828
Abstract of corresponding document: **US4504225**

Original models of plaster are obtained from impressions of the dentition of the upper and lower jaws of a patient with malocclusion. The teeth are then separated from the base of the models and reset in wax to a normal occlusion. The realigned teeth are fixed in place with wax, and impressions of the upper and lower models are taken to duplicate the rearranged models, forming working models made of plaster. The working models are mounted on an anatomic dental articulator and a wax occluding model is constructed of the new occlusion to cover both upper and lower arches. The working upper and lower models, together with the wax occluding model are buried in plaster in a split cast. The wax occluding model in the split cast is heated and the wax is melted and discharged out of the cast. Silicone resin is then placed into the impression of the occluding model and cured.



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INSTITUT NATIONAL
DE LA PROPRIÉTÉ INDUSTRIELLE

PARIS

(11) N° de publication : **2 369 828**
(A n'utiliser que pour les commandes de reproduction).

A1

DEMANDE DE BREVET D'INVENTION

(21) **N° 77 33235**

(54) **Dispositif de traitement d'orthodontie et procédé de fabrication.**

(51) Classification internationale (Int. Cl.²). **A 61 C 7/00; A 61 K 5/06.**

(22) Date de dépôt ..... 4 novembre 1977, à 15 h 16 mn.

(33) (32) (31) Priorité revendiquée : *Demande de brevet déposée au Japon le 5 novembre 1976, n. 132.323/1976 aux noms de Osamu Yoshii et Fujio Miura.*

(41) Date de la mise à la disposition du public de la demande ..... B.O.P.I. — «Listes» n. 22 du 2-6-1978.

(71) Déposant : HITO SUYEHIRO, résidant aux Etats-Unis d'Amérique.

(72) Invention de :

(73) Titulaire : *Idem* (71)

(74) Mandataire : Cabinet Z. Weinstein.

D Vente des fascicules à l'IMPRIMERIE NATIONALE, 27, rue de la Convention — 75732 PARIS *CEDEX 15*

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Un traitement classique d'orthodontie est accompli avec des bandes métalliques pourvues d'un moyen d'attache formé pour s'adapter aux dents, et qui est fixé aux dents avec du ciment, et un fil métallique y passe pour déplacer les dents. Dans ce cas, la force de correction (contrainte pour déplacer les dents) utilise principalement les forces élastiques du fil métallique lui-même, et on l'utilise généralement largement comme dispositif de traitement d'orthodontie.

Cependant, dans le traitement d'orthodontie utilisant cette technique avec plusieurs bandes, avec la flexion du fil métallique selon des formes compliquées, on a reconnu qu'il fallait des quantités énormes d'énergie et d'adresse ainsi que de longues périodes d'éducation. De même, ce traitement provoque non seulement un inconfort pour le patient, mais également d'autres problèmes comme des dents dégradées ou décalcifiées ou une maladie du périodonte provenant des particules alimentaires adhérant aux dents pendant le traitement d'orthodontie, et par ailleurs, le prix est énorme.

La présente invention a été conçue en vue de fabriquer un dispositifde traitement d'orthodontie par lequel une malocclusion puisse être traitée simplement en utilisant la force élastique de résines de silicone, comme force fonctionnelle au lieu du fil métallique actuellement employé, et comme il est facile à détacher, il ne provoque aucun inconfort pour le patient, et permet d'accomplir le traitement d'orthodontie en l'utilisant au lit et dans les heures de veille selon la nécessité.

D'abord, il est nécessaire de choisir un matériau élastique de fort poids moléculaire, satisfaisant suffisamment aux conditions spéciales et sévères d'un traitement intraoral. Le demandeur a trouvé que les résines de silicone étaient un matériau élastique approprié pour un traitement d'orthodontie, amenant les meilleurs résultats du point de vue science, construction et étude clinique. En effet, le matériau a été reconnu comme ayant une qualité scientifique et de construction telle que son élasticité ne se détériore pas quand il est dans la bouche, qu'il a une résistance à la rupture suffisante, et qu'il ne se déforme pas pendant de longues périodes de

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temps du fait de la force pendant le traitement. Etant donné ces propriétés importantes, le dispositif de traitement selon la présente invention peut être utilisé pour traiter les patients des étapes initiales jusqu'à la fin du traitement.

Par ailleurs, en changeant la partie durcisseur des résines de silicone et des catalyseurs et de leurs mélanges, on peut librement modifier la dureté de la résine de silicone moulée. On peut obtenir des forces allant d'une force légère à une force importante, ce qui est avantageux du point de vue clinique. Le dispositif conserve un dégré élevé de transparence sans avoir aucun goût ou aucune odeur, et il est préparé à partir d'une composition ne provoquant aucun mal au corps humain. On ne peut trouver ces propriétés dans aucun autre matériau de caoutchouc.

En plus des résines de silicone, les résines de polyuréthane ont des qualités quelque peu semblables à celles mentionnées ci-dessus, mais les résines de silicone offrent des avantages supplémentaires comme un temps de traitement de durcissement plus court en comparaison avec une résine de polyuréthane, et le processus de fabrication peut être accompli simplement, on peut donc par conséquent reconnaître une différence remarquable entre les deux résines. De plus, si l'on utilise des résines de polyuréthane pour préparer des dispositifs semblables, ces dispositifs se décomposent dans la bouche du patient et ne sont pas transparents. Par conséquent, ces dispositifs ne sont utilisés que pendant les étapes finales du traitement et ne peuvent être utilisés à partir de l'étape initiale.

En conséquence, le demandeur a découvert que le dispositif de traitement selon la présente invention, fait en résines de silicone pour la première fois, offrait un moyen pour traiter un patient du début jusqu'à la fin. Jusqu'à maintenant, cela n'était possible qu'en utilisant les bandes métalliques connues.

La présente invention est dirigée vers un dispositif de traitement d'orthodontie ainsi que son procédé de fabrication, utilisant les caractéristiques de la résine de silicone ci-dessus mentionnées.

L'invention sera mieux comprise, et d'autres buts, caractéristiques, détails et avantages de celle-ci apparaîtront

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plus clairement au cours de la description explicative qui va suivre, faite en référence aux dessins schématiques annexés donnés uniquement à titre d'exemple illustrant plusieurs modes de réalisation de l'invention et dans lesquels :

- la figure 1 est une vue occlusale d'un modèle original avec une malocclusion ;
- la figure 2 est une vue en élévation de plusieurs dents séparées du modèle de la figure 1 ;
- la figure 3 est une vue occlusale d'un modèle obtenu en réarrangeant dans la cire les dents du modèle original pour une occlusion normale ;
- la figure 4 est une vue occlusale de tout le dispositif de traitement d'orthodontie ;
- la figure 5 est une vue en élévation avant du dispositif de traitement d'orthodontie ;
- la figure 6 est une vue en coupe transversale suivant une ligne VI-VI de la figure 5 ;
- la figure 7 est une vue en coupe transversale extrême de la vue en coupe transversale faite suivant une ligne VII-VII de la figure 4 ;
- la figure 8 est une vue de comparaison montrant avant et après le traitement d'orthodontie, la figure 8A montrant avant et la figure 8B après le traitement ;
- la figure 9 montre le premier mode de réalisation de la présente invention, la figure 9A montrant une vue extrême de la condition dans laquelle un moule divisé (9) est séparé, et la figure 9B montre une vue en coupe transversale extrême de la condition où la résine de silicone est introduite dans le moule divisé, et la figure 9C montre une vue en coupe transversale extrême de la condition où les parties séparées du moule divisé sont jointes.
- la figure 10 montre un second mode de réalisation de la présente invention, la figure 10A montrant une vue de dessus d'un articulateur anatomique, la figure 10B montrant une vue latérale de la condition où la plaque en cire nécessaire pour fixer les modèles supérieur et inférieur en plâtre est fondue et est déchargée, et la figure 10C montre une vue latérale de la condition où la résine de silicone est mise en contact de pression sur la surface du modèle de travail pour produire

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le dispositif de traitement d'orthodontie, et la figure 10D montre une vue en coupe transversale suivant une ligne X-X de la figure 10A.

La présente invention concerne un premier procédé pour faire un dispositif de traitement d'orthodontie en résine de silicone en (a) préparant des modèles en plâtre de la mâchoire supérieure et de la mâchoire inférieure d'un patient comportant les dents présentant une malocclusion, (b) déterminant la relation centrique entre les dents supérieures et inférieures du patient en prenant une empreinte en cire, (c) prenant un transfert de l'arc facial des dents supérieures du patient pour établir la relation de la mâchoire supérieure avec la tête et la face, (d) plaçant l'arc facial dans un articulateur anatomique, (e) plaçant les modèles supérieur et inférieur de l'étape (a) dans l'articulateur anatomique en utilisant l'arc facial et l'empreinte en cire de l'étape (b) pour reproduire la relation entre les mâchoires supérieure et inférieure du patient et en fixant les modèles en plâtre de façon qu'ils soient attachés à l'articulateur (f) enlevant les dents des modèles et réalignant les dents dans la cire pour une occlusion normale, (g) reproduisant l'occlusion normale des modèles avec un matériau de reproduction pour former des empreintes négatives, (h) formant des modèles en plâtre positifs à partir des empreintes négatives, (i) ouvrant l'articulateur pour former un espace de 3 à 5 mm entre les bords incisifs supérieure et inférieurs, (j) plaçant de la cire dans l'espace pour obtenir une empreinte des dents supérieures et inférieures en occlusion normale, (k) plaçant les dents des modèles en plâtre supérieur et inférieur de l'étape (h) dans l'empreinte en cire de l'étape (j), (l) couvrant l'ensemble résultant de l'étape (k) de cire de façon que la cire ait sensiblement la même forme et la même épaisseur que le dispositif de traitement en résine de silicone, (m) transférant l'ensemble du modèle couvert de cire de l'étape (l) dans un moule divisé, (n) soumettant le moule divisé contenant le modèle couvert de cire à une chaleur suffisante pour faire fondre la cire et produire un vide, (o) enlevant la cire, (p) remplissant le vide de résine de silicone et durcissant la résine, et (q) enlevant

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le dispositif de traitement en résine de silicone.

La présente invention est également dirigée vers un second procédé de production du dispositif de traitement d'orthodontie en résine de silicone, en répétant sensiblement les étapes (a)-(h) indiquées ci-dessus, avec les étapes supplémentaires de (i) enlever les modèles en cire de l'articulateur et les remplacer par les modèles en plâtre de l'étape (h) tout en maintenant la même relation entre les mâchoires supérieure et inférieure, (j) ouvrir l'articulateur pour former un espace de 3 à 5 mm entre les bords incisifs supérieur et inférieur , (k) former une résine de silicone durcissable à chaud autour des dents supérieures et inférieures et durcir la résine et(l) enlever le dispositif de traitement résultant.

Bien que chaque procédé ci-dessus dentifié puisse être utilisé pour faire le dispositif de traitement d'orthodontie selon la présente invention, on préfère le premier procédé car il offre le moyen d'utiliser une pression appropriée pour forcer la résine de silicone dans chaque crevasse entourant les dents et le dispositif de traitement résultant offre une réplique précise des dents du patient en occlusion normale.

La présente invention est accomplie dans un procédé employant les étapes qui suivent :

(a) préparer les modèles en plâtre des mâchoires supérieure et inférieure du patient comportant des dents montrant une malocclusion.

Une empreinte est prise des dents supérieures et inférieures du patient et du tissu environnant en utilisant un matériau de reproduction pour obtenir une empreinte négative. Le matériau de reproduction est enlevé des dents et un vide est formé dans le matériau. Du plâtre est versé dans le vide de l'empreinte négative pour obtenir un moule positif en plâtre des dents supérieures et inférieures du patient.

(b) déterminer la relation centrique entre les dents supérieures et inférieures du patient en prenant une empreinte en cire.

De la cire est placée entre les dents supérieures et inférieures du patient pour obtenir une empreinte de

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l'occlusion pour déterminer la relation centrique des dents supérieures et inférieures. Cette empreinte en cire est utilisée ultérieurement pour bien aligner les modèles supérieure et inférieur en plâtre préparés à l'étape (a).

(c) prendre un transfert de l'arcade des dents supérieures du patient pour établir et reproduire la relation entre la mâchoire supérieure et la tête et la face.

On utilise l' arc facial pour prendre une empreinte en cire des dents supérieures du patient pour produire la relation entre la mâchoire supérieure et la tête et la face. Cette étape est critique dans le procédé selon l'invention, car elle offre le seul moyen pour produire avec précision la relation ultime des mâchoires supérieure et inférieure du patient, et ce processus sert de base pour bien aligner les modèles en plâtre avec lesquels le dispositif de traitement d'orthodontie doit être préparé. Le dispositif doit avoir la même relation entre les mâchoires supérieure et inférieure que celle du patient de façon que, quand le dispositif sera utilisé, la relation des dents s'adapte bien dans le dispositif pour forcer les dents à se déplacer vers une occlusion normale.

(d) placer l'arc facial dans un articulateur anatomique.

L' arc facial avec l'empreinte en cire des dents supérieures du patient est attachée à un articulateur anatomique pour bien aligner les modèles supérieur et inférieur en plâtre.

(e) placer les modèles supérieur et inférieur de l'étape (a) dans l'articulateur anatomique en utilisant l'arc facial et les faces masticatrices de l'étape (b) pour reproduire la relation entre les mâchoires supérieure et inférieure du patient et fixer les modèles en plâtre de façon qu'ils soient attachés à l'articulateur.

Ce processus est accompli en plaçant les dents du modèle en plâtre supérieur préparé à l'étape (a) dans l'empreinte en cire de l'arc facial qui a été attaché à l'articulateur anatomique. Du plâtre est placé au sommet du modèle supérieur et est forcé contre le sommet de l'articulateur et on le laisse sécher pour forcer ainsi le modèle supérieur à être attaché au sommet de l'articulateur. Quand le plâtre a séché, l'arc facial est enlevé de l'articulateur. Le modèle supérieur a

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été placé dans l'articulateur avec la même relation que la position naturelle des dents et de la mâchoire supérieures du patient.

