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**(54) Title**: METHOD FOR MONITORING DENTITION

**(54) Title:** PROCÉDÉ DE CONTRÔLE DE LA DENTITION

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**(57) Abstract**: The invention relates to a method for monitoring a property of the appearance of the teeth of a patient, said method including the following consecutive steps: A) acquiring, by means of a first acquisition apparatus, at least one first two-dimensional image of said teeth and of a first reference gauge, referred to as "initial image"; **B)** acquiring, by means of a second acquisition apparatus, at least one second two-dimensional image of said teeth and of a second reference gauge having the same appearance as the first reference gauge, referred to as "updated image"; C) standardizing the initial and updated images such that the representations of the first and second reference gauges on the standardized initial and updated images have the same appearance; **D)** before or after step C, marking the same region of the teeth on the initial and updated images; and **E)** comparing the appearance of said region in the standardized initial and updated images.

**(57) Abrégé :** L'invention concerne un procédé de contrôle d'une propriété d'aspect de dents d'un patient, ledit procédé comportant les étapes successives suivantes: A) acquisition, au moyen d'un premier appareil d'acquisition, d'au moins une première image bidimensionnelle desdites dents et d'une première jauge de référence, dite « image initiale »; **B)** acquisition, au moyen d'un deuxième appareil d'acquisition, d'au moins une deuxième image bidimensionnelle desdites dents et d'une deuxième jauge de référence présentant un même aspect que la première jauge de référence, dite « image actualisée »; C) normalisation des images initiale et actualisée de manière que les représentations des première et deuxième jauges de référence sur les images initiale et actualisée normalisées présentent un même aspect; **D)** avant ou après l'étape C, repérage d'une même région des dents sur les images initiale et actualisée; **E)** comparaison de l'aspect de ladite région sur les images initiale et actualisée normalisées.

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# METHOD FOR MONITORING DENTITION

## Technical area

The present invention provides a method for monitoring the positioning and/or shape and/or appearance of a patient's teeth and a computer program for implementing this method.

## State of the art

It's a good idea for everyone to have their teeth checked regularly, in particular to ensure that the position and/or shape and/or appearance of their teeth are not changing unfavorably.

During orthodontic treatment, any unfavorable progression may lead to a change in treatment. After orthodontic treatment, such an unfavorable evolution, known as “recurrence”, may lead to a repeat of treatment. Lastly, more generally, and independent of any treatment, a person may wish to monitor any possible movement and/or any change in the shape and/or appearance of the teeth.

Traditionally, checks are carried out by an orthodontist or a dentist, who are the only persons with the appropriate equipment. This monitoring is expensive. Additionally, the visits are restrictive.

US 2009/0291417 describes a method for creating and then modifying three-dimensional models, in particular for the manufacture of orthodontic appliances.

One aim of the present invention is to solve, at least in part, the above-mentioned problems.

## Summary of the invention

The invention provides a method for monitoring the position and/or shape of a patient's teeth, with said method comprising the following steps:

a) creation of a three-dimensional digital reference model of at least part of an arch, preferably at least one of the patient's arches, or an “initial reference model” and, preferably, for each tooth, definition, using the initial reference model, of a three-dimensional digital reference model of said tooth, i.e. the “tooth model”;

b) acquisition of at least one two-dimensional image of the patient's arches, the so-called “updated image”, under actual acquisition conditions;

c) analysis of each updated image and production, for each updated image, of an updated map relating to discriminant information;

d) optionally, determination of gross virtual acquisition conditions approximating said real acquisition conditions for each updated image;

e) searching, for each updated image, for a final reference model corresponding to the positioning and/or shape of the teeth at the time of acquisition of the updated image, the search preferably being performed using a metaheuristic method, preferably evolutionary, preferably via simulated annealing, and

f) for each tooth model, comparison of the positions of said tooth model in the initial reference model and in the reference model obtained upon completion of the preceding stages, the so-called “final reference model”, in order to determine tooth displacement between stages a) and b), and/or comparison of the shapes of the initial reference model and the reference model obtained upon completion of the preceding steps, known as the “final reference model”, in order to determine the deformation and/or displacement of teeth between the steps a) and b).

As will be seen in greater detail in the following description, a method for checking the positioning and/or shape of teeth according to the invention allows, on the basis of a simple image of the teeth, taken without precise pre-positioning of the teeth in relation to the image acquisition apparatus, such as a photograph taken by the patient, to accurately assess tooth displacement and/or deformation since the initial reference model was produced. This evaluation can also be carried out by a simple computer, server or cell phone.

Preferably, step e) includes

- an initial optimization operation to find the virtual acquisition conditions corresponding as closely as possible to real acquisition conditions in a reference model to be tested, determined based upon the initial reference model, and

- a second optimization operation that, by testing a plurality of said reference models to be tested, searches for the reference model that best matches the positioning and/or shape of the patient's teeth when the updated image is acquired in step b).

Preferably, a first optimization operation is performed for each test of a reference model to be tested in the second optimization operation.

Preferably, the first optimization operation and/or the second optimization operation, preferably the first optimization operation and the second optimization operation implement a metaheuristic method, preferably evolutionary, preferably simulated annealing.

Preferably, step e) comprises the following steps:

el) definition of a reference model to be tested as the initial reference model, then,

e2) following these steps, test virtual acquisition conditions with the reference model to be tested in order to finely approximate said real acquisition conditions;

e21) determination of virtual acquisition conditions to be tested;

e22) production of a two-dimensional reference image of the reference model to be tested under said virtual acquisition conditions to be tested;

e23) processing the reference image to produce at least one reference map representing, at least partially, said discriminant information;

e24) comparison of the updated and reference maps to determine a value for a first evaluation function, said value for the first evaluation function, with said value being dependent on the differences between said updated and reference maps and corresponding to a decision to continue or stop the search for virtual acquisition conditions approximating said actual acquisition conditions more accurately than said virtual acquisition conditions to be tested determined at the last occurrence of step e21);

e25) if said value for the first evaluation function corresponds to a decision to continue said search, modify the virtual acquisition conditions to be tested, then return to step e22);

e3) determining a value for a second evaluation function, said value for the second evaluation function depending on the differences between the updated and reference maps in virtual acquisition conditions best approximating said real acquisition conditions and resulting from the half occurrence of step e2), said value for the second evaluation function corresponding to a decision to continue or stop the search for a reference model approximating the shape and/or positioning of the teeth when acquiring the updated image more accurately than said reference model to be tested used in the half occurrence of step e2), and if said value for the second evaluation function corresponds to a decision to continue said search, modification of the reference model to be tested by deformation of the reference model to be tested and/or by displacement and/or deformation of one or more tooth models, then resumption in step e2).

A method of controlling the positioning and/or shape of teeth according to the invention may further comprise one or more of the following optional features:

- in step a), an occlusal plane is determined by the following operations:
  - I. determination of the points of the initial reference model that belong to one arch and that are at a distance from the other arch that is less than a preset distance, preferably less than 3 mm from the other arch, known as “contact points”;
  - II. optionally, filtering of some of the contact points, preferably so that the number of contact points belonging to the upper arch is identical to the number of contact points belonging to the lower arch, preferably by eliminating the points of one arch furthest from the other arch;

III. linear regression, preferably using the least squares method, on all remaining contact points to determine the occlusal plane;

- in step a), the following operations are performed:

i. projection, in an occlusal plane, of the contact points between the teeth of the patient's upper and lower arches, the contact points and/or occlusal plane preferably being determined according to steps I to III;

ii. determination of the barycenter of the projections of said contact points and creation of a reference frame, in the occlusion plane, centered on said barycenter;

iii. determination, in said reference frame, of the parabolic function having the highest correlation coefficient with the set of projections of the contact points;

iv. rotation of the set of contact point projections around the barycenter, and repetition the previous operation *iii* until the set of contact point projections has covered a given sector, preferably greater than 90°, greater than 180°, or even approximately 360°;

v. identification of the highest correlation coefficient for all the angular positions of the set of projections of contact points around the barycenter, and the axis of the corresponding parabolic function;

vi. determination of a median longitudinal plane of the initial reference model, with said plane passing through said axis and being perpendicular to the occlusal plane;

- in step a), a tooth model is at least partially delimited by the following operations:

i'. determination, at least in part, of the inner and outer gingival edges of the arch of the tooth in question, preferably by analysis of variations in the surface orientation of the initial reference model;

ii'. projection of inner and outer gingival edges in the occlusal plane;

iii'. identification of deformations of the projections of the inner and outer gingival edges corresponding to the interdental regions, the vertices of these deformations being called “points of approximation” (in an interdental region, the two projections each have a tip, with the two points pointing substantially towards each other, with the extremity of a tip being a point of approximation);

iv'. determination of the shortest path, on the surface of the initial reference model, between two points of approximation of inner and outer gingival edges, respectively, of an interdental region, preferably via a metaheuristic method, preferably evolutionary, preferably by simulated annealing, with said shortest path at least partially delimiting a tooth model;

- an updated image is acquired less than 7 days after step a), then steps c) to f) are carried out on the basis of this updated image;
- the time interval between steps a) and b) or between steps A and B may be greater than 1 week, 2 weeks, 1 month, 2 months or 6 months;
- in step b), a hand-held acquisition apparatus is used (in particular one that is not immobilized, e.g. by means of a support resting on the floor) and/or the patient's head is not immobilized;
- an individual device selected from the group consisting of a connected camera, a smartwatch, a digital tablet, a portable 3D scanner and a computer with an image acquisition system, such as a webcam or a digital camera, is used to carry out step b), and preferably, at least one of the steps, preferably all steps c) to f);
- in step b), a retractor is used with one, preferably more than two, preferably unaligned registration marks, and preferably the image of the registration marks on the updated image is used to
    - in step c), resize the image and/or,
    - in step d), approximately estimate the actual acquisition conditions;
- in step c), discriminant information is selected from the group consisting of contour information, color information, density information,

distance information, brightness information, saturation information, reflection information and combinations of the foregoing;

- in step c), the discriminant information is optimal discriminant information obtained by means of an optimization method according to the invention, described below;
- in step d), data supplied by the acquisition apparatus is used, preferably regarding its orientation;
- in step e2), the virtual acquisition conditions sought include calibration parameters for the acquisition apparatus used in step b);
- optimization is implemented using a metaheuristic method, preferably evolutionary, preferably by simulated annealing:
    - in step a), to at least partially determine a gingival margin delimiting a tooth model, and/or
    - in step e2), to search for virtual acquisition conditions corresponding to actual acquisition conditions, and/or
    - in step e), to search for a reference model corresponding to the updated image;
- said metaheuristic method is selected from the group formed by
    - the evolutionist algorithms, preferably chosen from among: evolutionary strategies, genetic algorithms, differential evolution algorithms, distribution estimation algorithms and artificial immune systems, Shuffled Complex Evolution path recomposition, simulated annealing, ant colony algorithms, particle swarm optimization algorithms, tabu search, and the GRASP method;
    - the kangaroo algorithm,
    - the Fletcher-Powell method,
    - the sound effects method,
    - stochastic tunneling,
    - climbing hills with random repetitions,
    - the cross-entropy method, and
    - hybrids of the above-mentioned metaheuristic methods;

- based on the comparison in step f), a map is produced showing changes in the shape of the initial reference model and/or the displacement of one or more tooth models;
- discriminant information used for the updated map and/or for the reference map, prior to being used, is optimized by means of an optimization process according to the invention described below, comprising steps Cl. to C3., and the acquired image is the updated image or the reference image, respectively, and the reference model is the initial reference model or the reference model to be tested, respectively.

The invention also relates to the use of a tooth positioning control method according to the invention

- to detect recidivism, and/or
- to determine the rate of change in tooth position, and/or
- to optimize the date of your appointment with an orthodontist or dentist, and/or
- to assess the effectiveness of orthodontic treatment, and/or
- to assess the evolution of tooth positioning towards a theoretical model corresponding to a determined tooth position, in particular improved positioning of teeth, and/or
- in dentistry.