L'empreinte de l'occlusion en cire préparée à l'étape (b) est placée sur les dents du modèle supérieur et y est attachée. Le modèle inférieur en plâtre de l'étape (a) est inséré à la partie inférieure de l'empreinte en cire qui est attachée au modèle supérieur. Du plâtre est versé sur la surface du modèle inférieur et l'articulateur est fermé et on laisse le plâtre sécher de façon que le modèle inférieur soit attaché à l'articulateur.

A ce point dans le procédé de l'invention, les modèles supérieur et inférieur en plâtre ont été attachés à l'articulateur de façon à établir une reproduction exacte de la relation des mâchoires et des dents du patient.

(f) enlever les dents des modèles et réaligner les dents dans la cire pour une occlusion normale.

Les dents en plâtre sont individuellement enlevées du modèle en plâtre par le moyen d'une scie à lame mince. Alors, de la cire est placée sur la base des modèles en plâtre d'où chaque dent a été enlevée, et les dents sont placées dans la cire et arrangées en occlusion normale. A ce point, les modèles supérieur et inférieur ont les dents placées de façon telle que le dispositif de traitement d'orthodontie en résine de silicone à faire avec le procédé selon l'invention déplace les dents vers la position formée par les modèles en cire.

(g) reproduire l'occlusion normale des modèles avec un matériau de reproduction pour former des empreintes négatives.

Un matériau de reproduction est formé autour des modèles en cire pour former des empreintes négatives en occlusion normale. Le matériau est enlevé des modèles et les empreintes montrent les vides des dents en occlusion normale.

(h) former des modèles positifs en plâtre à partir de l'empreinte négative.

Du plâtre est versé dans les vides de l'empreinte négative pour préparer des modèles positifs en plâtre qui montrent la position des dents du patient après traitement avec le dispositif de traitement d'orthodontie fait par le procédé selon

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l'invention.

(i) ouvrir l'articulateur pour former un espace de 3 à 5 mm entre les bords incisifs supérieur et inférieur.

L'articulateur est ouvert de façon qu'un espace de 3 à 5 mm, de préférence 4 mm, soit formé entre les bords incisifs supérieur et inférieur. Cet espace est nécessaire pour bien former le dispositif de traitement d'orthodontie parce que la résine de silicone remplira l'espace entre les dents et quand le patient mordra dans la résine pendant le traitement d'orthodontie, la force de morsure et l'élasticité de la résine aideront à déplacer les dents.

(j) placer la cire dans l'espace pour obtenir une empreinte des dents supérieures et inférieures en occlusion normale.

Cette étape est nécessaire pour obtenir la bonne relation entre les dents supérieure et inférieure. Cette empreinte sera ultérieurement utilisée pour remplacer les modèles en cire par les modèles en plâtre de l'étape (h) dans l'articulateur.

(k) placer les dents des modèles supérieur et inférieur en plâtre de l'étape (h) dans des empreintes en cire de l'étape (j).

Les modèles en plâtre en occlusion normale préparés à l'étape (h) sont placés dans l'empreinte en cire obtenue à l'étape (j). L'empreinte en cire est employée pour bien aligner les modèles supérieur et inférieur en plâtre. Cet assemblage est accompli séparément et en dehors de l'articulateur.

(l) couvrir l'assemblage résultant de l'étape (k) de cire de façon que la cire ait sensiblement la même forme et la même épaisseur que le dispositif de traitement en résine de silicone.

De la cire est placée sur toute la surface des dents et la partie représentant le tissu des modèles supérieur et inférieur, qui comprend la cire placée entre les dents à l'étape (k). La cire doit avoir sensiblement la même forme et la même épaisseur que le dispositif de traitement en résine de silicone qui doit être préparé dans le procédé comme on le décrira ci-après.

(m) introduire l'assemblage du modèle couvert de cire de l'étape (l) dans un moule divisé.

L'assemblage préparé à l'étape (l) est placé dans la

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moitié inférieure d'un moule divisé, et du plâtre est versé dans le moule pour couvrir toute la moitié inférieure du modèle assemblé. On laisse le plâtre sécher et durcir et un moyen de séparation est appliqué sur la couche de plâtre durci .

Le moule divisé est retourné et la plâtre est versé dans le moule, et la moule est fermé de façon que la partie supérieure exposée de l'assemblage soit totalement enfouie dans le plâtre mou. On doit utiliser suffisamment de plâtre pour qu'il couvre toute la surface du modèle assemblé, et cela peut être mis en évidence par le plâtre en excès qui s'écoule en dehors du moule. Le moule est alors serré en position fermée, et on laisse le plâtre sécher.

(n) soumettre le moule divisé contenant le modèle couvert de cire à une chaleur suffisante pour fondre la cire et produire un vide.

Tout le moule divisé contenant le modèle préparé à l'étape (m) est chauffé par exemple en le plaçant dans de l'eau bouillante pendant un temps suffisant pour faire fondre la cire.

(o) enlever la cire

Le moule divisé est ouvert et la cire fondue est enlevée laissant un vide autour des dents et du tissu du modèle en plâtre comportant l'espace entre les dents supérieure et inférieure.

(p) remplir le vide d'une résine de silicone durcissable à chaud et durcir la résine.

Un matériau de résine de silicone molle est placé dans le vide en quantité suffisante pour le remplir totalement. Le moule est fermé très serré de façon que la résine remplisse chaque espace et toutes les crevasses complètement, et que du matériau en excès s'écoule en dehors des vides. Le moule divisé est alors soumis à une chaleur comme de l'eau bouillante pendant une période de l'ordre de 40 minutes pour durcir la résine de silicone.

(q) enlever le dispositif de traitement en résine de silicone.

Le moule divisé est enlevé, refroidi, ouvert et le dispositif de traitement d'orthodontie en résine de silicone résultant est enlevé.

Comme étape finale, le dispositif de traitement résultant

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peut être enduit d'une solution de résine de silicone contenant deux résines différentes, comportant un catalyseur, pour produire une surface lisse, invisible et claire. Les deux solutions sont mélangées à un rapport de l'ordre de 10 à 1. Le processus indiqué ci-dessus est la méthode préférée, car le dispositif de traitement est obtenu en utilisant un moule divisé pour forcer la résine de silicone dans chaque espace et chaque crevasse du vide dans le modèle en plâtre.

Dans un second mode de réalisation de l'invention, on emploie un procédé semblable en ne répétant que les étapes (a) à (h) du procédé ci-dessus. Le second mode de réalisation est accompli par les étapes suivantes :

(a) préparer des modèles en plâtre des mâchoires supérieure et inférieure du patient comportant des dents montrant une malocclusion.

Une empreinte est prise des dents supérieures et inférieures du patient et du tissu environnant en utilisant un matériau de reproduction pour obtenir une empreinte négative. Le matériau de reproduction est enlevé des dents et un vide est formé dans le matériau. Du plâtre est versé dans le vide de l'empreinte négative pour obtenir un moule positif en plâtre des dents supérieures et inférieures du patient.

(b) déterminer la relation centrique entre les dents supérieures et inférieures du patient en prenant une empreinte en cire.

De la cire est placée entre les dents supérieures et inférieures du patient pour obtenir une empreinte de l'occlusion pour déterminer la relation centrique des dents supérieures et inférieures. Cette empreinte en cire est utilisée ultérieurement dans le procédé pour bien aligner les moules supérieur et inférieur en plâtre préparés à l'étape (a).

(c) prendre un transfert de l'arc facial des dents supérieures du patient pour établir et reproduire la relation entre la mâchoire supérieure et la tête et la face.

L'arc facial est utilisé pour prendre une empreinte en cire des dents supérieures du patient pour reproduire la relation entre la mâchoire supérieure et la tête et la face. Cette étape est critique dans le procédé selon l'invention, car

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elle offre le seul moyen pour reproduire avec précision la relation ultime entre les mâchoires supérieure et inférieure du patient, et ce procédé sert de base pour bien aligner les modèles en plâtre à partir desquels le dispositif de traitement d'orthodontie devra être préparé. Le dispositif doit avoir la même relation entre les mâchoires supérieure et inférieure que celle du patient de façon que, quand le dispositif sera utilisé, la relation des dents s'adapte bien dans le dispositif pour forcer les dents à se déplacer vers une occlusion normale.

(d)placer l'arc facial dans un articulateur anatomique.

L'arc facial avec l'empreinte en cire des dents supérieures du patient est attaché à un articulateur anatomique pour bien aligner les modèles supérieur et inférieur en plâtre.

(e) placer les modèles supérieur et inférieur de l'étape (a) dans l'articulateur anatomique en utilisant l'arc facial et l'empreinte de cire de l'étape (b) pour reproduire la relation entre les mâchoires supérieure et inférieure du patient, et fixer les modèles en plâtre de façon qu'ils soient attachés à l'articulateur.

Ce processus estaccompli en plaçant les dents du modèle supérieur en plâtre préparé à l'étape (a) dans l'empreinte en cire de l'arc facial qui a été attachée à l'articulateur anatomique. Du plâtre est placé au sommet du modèle supérieur et est forcé contre le sommet de l'articulateur et on le laisse sécher, forçant ainsi le modèle supérieur à être attaché au sommet de l'articulateur. Quand le plâtre a séché, l'arc facial est enlevé de l'articulateur. Le modèle supérieur a maintenant été placé dans l'articulateur avec la même relation que la position naturelle des dents et de la mâchoire supérieures du patient.

L'empreinte en cire de l'occlusion préparée à l'étape (b) est placée sur les dents du modèle supérieure et y est attachée. Le modèle inférieur en plâtre de l'étape (a) est inséré dans la partie inférieure de l'empreinte en cire qui est attachée au modèle supérieur. Du plâtre est versé sur la surface du modèle inférieur et l'articulateur est fermé, et on

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laisse le plâtre sécher de façon que le modèle inférieur soit attaché à l'articulateur. Jusqu'à ce point dans le procédé selon l'invention, les modèles supérieur et inférieur en plâtre ont été attachés à l'articulateur de façon à reproduire exactement la relation entre les mâchoires et les dents du patient.

(f) enlever les dents des modèles et réaligner les dents dans la cire pour une occlusion normale.

Chaque dent en plâtre est enlevée du modèle en plâtre par le moyen d'une scie à lame mince. Alors, de la cire est placée sur la base des modèles en plâtre d'où chaque dent a été enlevée, et les dents sont placées dans la cire et arrangées en occlusion normale. A ce point, les modèles supérieur et inférieur ont les dents placées de façon que le dispositif de traitement d'orthodontie en résine de silicone à faire avec le procédé selon l'invention, déplace les dents vers la position formée par les modèles en cire.

(g) reproduire l'occlusion normale des modèles avec un matériau de reproduction pour former des empreintes négatives.

Un matériau de reproduction est formé autour des modèles en cire pour former des empreintes négatives en occlusion normale. Le matériau est enlevé des modèles et les empreintes montrent des vides des dents en occlusion normale.

(h) former des modèles positifs en plâtre à partir des empreintes négatives.

Du plâtre est versé dans les vides de l'empreinte négative pour préparer des modèles positifs en plâtre qui montrent la position des dents du patient après traitement avec le dispositif de traitement d'orthodontie selon l'invention.

(i) enlever les modèles en cire de l'articulateur et les remplacer par les modèles en plâtre de l'étape (h) tout en maintenant la même relation entre les mâchoires supérieure et inférieure.

Les modèles en plâtre reproduits et préparés à l'étape (h) sont montés sur l'articulateur selon les étapes suivantes :

(1) le modèle supérieur en cire est enlevé de l'articulateur et le modèle supérieur en plâtre est placé sur le modèle inférieur en cire de façon que le modèle en plâtre

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conserve exactement le même relation avec le modèle inférieur en cire que celle du modèle supérieur en cire qui a été enlevé. A ce point, le modèle supérieur est fait en plâtre et le modèle inférieur a les dents placées dans la cire.

(2) du plâtre est versé au sommet du modèle supérieur en plâtre et l'articulateur est fermé de façon que, quand le plâtre sèche, le modèle supérieur en plâtre soit attaché à l'articulateur.

(3) le modèle inférieur en cire est enlevé de l'articulateur et est remplacé par le modèle inférieur en plâtre de l'étape (h) en plaçant le modèle inférieur en plâtre en alignement avec le modèle supérieur maintenant attaché à l'articulateur à la façon décrit ci-dessus. Du plâtre est alors versé sur la surface du modèle inférieur en plâtre, l'articulateur est fermé et lors du séchage du plâtre, le modèle inférieur est attaché à l'articulateur.

(j) ouvrir l'articulateur pour former un espace de 3 à 5 mm entre les bords incisifs supérieur et inférieur.

De nouveau, cet espace est nécessaire pour bien former le dispositif de traitement en résine de silicone indiqué précédemment à l'étape (i) du premier processus.

(k) former une résine de silicone durcissable à chaud autour des dents supérieures et inférieures, et durcir la résine.

De la résine de silicone molle est pressée à la main sur toute la surface des dents à l'avant et à l'arrière, et entre les dents supérieures et inférieures pour remplir l'espace créé dans l'étape précédente. La résine est configurée à la forme finale du dispositif de traitement en retirant tout matériau en excès. Tout l'ensemble est alors soumis à une chaleur par exemple en le plaçant dans l'eau bouillante pendant environ 40 minutes pour durcir la résine. On comprendra que dans chaque processus de la présente invention, la résine peut être durcie en chauffant à une température de 100 à 130°C, par exemple au moyen d'eau bouillante ou d'air chaud.

(l) enlevement du dispositif de traitement résultant.

Après durcissement de la résine, tout l'ensemble du modèle en plâtre où est appliquée la résine de silicone est refroidi, l'articulateur est ouvert et le dispositif de traitement

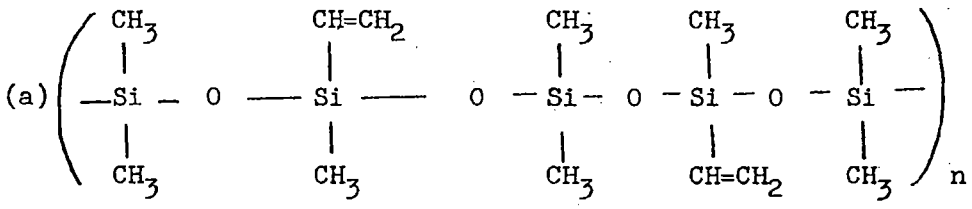
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résultant est enlevé du moule en plâtre.

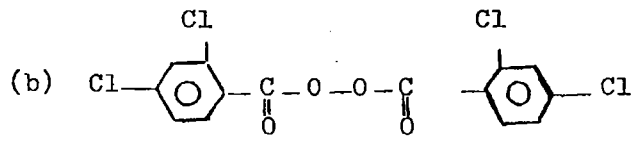
Le dispositif peut alors être enduit de la solution de résine de silicone à deux composants qui a été décrite ci-dessus, pour donner un produit final ayant un fini lisse.

On peut employer divers types de résines de silicone dans la présente invention, à condition qu'elles aient les bonnes propriétés physiques pour déplacer les dents d'un patient d'une malocclusion à une occlusion normale. Les propriétés offertes par les résines de silicone employées dans la présente invention comprennent des résines facilement durcissables en les soumettant à la chaleur de l'ordre de 100 à 130°C, sans odeur, goût ou aucun ingrédient chimique pouvant être néfaste pour le corps. De plus, les résines selon la présente invention sont transparentes, on peut donc voir les dents et les gencives du patient àtravers le dispositif de traitement.

Les résines de silicone employées dans la présente invention sont préparées dans une composition contenant (a) un matériau de base de résine de silicone et (b) un catalyseur comportant une huile telle qu'une huile de silicone. Bien que divers types de résines de silicone puissent être employés ayant les propriétés indiquées ci-dessus, des exemple comprennent les matériaux ayant la formule qui suit :



Le catalyseur employé dans la composition de résine de silicone comprend ceux représentés par la formule qui suit :



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La composition du catalyseur comporte une huile telle qu'une huile de silicone. La composition du catalyseur contient environ 40 à environ 50% du catalyseur et environ 50 à environ 60% de l'huile. Le rapport de la résine de silicone à la composition du catalyseur peut être de l'ordre de 100 g de (a) à 1-2g de (b), respectivement.

La composition de résine de silicone peut être préparée en mélangeant ensemble (a) et (b) dans un mélangeur pendant un temps suffisant pour obtenir un mélange physique complet des matériaux. La composition résultante peut être alors stockée dans un endroit froid comme un réfrigérateur.

Les propriétés de la résine de silicone à employer dans le présente invention sont les suivantes :

1) dureté (norme JIS)	environ 40 à environ 60
2) résistance à la traction	environ 85 à environ 130kg/cm^2
3) contrainte	environ 400 à environ 560%
4) poids moléculaire	environ 6 x 10^5(base de silicone)
5) module à 200%	environ 35 à environ 45 kg/cm^2

La figure 1 montre le modèle en plâtre original après avoir pris une empreinte de la malocclusion d'un patient à traiter, comportant des dents 1 également faites en plâtre.

La figure 2 montre les dents respectives enlevées du modèle original de la figure 1, et la figure 3 montre la condition dans laquelle les dents sont réarrangées pour une occlusion normale en utilisant de la cire 2 employée pour monter et fixer les dents. La figure 4 montre le dispositif de traitement d'orthodontie complet utilisant de la résine de silicone 14 comme ébauche, et la figure 5 montre le dispositif ayant des trous de ventilation 3 pour la respiration, et les dents montrées en pointillé sont des empreintes négatives des dents qui sont réarrangées pour obtenir l'occlusion normale. Les dents mal alignées du patient à traiter sont insérées dans le dispositif ayant les empreintes négatives lorsque le patient ferme ses mâchoires. Quand le dispositif en

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résine de silicone est déformé par les dents, il se produit une force de remise en place de la résine, et la force de correction force les dents à se déplacer vers l'occlusion normale du dispositif.

La figure 6 est une vue en coupe transversale faite suivant une ligne VI-VI de la figure 5, et la figure 7 est une vue en coupe extrême suivant une ligne VII-VII de la figure 4, montrant un moule concave 4 du dispositif pour insertion d'une molaire de la mâchoire supérieure, et un moule concave 5 pour une molaire de la mâchoire inférieure. La figure 8 est une comparaison montrant les conditions avant et après traitement d'orthodontie avec le dispositif selon l'invention, la figure 8A montrant avant le traitement et la figure 8B montrant après le traitement, et elles montrent également une dent antérieure 6 de la mâchoire supérieure et une dent antérieure 7 de la mâchoire inférieure. La figure 8A montre l'espace du côté de la lèvre de la dent antérieure supérieure et du côté de la langue de la dent antérieure inférieure. La figure 8B ne montre pas cet espace du fait du mouvement de la dent avec la force d'orthodontie produite par la force de remise en place de la résine pendant le traitement.

La figure 9 montre le premier mode de réalisation de la présente invention, la figure 9A montrant la conditions où le moule divisé 9 est séparé et contient les modèles en plâtre avec les dents en occlusion normale enfouies dans le plâtre 12, et 9B montre la condition où la résine de silicone 8 est introduite ou versée dans la moitié inférieure du moule divisé, et 9C montre la condition où le moule divisé et séparé est joint et la résine de silicone 8 entoure totalement les dents, et le repère 10 indique un organe de connexion du moule.

La figure 10 montre le second mode de réalisation de la présente invention, et la figure 10A est une vue de dessus de l'articulateur anatomique 11, 10B en est une vue latérale, montrant la condition dans laquelle la plaque en cire est fondue et est évacuée, et dans cette position, la résine de silicone est en contact de pression est moulée sur les modèles en plâtre pour former le dispositif de traitement d'orthodontie. La figure 10C est une vue latérale du dispositif de traitement d'orthodontie

formé avec la résine de silicone, et quand ce dispositif est durci à l'eau chaude ou à l'air chaud, on obtient un produit final. La figure 10D est une vue en coupe transversale faite suivant une ligne X-X de la figure 10A. Le repère 12 indique un modèle de travail, et le repère 14 indique le dispositif de traitement d'orthodontie.

Le dispositif de traitement en résine de silicone préparé ci-dessus comporte des empreintes négatives ou vides qui représentent les dents du patient, et déplace les dents vers une position souhaitée comme une occlusion normale pendant le traitement. Un traitement d'orthodontie complet est accompli (a) en ouvrant la bouche du patient pour exposer les mâchoires et les dents supérieures et inférieures, (b) en adaptant le dispositif en utilisant la pression des doigts pour forcer le dispositif sur les dents supérieures, (c) en fermant la mâchoire inférieure pour forcer le dispositif sur les dents inférieures. Le mouvement réel des dents est accompli (d) en forçant les dents supérieures et inférieures pendant de courtes périodes de temps, de préférence de l'ordre de 10 à 20 secondes pour forcer le dispositif à placer une certaine pression ou une certaine force contre les dents, en relâchant les mâchoires pour relâcher la pression et en répétant le serrage et la relaxation pendant les heures de veille du patient, (e) en maintenant le dispositif sur les dents du patient pendant les heures de sommeil, et (f) en répétant les étapes (d) et (e) pendant une période de temps suffisante pour déplacer les dents jusqu'à la position souhaitée.

On comprendra que lorsque la malocclusion est sévère et que les dents doivent être déplacées sur des distances considérables, il peut être nécessaire d'utiliser plusieurs dispositifs de traitement selon l'invention, de façon que les dents puissent être déplacées de courtes distances avec chaque traitement selon les processus ci-dessus. De plus, s'il faut plusieurs dispositifs pour le traitement, chaque dispositif peut être préparé selon le processus ci-dessus.

Le dispositif de traitement d'orthodontie obtenu selon la présente invention produit une occlusion normale sur la base

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des dents rangées du patient. Tandis que les dents sont graduellement corrigées après l'avoir placé dans la bouche, il ne provoque pas de contrainte indue sur les dents ou sur la structure du périodonte, la force de correction peut donc agir et par suite, le traitement d'orthodontie peut être accompli.

Etant donné ses propriétés, le dispositif de traitement d'orthodontie moulé en résine de silicone ne peut être déformé en permanence et il ne subit pas de changement dû aux contraintes. Sa dureté peut être librement modifiée et il peut être transparent sans aucun goût ni odeur, tout en offrant les points avantageux de procurer non seulement un excellent traitement d'orthodontie mais également une facilité d'utilisation de la part du patient.

En particulier, la présente invention est avantageuse en la comparant avec des résines de polyuréthane connues, car le temps de polymérisation du polyuréthane est de l'ordre de 20 minutes et par conséquent la présente invention permet de raccourcir énormément le temps de fabrication. De même, la résine de polyuréthane produit de la mousse d'acide carbonique gazeux en grandes quantités, quand elle réagit avec l'eau dans le plâtre, et par conséquent, le modèle de travail doit être fabriqué en utilisant des résines spéciales, et cela présente l'inconvénient de produire des déformations dues au fort retrait résultant du durcissement à chaud de la résine. Par conséquent, dans le cas où l'on utilise une résine de silicone selon la présente invention, on peut employer du plâtre pour faire le modèle de travail et il ne se produit absolument aucune déformation, et par suite, le dispositif de traitement d'orthodontie peut être produit avec une meilleure précision.

Par ailleurs, en utilisant des résines de polyuréthane, la manipulation du liquide non dilué est dangereuse, et un dégonflement pendant le processus d'agitation pour supprimer la mousse avec une pompe à vide, est nécessaire pour empêcher la formation de mousse de polyuréthane. De même, il faut utiliser un compresseur à haute pression et un autoclave et par ailleurs, dans le moulage, il faut un broyeur de grandes dimensions, cela présente donc les complications et les

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inconvénients de l'utilisation de machines spéciales. Au contraire, la présente invention est extrêmement sure, car on emploie la résine de silicone, éliminant la suppression de la mousse pendant le processus d'agitation ainsi que les procédures de polissage et de finissage et en conséquence, elle a beaucoup d'effets excellents.

Bien entendu, l'invention n'est nullement limitée aux modes de réalisation décrits et représentés qui n'ont été donnés qu'à titre d'exemple. En particulier, elle comprend tous les moyens constituant des équivalents techniques des moyens décrits ainsi que leurs combinaisons, si celles-ci sont exécutées suivant son esprit et mises en oeuvre dans le cadre des revendications qui suivent.

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R E V E N D I C A T I O N S

-:-:-:-:-:-:-:-:-:-:-:-:-:-:

1. Procédé pour fabriquer un dispositif de traitement d'orthodontie en résine de silicone, caractérisé en ce qu'il comprend les étapes de :

(a) préparer des modèles en platre des machoires supérieure et inférieure d'un patient comportant des dents présentant une malocclusion,

(b) déterminer la relation centrique entre les dents supérieures et inférieures du patient en prenant une empreinte en cire,

(c) prendre un transfert de l'arc facial des dents supérieures du patient pour établir et reproduire la relation de la machoire supérieure avec la tête et la face,

(d) placer l'arc facial dans un articulateur anatomique,

(e) placer les modèles supérieur et inférieur de l'étape (a) dans ledit articulateur anatomique en utilisant l' arc facial et l'empreinte en cire de l'étape (b) pour reproduire la relation entre les machoires supérieure et inférieure du patient et fixer les modèles en platre de façon que les modèles soient attachés à l'articulateur,

(f) enlever les dents des modèles et réaligner les dents dans la cire pour obtenir une occlusion normale,

(g) reproduire l'occlusion normale des modèles avec un matériau de reproduction pour former des empreintes négatives,

(h) former les modèles positifs en platre à partir des empreintes négatives.

2. Procédé selon la revendication 1, caractérisé en ce qu'il comprend les étapes supplémentaires de :

(i) ouvrir l'articulateur pour former un espace de 3 à 5 mm entre les bords incisifs supérieur et inférieur,

(j) placer de la cire dans l'espace pour obtenir une empreinte des dents supérieures et inférieures en occlusion normale,

(k) placer les dents des modèles supérieur et inférieur en platre de l'étape (h) précitée dans l'empreinte en cire de l'étape (j),

(l) couvrir l'ensemble résultant de l'étape (k) de cire de façon qu'elle ait sensiblement la même forme et la même épaisseur que le dispositif de traitement en résine de silicone,

(m) transférer l'ensemble du modèle couvert de cire de l'étape (l) dans un moule divisé,

(n) soumettre le moule divisé contenant le modèle couvert de cire à une chaleur suffisante pour faire fondre la cire et produire un vide,

(o) enlever la cire,

(p) remplir le vide d'une résine de silicone durcissable à chaud et durcir la résine, et

(q) enlever le dispositif de traitement en résine de silicone.

3. Procédé selon la revendication 1, caractérisé en ce qu'il comprend de plus les étapes de :

(i) enlever les modèles en cire de l'articulateur et les remplacer par les modèles en platre de l'étape (h) précitée tout en maintenant la même relation entre les machoires supérieure et inférieure,

(j) ouvrir l'articulateur pour former un espace de 3 à 5 mm entre les bords incisifs supérieur et inférieur,

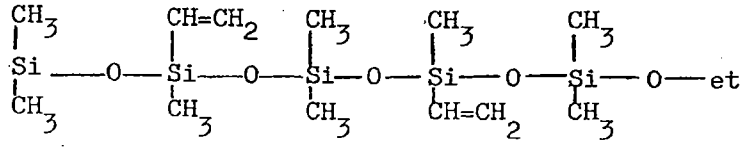
(k) former une résine de silicone durcissable à la chaleur autour des dents supérieures et inférieures et durcir la résine; et

(l) enlever le dispositif du traitement résultant.