In particular, the method can be used during orthodontic treatment, especially to monitor progress, with step a) being carried out less than 3 months, less than 2 months, less than 1 month, less than 1 week, less than 2 days after the start of treatment, i.e. after being fitted with a device intended to correct the positioning of the patient's teeth, a so-called "active retainer".

The procedure can also be used after orthodontic treatment, to check that the positioning of the teeth is not changing unfavorably ("recidivism"). Step a) is then preferably carried out less than 3 months, less than 2 months, less than 1 month, less than 1 week, less than 2 days after the end of treatment, i.e. after the fitting of an appliance designed to hold the teeth in position, known as a "passive retainer".

In one embodiment, in order to exclusively control tooth movement, the tooth models are considered to not be changeable in step e). In particular, in step e3), the reference model to be tested can only be modified by moving one or more tooth models.

The invention also relates to the use of a tooth shape control method according to the invention:

- to visualize and/or measure and/or detect dental plaque, and/or incipient decay, and/or microcracking, and/or wear, for example as a result of bruxism or the use of active or passive orthodontic appliances, particularly in the event of breakage or detachment of an orthodontic arch;
- to visualize and/or measure and/or detect a change in volume, in particular during tooth growth or following intervention by a dentist or orthodontist, e.g. a deposit of glue on the surface of the teeth;
- to assess the need for interceptive treatment, prior to any orthodontic treatment, in particular to assess the benefits of orthodontic treatment.

In one embodiment, in order to exclusively check tooth deformation, it is considered in step e) that the tooth models are fixed, i.e. they have not moved between steps a) and b). In particular, in step e3), the reference model to be tested can only be modified by deforming one or more tooth models.

In particular, comparison of the shapes of the initial and final reference models to determine tooth deformation between steps a) and b) can be achieved by comparing the shape of one or more tooth models in the initial and final reference models.

The invention further relates to a method for checking an appearance property of a patient's teeth, with said method comprising the following successive steps:

A. acquisition, by means of a first acquisition apparatus, of at least one first two-dimensional image of said teeth and of a first reference gauge, referred to as the “initial image”;
B. acquisition, by means of a second acquisition apparatus, of at least a second two-dimensional image of said teeth and a second two-dimensional

reference gauge with the same appearance as the first reference gauge, the so-called “updated image”;

C. standardization of the initial and updated images so that the representations of the first and second reference gauges on the initial and updated standardized images have the same appearance;

D. before or after step C., registration marking the same tooth region on the initial and updated images;

E. comparison of the appearance of said region on the initial and updated standardized images.

A method of checking a tooth appearance property according to the invention preferably comprises one or more of the following optional features:

- the time interval between steps A. and B. is greater than 1 week;
- the first acquisition apparatus and/or the second acquisition apparatus are cameras and/or cell phones;
- acquisitions in steps A. and/or B. are carried out with flash lighting;
- the reference gauges used for each of steps A. and B. have the same appearance;
- the reference gauges used for each of steps A. and B. are attached to a dental retractor;
- the acquisitions in steps A. and/or B. are carried out using an acquisition kit according to the invention, described below;
- the reference gauges used for each of steps A. and B. are registration marks;
- the first and/or second acquisition apparatus includes a computer program comprising program code instructions for locating the mark(s) on the retractor in real time, analyzing its/their position(s) and/or dimensions, in particular the relative position(s) of several mark(s) and, as a result, providing an indication, preferably light or sound, so as to inform the user of said acquisition apparatus;

- in step D., registration marking comprises a comparison of discriminant information common to both the initial and updated images, followed by an identification of the position of said region relative to said common discriminant information;
- in step D., locating the region on the initial and/or updated images comprises a search for virtual acquisition conditions under which the first and/or second acquisition apparatus, respectively, would have acquired said initial and/or updated image, respectively, by observing a three-dimensional digital reference model of the patient's arches.
- in step D., locating the region on the initial and/or updated images involves carrying out a method for evaluating the actual acquisition conditions according to the invention, as described below.

The invention also relates to an acquisition kit, in particular for carrying out step b), A. or B., which acquisition kit comprises:

- a dental retractor designed to be placed in a patient's mouth and featuring a registration mark;
- an image acquisition apparatus comprising
  - a display screen,
  - a computer memory containing information about conditions acquisition targets,
  - a computer program comprising program code instructions for simultaneously displaying an image on said screen and a reference, said reference being in a position such that, when the registration mark corresponds to the reference on the display, the acquisition apparatus complies with target acquisition conditions.

An acquisition kit according to the invention can in particular be used in step b) of a method for checking the positioning and/or shape of teeth according to the invention, or in steps A. and/or B. of a method for checking the appearance properties of teeth, and more generally for any method involving the assessment of image acquisition conditions.

As will be seen in greater detail later in this description, an acquisition kit according to the invention makes it possible, in particular, to position the acquisition apparatus in a position

which substantially corresponds to a preset position, for example a position considered optimal for the desired verification. An acquisition kit according to the invention thus makes it possible to considerably improve information processing speed for the implementation of control procedures according to the invention.

An acquisition kit according to the invention preferably has one or more of the following optional features:

- the acquisition apparatus is a cell phone;
- the reference is selected from the group consisting of
  - a point,
  - a geometric shape, preferably a circle, square, rectangle or line,
  - an area of the same color as said marker,
  - a shape identical to the shape of said registration mark,
  - a shape complementary to the shape of said registration mark, in particular to form a meaningful shape, such as a geometric form, a letter or text, a drawing, or a pattern, and
  - combinations thereof;
- the retractor has several non-aligned registration marks, preferably in the same plane;
- the registration mark is positioned so that, when it corresponds to the said reference on the screen, it is less than 1 cm from one edge of the screen.

The invention also relates to a method for acquiring a two-dimensional image of a part of a dental arch, or of a dental arch or of both dental arches of a patient by means of an acquisition kit according to the invention, in particular for the implementation of a two-dimensional image. step b), A. and/or B. This process is remarkable in that it comprises the following successive steps:

(a) determination of target acquisition conditions, e.g. as a function of a treatment to be applied, in particular for an orthodontic treatment, and determination of suitable matching conditions adapted so that matching a retractor registration mark to a

reference displayed on the acquisition apparatus screen results in the application of target acquisition conditions;

(b) programming the acquisition apparatus to display the reference in a position such that said matching results in the application of the target acquisition conditions;

(c) positioning the retractor in the patient's mouth;

(d) position the acquisition apparatus so that the registration mark and the reference correspond, and thus apply the target acquisition conditions;

(e) acquisition of the acquirable image in the position of the acquisition apparatus adopted in the previous step.

The target acquisition conditions are those that enable the acquisition apparatus to be optimally positioned to acquire the image. Preferably, the target acquisition conditions are determined in function of the teeth to be observed.

Preferably, an acquisition method according to the invention is used for those steps of the control methods according to the invention requiring the acquisition of a two-dimensional image of a part of one or both dental arches of a patient, in particular for steps b).

Preferably, the cycle of steps (a) to (e) is repeated several times, preferably more than twice, or even more than three times, with different target acquisition conditions.

For example, to measure the displacement of a tooth, the first target acquisition conditions may correspond to a positioning 40 cm from the retractor, in front of and at the height of the retractor. Second and third target acquisition conditions may correspond to positioning at 40 cm from the retractor, at retractor height, at 45° to the right and left of the sagittal plane, respectively.

Preferably, steps (c), (d) and (e) are carried out by a person with no university training in orthodontics and/or outside any medical, dental or orthodontic practice, and/or without the use of a mechanical stabilization device for the acquisition apparatus and/or without the use of any device other than a cell phone and/or without the use of any device other than a cell phone and/or without use of a standard calibration gauge.

The invention also relates to a method for optimizing discriminant information extracted from a two-dimensional image of a patient's dental arches, known as the “acquired image”, by means of a digital three-dimensional reference model of at least part of one of the patient's arches, or of one or both of the patient's arches, said method comprising the following steps:

Cl. evaluation of the quality of the discriminant information and of a quality threshold, filtering so as to retain only discriminant information with a quality higher than the quality threshold, and definition of the “discriminant information to be tested” as the selected discriminant information;

C2. test for agreement between the discriminant information to be tested and said model reference;

C3. evaluation of the test result, and based on this evaluation:

- add information discriminating not retained a discriminant information to be tested and/or deletion of discriminant information in the discriminant information to be tested, then repeated in step C2. or,
- definition of discriminating optimal as the discriminant information to be tested.

Preferably, an optimization method according to the invention also comprises one or more of the following optional features:

- discriminant information is selected from the group consisting of contour information, color information, density information, distance information, brightness information, saturation information, reflection information, and combinations of these;
- stage C2. comprises the following steps:
  - search for virtual acquisition conditions approximating, preferably optimally, real acquisition conditions in which said acquired image has been acquired and observation of the reference model under said virtual acquisition conditions so as to obtain a reference image;
  - processing of the acquired image and the reference image to produce at least one acquired map and one reference map, respectively, said acquired and reference maps representing said discriminant information;

- comparison of the acquired and reference maps in order to determine a degree of concordance, the result of the test in step C2. preferably being equal to the said degree of concordance;
- the search for virtual acquisition conditions approximating the following stages:
  01) optionally, determination of coarse virtual acquisition conditions approximating said real acquisition conditions, preferably by analyzing the representation, on the acquired image, of a retractor used during acquisition of the acquired image;
  02) determination of virtual acquisition conditions to be tested;
  03) production of a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;
  04) reference image processing to produce a reference map representing said discriminant information;
  05) comparison of acquired and reference maps in order to determine a value for an assessment function, with said value for the assessment function depending on the differences between said acquired and reference maps and corresponding to a decision to continue or stop the search for virtual acquisition conditions approximating the actual acquisition conditions with greater accuracy than said virtual acquisition conditions to be tested;
  if said value for the assessment function corresponds to a decision to continue said search, modifying said virtual acquisition conditions to be tested, then returning to step 03);
  otherwise, assessment of actual acquisition conditions by said virtual acquisition conditions to be tested;
- the determination of the discriminant information to be added and/or to be added in step C3. results from the implementation of a metaheuristic method, preferably evolutionary.

The invention also relates to a method for evaluating the actual acquisition conditions of a two-dimensional image of a patient's teeth, the so-called “acquired image”, said method comprising the following steps:

001) creation of a three-dimensional digital reference model of at least part of a patient's arch, preferably of one arch, preferably of both arches;

002) analysis of the acquired image and production of a map relating to a discriminant information, known as the “acquired map”;

003) research from conditions acquisition virtual approximating said real acquisition conditions, preferably following steps 01) to 05).

One or more of the optional features of step a) are applicable to step 001). In particular, the reference model can be prepared by a scan, based on measurements taken on the patient's teeth or on a physical model of the teeth, for example a plaster model.

One or more of the optional features of step c) are applicable to step 002).

The invention also relates to:

- a computer program, and in particular a specialized cell phone application, comprising program code instructions for execution of one or more, preferably all steps b) to f) or A. to E. or Cl a C3, when said program is executed by a computer,
- a computer medium on which such a program is stored, for example a memory or a CD-ROM, and
- a personal device, in particular a cell phone or tablet, in which such a program is loaded.

The invention also relates to a system comprising

- a three-dimensional scanner suitable for carrying out step a) of a method for checking the positioning and/or shape of teeth according to the invention, or step 001).
- a personal device, preferably a cell phone, loaded with a program according to the invention.

**Definitions**

“Patient” refers to any person for whom a procedure is carried out in order to monitor their teeth, whether that person is ill, or whether that person is undergoing treatment.

A ”dental professional” is defined as a dentist, orthodontist or orthodontic laboratory.

“Dentist” refers to a dentist or dental assistant working under the responsibility of a dentist.