4. Procédé selon l'une quelconque des revendications 1 à 3, caractérisé en ce que la résine est durcie à une température comprise entre 100 et 130°C environ.

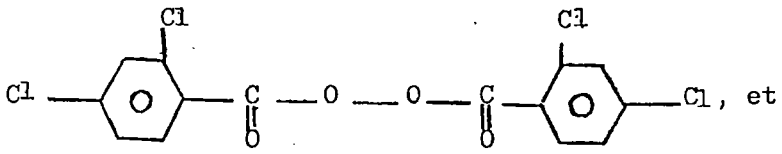
5. Procédé selon l'une quelconque des revendications 1 à 3, caractérisé en ce que la résine de silicone est une composition contenant :

(a) une résine de silicone ayant la formule suivante



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(b) une composition catalytique contenant
(1) un composé ayant pour formule



(2) une huile de silicone.

6. Procédé pour le traitement complet d'une malocclusion des dents d'un patient avec un dispositif de traitement d'orthodontie en résine de silicone ayant des empreintes négatives qui reproduisent les dents et qui déplacent les dents jusqu'à une position souhaitée, caractérisé en ce qu'il comprend les étapes :

(a) ouvrir la bouche du patient pour exposer les machoires et dents supérieures et inférieures,

(b) adapter le dispositif par la pression des doigts pour forcer le dispositif sur les dents supérieures,

(c) fermer la machoire inférieure pour forcer le dispositif sur les dents inférieures,

(d) serrer les dents supérieures et inférieures ensemble pendant de courtes périodes de temps pour forcer le dispositif à exercer une pression contre les dents, relâcher les machoires pour alléger la pression et répéter les opérations de serrage et de relaxation pendant les heures de veille du patient,

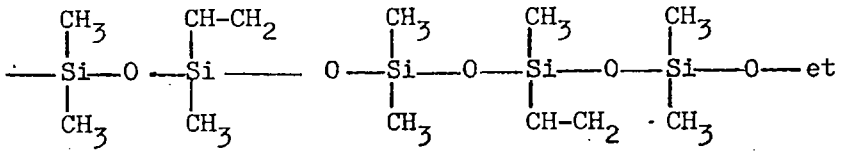
(e) maintenir le dispositif sur les dents du patient pendant les heures de sommeil, et

(f) répéter les étapes (d) et (e) pendant une période de temps suffisante pour déplacer les dents à la position souhaitée.

7. Procédé selon la revendication 6, caractérisé en ce que la résine de silicone précitée est une composition contenant :

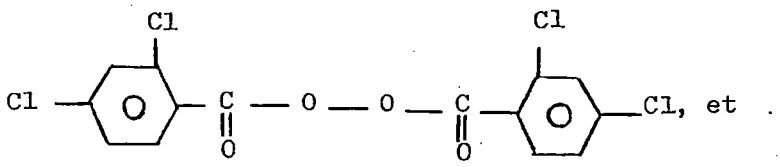
(a) une résine de silicone ayant la formule suivante

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(b) une composition catalytique contenant

(1) un composé ayant pour formule

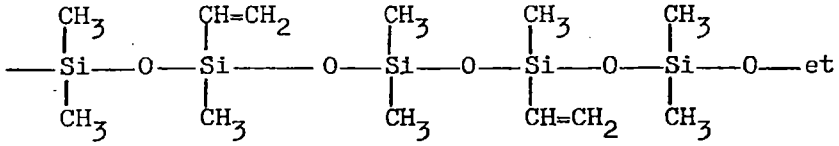


(2) une huile de silicone.

8. Dispositif de traitement d'orthodontie pour le traitement complet des dents d'un patient, caractérisé en ce qu'il a des empreintes supérieure et inférieure négatives qui reproduisent les dents supérieures et inférieures du patient, et en ce qu'il déplace les dents vers une position souhaitée pendant le traitement.

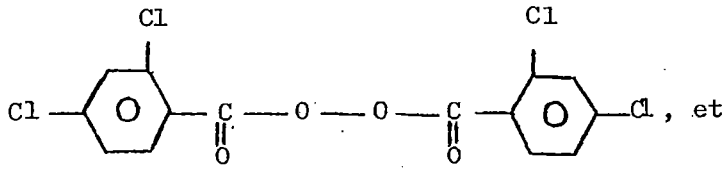
9. Dispositif selon la revendication 8, caractérisé en ce que la résine de silicone précitée est une composition contenant

(a) une résine de silicone ayant la formule qui suit



(b) une composition catalytique contenant

(1) un composé ayant pour formule



(2) une huile de silicone.

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FIG. 1

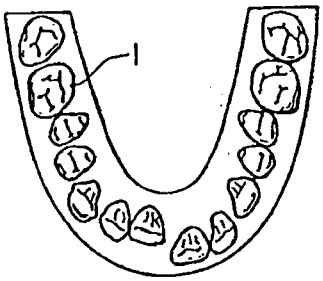


FIG. 2

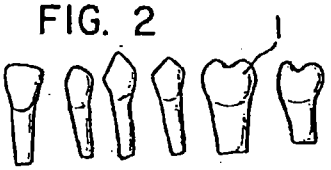


FIG. 3

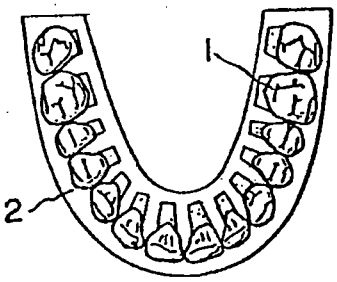


FIG. 4

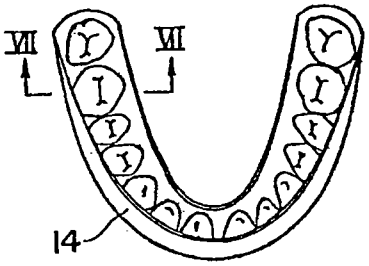


FIG. 5

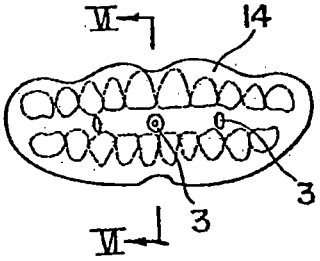


FIG. 6

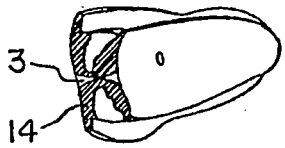


FIG. 7



FIG. 8A

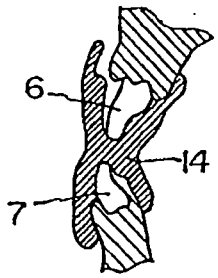


FIG. 8B

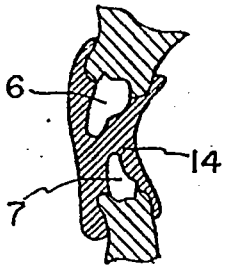


FIG. 9A

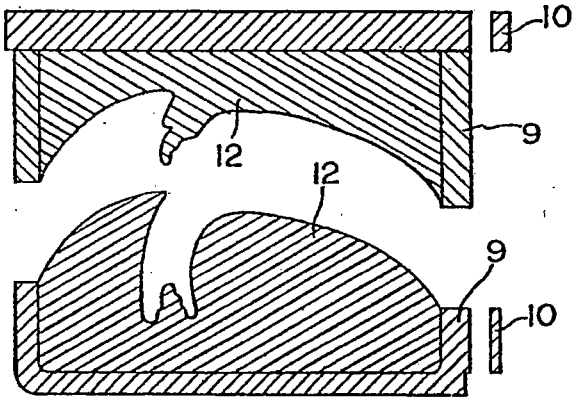


FIG. 9B

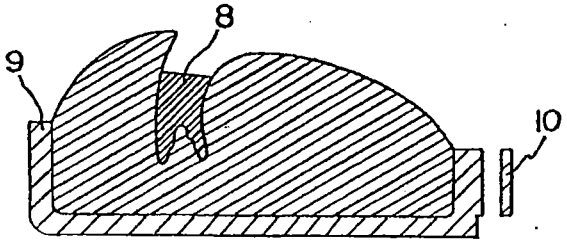


FIG. 9C

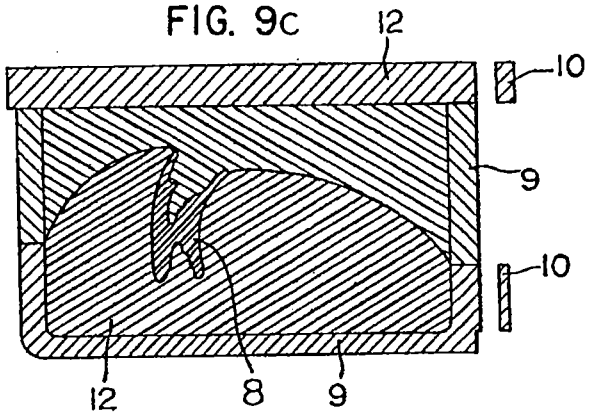


FIG. 10A

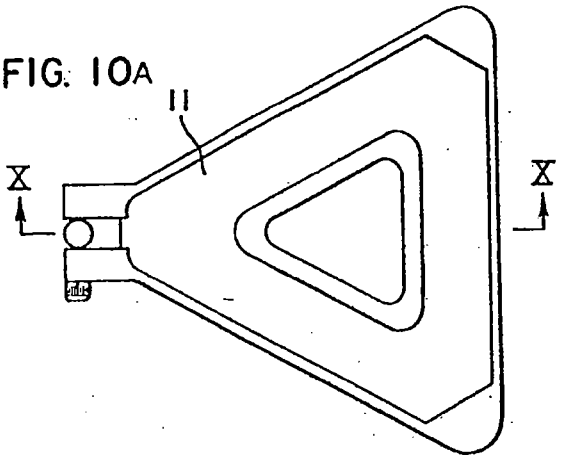


FIG. 10B

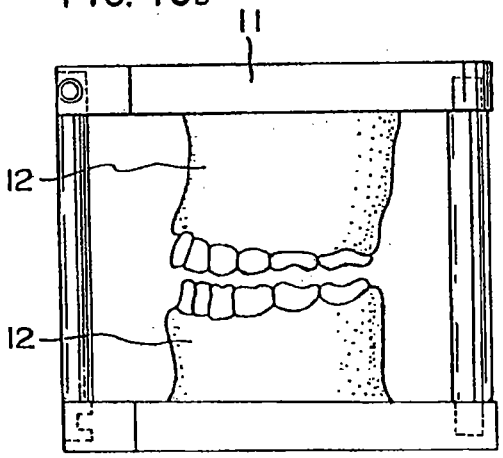


FIG. 10C

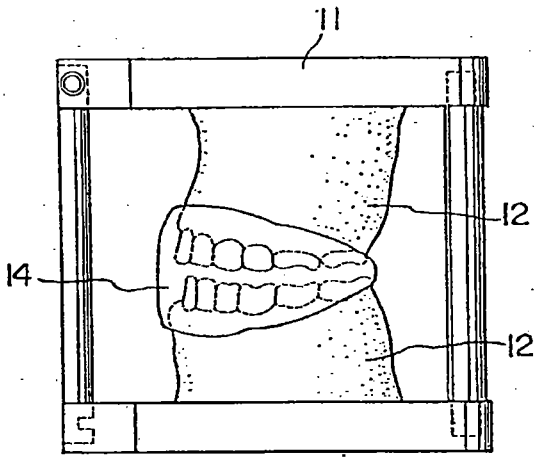
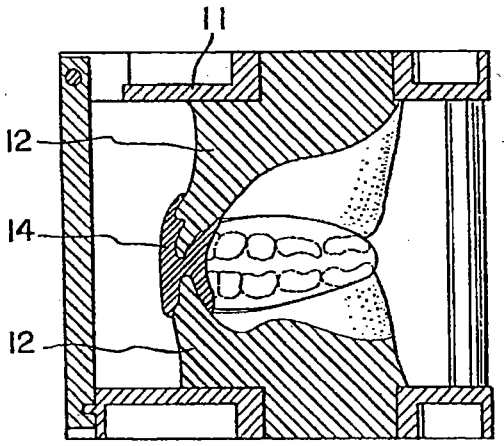


FIG. 10D



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor: Chunhua LI, et al.	Group Art Unit: 3732
Serial Number: 13/470,681	Examiner: Unassigned
Filing Date: May 14, 2012	**CONFIRMATION NO: 5655**
Title: MULTILAYER DENTAL APPLIANCES AND RELATED METHODS AND SYSTEMS	

FILED ELECTRONICALLY ON: August 2, 2012

Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

INFORMATION DISCLOSURE STATEMENT UNDER 37 CFR §1.97

Sir:

An Information Disclosure Statement along with attached PTO/SB/08 is hereby submitted. A copy of each listed publication is submitted, if required, pursuant to 37 CFR §§1.97-1.98, as indicated below.

The Examiner is requested to review the information provided and to make the information of record in the above-identified application. The Examiner is further requested to initial and return the attached PTO/SB/08 in accordance with MPEP §609.

The right to establish the patentability of the claimed invention over any of the information provided herewith, and/or to prove that this information may not be prior art, and/or to prove that this information may not be enabling for the teachings purportedly offered, is hereby reserved.

This statement is not intended to represent that a search has been made or that the information cited in the statement is, or is considered to be, prior art or material to patentability as defined in §1.56.

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A. ☒ *37 CFR §1.97(b).* This Information Disclosure Statement should be considered by the Office because:

☐ (1) It is being filed within 3 months of the filing date of a national application and is other than a continued prosecution application under §1.53(d);

-- OR --

☐ (2) It is being filed within 3 months of entry of the national stage as set forth in §1.491 in an international application;

-- OR --

☒ (3) It is being filed before the mailing of a first Office action on the merits;

-- OR --

☐ (4) It is being filed before the mailing of a first Office action after the filing of a request for continued examination under §1.114.