“Dentition” refers to the patient's two dental arches.

An image of an arch is, of course, a partial representation of that arch.

A “cell phone” is a device weighing less than 500 g, equipped with a sensor enabling it to capture images, capable of exchanging data with another device more than 500 km away from the cell phone, and capable of displaying said data, and in particular said images.

For a tooth positioning control process, the “acquisition conditions” specify the position and orientation in space of an image acquisition apparatus relative to the patient's teeth or a model of the patient's teeth, and preferably the calibration of this image acquisition apparatus.

The “calibration” of an acquisition apparatus consists of all the calibration parameter values. A calibration parameter is a parameter intrinsic to the acquisition apparatus (unlike its position and orientation), the value of which affects the acquired image. For example, the aperture value is a calibration parameter that modifies the depth of field. Exposure time is a calibration parameter that modifies the brightness (or “exposure”) of the image. Focal length is a calibration parameter that modifies the angle of view, i.e. the degree of “zoom”. “Sensitivity” is a calibration parameter that modifies the reaction of a digital acquisition apparatus' sensor to incident light.

Preferably, calibration parameters are chosen from the group consisting of aperture, exposure time, focal length and sensitivity.

The “occlusal plane” is the plane that provides the best linear correlation with the set of contact points between the teeth of the upper arch and the teeth of the lower arch.

The “median longitudinal plane” is the roughly vertical plane, when the patient is holding the head upright, that separates the right and left parts of each arch in a roughly symmetrical fashion.

A “tablet” is a portable computer with a touch screen.

A 3D scanner is a device used to obtain a three-dimensional representation of an object.

By “image” we mean a two-dimensional picture, such as a photograph. An image is made up of pixels.

An “acquirable” image (“preview”) is the image that the acquisition apparatus can acquire.

recording at a given moment. For a camera or telephone, this is the image that appears on the screen when the photo or video acquisition application is running.

“Discriminant information” is characteristic information that can be extracted from an image (*“image feature”)*, classically by computer processing of the image.

image.

Discriminant information can have a variable number of values. For example, contour information may be equal to 1 or O, depending on whether a pixel belongs to a contour. Brightness information can take on a large number of values. Image processing enables discriminant information to be extracted and quantified.

Acquisition conditions are deemed “virtual” when they correspond to a simulation in which the acquisition apparatus would be in said acquisition conditions (theoretical positioning and preferably calibration of the acquisition apparatus).

“Including one” or “containing one” or “presenting one” means “comprising at least one”, unless otherwise specified.

In the various processes described, references to steps are identical if the steps are similar or identical.

**Brief description of the figures**

Further features and benefits of the invention will become apparent from the following detailed description and the accompanying drawing, in which:

- figure 1 shows a flow chart illustrating the implementation of a tooth positioning and/or shape control process according to the invention,
- figure 2 shows an example of an initial reference model,
- figure 3 shows the treatment performed to determine the occlusal plane,
- figure 4 (4a-4d) illustrates the step required to determine tooth models in a reference model,
- figure 5 (5a-5d) illustrates the acquisition of updated images and the cutting operation,
- figure 6 (6a-6b) illustrates the processing of an updated image, enabling determination of tooth contours,
- figure 7 schematically illustrates the relative position of registration marks 12 on updated images $14_1$ and $14_2$ of a retractor 10, depending on the viewing direction (dashed line),
- figure 8 shows a map resulting from the implementation of a process of control of the shape of a patient's teeth according to the invention,
- figure 9 shows a flow chart illustrating the implementation of a tooth appearance control process according to the invention,
- figure 10 shows a flow chart illustrating the implementation of a process for optimizing discriminant information according to the invention,
- figure 11 shows a reference map prepared to show reflection information, and
- figures 12a and 12b show two views of a three-dimensional model with two different focal lengths.

**Detailed description of a method for controlling tooth positioning**

A method for controlling tooth positioning according to the invention comprises the above-mentioned steps.

**In step a),** an initial reference model of the patient's arches, or part of them, is created (see figure 2).

The initial reference model is a three-dimensional digital model of the patient's arches, for example of the types .stl or .Obj, .DXF 3D, IGES, STEP, VDA, or point clouds. Advantageously, such a so-called “3D” model can be viewed from any angle.

For follow-up orthodontic treatment, the initial reference model is preferably prepared at the start of treatment. The initial reference model may correspond to the position of the patient's teeth prior to treatment, or to the positioning of the patient's teeth that the treatment is designed to achieve. In this case, the reference model is typically calculated based on a first three-dimensional model corresponding to the positioning of the patient's teeth prior to treatment.

For recidivism control, the initial reference model is preferably prepared less than six months, preferably less than three months, preferably even less than one month after the end of orthodontic treatment, generally immediately after the end of orthodontic treatment. It thus corresponds to a more or less optimal positioning of the teeth.

The initial reference model can also be prepared independently of any treatment, for example because the patient wishes to monitor tooth movements.

The initial reference model can be prepared from measurements taken on the teeth or on a physical model of the patient's teeth, such as a plaster model.

The initial reference model is preferably created using a professional device, such as a 3D scanner, preferably implemented by a healthcare professional, such as an orthodontist or orthodontic laboratory. In an orthodontic practice, the patient or the physical model of his or her teeth can be advantageously arranged in a precise position, and the professional device can be perfected. The result is a highly accurate initial reference model. The initial reference model preferably provides information on the positioning of the teeth with an error of less than 5/10 mm, preferably less than 3/10 mm, preferably less than 1/10 mm.

<u>Orientation of the initial reference model</u>:

Preferably, the orientation of the initial reference model in space is determined, and in particular preferably in the occlusal plane and in the median longitudinal plane.

The occlusal plane and median longitudinal plane can be determined manually, in an approximate manner. However, the inventors have discovered methods to determine these planes by computer processing.

The reference model is preferably a model of the arches with the mouth closed, i.e. in a position in which the teeth of the upper arch are in contact with the teeth of the lower arch.

Typically, the initial reference model provided by a three-dimensional scanner is used to distinguish the upper arch from the lower arch. Typically, the model is stored in the form of two files corresponding respectively to these arches, and including data enabling the models of these arches to be positioned relative to each other in the occlusion position.

Preferably, to estimate the points of contact between the teeth of the upper and lower arches, a set of points is determined for the upper and lower arch model that are at a distance less than a preset limit, preferably being less than 3 mm, preferably around 2 mm. All other points in these models are then ignored, leading to the representation shown in figure 3b. Linear regression is then used to determine the occlusal plane ("plane 1" in Fig. 3c).

The initial reference model can then be oriented in the occlusal plane (Fig. 3d)

If the initial reference model does not include data enabling the upper and lower arches to be positioned in relation to each other, an occlusal mortise is preferably used, showing the contact points between the upper teeth and the lower teeth, then the upper and lower arch models are repositioned in relation to the occlusal bite.

The median longitudinal plane is perpendicular to the occlusal plane, but its orientation is unknown.

Preferably, the following procedure is used to determine the orientation of the plane longitudinal median:

We consider axes [Ox) and [Oy) in the occlusal plane, with point O being the barycenter of the normal projections of the contact points onto the occlusal plane.

- In this reference frame (xOy), we are looking for the curve, preferably parabolic, with the highest correlation coefficient with the set of said projections.

- The set of contact point projections is then moved into the occlusal plane, by rotation around point O, and the previous step is repeated from this new angular position of the contact point projections.

The cycle of previous operations is continued, preferably until the machine is running the set of contact points by 360° around barycenter 0. The correlation coefficients corresponding to the different orientations of the set of contact points are then compared. The axis of the curve with the highest correlation coefficient is then considered to be included in the median longitudinal plane, enabling the orientation of the latter to be defined exactly.

The orientation in space of the initial reference model is ams1 perfectly and rapidly determined.

Creating tooth models

In the initial reference model, a part corresponding to a tooth, or “tooth model”, is delimited by a gingival margin, which can be broken down into an inner gingival margin (on the inside of the mouth in relation to the tooth), an outer gingival margin (facing the outside of the mouth in relation to the tooth) and two lateral gingival margins. The gingival margins correspond to regions in which the orientation of the surface defined by the initial reference model undergoes strong modifications. These variations in orientation can be identified using known techniques, for example by identifying changes in the direction of the normal to the modeled surface. Figure 4a shows a view of the initial reference model processed to reveal these changes in direction. Figure 4b shows the inner gingival margin that can be extracted by analyzing the image in figure 4a.

Several views of the initial reference model are thus analyzed, making it possible to determine the inner and outer gingival margins in three dimensions, as shown in figure 4c.

Furthermore, when projected in the occlusal plane, the inner and outer gingival contours of an arch approach each other on either side of a tooth. To determine the lateral gingival margin of a tooth, we look for the shortest path, on the surface of the initial reference model, between the two points of the inner and outer gingival margins that are closest to each other and roughly facing each other. The search for the shortest path between two points on a three-dimensional model calls on optimization techniques that are well

known. Preferably, this search results from a metaheuristic method, preferably evolutionary, preferably simulated annealing.

Two adjacent lateral gingival margins and the parts of the inner and outer gingival margins that connect these lateral gingival margins are used to delimit a tooth at gingival level. Bearing in mind that a tooth extends from the gingival contour towards the occlusal plane, it is thus possible to determine which parts of the initial reference model correspond to which teeth ("tooth models"). Figure 4d shows all the tooth models in an arch.

The initial reference model can be stored in a centralized database, grouping together the initial reference models of a variety of patients. This database can be physically installed in a specialized facility. It can also be installed in a laboratory or orthodontic practice, which limits the transfer of confidential information.

In one embodiment, the initial reference model is given to the patient. Preferably, a computer file corresponding to the initial reference model is saved on a removable medium, for example on a USB stick or electronic card, preferably on the patient's cell phone, tablet or laptop, and in particular on the personal device that will preferably be used in steps b) and following. Preferably, the patient or a dental professional will load the initial reference model into said individual device or make it available for loading onto said individual device. The patient preferably downloads the initial reference model from the internet.

In a preferred embodiment, the reference model is not given to the patient. Preferably, the reference model is only made available to a specialized facility to implement steps c) to f). It can remain stored in the facility where it was created in step a) and where, preferably, steps c) to f) are carried out.

**In step b),** an updated image of part of an arch, an arch or the arches **is** taken using an image acquisition apparatus. Step b) is preferably performed by the patient or someone close to the patient, but can also be performed by a dentist.

<u>Acquisition</u>

Preferably, the updated image is taken after a time interval Δt following step a). The time interval Δt can be predetermined. It can be constant, irrespective of the occurrence of the process, i.e. it covers the first or subsequent execution of the process. It can be variable, depending for example on the results obtained following an earlier execution of the process. In particular, to monitor recidivism, the time interval Δt may be even shorter since this execution has made it possible to detect any significant drift.

In a preferred embodiment, the time interval Δt is determined by the orthodontist, based on a control schedule. Depending on the position of the teeth, the orthodontist can modify this schedule and alter the time interval Δt accordingly. In one embodiment, the method for checking tooth positioning according to the invention is carried out several times, the time intervals between each execution may be identical or different. The time intervals between two successive executions can all be determined prior to the first execution to correspond to a check schedule drawn up by the orthodontist.

The time interval Δt can also be indeterminate, depending for example on patient decisions. For example, the creation of an updated image can be carried out on the occasion of a dental appointment or at any time when the patient wishes, or even independently of any orthodontic treatment.

The time interval Δt is preferably determined to correspond to a potentially significant change in tooth positioning.

For example, for recidivism control, the time interval Δt is preferably less than three months in the first year after treatment. After this first year, the time interval Δt is preferably greater than one month, or even greater than six months or more. In particular, for the detection of tooth decay, a time interval of between six and eighteen months is appropriate.