B. ☐ *37 CFR §1.97(c).* Although this Information Disclosure Statement is being filed after the period specified in *37 CFR §1.97(b),* above, it is filed before the mailing date of the earlier of (1) a final office action under §1.113, (2) a notice of allowance under §1.311, or (3) an action that otherwise closes prosecution on the merits, this Information Disclosure Statement should be considered because it is accompanied by one of:

☐ a statement as specified in §1.97(e) provided concurrently herewith;

-- OR --

☐ a fee of $180.00 as set forth in §1.17(p) authorized below, enclosed, or included with the payment of other papers filed together with this statement.

C. ☐ *37 CFR §1.97(d).* Although this Information Disclosure Statement is being filed after the mailing date of the earlier of (1) a final office action under §1.113 or (2) a notice of allowance under §1.311, it is being filed before payment of the issue fee and should be considered because it is accompanied by:

i. a statement as specified in §1.97(e);

-- AND --

ii. a fee of $180.00 as set forth in §1.17(p) is authorized below, enclosed, or included with the payment of other papers filed together with this Statement.

D. ☐ *37 CFR §1.97(e).* Statement.

☐ A statement is provided herewith to satisfy the requirement under 37 CFR §§1.97(c);

-- AND/OR --

☐ A statement is provided herewith to satisfy the requirement under 37 CFR §§1.97(d);

-- AND/OR --

☐ A copy of a dated communication from a foreign patent office clearly showing that the information disclosure statement is being submitted within 3 months of the filing date on the communication is provided in lieu of a statement under 37 C.F.R. § 1.97(e)(1) as provided for under MPEP 609.04(b) V.

E. ☐ *Statement Under 37 C.F.R. §1.704(d).* Each item of information contained in the information disclosure statement was first cited in a communication from a foreign patent office in a counterpart application that was received by an individual designated in § 1.56(c) not more than thirty (30) days prior to the filing of this information disclosure statement. This statement is made pursuant to the

requirements of 37 C.F.R. §1.704(d) to avoid reduction of the period of adjustment of the patent term for Applicant(s) delay.

F. ☒ *37 CFR §1.98(a)(2).* The content of the Information Disclosure Statement is as follows:

☐ Copies of each of the references listed on the attached Form PTO/SB/08 are enclosed herewith.

-- OR --

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G. ☒ *37 CFR §1.98(a)(3).* The Information Disclosure Statement includes non-English patents and/or references.

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I. ☒ *Fee Authorization*. The Commissioner is hereby authorized to charge the above-referenced fees of $0.00 and charge any additional fees or credit any overpayment associated with this communication to Deposit Account No. 23-2415 (Docket No. 22773-826.201).

Respectfully submitted,

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PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : A61C 13/00 | A1

(11) International Publication Number: WO 98/32394

(43) International Publication Date: 30 July 1998 (30.07.98)

(21) International Application Number: PCT/US98/00891

(22) International Filing Date: 20 January 1998 (20.01.98)

(30) Priority Data:
08/789,918 28 January 1997 (28.01.97) US

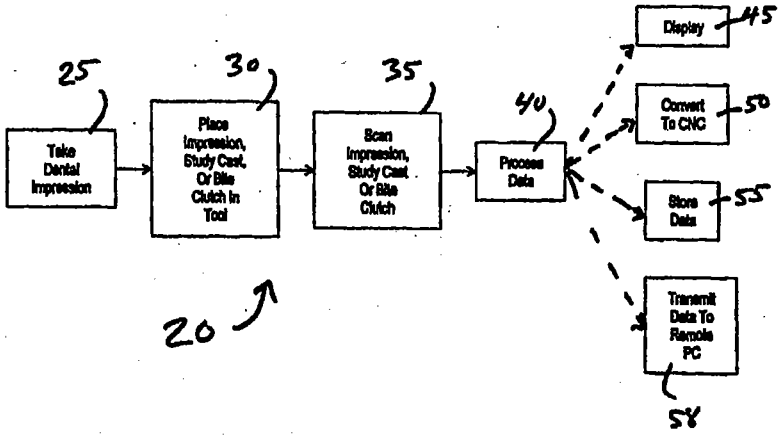
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(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: DENTAL SCANNING METHOD AND APPARATUS



(57) Abstract

A dental and soft tissue scanning method and system is disclosed which uses fast laser line scanning techniques of negative image impressions, whereby an array of electronic data is generated. In operation, the array of negative image scan data is generated by a scanner (60) and provided to a processor (501). The negative image scan data may be saved in a memory device (504) as a permanent record of the baseline condition of the patient's teeth, or temporarily, prior to one of several other options. The processor (501) may convert the data to a positive image for display on the video display unit (503) for teaching or educational purposes with the patient. Alternatively, the positive information data may be transmitted to a remote PC (505) for storage, study by a consulting dentist (or physician), or fabrication of a study cast by fabrication device (507). These and other options may be selected by the user of computer (500) via the input device (506). The programming operation of the processor (501) provides for scanning each of the upper and lower impressions and the bite registration impression. These scans provide the information necessary to create an electronic equivalent of a physical study cast.

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DENTAL SCANNING METHOD AND APPARATUS

FIELD OF THE INVENTION

The present invention relates generally to a system of dental modeling and imaging which creates digital images of teeth topography; and more particularly relates to scanning a dental impression wherein a set of negative image electronic data of the patient's teeth and surrounding soft tissue is created which can be electronically manipulated, displayed, stored and transmitted for uses relating to creating dental appliances and diagnosis, among others.

BACKGROUND OF THE INVENTION

Dental study casts are an integral part of a dentist's understanding of how a patient's teeth and bite function in a static relationship. This static relationship serves three important functions. The primary function is one of a diagnostic function for interpretation of any discrepancies or problems that exist within the bite relationship. The second function is educational. For example, the study casts provide better communication as a concrete model while helping the patient understand any discrepancies that may exist in the way their teeth function in that static relationship. Third, the dental study casts serve an important medical/legal function in defining the pre-existing static bite relationship prior to the performance of any work. This work can be defined either from an oral surgical standpoint, prosthetic standpoint or orthodontic/periodontal standpoint.

Significant complications are associated with study casts, however, since the casts need to be stored for an extended period (generally seven years). For example, the storage of the study casts requires large amounts of space in humidity controlled environments, as well as extensive laboratory procedures involving OSHA guidelines and space utilization for the study casts to be constructed. In addition, a significant amount of turn-around time is required for the curing process of the plastic study casts to occur. In light of these significant constraints as well as the importance associated with having an accurate recording of the pre-existing bite relationship, there arises a need for an apparatus (or system) and method in which electronic image data can be collected from an impression to circumvent the need for storage of physical study casts.

Prior to discussing a summary of the present invention, however, detailed discussions of the construction of a working model (study cast) of the teeth and other prior art devices will be presented.

As noted above, in order to study dental work to be performed on a patient's teeth, a working model of the teeth constructed of a plaster study cast is

created. The plaster cast is based on a series of impressions taken to obtain the geometry of the teeth. To take an impression, alginate impression material is poured into a tray (i.e., an impression tray) which is then introduced into the patient's mouth for a period of time (typically one to two minutes). The impression material sets about the teeth and soft tissues forming a negative impression. The patient also bites into a soft material for registering a simultaneous imprint of the upper and lower teeth which records the relationship of the teeth in the upper and lower jaws respectively in three planes of space.

Once the impressions have set, they are sent to a lab to be processed into an upper and lower plaster study cast. The study casts are articulated together via the bite registration material to reproduce the bite of the patient. After construction, the study casts are returned to the dentist/orthodontist as a working study cast.

A serious drawback of this method is the number of labor intensive steps required to produce the study casts, the space and legal storage requirements of the study casts, and the inability to interface the study casts interactively with other diagnosis information (e.g., photographs and radiographs). Accordingly, if additional work is required, the cast fails in some way or is damaged, and/or the cast is lost, then an additional impression series must be taken. Therefore, there also exists a need in the art to develop a set of electronic data from the series of dental impressions wherein only a single impression need be taken for multiple interactive functions.

In the past, several devices have been designed for the electronic imaging of teeth. Also, other devices are known which utilize numerical data to create prototype devices. While known examples of such systems and devices follow, generally such systems do not provide the accuracy required for orthodontic work. Instead, such systems are generally useful only for crowns, fillings, etc.

U.S. Patent No. 4,182,312 generally discloses a dental probe having a stylus which is connected through a rod to a three position transducer. Three signals are produced for indicating the position of the probe at any point to which the probe is applied. The transducers are mounted on an index tray which is adapted to be fastened to the jaw of the patient. Thus the patient's jaw becomes the origin against which all measurements are made. Contact between the tip of the stylus and the patient's tissue completes a circuit to turn on a recording mechanism which receives the transducer's outputs.

U.S. Patent No. 4,611,288 generally discloses a method of producing dental prostheses (e.g., crowns, inlays, dentures and the like) using an optical impression taken of the oral region with nontraumatic radiation. The reflected waves

are transformed into numerical data which is used to operate a numerically controlled machine in the fabrication process.

U.S. Patent No. 4,752,964 generally discloses an apparatus for producing, from an object having a three-dimensional shape, a shape equivalent or analogous to the three-dimensional shape. Here, light is irradiated to the object in an optical cutting plane. The light is picked up by an image pick-up device, and two-dimensional positions of the light are obtained in a direction perpendicular to the optical cutting plane to determine its three dimensional shape.

U.S. Patent No. 4,935,635 generally discloses a three-dimensional point measuring system which includes a laser diode for projecting a triangulating beam at a surface to be mapped, with the beam scanned repeatedly across the surface. Photodetectors detect the position of the beam as reflected from the mapped surface, given by triangulation Z-axis or depth information. Correlation of a particular point with the position of the scanner along the scan line gives Y-axis information, or information in a width direction. The scanner and diode are mounted on a slide or platform device which moves perpendicularly to the Y axis in the direction in an out of the mouth, driven by a stepper motor, and the monitored position of the stepper motor is coordinated with the other information on each spot to yield X-axis information.

U.S. Patent No. 5,198,877 generally discloses a method and apparatus for optically sampling numerous points on the surface of an object to remotely sense its shape utilizing two stages. The first stage employs a moveable non-contact scanner, which in normal operation sweeps a narrow beam of light across the object, illuminating a single point of the object at any given instant in time. The location of that point relative to the scanner is sensed by multiple linear photodetector arrays behind lenses in the scanner. These sense the location by measuring the relative angular parallax of the point. The second stage employs multiple fixed but widely separated photoelectronic sensors, to detect the locations of several light sources affixed to the scanner. Individual light sources are distinguished by time-multiplexing their on-off states. A coordinate computer calculates the absolute spatial positions where the scanner light beam is incident on the object to generate a computer model.

U.S. Patent No. 5,224,049 discloses a method for use in preparing a dental prosthesis and U.S. Patent No. 5,347,454 generally discloses a system for use in preparing a dental prosthesis.

U.S. Patent No. 5,448,472 discloses a method for collecting three-dimensional surface information in dental applications via a video camera. A tape strip is applied to a tooth surface to provide a distance reference or standard for use by a computer in analyzing the video data to determine actual distances. The tape strips

are additionally provided with identification markings identifying the type of surfaces and the teeth to which the tape strips are attached.

Each of the foregoing systems, devices and methods suffer the drawback in that bulky, expensive specialized devices are required. The processes are extremely time consuming or require the introduction of devices into the patient's mouth for extended periods of time or which leads to patient discomfort. Also, these systems are limited to dental restorative procedures only. Reduced accuracy and precision of the measurements also greatly limit the usefulness of these systems to direct scanning of the dental impressions, study casts or both.

Therefore, there arises a need for a cost effective, relatively fast, and efficient system and method for electronically scanning dental surfaces or dental materials such that the resulting data may be manipulated for a wide variety of dental and/or medical purposes and uses.

SUMMARY OF THE INVENTION

The present invention provides an improved dental and soft tissue scanning method and system, using fast laser line scanning techniques whereby an array of electronic data is generated. The electronic data which is generated may be used for a number of purposes including visual display, storage of a patient base-line, creation of one or more study casts, and transmission to a remote location for analysis, among others. The elimination of the requirement to routinely construct study casts is also accomplished. The principles of the present invention may be utilized in connection with the scanning of other parts of the human body for later analysis, as well as diagnosis and construction of appliances, braces and other dental applications. Therefore, while the present invention is described in connection with the taking of an impression of a patient's teeth and surrounding soft tissues, any number of other applications may exist.

In a preferred embodiment of a method and system constructed according to the principles of the present invention, there is provided several components which comprise the system. These components include a set of fixtured dental impression trays, a fixtured clutch device to record the bite registration, a tool for holding the dental impression tray(s), a scanner device, and a processor operatively connected to the scanner for receiving the data from the scanner device. Preferably the processor takes the negative image data and converts the data to a positive three dimensional image for display, transmission, conversion to CNC (Computer numeric control) data for prototyping, etc. Optionally, the image data may also be taken from a study cast. Further, such data may optionally be stored as

negative image data and retrieved for use at a later date (e.g., in the event that additional positive reproductions are desired or required to be constructed).

Therefore according to one aspect of the invention, there is provided, a method of generating a set of electronic data from a dental impression or study cast, comprising the steps of: forming a dental impression of a patient's teeth and surrounding soft tissue; mounting the dental impression or study cast in a fixture; scanning the impression with a laser device along 3 axes, wherein a set of electronic data is developed which corresponds to the impression.

A further aspect of the present invention is the method as recited above, wherein the electronic data is constructed as a negative image of the patient's teeth and surrounding soft tissue. Yet another aspect of the present invention includes the step of converting the negative image data to a set of positive three dimensional image data for analysis.

These and other advantages and features which characterize the present invention are pointed out with particularity in the claims annexed hereto and forming a further part hereto. However, for a better understanding of the invention, reference should be had to the following drawing and detailed description.

BRIEF DESCRIPTION OF THE DRAWING

Referring to the drawing, wherein like numerals represent like parts throughout the several views:

Figure 1 illustrates the method steps 20 used to practice the principles of the present invention.

Figures 2a and 2b illustrate perspective views of lower 200 and upper 220 impression trays, respectively, used in connection with the present invention.

Figure 3a illustrates a perspective view of a registration tray 300 used in connection with the present invention.

Figure 3b diagrammatically illustrates the preferred arrangement and configuration of the impression material retaining mesh 306 used in connection with tray 300.

Figure 4 illustrates a perspective view of a preferred embodiment base 400 and X-Y-Z axis devices 401 used in connection with scanner 60.

Figure 5 diagramatically illustrates the functional blocks associated with the processor, memory, and remote computer associated with processing the data from the scanner 60.

Figure 6 is a perspective view of a positive image of a scanned portion of a study cast.

DETAILED DESCRIPTION

A detailed discussion of the various devices comprising a preferred embodiment system will be deferred pending a discussion of the overall method steps used to practice the present invention.

1. Overview

Referring first to Fig. 1, the overall method of the present invention is illustrated generally by the designation 20. First, at block 25, a dental impression of a patient's teeth and surrounding soft tissues (hereafter referred to collectively as "teeth" for convenience) is taken. The impression material hardens, forming a negative image of the teeth. The lower 200 and upper 220 trays used in connection with taking the impression are described below and are best seen in Figures 2a and 2b respectively. The bite/clutch tray 300 used in connection with determining the correct spatial orientation and relationship between the upper and lower impressions is described below and is best seen in Figures 3a and 3b.

At block 30, the impression tray 200 or 220 is placed in the tool or fixture 600 (described below and best seen in Fig. 5). The fixture 600 is used to securely hold the tray 200, 220, and/or 300 during the scanning step. The fixture 600 may also aid the scanning step by helping rotate the mold so that the image data can be properly generated. It will be appreciated that during this step at least one of the trays 200 and 220 include the hardened impression material which defines a negative image impression or mold of a patient's teeth.

Next at block 35, the scan of the impression occurs. In the preferred embodiment, a scanner manufactured by Laser Design Inc. of Minneapolis, Minnesota designated as model number 8849648 may be used. The operation and scanning methodology used by this type of scanner is generally described in U.S. Patent No. 5,124,524 (which is hereby incorporated herein by reference). Generally, this type of scanner is referred to as a line scanner device. It will be appreciated that for a complete study cast of the upper and lower teeth, two scans of the negative image impressions occur (i.e., one lower and one upper). Further, in order to properly reference the two sets of teeth together, a scan of the bite tray 300 impression also takes place.

Referring now to Figures 1 and 6, at block 40 the image data is processed by processor 501. Such processing may include converting the negative image scan data into a positive image for display on a video display unit 503 (at optional block 45); converting the negative image scan data into CNC or other format of output for use by a fabrication device 507 (also known as a prototyping apparatus) (at optional block 50); storing the negative image scan data in a memory

location or device 504 (at optional block 55); and/or transmitting the negative image scan data to a remote processor 505 via modem block 502 (at optional block 58).

In the preferred embodiment, one commercially available software package which may be used to generate three dimensional images from the line scan data is the package sold under the designation DataSculpt software available from Laser Design Inc. of Minneapolis, Minnesota.

2. Detailed Description of Components

Turning now to Figures 2a and 2b, the lower impression tray 200 and upper impression tray 220 are illustrated. The trays 200 and 220 are shown without impression material located thereon in order to more clearly illustrate the size and configuration of the respective trays. The trays 200 and 220 are generally horseshoe shaped with an elongate member 204 and 224 (respectively) integrally attached to and extending away from the arcuate portion of the horseshoe section. The elongate members 204 and 224 are generally within the same mean plane formed by the horseshoe section. However, those of skill in the art will appreciate that other locations and arrangements may be utilized. The upper tray 220 also includes a domed element 225 which is integrally formed and connects the interior portion of the horseshoe section of the tray 220.

Each of the trays 200 and 220 also includes a first end 201 and 221 (respectively) which is inserted into a patient's oral cavity during the process of taking the impression and a second end 202 and 222 (respectively) which includes a handle for helping insert and remove the trays. Located proximate the second ends 202 and 222 are holes 203 and 223 (respectively) which are arranged and configured to aid in the registration process of the scanning procedure (i.e., the holes 203 and 223 on the handles may be used in conjunction with the mounting fixture 600). However, including such holes 203 and 223 and/or using the holes in the registration process is optional.

Slots 206 and 226 are formed in the lower and upper trays 200 and 220 (respectively) to aid in the expansion of the impression material when a patient bites into the same, as well as helping retain the impression material on the tray 220 and 226 (and in a fixed manner) after removal from a patient's mouth and during scanning. Only several of the plurality of slots 206 and 226 are designated by the reference numerals in the Figures for the purpose of clarity. Also, those of skill in the art will appreciate that the number and arrangement of the slots 206 and 226 may be changed, with the slots 206 and 226 shown in Figures 2a and 2b being illustrative.

The trays 200 and 226 are preferably constructed by means of plastic injection molding process and of a material suitable for medical and dental purposes. Such material should also be selected to be rigid enough to hold the impression material in a stable fashion during scanning and be capable of being sanitized or sterilized.

Turning now to Figures 3a and 3b, the bite registration tray 300 is illustrated. Tray 300 is shown without impression material located thereon in order to more clearly illustrate the size and configuration of the tray. The tray 300 is generally horseshoe shaped with an elongate member 304 integrally attached to and extending away from the arcuate portion of the horseshoe section generally in the same mean plane formed by the horseshoe section.

Tray 300 includes a first end 301 which is inserted into a patient's oral cavity during the process of taking the impression and a second end 302 which includes a handle for helping insert and remove the tray 300. Located proximate the second end 302 is hole 303 which is arranged and configured to aid in the registration process of the scanning procedure (i.e., the holes on the handles may be used in conjunction with the mounting fixture 600). However, including such hole 303 and/or using the hole in the registration process is optional.

Figure 3b illustrates the bite tray 300 without the elongate member 304 and including an impression retaining mesh material 306 generally located within the horseshoe section. The material 306 is used to retain the impression material on the tray. It will be appreciated that this configuration allows a patient to bite into the impression material on either side of the mean plane formed by the horseshoe portion of tray 300 to register the upper and lower impressions relative to one another so that study casts, visual displays, etc. can be created with the proper spatial relationships. In the preferred embodiment, tray 300 is constructed in a manner similar to that described above in connection with trays 200 and 220.

The scanning tool or fixture 600 is best seen in Figure 5. In the preferred embodiment, the fixture 600 is arranged and configured to securely hold the trays 200, 220, and 300 while rotating and/or moving on the fixture platform 402 (best seen in 4) as the array of negative image electronic data from the negative impression(s) is being generated by the scanner 60.

Referring to Figures 4 and 5, the scanner is designated generally at 60. As noted above, the scanner 60 and its operation is described in detail in U.S. Patent No. 5,124,524. Also shown in Figure 4 is the Z-axis column 407 which preferably provides precise vertical linear motion with a screw and nut assembly. Scanner mounting member 404 is operatively connected to the Z-axis column 407. Rotary stage 402 preferably provides precise rotational movement in the range of

.001" quadrature resolution. X-axis stage 406 and Y-axis stage 405 provide X and Y coordinate control and preferably use lead screw assemblies. Column 403 is attached to base 400 and supports the scanner 60. In Figure 5, the X axis stage 406 , Y axis stage 405, the Z axis stage 407 and the rotational stage 402 are together referred to as block 401.

Still referring to Figure 5, the functional blocks of the electronic components of the present invention are illustrated. The components include a computer 500 which preferably includes a processor 501, a video display unit 503, a memory device 504, a user input device 506 (e.g., a mouse and/or keypad), and a modem 502. Also illustrated is a remote computer 505, a fabrication device 507, and the scanner 60 (and its attendant X-Y-Z axis controllers and motors).

It will be appreciated by those of skill in the art that the computer 500 may be a personal computer (e.g., a Pentium based PC) or a special purpose computer. Further, the video display unit 503 may include any number of display devices such as cathode ray tubes, LCD displays, etc. Still further, the memory device 504 may include hard drives, floppy drives, magnetic tape, CD-ROM, random access memory, and read-only memory devices. Further, the modem 502 is illustrated to show a communications capability. Such capability may also be by way of a network, etc.

Fabrication device 507 may be connected directly to the computer 500 or may be connected to a remote computer 505. The fabrication device 507 may be any number of devices which can utilize computer generated data and create a three-dimensional object from such data. One example of such a machine are the devices utilizing stereo lithography technology manufactured by 3-D Systems of Valencia, California under the model designations SLA-250 and SLA-500. Another example is the device utilizing filament technology (fused deposition modeling) manufactured by Statasys Corporation of Minneapolis, Minnesota under the model designation FDM-1500.

In operation the array of negative image scan data is generated by the scanner 60 and provided to the processor 501. The negative image scan data may be saved in a memory device 504 as a permanent record of the baseline condition of the patient's teeth, or temporarily prior to one of several other options. For example, the data may be converted to a positive image and stored in that fashion as a permanent record of the baseline condition. Alternatively, the positive image may be displayed on the video display unit 503 for teaching or educational purposes with the patient. Still further, the positive information data may be transmitted to a remote PC 505 for storage, study by a consulting dentist (or physician), or fabrication of a study cast by fabrication device 507. The fabrication device 507 may optionally be connected

directly to computer 500. These and other options may be selected by the computer 500 user via the input device 506.

The programming operation of the processor 501 provides for scanning each of the upper and lower impressions and the bite registration impression. These scans provide the information necessary to create an electronic equivalent of the prior art physical study casts. By using negative image impressions and a line scanner, high resolution and speed are gained wherein high quality study casts may be generated by a fabrication device 507 thereby replacing older methods of constructing the same. Although such fabricated casts may still be saved, since the data is generated and stored electronically, the problems associated with storage of prior art study casts may be reduced and/or eliminated. Further, the data may be used any number of times in different ways to accomplish a more robust practice.

It will be appreciated that the principles of this invention apply not only to the devices used to implement the invention, but also the method in general of generating an electronic array of dental impression scan image data from one or more negative impressions. For example, it is possible to scan existing study casts in order to generate an electronic data set and view the set in three dimensions as seen in Fig. 6 at the designation 18. By doing so, the image may be manipulated and/or stored as described above. Further, by doing so, the requirement to store existing study casts may be reduced or eliminated.

It is also contemplated that other impressions of a patient's body may be taken to form a negative image mold. The present invention may also be used to scan such negative images. A further extension of the present invention is to generate a direct scan image of teeth in a patient's oral cavity with a tool inserted in a patients mouth and provided to central processor 501.

While a particular embodiment of the invention has been described, it will be understood that by those skilled in the art that the invention is not limited by the application, embodiment or the particular devices disclosed and described herein. It will be appreciated that other devices that embody the principles of this invention and other applications therefor other than as described herein can be configured within the spirit and intent of this invention. The system described herein is provided as only one example of an embodiment that incorporates and practices the principles of this invention. Other modifications and alterations are well within the knowledge of those skilled in the art and are to be included within the broad scope of the appended claims.

What is claimed is:

1. A method of generating a set of electronic data from a dental impression or study cast, comprising the steps of:

a) providing a dental impression of a patient's teeth and surrounding soft tissue;

b) mounting the dental impression in a fixture;

c) scanning the impression with a laser line scanner device along three axes, wherein a set of electronic data is developed which corresponds to the impression.

2. The method of claim 1, wherein the electronic data is constructed as a negative image of the patient's teeth and surrounding soft tissue.

3. The method of claim 2, further comprising the step of converting the negative image data to a set of positive image data.

4. The method of claim 3, wherein the converting step is processed with a central processing unit.

5. The method of claim 3, further comprising the step of displaying the positive image data as a three dimensional output on a video display device.

6. The method of claim 1, further comprising the step of storing the electronic data in a computer memory location.

7. The method of claim 1, further comprising the step of fabricating orthodontic study casts, retention devices, and other dental applications from the electronic data using a prototype device.

8. The method of claim 1, further comprising the steps of scanning a first impression of the lower teeth and soft tissue of a patient, scanning a second impression of the upper teeth and soft tissue of a patient, and scanning a third registration impression of the patient to spatially orient the first and second impressions relative to one another, wherein an array of negative image electronic data is generated of the complete teeth and soft tissue of a patient which is spatially oriented properly.

9. The method of claim 8, further comprising the step of fabricating orthodontic study casts, retention devices, and other dental applications from the array of negative image electronic data using a prototype device.

10. A method of generating a set of electronic data of the teeth and soft tissues inside of a human oral cavity from a dental impression, comprising the steps of:

a) scanning the impression or study cast along three axes to generate a plurality of scan data;

b) creating a set of electronic data from the scan data which corresponds to the impression; and

c) relating the scan data to each other, wherein the impression images of the teeth and soft tissues are accurately related to each other.

11. A system for generating a set of electronic data of the teeth and soft tissues inside of a human oral cavity from a dental impression, comprising:

a) impression means for creating a negative impression mold of the teeth and soft tissue of a patient;

b) fixture means for securely holding the impression means during movement of the impression;

c) a line scanner for moving the fixture means and generating an array of negative image electronic data of the mold; and

d) means for converting the array of negative image electronic data to an array of positive image electronic data.

12. The system of claim 11, wherein the positive image electronic data includes a first set of electronic data resulting from a scan of a patient's upper teeth and soft tissue, a second set of electronic data resulting from a scan of the patient's lower teeth and soft tissue, and a third set of electronic data resulting from a scan of a registration impression of the patient's upper and lower teeth and soft tissue.

13. The system of claim 11, wherein the converting means is a central processing unit.

14. The system of claim 11, further comprising the step of display means for displaying the positive image electronic data, wherein the electronic data may be visually perceived.