Preferably, at least one reminder informing the patient of the need to create an updated image is sent to the patient. This reminder can be in paper form or, preferably, in electronic form, for example in the form of an e-mail, an automatic alert from the specialized mobile app or an SMS. Such a reminder can be sent by the orthodontic practice or laboratory, or by the dentist, or by the patient's specialized mobile app, for example.

In a preferred embodiment, an updated image is acquired before the teeth have been able to move significantly, substantially at the same time as the creation of the initial reference model, preferably less than 7 days, less than 3 days, less than 1 day after step a), i.e. before the teeth have been able to move significantly. Running the process with this updated image advantageously verifies that the process does not lead to the detection of any difference between the initial and final reference models, and therefore works correctly.

In one embodiment, the updated image can be acquired before the initial reference model is created. For example, steps a) and b) can be carried out at the end of the process and at the start of orthodontic treatment, respectively. In this way, it is possible to assess the effectiveness of treatment in the absence of a 3D model at the start of treatment. In particular, the time interval Δt' between steps a) and b) in this embodiment can take the values described above for Δt.

Image acquisition apparatus

Preferably, the image acquisition apparatus is a personal device commonly available on the market, for example a cell phone, a so-called “digital camera” or a digital camera.

“Connected” means a so-called “smart watch”, or a tablet or personal computer, fixed or portable, with an image acquisition system, such as a webcam or a camera, preferably a digital camera.

Although the updated image can be created by a dentist in particular, it is preferably created by the patient himself or by one of his relatives.

In particular, the updated image can be created by a person who has no particular knowledge of orthodontics, and in particular has no diploma in orthodontics or dentistry.

Preferably, the same acquisition apparatus is used to capture all updated images.

The image acquisition apparatus weighs preferably less than 3 kg, less than 2 kg, less than 1 kg, less than 500 g, preferably less than 300 g.

Step b) can thus advantageously be carried out at a distance from step a), i.e. in a different location from that in which step a) is carried out, in particular more than 50 m, more than 100 m, more than 1 km from the location where step a) is carried out, in particular outside an

orthodontic laboratory. In one embodiment, step b) is not carried out in a dental practice, orthodontic practice or orthodontic laboratory, except possibly during a patient training session.

Preferably, the updated image is a photograph, in particular a panoramic photograph. In one embodiment, the updated image is extracted from a film.

In a preferred embodiment, the process uses several updated images to provide at least one representation of each tooth, preferably at least three updated images corresponding to a front, right and left view of the patient's teeth.

Preferably, in step b), at least one updated image is taken in the closed-mouth position and at least one updated image is taken in the open-mouth position. The closed-mouth image can be used to identify relative displacements between the two arches. The updated open-mouth image makes it easier to identify the relative teeth, without the upper-arch teeth obscuring the lower-arch teeth or vice versa.

Updated images can be taken for either the upper or lower arch, or preferably for both arches, in whole or in part.

Several similar images (representing approximately the same teeth) may also be useful in order to search for the best score. Depending on the acquisition conditions, discriminant information may in particular lead to the following scores depending on the updated image used.

Preferably, a dental retractor is used in step b), as shown in Figures 5a and 5c. The primary function of the retractor is to spread the lips to improve visibility of the teeth. Preferably, a retractor is given to the patient, for example when an appointment with your orthodontist or dentist.

The image acquisition apparatus preferably provides color and/or infrared images of the patient's mouth, or even the patient's face. Color images preferably represent the patient's mouth in its true colors. Infrared images advantageously show teeth with excellent contrast.

Preferably, the image acquisition apparatus includes a specialized application for implementing step b), but also, preferably, subsequent steps, preferably all subsequent steps. Preferably, this application manages reminders and informs the patient of the need to create an updated image.

Preferably, the specialized application is loaded onto an image acquisition apparatus from a physical medium such as a USB drive or CD-ROM, or it is downloaded from the Internet or wirelessly. In one embodiment, the specialized application is provided to the patient by the orthodontic practice and/or laboratory. In particular, it can take the form of an app of the type commonly downloaded to iPhones of the Apple® brand or devices of any brand running the Android® operating system or any other operating system.

The image acquisition apparatus preferably comprises a camera or a video or infrared camera, which the user, e.g. the patient or one of their relatives, positions by means of a viewfinder or screen, before operating it.

Detection and acquisition kit

A method for checking the positioning of teeth according to the invention does not require precise positioning of the image acquisition apparatus relative to the teeth.

In one embodiment, no positioning constraints are imposed to ensure that the image acquisition apparatus is located within 30 cm, 20 cm, 10 cm or 5 cm of a specific location.

Preferably, however, the image-acquisition apparatus includes verification means to facilitate its approximate positioning relative to the patient prior to acquisition of the updated image.

The user can be guided through the acquisition process by written and/or voice prompts. By

For example, the personal device may announce “take a photo from the front”, emit a signal to inform the user that the photo is acceptable or that, on the contrary, he/she must take another photo, announce “take a photo from the right”, preferably displaying an arrow to orient the user, etc. The completion of the acquisition process may also be announced by the device. The device can also help with positioning, for example by visual prompts (e.g. by displaying arrows), and/or audio messages (such as a

series of beeps, the frequency of which increases as the device's positioning improves), and/or written and/or vocal prompts (“higher”, “lower”, etc.).

In particular, verification means can include references that appear on the viewfinder or screen. The references may, for example, comprise a line intended to be aligned with the general direction of the juncture between the upper and lower teeth when the teeth are clenched by the patient, and/or a vertical line intended to be aligned with the joint between the two upper incisors. The references can also refer to other parts of the patient. For example, they may take the form of marks corresponding to the position of the eyes, or take the form of a shape in which the patient's mouth or face is to be positioned.

The reference(s) are preferably “immobile” on the screen, i.e. they do not move on the screen when the acquisition apparatus is in motion.

In a preferred embodiment, the reference(s) each correspond(s) to a registration mark carried by a reference frame attached to the patient, i.e. the patient did not present before the process was implemented, preferably carried by a dental retractor. A reference point can also be a piece bitten off by the patient.

The registration mark can have a surface area of more than 0.5 mm2, preferably more than 1 mm2. preferably more than 2 $mm^2$, preferably more than 5 $mm^2$. preferably more than 10 $mm^2$, or even more than 20 $mm^2$, or even more than 30 $mm^2$, and/or less than 50 $mm^2$.

The larger the size of a registration mark, the more accurate the positioning of the acquisition apparatus.

The markings can be identical or different.

In particular, the marks can differ according to their position, for example whether they are on the upper or lower part of the reference frame, and in particular of the retractor, or to the right or left of the reference frame, and in particular of the retractor.

The registration mark may be identical to or different from the corresponding reference.

It is preferably geometrical in shape, for example a point or one or more dashes,

for example parallels, a star, a circle, an oval, a regular polygon, in particular a square, a rectangle or a rhombus.

The registration mark can also be an image, a letter, a number or a sequence of letters and/or numbers.

The registration mark is preferably of a different color from the surrounding surface of the retractor, preferably to provide high contrast.

A registration mark can be visible or invisible to the naked eye, as long as it appears on the display of the acquisition apparatus.

To improve accuracy, the marks are preferably spaced apart from each other so that, when they are aligned with their respective references on the screen, at least the first and second registration marks are within 3 cm, preferably within 2 cm, preferably within 1 cm, preferably within 0.5 cm, of the first and second edges, respectively, of the screen. The first and second edges are preferably on opposite edges of the screen.

The registration mark may have one or more dimensions and/or a shape and/or color identical to or different from that of the corresponding reference.

The “match” between a reference and a registration mark is a predefined arrangement of one in relation to the other. It indicates a particular positioning of the acquisition apparatus in relation to the registration mark. The match depends on the nature of the reference and the registration mark. The predefined situation, which corresponds to target acquisition conditions, may in particular be a total or partial superimposition, juxtaposition or alignment of the reference and the registration mark.

The exact superimposition of the reference and registration marks not only makes it possible to determine the direction towards which the acquisition apparatus lens should point and/or the distance between the acquisition apparatus and the retractor, and also, if the reference and/or registration mark is asymmetrical, the orientation of the acquisition apparatus around this direction.

Dimensions and/or surfaces of a registration mark and the corresponding reference and/or the distance between several registration marks and between

the corresponding references can be used to adjust the distance between the acquisition apparatus and the arches.

The reference can be, for example

- a fixed line, on which the user must, for example, align the registration marks,
- a shape, preferably asymmetrical, corresponding to the shape of a registration mark to be superimposed, for example a point which the user is to superimpose on the registration mark, or a circle in which the user is to position the registration mark,
- a colored shape corresponding to the color of a registration mark to be superimposed,
- a shape complementary to the shape of a registration mark, preferably in such a way that mapping the registration mark to the reference leads to a meaningful shape, such as a geometric shape, a letter or text, a drawing or a design, for example.

In a preferred embodiment, the references are defined, at least in part, based on information provided by the initial reference model. For example, following the principles of “augmented reality”, the reference may be a view of the initial reference model, for example a front view or a right view or a left view of the initial reference model, made visible, in transparent form, on the screen of the image acquisition apparatus during acquisition. This makes it very easy for the patient to superimpose such a view approximately on the teeth to be photographed.

In a preferred embodiment, acquisition is performed using an acquisition kit according to the invention comprising:

- a dental retractor, preferably made of a biocompatible material, with a registration mark;
- an image acquisition apparatus, preferably of the type described above, having a screen for displaying an acquirable image, and a computer program comprising program code instructions for displaying the image on the screen. at least one reference on said screen, said reference being preferably immobile on the screen, and arranged in a position known as the “match position” in which, when the registration mark corresponds to the

reference on the display, the scanned image shows the retractor at a predetermined viewing angle and/or distance.

A kit according to the invention advantageously enables image acquisition without the need for a specialist person, in particular an orthodontist. In particular, image acquisition can be carried out by the patient himself or by one of their relatives, using a simple cell phone, anywhere, and especially outside a medical, dental or orthodontic practice.

In addition, the image acquisition apparatus does not need to be mechanically stabilized, for example by means of a tripod or by integration into a floor-mounted device.

Of course, an acquisition kit does not allow very precise positioning of the acquisition apparatus in relation to the teeth.

In particular, the accuracy of positioning the retractor in relation to the teeth is limited. The person creating the images also positions the image acquisition apparatus in an approximate manner, despite the matching of the 1st drilling in relation to the reference on the screen. As we will see in more detail in the

As described below, however, image processing does not require very precise positioning of the acquisition apparatus at the time the images are acquired.

Unlike the previous technique, for example described in WO2006/065955, it is in particular not necessary, at the time of image acquisition, to use registration marks the positioning of which is perfectly defined in relation to the teeth, in particular because they have been fixed to the teeth themselves or because they result from local modification of a tooth at a specific point, for example by laser.

The ability to acquire images with limited precision is a considerable advantage, since it makes acquisition possible anywhere and by anyone. In particular, the patient no longer needs to visit the orthodontist.

Preferably, no measurements are taken on the teeth to bring the acquisition apparatus into the matching position.

Preferably, no registration mark corresponding to a reference appearing on the screen is attached directly to the patient's teeth, gums or dental arches.

In particular, the acquisition apparatus can be a cell phone, and the program can be a specialized cell phone app.

The retractors can have any of the features of the retractors used to date. Typically, the retractor comprises a support base with a rim extending around an opening and arranged so that the patient's lips can rest on it, allowing the patient's teeth to show through said opening (Fig. 5a and Fig. 5c).

The support base, for example made of plastic, is preferably substantially flat in shape and weighs less than 500 g, preferably less than 300 g. The opening is preferably arranged substantially in the center of the support. The surface area of the opening is preferably greater than 15 $cm^2$, greater than 30 $cm^2$, greater than 40 $cm^2$, greater than 50 $cm^2$, and/or less than 100 $cm^2$, less than 80 $cm^2$, less than 60 $cm^2$.