15. The system of claim 11, further comprising a memory device for storing the positive image electronic data.

5

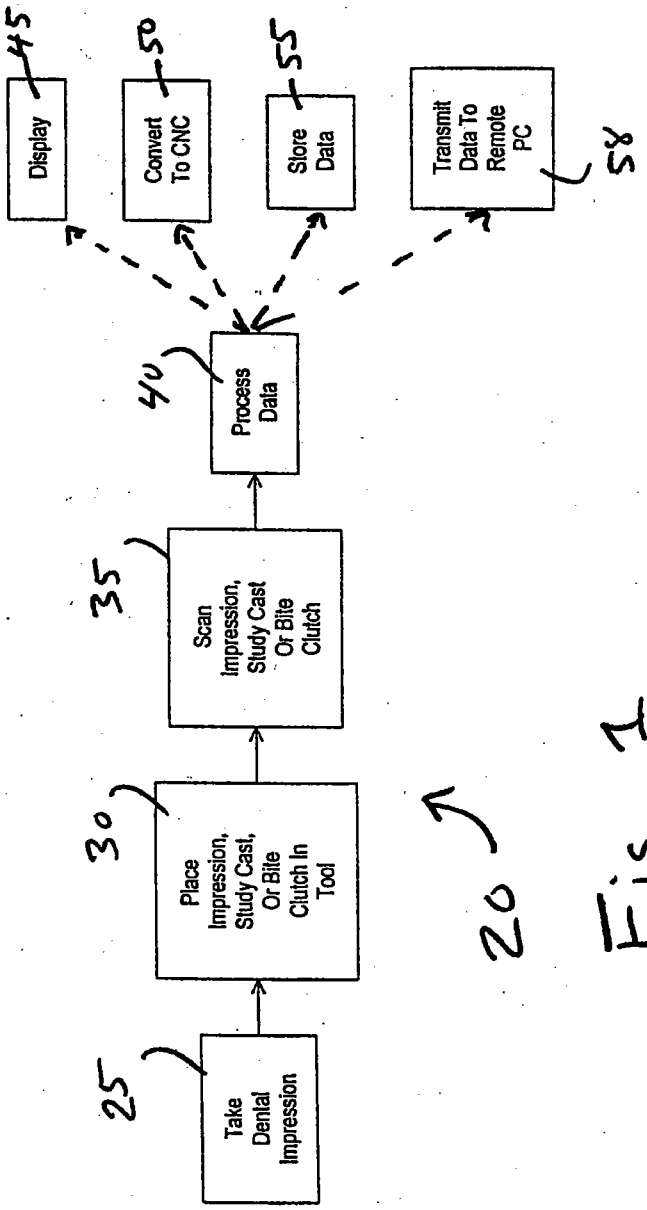

Take Dental Impression
25
Place Impression, Study Cast, Or Bite Clutch In Tool
30
Scan Impression, Study Cast Or Bite Clutch
35
Process Data
40
Display
45
Convert To CNC
50
Store Data
55
Transmit Data To Remote PC
58
20