Preferably, as shown in Figure 5a, the retractor comprises a number of markings, preferably non-aligned, preferably coplanar.

Preferably, the retractor features at least three markings and the is used to display one or more corresponding references on the display of the acquisition apparatus.

In one embodiment, the positioning of the image acquisition apparatus results solely from matching references appearing on the screen of the acquisition apparatus with the corresponding registration marks, preferably with registration marks of a dental retractor.

In one embodiment, the reference(s) appearing on the screen are determined according to the patient and/or the therapeutic treatment. In other words, the computer program is parameterized according to the patient so that the images acquired correspond specifically to the patient's needs. Advantageously, at the time of image acquisition, the acquisition apparatus is thus placed in a position that is substantially optimal in terms of the patient's particular features and/or the therapeutic treatment being applied.

As will be seen in greater detail later in this description, the retractor's registration marks preferably have several functions. First, they guide the positioning of the image acquisition apparatus at the time of image acquisition, by means of corresponding references appearing on the acquisition apparatus display.

In step c), they also enable the updated images to be cropped. Lastly, the registration marks on the retractor, which appear on the images, in step d), allow the approximate virtual acquisition conditions approaching the actual acquisition conditions to be determined, which allows data processing to be accelerated.

Steps c) and following are best carried out either on the patient's own device, preferably using the device used in step b), or with an app at a dental professional's office, or with a dedicated third-party server.

**In step c),** each updated image is analyzed to produce, for each updated image, an updated map relating to at least one piece of discriminant information.

Cropping

Image analysis may involve cropping the updated image in order to isolate the relevant part, in particular to remove from the updated image, at least partially, those elements which were not the subject of the initial reference model, such as the patient's nose or eyes, or the retractor. This modification, or “cropping”, is facilitated by registration marks on the updated image.

In particular, as shown in Figures 5a and 5c, the retractor 10 preferably has at least three non-aligned registration marks 12. If the retractor is in several parts, for example classically in two parts, each part preferably has at least three non-aligned registration marks.

The shape of a registration mark, for example an asymmetrical shape, can also be used to locate the position of the retractor in the updated image.

Preferably, the markers have shapes and/or colors that make them easy to identify in an updated image. For example, they can be black while the rest of the retractor is white in color.

In one embodiment, the markers have shapes and/or colors that enable them to be individually identified. For example, they may each be a different color.

By identifying the registration marks on the updated image, it is possible to identify the area of the updated image containing the elements that were the subject of the initial reference model,

i.e. the teeth and gums. The updated image can then be cropped accordingly. Comparison of Figures 5a and 5b, or 5c and 5d, shows the effect of cropping on an updated image.

Updated map

An updated map presents discriminant information in the updated image reference frame. For example, figure 6b is an updated tooth contour map obtained from the updated image of figure 6a.

Discriminant information is preferably chosen from the group consisting of contour information, color information, density information, a distance information, brightness information, saturation information, reflection information and combinations of these.

A person of skill in the art know how to process an updated image to reveal discriminant information. This processing involves, for example, the application of well-known masks or filters provided by image processing software. Such processes can be used, for example, to detect high-contrast regions and determine contours.

These processes include one or more of the following well-known and preferred methods:

- by applying a Canny filter, in particular to search for contours using Canny's algorithm;
- by applying a Sobel filter, in particular for calculating derivatives using the extended Sobel operator;
- by applying a Laplace filter, to calculate the Laplacian of an image;
- by blob detection on an image (“Blob detector”);
- by applying a threshold to apply a fixed threshold to each element of a vector;
- by resizing, using ratios between pixel areas (“Resize(Area)”) or bi-cubic interpolations on the pixel environment;
- by erosion of the image using a specific structuring element;
- by expansion of the image with a specific structuring element;

- by retouching, in particular using regions near the restored area;
- by applying a bilateral filter;
- by applying a Gaussian blur;
- by applying an Otsu filter, to find the threshold that minimizes intra-class variance;
- by applying an A* filter, to find a path between points;
- by applying an adaptive threshold to a vector;
- by applying an equalization filter to a histogram of a grayscale image in particular;
- by BlurDetection, to calculate the entropy of an image using its Laplacian;
- by contour detection ("FindContour") of a binary image;
- by color fill ("FloodFill"), in particular to fill a connected element with a specific color.

The following non-limiting methods, although not preferred, can also be used:

- by applying a "MeanShift" filter, in order to find an object on an image projection;
- by applying a "CLAHE" filter, for "Contrast Limited Adaptive Histogram Equalization";
- by applying a "Kmeans" filter, to determine the cluster center and the groups of samples around clusters;
- by applying a DFT filter, in order to perform a discrete, direct or inverse Fourier transformation of a vector;
- by calculating moments;
- by applying a "HuMoments" filter to calculate invariants of Hu invariants;
- by calculating the integral of an image;
- by applying a Scharr filter, which calculates an image derivative using a Scharr operator;
- by searching for the convex set of points ("ConvexHull");

- by searching for contour convexity points (“ConvexityDefects”);
- by shape comparison (“MatchShapes”);
- by checking whether points are in a contour (“PointPolygonTest”); by detecting Harris contours (“ComerHarris”);
- by searching for the minimum eigenvalues of gradient matrices to detect corners (“ComerMinEigenVal”);
- by applying a Hough transform to find circles in a greyscale image (“HoughCircles”);
- by Active contour modeling (tracing the contour of an object from an image) 2D potentially “noisy”;
- by calculating a field of forces, called GVF (“gradient vector flow”), in a part of the image;
- by Cascade Classification;
- by “Deepleraning” [sic].

Preferably, the discriminant information is optimized by means of an optimization process according to the invention comprising steps Cl to C3.

**In optional step d),** the actual acquisition conditions in step b) are roughly determined. In other words, at least the relative position of the image acquisition apparatus at the time it took the updated image (position of the acquisition apparatus in space and orientation of this device). Step d) advantageously limits the number of tests on virtual acquisition conditions in step e), and therefore speeds up step e) considerably.

Preferably, one or more heuristic rules are used. For example, it is preferable to exclude from the virtual acquisition conditions likely to be tested in step e), the conditions corresponding to a position of the image acquisition apparatus behind teeth or at a distance from the teeth greater than 1 m.

In a preferred embodiment, as illustrated in figure 7, registration marks shown on the updated image, and in particular registration marks 12 on the retractor, are used to determine a region of the substantially conical space delimiting virtual acquisition conditions likely to be tested in step e), or the “test cone”.

Specifically, at least three non-aligned registration marks 12 are arranged on the retractor 10, for example, and their relative positions on the retractor are precisely measured.

The registration marks are then marked on the updated image, as described above. Simple trigonometric calculations are used to approximately determine the direction in which the updated image was taken. A cone oriented in this direction, whose vertex is at the level of the retractor and whose half-angle at the vertex is preferably less than 10°, preferably less than 5°, for example 3°, can then be defined as a “test cone”. The half-angle at the apex corresponds to a degree of uncertainty. The smaller the half-angle at the vertex, the greater the probability that the virtual acquisition conditions corresponding to the real acquisition conditions are outside the test cone.

For example, when the updated image is taken perpendicular to the plane of the three markings on the retractor, it can be deduced that the acquisition apparatus was substantially in a test cone the axis of which is substantially perpendicular to this plane during capture of the updated image. If the relative positions of the three registration marks on the updated image are different from those of the registration marks on the retractor, the axis of the test cone to which the search for the position of the acquisition apparatus is limited when the updated image is acquired is tilted with respect to the plane of the registration marks, as shown in figure 7.

In a particular embodiment, as illustrated in Figures 5a and 5c, the retractor comprises independent left and right parts, each of which has at least three, preferably at least four, registration marks. A left test cone can thus be determined by means of the registration marks on the left part, and a right test cone can be determined by means of the registration marks on the right part of the retractor. The virtual acquisition conditions that can be tested may then be limited to positions of the acquisition apparatus in the space belonging to these two test cones. We can also consider that the best assessment of the acquisition apparatus position corresponds to the average position between the best position in the left test cone and the best position in the right search cone.

The position of the registration marks on the updated image can also be used to assess the attitude of the acquisition apparatus when capturing the updated image. For example, if two registration marks are known to be substantially aligned in a horizontal direction during acquisition of the updated image, the direction of the line containing these two points on the updated image provides an indication of the orientation of the acquisition apparatus under actual acquisition conditions.

Finally, the size and surface of the registration marks on the updated image, or their spacing, can be used to assess the distance between the image acquisition apparatus and the teeth when the updated image is acquired, and thus to reduce the test cone to a truncated cone.

In optional step d), data supplied by the acquisition apparatus and relating to its orientation, such as gyroscopic data, can also be used.

Preferably, in step d), the calibration of the actual acquisition apparatus in step b) is roughly determined.

The manner in which each calibration parameter affects the acquired image is well known. In particular, the operation of an acquisition apparatus can be classically modeled in such a way as to be able to test a particular calibration on the acquired image. The inventors have inverted such a model, without any particular technical difficulty, so that by analyzing the representation of the retractor, it is possible to roughly assess the calibration of the acquisition apparatus in step b).

For example, the ratio between the area of the registration marks on the updated image and the area of the updated image is used to evaluate the focal length of the acquisition apparatus in step b). The representation of a registration mark whose optical characteristics are known enables exposure time and sensitivity to be evaluated.

In a preferred embodiment, a registration mark is a relief that does not extend exclusively in the general plane of the retractor, corresponding to a plane parallel to the frontal (or coronal). Preferably, a registration mark is a relief that extends in a plane substantially perpendicular to the general plane of the retractor. In particular, the relief can take the form of a tongue which, when the retractor is in its operating position, extends towards the back of the mouth.

Analysis of the representation of this relief allows assessment of the depth of field. Alternatively, two registration marks that are not in the same frontal plane can be used for this purpose.

Step d) allows only a rough assessment of the actual acquisition conditions. Step d) does, however, identify a small set of virtual acquisition conditions that are likely to correspond to the actual acquisition conditions, and within this set, virtual acquisition conditions that provide the best starting point for step e1) described below.

Step d) also detects updated images that are unsuitable for further processing, e.g. an updated image that does not show registration marks. Preferably, the process is then resumed in step c) with a new updated image.

Of course, the various methods that can be used in step d) can be combined.

The aim of step e) is to modify the initial reference model until a final reference model is obtained that corresponds to the updated image. Ideally, the final reference model is a three-dimensional digital reference model from which the updated image could have been taken if this model had been real.

A succession of “to-be-tested” reference models is then tested, the choice of a reference model to be tested preferably depending on the level of correspondence of the previously tested “to-be-tested” reference models with the updated image. This choice is preferably made by following a known optimization procedure, in particular chosen from metaheuristic optimization procedures, preferably evolutionary, in particular in simulated annealing procedures.

**In step e1),** it is determined that the reference model to be tested is the initial reference model from the first execution of step e2).

**In step e2)**, virtual acquisition conditions to be tested are first determined, i.e. a virtual position and orientation likely to correspond to the actual position and orientation of the acquisition apparatus when the updated image is captured, but also preferably a virtual calibration likely to correspond to the actual calibration of the acquisition apparatus when the updated image is captured.

The first virtual acquisition conditions to be tested may be random. Preferably, they are chosen from the limit set determined in step d), and even more preferably, correspond to virtual acquisition conditions corresponding, according to step d), to the most promising virtual acquisition conditions, i.e. constituting the best springboard for approaching, as quickly as possible, real acquisition conditions (step e21)).

The image acquisition apparatus is then virtually configured under the virtual acquisition conditions to be tested, in order to acquire a reference image of the reference model under these virtual acquisition conditions to be tested. The reference image thus corresponds to the image that the image acquisition apparatus would have taken if it had been positioned, relative to the reference model to be tested, and optionally calibrated in the virtual acquisition conditions to be tested (step e22)).

If the updated image was taken at the same time as the reference model, and if the virtual acquisition conditions are exactly the same as the actual acquisition conditions, then the reference image is exactly superimposable on the updated image. Differences between the updated image and the reference image result from errors in the evaluation of the virtual acquisition conditions (if they do not correspond exactly to the actual acquisition conditions) and from tooth displacements between step b) and the reference model to be tested.

To compare the updated and reference images, the discriminant information on both images is compared. More precisely, a reference map representing the discriminant information is created from the reference image (step e23).

The updated and reference maps, both relating to the same discriminant information, are then compared, and the difference between the two maps is assessed by means of a score. For example, if the discriminant information is tooth contour, we can compare the average distance between the points of the tooth contour that appear on the reference image and the points of the corresponding contour that appear on the updated image, the lower the distance, the higher the score.

Preferably, the virtual acquisition conditions include the calibration parameters of the acquisition apparatus. The higher the score, the closer the tested calibration parameter values are to the values of the calibration parameters of the acquisition apparatus used in step b). For example, if the tested diaphragm aperture

is far from that of the acquisition apparatus used in step b), the reference image shows blurred and sharp regions that do not correspond to the blurred and sharp regions of the updated image. If the discriminant information is tooth contour, the updated and reference maps will therefore not represent the same contours and the score will be low.

The score can be, for example, a correlation coefficient.

The score is then evaluated by means of a first evaluation function. The first evaluation function is used to decide whether cycling on step e2) should be continued or stopped. The first evaluation function can, for example, be equal to 0 if cycling is to be stopped or equal to 1 if cycling is to continue.

The value of the first evaluation function may depend on the score achieved. For example, it may be decided to continue cycling through step e2) if the score does not exceed a first threshold. For example, if an exact match between the updated and reference images leads to a score of 100%, the first threshold may be, for example, 95%.

Of course, the higher the first threshold, the more accurate the evaluation of virtual acquisition conditions will be if the score manages to exceed this first threshold.

The value of the first evaluation function may also depend on scores obtained with previously tested virtual acquisition conditions.

The value of the first evaluation function may also depend on random parameters and/or the number of cycles already performed in step e2).

In particular, it is possible that, despite the repetition of cycles, virtual acquisition conditions cannot be found that are sufficiently close to real acquisition conditions for the score to reach said first threshold. The first evaluation function can then lead to a decision to quit cycling even though the best score obtained has not reached said first threshold. This decision may result, for example, from a number of cycles that exceeds a predetermined maximum number.

A random parameter in the first assessment function may also allow further testing of new virtual acquisition conditions, even though the score appears satisfactory.

The evaluation functions traditionally used in metaheuristic optimization processes, preferably evolutionary, in particular in simulated annealing processes, can be used for the second evaluation function.

If the value of the first evaluation function indicates that it is decided to continue cycling on to step e2), the virtual acquisition conditions tested are modified (step e25)) and a cycle is repeated (step e2)) consisting of producing a reference image and a reference map, then comparing this reference map with the updated map to determine a score.

The modification of the virtual acquisition conditions corresponds to a virtual displacement in space and/or a modification of the orientation and/or, preferably, a modification of the calibration of the acquisition apparatus. This modification can be random, provided however that the new virtual acquisition conditions to be tested still belong to the set determined in step d). The modification is preferably guided by heuristic rules, for example by favoring those modifications which, according to an analysis of the previous scores obtained, appear the most favorable for increasing the score.

Figures 12a and 12b illustrate, for example, the effect of a change in virtual acquisition conditions, in this case a change in focal length, on the reference image.

Cycling on e2) is continued until the value of the first evaluation function indicates that it is decided to exit this cycling and continue to step e3), for example if the score reaches or exceeds said first threshold.

Optimization of the virtual acquisition conditions in step e2) is preferably performed using a metaheuristic method, preferably evolutionary, preferably a simulated annealing algorithm. Such an algorithm is well known for non-linear optimization.

If cycling has been terminated at step e2), without a satisfactory score having been achieved, e.g. without the score having reached said first threshold, the process can be stopped (failure situation) or resumed at step c) with new discriminant information and/or with a new updated image. The process can also be continued with the virtual acquisition conditions corresponding to the best score achieved. A warning can be issued to inform the user of the error in the result.

If cycling has been terminated in step e2) even though a satisfactory score has been obtained, for example because the score has reached or even exceeded said first threshold, the virtual acquisition conditions correspond substantially to the real acquisition conditions.

Preferably, virtual acquisition conditions include the calibration parameters of the acquisition apparatus. In this way, the method allows the values of these parameters to be evaluated without the need to know the nature of the acquisition apparatus or its setting. Step b) can therefore be carried out without any particular precautions, for example by the patient himself using his cell phone.

In addition, the actual calibration test is performed by comparing an image with an image.

updated with views of an initial reference model under the virtual acquisition conditions being tested. Advantageously, it does not require the updated image to show a calibration standard gauge, i.e. a gauge whose characteristics are precisely known, enabling the calibration of the acquisition apparatus to be determined.

WO2006/065955, incorporated by reference, describes the use of images to produce three-dimensional models in the field of orthodontic treatment. However, this document does not describe a method for using simple photographs, typically presenting partial images of teeth, blurred image portions and variable reflections, taken generally non-simultaneously, without the need to select remarkable points on the images, and with an acquisition apparatus whose calibration is not known.

In a method for checking tooth positioning according to the invention, the updated images are not used to create a completely new, updated three-dimensional model, but only to modify the initial, very precise reference model. In particular, a completely new, updated three-dimensional model created from simple photographs taken without any particular precautions would be too imprecise for a comparison with the initial reference model to lead to any conclusions about tooth displacement.

Differences may still exist between the virtual acquisition conditions determined and the actual acquisition conditions, in particular tooth edges that have moved between steps a) and b). The correlation between updated and reference images can then be

further improved by repeating step e2), the reference model to be tested then being modified by moving one or more tooth models (step e3)).

The search for a reference model that best approximates the positioning of the teeth during acquisition of the updated image can be carried out in the same way as the search for virtual acquisition conditions that best approximate the actual acquisition conditions (step e2)).

In particular, the score is evaluated by means of a second evaluation function. The second evaluation function is used to decide whether cycling on steps e2) and e3) should be continued or stopped. The second evaluation function can, for example, be equal to 0 if cycling is to be stopped or equal to 1 if cycling is to be continued.

The value of the second evaluation function preferably depends on the best score obtained with the reference model to be tested, i.e. the differences between the updated and reference maps, under virtual acquisition conditions that best approximate said real acquisition conditions.

The value of the second evaluation function may also depend on the best score obtained with one or more reference models tested previously.

For example, it may be decided to continue cycling if the score does not exceed a second minimum threshold. The value of the second evaluation function may also depend on random parameters and/or the number of cycles already performed in steps e2) and e3).

The evaluation functions classically used in metaheuristic optimization processes, preferably evolutionary, in particular in simulated annealing processes, can be used for the second evaluation function.

If the value of the second evaluation function indicates that it is decided to continue cycling on steps e2) and e3), the reference model to be tested is modified and a new cycle is run (steps e2) and e3)) with the new reference model to be tested.

The modification of the reference model to be tested corresponds to the displacement of one or more tooth models. This modification can be random. The modification is preferably guided by heuristic rules, for example by favoring those modifications which, according to an analysis of previous scores obtained, appear most favorable for increasing the score.

Preferably, the displacement of a tooth model with the greatest impact on the score is sought, the reference model to be tested is modified by displacing this tooth model, and then the cycling is continued through steps e2) and e3) in order to optimize the score. We can then search for the tooth model with the greatest impact on score improvement, and again find the optimal displacement of this other tooth model on the score. We can continue in this way with each tooth model.

After this, a cycle can be repeated on all tooth models, until a score above the second threshold is achieved. Of course, other strategies can be used to move one or more tooth models into the reference model to be tested and search for the maximum score.

Cycling through steps e2) and e3) is continued until the value of the second evaluation function indicates that it is decided to exit this cycling and continue with step f), for example if the score reaches or exceeds said second threshold.

The search for a reference model with cycling through steps e2) and e3) to find the positions of the tooth models that optimize the score is preferably performed using a metaheuristic method, preferably evolutionary, preferably a simulated annealing algorithm. Such an algorithm is well known for non-linear optimization.

If cycling has been terminated at steps e2) and e3) without a satisfactory score having been obtained, for example without the score having reached said second threshold, the process can be stopped (failure situation) or resumed at step c) with new discriminant information and/or with a new updated image.

If it is decided to restart the process in step c) on the basis of another piece of discriminant information and/or another updated image because the first threshold or the second threshold has not been reached, the choice of the new piece of discriminant information and/or the new updated image may depend on the scores obtained previously, in order to favor the piece of discriminant information and/or the updated image which, with regard to these scores, appear to be the most promising.

New discriminant information, obtained for example by combining other discriminant information already tested, can be used. If required, one or more new, updated images may also be acquired. Preferably, indications are provided to guide the positioning of the acquisition apparatus for the capture of this new updated image. For example, the patient may be told that he should take a picture of the right side of his lower arch.

If cycling has been terminated on steps e2) and e3) without a satisfactory score having been obtained, the process can also be continued with the reference model and virtual acquisition conditions corresponding to the best score achieved. A warning can be issued to inform the user

of the error in the result.

If cycling has been terminated in steps e2) and e3) while a satisfactory score has been obtained, for example because the score has reached or even exceeded said second threshold, the virtual acquisition conditions correspond substantially to the real acquisition conditions and the tooth models in the reference model obtained (known as the “final reference model”) are substantially in the position of the patient's teeth at the time of step b).

Cycling through steps e2) and e3) advantageously improves the evaluation of the acquisition apparatus calibration parameters in step b).

**In step f),** the final reference model, resulting from optimization by shifting the tooth models, is compared with the initial reference model. The final reference model corresponds substantially to the updated image. By comparing step f), it is possible to observe the differences between tooth positioning in step a) (initial reference model) and during acquisition of the updated image (step b)). In this way, it is possible to accurately determine the movements of individual teeth between these two stages.

By repeating steps b) and following, it is also possible to evaluate the rate of change in tooth position, and thus measure the effectiveness of orthodontic treatment, for example. A method for monitoring tooth position according to the invention can, for example, be used to remotely monitor the progress of an orthodontic treatment, and thus optimize patients' appointments with their orthodontists.

In a preferred embodiment, the testing procedure according to the invention is carried out several times for the same patient, preferably successively with several discriminating items of information, preferably more than 2, more than 3, more than 5 discriminating items of information for each updated image and/or with several updated images, preferably more than 2, more than 3, more than 5 updated images. The assessment of tooth displacement

can thus be refined by taking into account the different scores obtained. By comparing these scores, discriminant information and/or unsatisfactory updated images can be eliminated.

Depending on the displacement measured, practical information can be generated. If the displacement is small, this practical information may be that no action needs to be taken. On the contrary, if one or more teeth have shifted significantly, the information may be to plan a visit to the dentist or orthodontist. Preferably, the practical information depends on the degree of tooth displacement. In one embodiment, an appointment can be automatically made with the dentist or orthodontist, depending on the magnitude and/or nature of the detected displacements.

In one embodiment, the practical information is used to modify the time interval after which the patient should be notified that a new, updated image is to be created.

In one embodiment, the individual device can display images or even a sequence of images showing the positioning of teeth at different times. These images can be presented as an animation, for example in the form of a slide show or film.

Preferably, the image acquisition apparatus is a telephone that enables the results obtained by implementing the process to be transmitted, preferably in a secure manner.

For example, communication can be carried out, at least in part, over the air, preferably using at least one protocol chosen from the edge, 3G, 4G, udmsa, hpdmsa, Bluetooth and WIFI protocols, or any other protocol suitable for mobile or transportable equipment, by wired synchronization with the personal computer, or by optical transmission.