Fig. 1

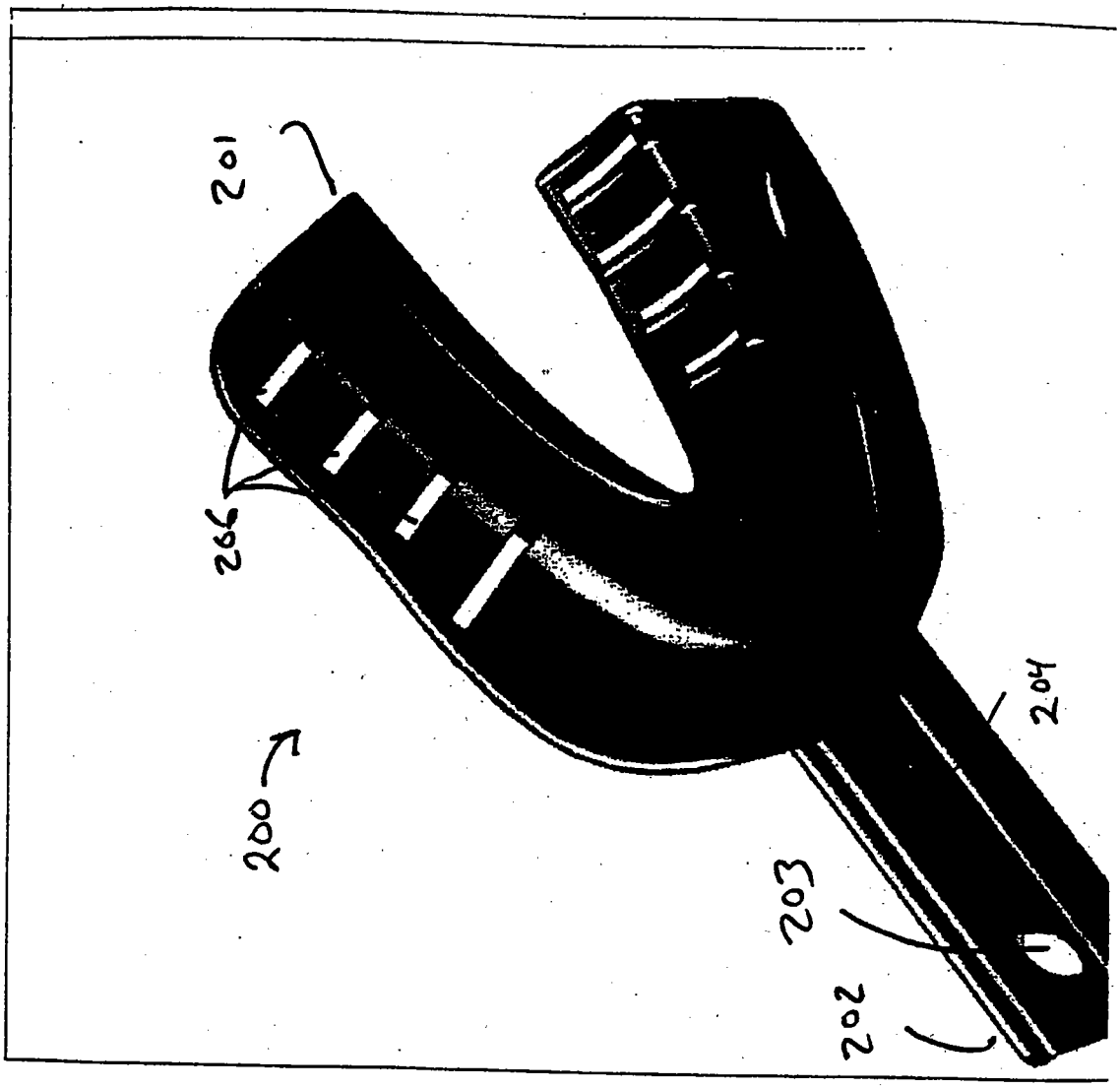


Fig 2a

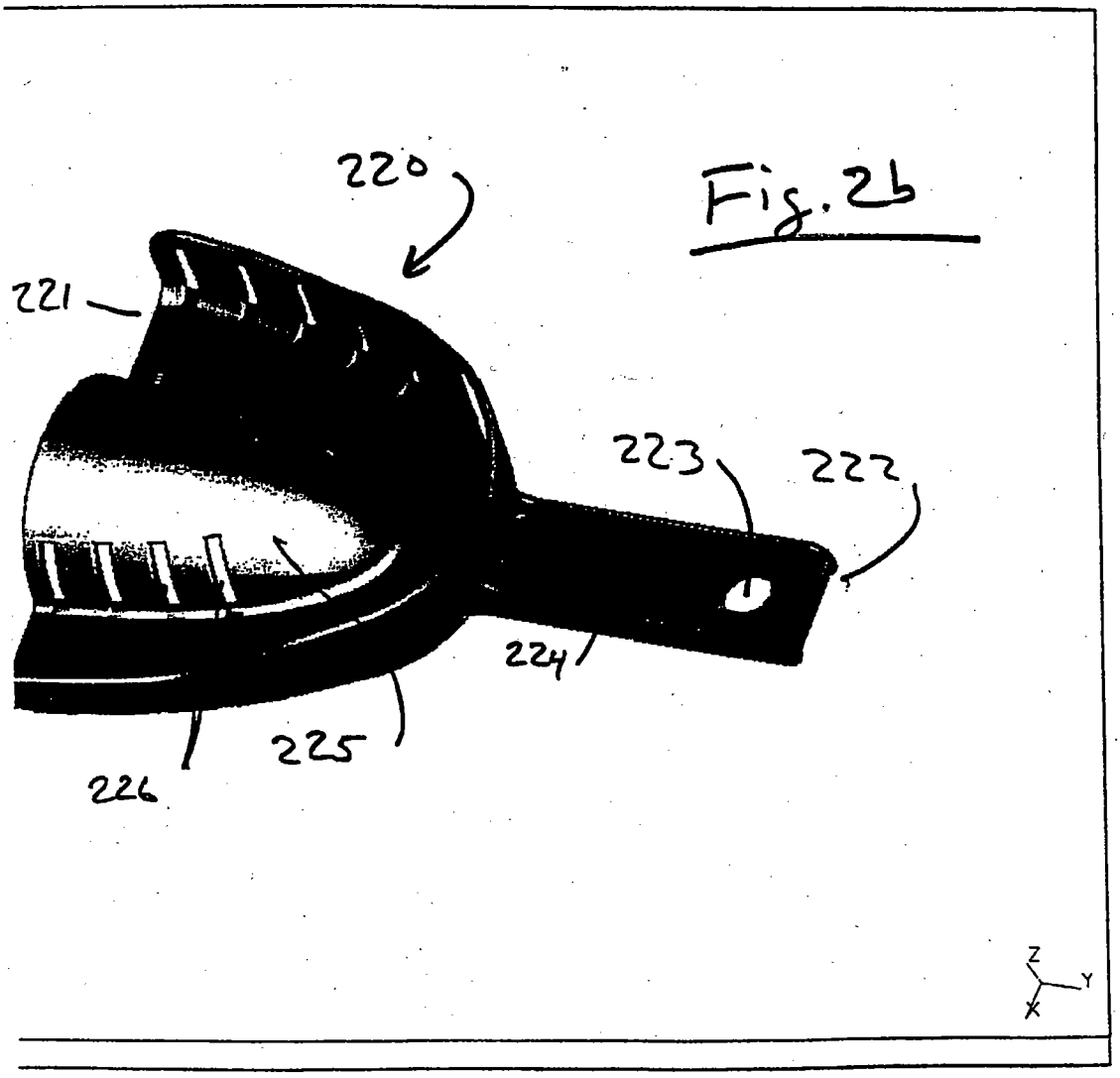


Fig. 2b

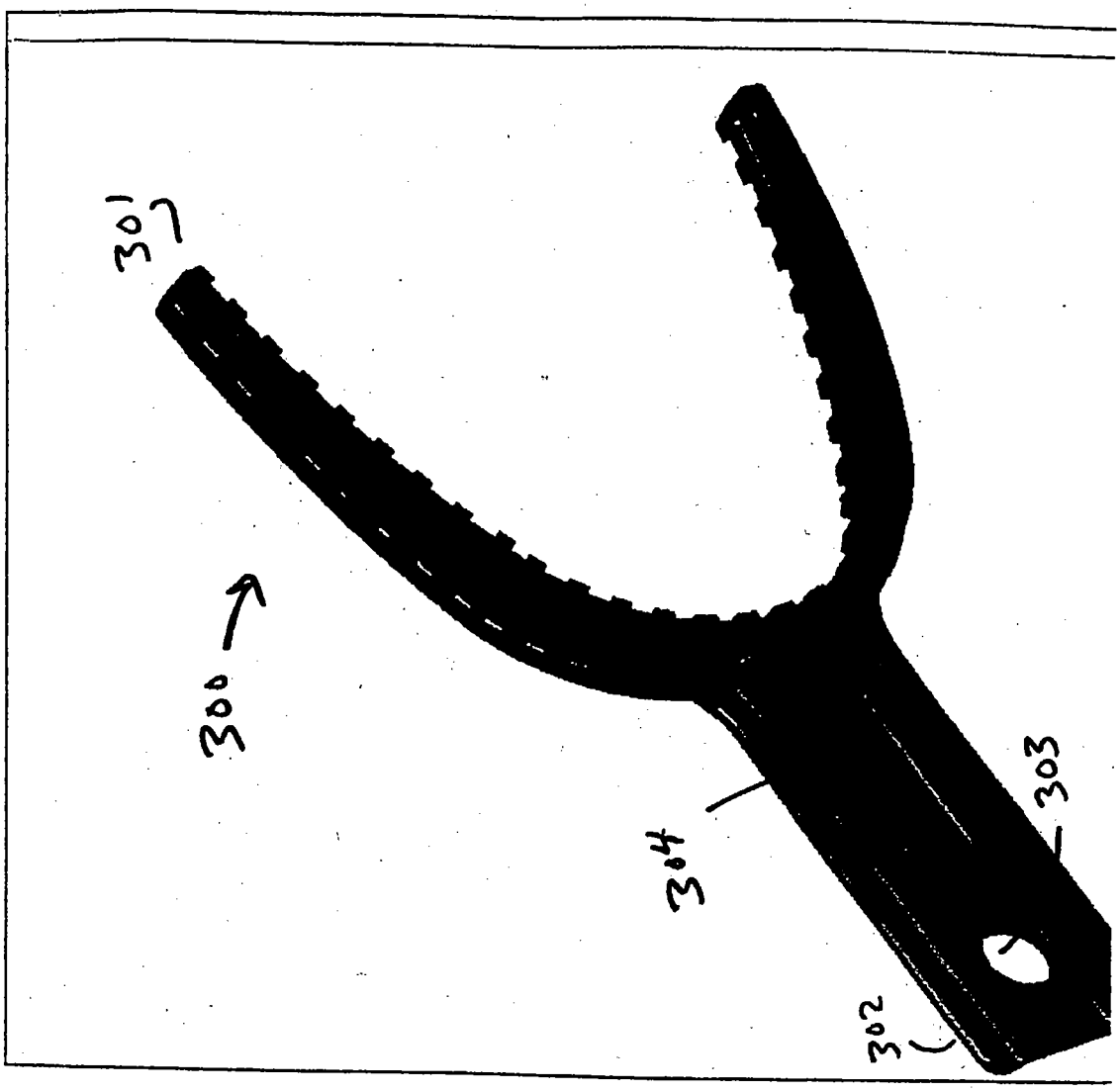


Fig. 3c

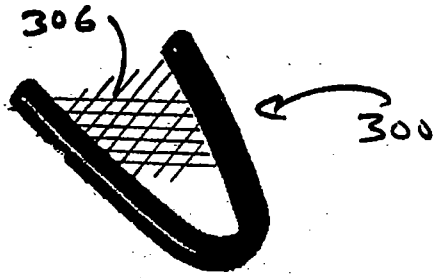


Fig. 3b

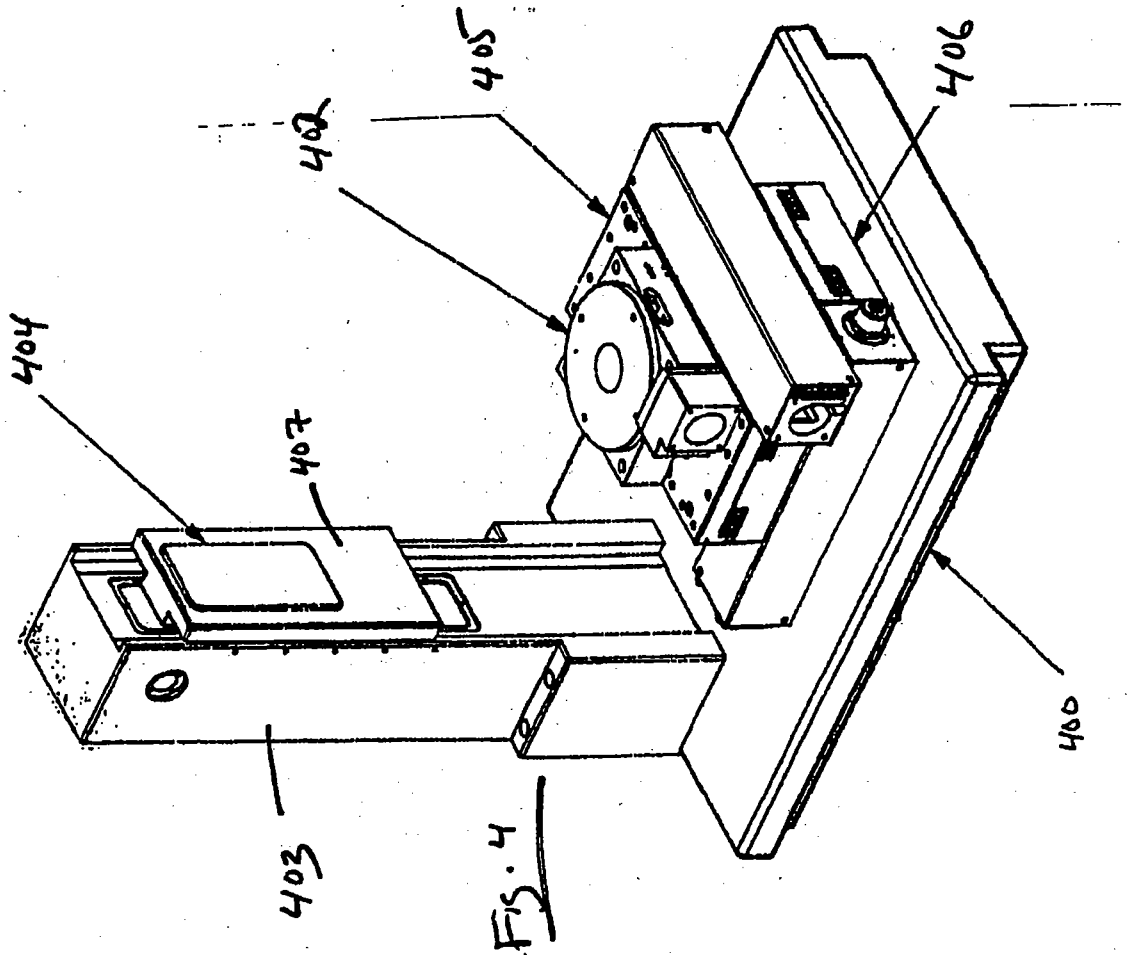


Fig. 4

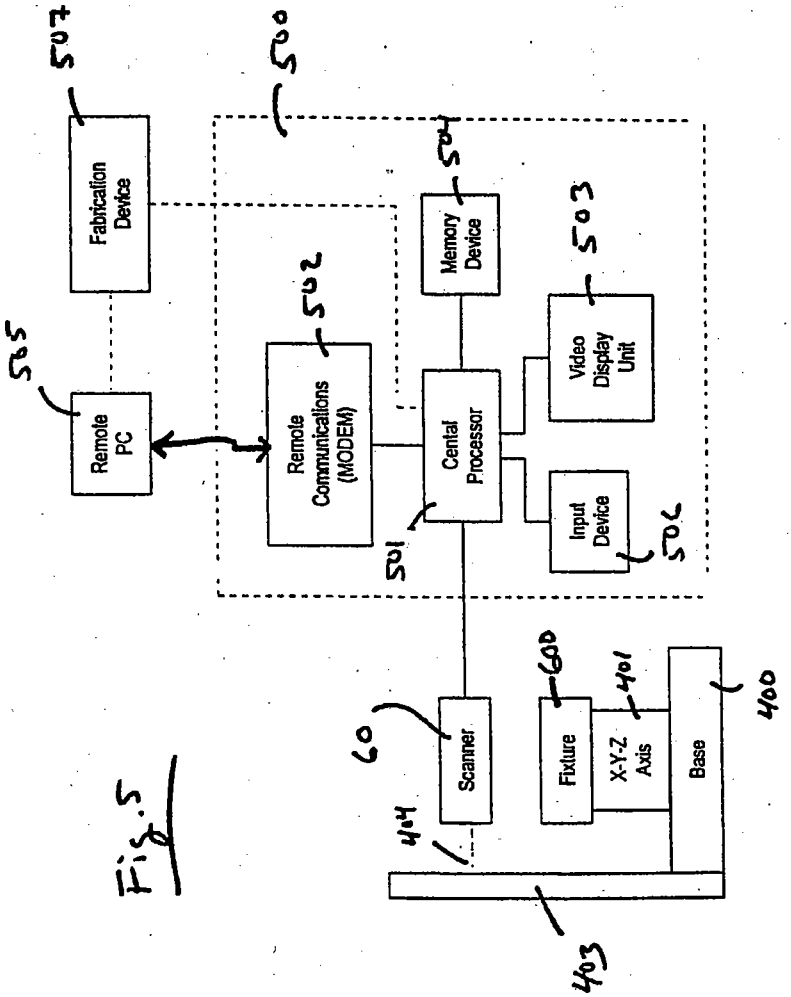

507
500
Fabrication Device
504
Memory Device
503
505
502
Video Display Unit
Remote PC
Remote Communications (MODEM)
Central Processor
Input Device
501
506
600
401
400
60
Scanner
Fixture
X-Y-Z Axis
Base
404
403

Fig. 5



Fig. 6

INTERNATIONAL SEARCH REPORT

Inte. onal Application No
PCT/US 98/00891

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61C13/00

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61C

Documentation searched other than minimumdocumentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 338 198 A (WU) 16 August 1994 see the whole document	1-6,8, 10-15

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publicationdate of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of theinternational search	Date of mailing of the international search report
29 May 1998	12/06/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040. Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Vanrunxt, J

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte. .onal Application No
PCT/US 98/00891

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5338198 A	16-08-1994	CA 2124154 A	23-05-1995

Form PCT/ISA/210 (patent family annex) (July 1992)

Substitute for form 1449/PTO **INFORMATION DISCLOSURE STATEMENT BY APPLICANT** *(Use as many sheets as necessary)*				***Complete if Known***	
				Application Number	13/470,681
				Filing Date	May 14, 2012
				First Named Inventor	Chunhua Li
				Art Unit	3732
				Examiner Name	Unassigned
Sheet	1	of	21	Attorney Docket Number	22773-826.201

U.S. PATENT DOCUMENTS

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	1.	US 2,467,432	04/19/1949	Kesling	
	2.	US 2002/0006597 A1	01/17/2002	Andreiko et al.	
	3.	US 2003/0009252 A1	01/09/2003	Pavlovskaia et al.	
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	5.	US 2003/0224311 A1	12/04/2003	Cronauer	
	6.	US 2004/0128010 A1	07/01/2004	Pavlovskaia et al..	
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	21.	US 4,324,546	04/13/1982	Heitlinger et al.	
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	26.	US 4,504,225	03/12/1985	Yoshii	
	27.	US 4,505,673	03/19/1985	Yoshii	
	28.	US 4,526,540	07/02/1985	Dellinger	
	29.	US 4,575,330	03/11/1986	Hull	

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				First Named Inventor	Chunhua Li
				Art Unit	3732
				Examiner Name	Unassigned
Sheet	2	of	21	Attorney Docket Number	22773-826.201

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	31.	US 4,591,341	05/27/1986	Andrews	
	32.	US 4,609,349	09/02/1986	Cain	
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	36.	US 4,664,626	05/12/1987	Kesling	
	37.	US 4,676,747	06/30/1987	Kesling	
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	40.	US 4,763,791	08/16/1988	Halverson et al.	
	41.	US 4,793,803	12/27/1988	Martz	
	42.	US 4,798,534	01/17/1989	Breads	
	43.	US 4,836,778	06/06/1989	Baumrind et al.	
	44.	US 4,837,732	06/06/1989	Brandestini et al.	
	45.	US 4,850,864	07/25/1989	Diamond	
	46.	US 4,850,865	07/25/1989	Napolitano	
	47.	US 4,856,991	08/15/1989	Breads et al.	
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	50.	US 4,889,238	12/26/1989	Batchelor	
	51.	US 4,890,608	01/02/1990	Steer	
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	53.	US 4,936,862	06/26/1990	Walker et al.	
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	57.	US 4,975,052	12/04/1990	Spencer et al.	
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				Filing Date	May 14, 2012
				First Named Inventor	Chunhua Li
				Art Unit	3732
				Examiner Name	Unassigned
Sheet	3	of	21	Attorney Docket Number	22773-826.201

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	59.	US 5,011,405	04-31-1991	Lemchen	
	60.	US 5,017,133	05/21/1991	Miura	
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	74.	US 5,176,517	01/05/1993	Truax	
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	76.	US 5,186,623	02/16/1993	Breads et al.	
	77.	US 5,257,203	10/26/1993	Riley et al.	
	78.	US 5,273,429	12/28/1993	Rekow et al.	
	79.	US 5,278,756	01/11/1994	Lemchen et al.	
	80.	US 5,328,362	07/12/1994	Watson et al.	
	81.	US 5,338,198	08/16/1994	Wu et al.	
	82.	US 5,340,309	08/23/1994	Robertson	
	83.	US 5,342,202	08/23/1994	Deshayes	
	84.	US 5,368,478	11/29/1994	Andreiko et al.	
	85.	US 5,382,164	01/17/1995	Stern	
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	87.	US 5,431,562	11/11/1995	Andreiko et al.	

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				First Named Inventor	Chunhua Li
				Art Unit	3732
				Examiner Name	Unassigned
Sheet	4	of	21	Attorney Docket Number	22773-826.201

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	88.	US 5,440,326	08/08/1995	Quinn	
	89.	US 5,440,496	08/08/1995	Andersson et al.	
	90.	US 5,447,432	09/05/1995	Andreiko et al.	
	91.	US 5,452,219	09/19/1995	Dehoff et al.	
	92.	US 5,454,717	10/03/1995	Andreiko et al.	
	93.	US 5,456,600	10/10/1995	Andreiko et al.	
	94.	US 5,474,448	12/12/1995	Andreiko et al.	
	95.	US 5,518,397	05/21/1996	Andreiko et al.	
	96.	US 5,528,735	06/18/1996	Strasnick et al.	
	97.	US 5,533,895	07/09/1996	Andreiko et al.	
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	100.	US 5,562,448	10/08/1996	Mushabac	
	101.	US 5,587,912	12/24/1996	Andersson et al.	
	102.	US 5,605,459	02/25/1997	Kuroda et al.	
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	116.	US 5,799,100	08/25/1998	Clarke et al.	

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	117.	US 5,800,174	09/01/1998	Andersson	
	118.	US 5,823,778	10/20/1998	Schmitt et.al.	
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	120.	US 5,857,853	01/12/1999	van Nifterick et al.	
	121.	US 5,866,058	02/02/1999	Batchelder et al.	
	122.	US 5,879,158	03/09/1999	Doyle et al.	
	123.	US 5,880,961	03/09/1999	Crump	
	124.	US 5,880,962	03/09/1999	Andersson et al.	
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	127.	US 5,964,587	10/12/1999	Sato	
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	142.	US 6,217,334	04/17/2001	Hultgren	
	143.	US 6,244,861	06/12/2001	Andreiko et al.	
	144.	US 6,309,215	10/30/2001	Phan et al.	
	145.	US 6,315,553	11/13/2001	Sachdeva et al.	

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				First Named Inventor	Chunhua Li
				Art Unit	3732
				Examiner Name	Unassigned
Sheet	6	of	21	Attorney Docket Number	22773-826.201

U.S. PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] *(if known)*	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
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	148.	US 6,382,975	05/07/2002	Poirier	
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	159.	AU 3031677 A	05/10/1979	Yoshii		
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	166.	EP 0299490 A2 (in German with English abstract)	01/18/1989	Steinbichler et al.		
	167.	EP 0376873 A2	07/04/1990	Shafir		
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	169.	EP 0541500 A1	05/12/1993	Andersson et al.		

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Continued on the next page with more references.

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NON PATENT LITERATURE DOCUMENTS			
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