As is now clear, a method for checking the positioning of teeth according to the invention enables precise and effective control of the positioning of the patient's teeth, with virtually no restriction on the patient. In particular, simple photographs taken without any special precautions, for example with a cell phone, are sufficient. The patient can thus easily carry out the procedure.

## Detailed description of a method for controlling tooth shape

The invention also relates to a method for checking the shape of a patient's teeth. In step a), however, the definition of tooth models is not essential for this check.

Preferably, in step e), for each updated image, a final reference model corresponding to the shape of the teeth at the time of acquisition of the updated image is sought, the search preferably being carried out by means of a metaheuristic method, preferably evolutionary, preferably by simulated annealing, in particular by means of one of the metaheuristic methods described above.

Preferably, as described for step e), this search involves two nested optimization loops.

In the first optimization operation, virtual acquisition conditions are optimized in a reference model to be tested, which is initially the initial reference model, to match the actual acquisition conditions as closely as possible. In particular, a search is made for the virtual position of the acquisition apparatus relative to the reference model to be tested, which offers the view of this reference model to be tested, i.e. the reference image, which is closest to the updated image.

Preferably, as described above, a virtual calibration is also sought which may correspond to the actual calibration of the acquisition apparatus when the updated image is captured.

In the second optimization operation, the reference model to be tested is modified, the first optimization operation is repeated, and these two operations are repeated until the reference model to be tested and the virtual position of the acquisition apparatus are found, resulting in the reference image that is closest to the updated image.

These operations are similar to those described for the tooth positioning control process, and the optional features of the latter are optionally applicable.

However, following the tooth positioning control procedure described above, the reference model is modified by moving one or more tooth models. No deformation of the tooth models or of the initial reference model is required.

To check the shape of the teeth, the reference model is modified by changing the shape of the reference model to be tested, in particular one or more tooth models. Tooth models do not need to be moved.

Of course, it is preferable to carry out both types of modification to the reference model to be tested, in order to determine a final reference model that takes into account both tooth displacement and tooth deformation.

For example, a third optimization operation can be carried out, focusing on tooth displacement and framing the first two optimization operations, with the second optimization focusing on the shape of the tooth models or reference model to be tested. It is also possible to carry out only the first two optimization operations by modifying, if necessary, simultaneously, the shape and position of the tooth models in the second optimization operation.

A third optimization operation can also be carried out, relating to the shape of the tooth models or the reference model to be tested, and framing the first two optimization operations, with the second optimization operation relating to the displacement of the tooth models. For example, a final reference model “to be tested” is first searched for, taking into account, to the extent possible, the displacement of the tooth models, the final reference model to be tested corresponding to the final reference model of a step e) of a tooth positioning control process described above, and then a search is made for whether a deformation of the final reference model to be tested can lead to a better match with the updated image. For this search, the final reference model to be tested is deformed, the first two optimization operations are repeated, and then, depending on the match obtained, the search is stopped or continued by performing a new deformation of the final reference model to be tested, and by running the first two optimization operations.

Preferably, the first optimization operation and/or the second optimization operation and/or the third optimization operation, preferably the first optimization operation and the second optimization operation and the third optimization operation, implement a metaheuristic method, preferably evolutionary, preferably simulated annealing, in particular one of the aforementioned metaheuristic methods.

Preferably, to control tooth deformation, step e) comprises

- a first optimization operation to find virtual acquisition conditions that best match the real acquisition conditions in a reference model to be tested, determined from the initial reference model, and
- a second optimization operation enabling us to find, by testing a plurality of said reference models to be tested, the reference model best corresponding to the shape of the patient's teeth at the time of acquisition of the updated image in step b), preferably best corresponding to the shape and positioning of the patient's teeth at the time of acquisition of the updated image in step b).

Preferably, a first optimization operation is performed for each test of a reference model to be tested during the second optimization operation.

Step e) may include the following steps:

e'1) definition of the reference model to be tested as the initial reference model then,

e'2) following these steps, testing virtual acquisition conditions with the reference model to be tested in order to finely approximate said real acquisition conditions;

e'21) determination of virtual acquisition conditions to be tested;

e'22) creation of a two-dimensional reference image of the reference model to be tested in said acquisition conditions to be tested;

e'23) processing the reference image to produce at least one reference map representing said discriminant information;

e'24) comparison of updated and reference maps in order to determine a value for a first evaluation function, said value for the first evaluation function depending on the differences between the said updated and reference maps and corresponding to a decision to continue or stop the process search for virtual acquisition conditions approximating said real acquisition conditions more accurately than said virtual acquisition conditions to be tested determined at the half first occurrence of step e'21);

e'25) if said value for the first evaluation function corresponds to a decision to continue said search, resumed in step e'21) by modifying the virtual acquisition conditions to be tested;

e'3) otherwise determining a value for a second assessment function, said value for the second evaluation function depending on the differences between the updated and reference maps in the virtual acquisition conditions best approximating said real acquisition conditions and resulting from the last occurrence of step e'2), said value for the second evaluation function corresponding to a decision to continue or stop research of a reference model approximating the shape, and possibly the positioning, of the teeth at the time of acquisition of the updated image with greater accuracy than said reference model to be tested used upon the last occurrence of step e'2), and
if said value for the second assessment function corresponds to a decision to continue said research, modification of the reference model to be tested by deformation of one or more tooth models, or of the reference model to be tested, and possibly by moving one or several tooth models, then repeated in step e'2).

Upon completion of this process, a reference model is created for testing, known as the “final reference model”, which corresponds to the initial reference model deformed to match the updated image as closely as possible.

Comparison of the initial and updated reference models involves comparing the spatial coordinates of the points on the surfaces defined by the two reference models. In this way, any changes in shape between step a) and step b) can be deduced.

Preferably, a mapping of the tooth is produced, showing the changes in shape. Preferably, as shown in figure 8, the color of an area of the mapping is a function of the extent of change in shape of that area. In particular, Figure 8 shows a zone 16 indicating a tooth fracture.

Of course, the method for checking the shape of a patient's teeth can be used to detect the addition or subtraction of material, as well as constant-volume deformation. It can also be used to detect tooth displacements, even without a tooth model. However, in the absence of a tooth model, it cannot distinguish between tooth deformation and tooth displacement.

**Detailed description of a method for checking the appearance of teeth**

Checking the evolution of tooth color from photographs taken in different camera positions or in different light environments shows that this comparison does not allow us to assess an evolution in the appearance of these teeth.

This kind of tooth color control requires special care, particularly when it comes to accurately defining the position of the camera and its lighting environment.

There is therefore a need for a method of controlling the color, and more generally an appearance property, of teeth in a simpler way, and in particular by avoiding these particular precautions.

One aim of the invention is to meet this need.

The invention provides a method for checking the appearance properties of a patient's teeth, said method comprising the steps A. to E. described above, shown in figure 9.

As will be seen in greater detail later in the description, this method makes it possible to assess whether the appearance, in particular the color, of one or more teeth has been altered, even when the conditions for acquiring photographs of a patient's teeth are not predefined, for example because the photographs were taken in a light environment or in any position of the acquisition apparatus, in particular by the patient. By “appearance property” we mean a property relating to appearance. The appearance property can be chosen in particular from the group consisting of color, opalescence, fluorescence, gloss, transparency, and combinations of these properties.

The term “appearance” refers to a value or set of values used to quantify an aspect property. Unless otherwise indicated, the “appearance” mentioned in the present description refer to the appearance property that can be controlled by the method.

Steps A. and B.

Steps A. and B. can be performed in the same way as step b) above.

Steps A. and B. are best carried out by the patient or someone close to the patient, but can also be performed by a dentist.

The time interval between these steps can be as described above between steps a) and b), for example greater than 1 week, 2 weeks, 1 month or 3 months.

The first acquisition apparatus may be identical to or different from the second acquisition apparatus. It can be an acquisition apparatus chosen from those that can be used for step b), in particular a camera or a cell phone.

Preferably, the acquisitions in steps A. and/or B. are carried out using flash. This improves results. Preferably, the initial and/or updated image is overexposed.

The reference gauges used for each of steps A. and B. have the same appearance. Preferably, they are placed in the same position relative to the patient's teeth for each step.

Preferably, dental retractors are used for each of steps A. and B. These retractors may be identical or different. Preferably, the reference gauge is carried by a retractor for at least one of steps A. and B., preferably for each of steps A. and B. Preferably, even if the retractors used for each of steps A. and B. are different, the reference gauges are arranged on the retractors in the same position relative to the retractor opening 14 which reveals the patient's teeth (Fig. 5a).

Preferably, the reference gauge is positioned on the retractor so that it is at in proximity to the teeth the appearance of which is to be examined. Preferably, the reference gauge is positioned less than 3 cm, preferably less than 2 cm, more preferably less than 1 cm from the part of the retractor intended to be introduced into the patient's mouth.

Preferably, each retractor has several identical or different reference gauges. Preferably, several different reference gauges of the same retractor present different aspects. The conclusions drawn from the comparison of normalized images can advantageously be richer.

A reference gauge can be, for example, a point that can be located on the retractor and the appearance of which is known, for example with color parameters L*, and/or a* and/or b*, measured in accordance with NF ISO 7724, that are known. The reference gauge can be, in particular, a registration mark as described above.

The acquisition conditions specify the spatial position and/or orientation of the acquisition apparatus relative to the retractor.

To improve the accuracy of aspect control, it is preferable for the acquisition conditions to be substantially the same in steps A. and B. For example, it is preferable for both images to be taken substantially from the front. Preferably, the image acquisition apparatus used for at least one, and preferably for each of steps A. and B., features means to facilitate its positioning relative to the patient prior to image acquisition.

The location means preferably interact with registration marks on the retractor. Preferably, the acquisition apparatus is programmed so that in real time, to detect registration marks on the retractor, analyze their relative positions or dimensions and, as a result, inform the user of the device to modify the position of the acquisition apparatus in relation to the patient's teeth.

These location means can have one or more of the characteristics of the location means described above for step b).

Preferably for at least one, preferably for each of steps A. and B., an acquisition kit according to the invention is used and, preferably, an acquisition method is used including steps (a) to (e). Preferably, the target acquisition conditions are the same in the report from the first and second acquisition apparatus, so that the acquisition apparatus will guide the user in order for the initial and updated images to be taken under substantially identical acquisition conditions.

Preferably, the target acquisition conditions are determined as a function of the teeth whose aspect properties are to be checked. For example, the target acquisition conditions preferably correspond to an image taken facing the patient for a check on an incisor, and they preferably correspond to a lateral image taken for a check on a molar.

Step C.

Step C. consists of normalizing, i.e. “correcting” the initial image and/or the updated image so that, after correction, the representations of the reference gauge on these images have the same appearance. Since the reference gauge has not changed its appearance between steps A. and B., any differences in the appearance of the representations of the teeth on the initial and updated normalized images correspond to actual differences in the appearance of the teeth.

First, we search for the reference gauge on the initial image and on the updated image. A simple image analysis is all it takes. Standardization can be performed on the initial image only in order to modify the representation of the reference gauge so that its appearance is identical to that of the representation of said reference gauge on the updated image. Standardization can be alternatively performed on the updated image only in order to modify the representation of the reference gauge so that its appearance is identical to that of the representation of said reference gauge on the initial image. Finally, standardization can be performed on the updated image and on the initial image in order to modify the representations of the reference gauges so that their appearance is identical to that of a standard gauge.

Image standardization is a well-known technique in image processing. White balance is an example of image standardization.

Step D.

Before or after step C., it is necessary to identify, on each of the initial and updated images, a region of the teeth whose evolution in appearance is to be evaluated.

The use of registration marks or reference gauges is possible, but imprecise. Preferably, the initial and updated images are analyzed to represent discriminant information, of the type described above, such as tooth contours.

The analysis of the initial and updated images may include one or more features from step c), in particular relating to the nature of the discriminant information and to the processing to determine discriminant information. Discriminant information is

preferably optimized by means of an optimization process comprising steps Cl to C3
We then look for discriminant information common to both the initial and updated images.

The discriminant information common to both the initial and updated images can then be used as a reference to locate the said region on both images. For example, the contour of the gums may show a succession of “spikes” between the teeth. This contour depends on the teeth in question and can therefore be used as a reference.

In an improved embodiment, the initial and updated images are referenced to a reference model, preferably produced in accordance with step a) (initial reference model) or resulting from the implementation of a tooth shape and/or positioning control process according to the invention (final reference model).

This registration can be carried out as described above to locate the updated image as part of the tooth shape and/or positioning control procedures. Unlike these procedures, however, modification of the initial reference model to arrive at the final reference model is optional.

To locate an image with respect to the reference model, it is sufficient to search for the virtual acquisition conditions under which the acquisition apparatus would have acquired said image by observing said reference model. This search is preferably carried out using a metaheuristic method, such as those described above.

For this purpose, a procedure for evaluating the actual acquisition conditions according to the invention, described below, is preferably used. This method is preferably used for each of the initial and updated images using the reference model. It enables these images to be “projected” onto the reference model, and thus a point in these images to be identified on the reference model.

In this way, a region of the teeth where the evolution of appearance is to be assessed can be identified with a high degree of precision on each of the initial and updated images.

<u>Step E</u>.
It is then possible to measure the aspects of the said region on each of the initial images.
and to compare them in order to detect and assess differences in appearance.

A method for controlling the appearance of teeth according to the invention can be used for both therapeutic and non-therapeutic purposes. In particular, it can be used for:

- detect and/or measure a change in the color of teeth or the appearance and/or evolution of stains on teeth, or detect and/or measure calcification of teeth;

- check the effects on the appearance of teeth of a dietary habit or hygiene or of a treatment, for example a whitening treatment, or of a product, in particular a toothpaste, in particular for whitening teeth or for combating calcification or the appearance of stains.

For example, a method for checking the appearance of teeth according to the invention can be used to check the effects on the appearance of teeth of chewing gum or drinking coffee or tea, or smoking or taking drugs, or brushing teeth.

In a preferred embodiment, the patient simply takes regular photographs with a cell phone to create up-to-date images. Preferably, thanks to an app loaded into the phone, the patient can then compare the appearance of the teeth in these photographs.

In one embodiment, the application normalizes the photographs in order to make them comparable, then proposes a dynamic display of the corrected photographs, by

for example, in the form of a slide show or film.

## Detailed description of a method for evaluating actual acquisition conditions

Particularly for the implementation of a method for controlling the shape, size and form of a product. to optimize the quality of discriminant information, the invention provides a method for evaluating, on the basis of a two-dimensional image of a patient's dental arches, referred to as the “acquired image”, the actual acquisition conditions (position of the acquisition apparatus in space, orientation of this device and, preferably, calibration of the acquisition apparatus) of said acquired image, said method comprising the following steps:

001) production of a three-dimensional digital reference model of at least part of one of the patient's arches, preference of one of the patient's arches, preference of two of the patient's arches,

002) analysis of the acquired image and production of a map relating to discriminant information, known as the “acquired map”;

003) search for virtual acquisition conditions that optimally approximate said real acquisition conditions, following steps 01) to 05) below:

01) optionally, determination of coarse virtual acquisition conditions approximating said real acquisition conditions, preferably by analyzing the representation, on the acquired image, of a retractor used during acquisition of the acquired image;

02) determination of virtual acquisition conditions to be tested;

03) production of a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;

04) reference image processing to produce at least one reference map representing said discriminant information;

05) comparison of acquired and reference maps to determine a value for an evaluation function, said value for the evaluation function depending on the differences between said acquired maps and reference and corresponding to a decision to continue or stop the search of conditions acquisition virtual approximating the acquisition conditions with greater accuracy than said virtual acquisition conditions to be tested;

06) if said value for the evaluation function corresponds to a decision from continue said research, modification said virtual acquisition conditions to be tested, then return to step 03);

if not, evaluation of the actual acquisition conditions by said virtual acquisition conditions to be tested.

Preferably, the actual acquisition conditions to be assessed include one or more of the following calibration parameters: aperture, exposure time, exposure time, focal length and sensitivity.

In the assessment method, the modification of the virtual acquisition conditions to be tested in step 06) is preferably carried out by means of a metaheuristic method, preferably evolutionary, preferably simulated annealing, preferably using one of the above-mentioned metaheuristic methods.

An evaluation method according to the invention is preferably used whenever it is necessary to evaluate the actual acquisition conditions of an image. This image, which may in particular, an updated image acquired in step b) or B., or an initial image acquired in step A., is referred to as an “acquired image”.

Creating the reference model in step 001) may involve one or more of the following steps optional features of step a).

The acquisition of the acquired image may include one or more of the features, even if optional, of step b). Preferably, it implements an acquisition kit according to the invention, and preferably an acquisition method according to the invention.

Step 01) for determining the rough virtual acquisition conditions may include one or more of the features, even if optional, of step c).

Stages 02) to 06) may include one or more of the features, even optionally, of steps e21) to e25), respectively.

**Detailed description of a process for optimizing discriminant information**

A method of optimizing or “selecting” discriminant information according to the invention is intended to improve the reliability of initial discriminant information extracted from a two-dimensional image of a patient's dental arches, or “image acquired”, in particular an initial image from a step A. or an updated image from a step B. or b), acquired under real acquisition conditions.

“Optimization” of discriminant information is therefore a selection of discriminant information, following an iterative process, in order to select from the image the most relevant discriminant information to best control positioning and/or the shape of the patient's teeth.

The method is based on a digital three-dimensional reference model of at least part of a patient's arch, in particular an initial reference model from step a).

As shown in Figure 10, it comprises the following steps:

Cl. evaluating the quality of initial discriminant information and a quality threshold, filtering to retain only discriminant information, preferably all the initial discriminant information presenting a quality threshold, and definition of “discriminant information to be tested”;

C2. “matching” test between the discriminant information to be tested and the reference model;

C3. depending on the result and a test result assessment function:

- addition of discriminant information not retained to discriminant information to be tested and/or deletion of discriminant information from the discriminant information to be tested, then repeated in step C2. or,
- definition of optimal discriminant information as the discriminant information to be tested.

The discriminant information can be any of the discriminant information described above. By way of example, the discriminant information may be contour information.

The initial discriminant information is obtained by analyzing the acquired image, as described in step c).

Methods according to the invention using such initial discriminant information implement optimizations that produce better results if the discriminant information is both abundant and of good quality. One aim of the optimization process is therefore to improve the quality of the initial discriminant information.

In step Cl., the quality of the initial discriminant information is assessed. In the case of a contour, for example, contrast analysis provides more or less reliable information: an area of high contrast can be assimilated to an area corresponding to a contour with a high probability, and the quality of the points in this area will therefore be high. On the other hand, a low-contrast area, such as a blurred zone, can be assimilated to an area corresponding to a contour with a low probability, and the quality of the points in this area will be low. In this example, the probability of a point in the acquired image belonging to the contour can be chosen as an indicator of the “quality” of the discriminant information.

A quality threshold is used to filter the initial discriminant information. If the quality threshold is high, the discriminant information retained after filtering will be few in number, but highly reliable. If the quality threshold is low, the discriminant information retained will be abundant, but unreliable. In the example of contour information, image analysis will then lead to the retention of “false” contour points, i.e. points which,

will be mistakenly considered as belonging to the contour of teeth and gums.

In a preferred embodiment, the quality threshold is high in order to retain only highly reliable discriminating test information.

In step C2, concordance is tested, i.e. a degree of concordance is determined between the discriminant information to be tested and the reference model.

Preferably, an “acquired” map of the discriminant information to be tested is produced as a result of processing the acquired image.

Preferably, we then proceed according to steps 01) to 06), and in particular steps below:

02) determination of virtual acquisition conditions to be tested;

03) production of a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;

04) reference image processing to produce at least one map of reference representing discriminant information;

05) comparison of acquired and reference maps in order to determine a value for an evaluation function, said value for the evaluation function depending on the differences between said acquired and reference maps and corresponding to a decision to continue or stop the process search for virtual acquisition conditions that approximate real acquisition conditions more accurately than said virtual acquisition conditions to be tested;

06) if said value for the evaluation function corresponds to a decision to continue said research, modification of said conditions virtual acquisitions to be tested, then repeated in step 03);

otherwise, evaluation of actual acquisition conditions by said virtual acquisition conditions to be tested.

In step 04), the reference image is processed to produce a reference map representing said discriminant information. The selection criteria of the discriminant information represented on the reference map may be identical or different to those used to select the discriminant information to be tested.

Preferably, the discriminant information represented on the reference map is selected using the same criteria as the discriminant information to be tested.

In the example of a contour, reference image processing can consist of retaining the points in the reference image corresponding to a contour with a high probability.

The probability of a point in the reference image belonging to the contour can be determined in the same way as for acquired image processing, and can also be used as an indicator of the quality of the discriminant information. The quality threshold can also be identical to that used for acquired image processing. The contour represented on the reference map is then similar to that represented on the acquired map, and in particular

is virtually identical in length.

Steps 01) to 06) determine, with the reference model, the following conditions

10 virtual acquisition conditions that approximate the actual acquisition conditions of the acquired image. Observing the reference model under these virtual acquisition conditions results in a view that best matches the acquired image. However, the search for virtual acquisition conditions is based on the discriminant information to be tested. The

The degree of correspondence depends on the discriminant information to be tested. The higher the quality and quantity of the discriminant information to be tested, the better the degree of correspondence between the view of the reference model under virtual acquisition conditions and the acquired image, and the higher the degree of concordance between the reference model and the acquired image.

discriminant information to be tested and the reference model.

The degree of agreement can be measured, for example, by the inverse of the difference between

- the reference map relative to the image of the reference model observed under virtual acquisition conditions that best approximate the actual acquisition conditions resulting from the execution of steps 01) to 06), and
- the “acquired” card representing the discriminant information to be tested, corresponding to the acquired image

weighted by the amount of discriminant information to be tested.

For a contour, for example, the degree of concordance can be the ratio of the number of points that belong to both the contour of the reference map and the contour of the reference map.

acquired map, on the total number of points of the acquired map contour, or the product of the inverse of the average distance between the contours represented on said acquired and reference maps, and the length of the contour represented on the acquired map. The “best guess” approximation of the actual acquisition conditions based on the discriminant information to be tested can be evaluated by a result or “score”,

for example by the degree of match. The aim of the C2. and C3. cycle is to optimize this result by acting on the discriminant information to be tested.

This optimization is similar to that used for tooth positioning and/or shape control procedures. However, these procedures act on the initial reference model, by moving the tooth models and/or deforming the reference model, whereas the process for optimizing the discriminant information acts on the discriminant information used to create the acquired map.

The operation performed in step C3. is determined by an evaluation function for the test result in step C2. Preferably, the evaluation function takes into account results obtained in previous C2.-C3. cycles.

In particular, the process can be stopped if the evaluation function indicates that further C2.-C3. cycles do not improve the result, for example because one or more C2.-C3. cycles have failed to improve it or have failed to improve it significantly. The discriminant information tested in the C2.-C3. cycle that led to the best result is then considered optimal.

Alternatively, a new C2.-C3. cycle can be started, after modifying the discriminant information to be tested. The modification to be made to the discriminant information just tested may consist in adding or deleting discriminant information. A decision to add discriminant information may be taken, for example, if the last result was the best obtained to date and if, according to the evaluation function, the result can be further improved. Preferably, the discriminant information added is that which, of the discriminant information not selected in step Cl. and not yet tested, has the best quality.

For example, when the discriminant information is contour information, the addition of discriminant information may consist in adding points of the image not initially retained, never before added and whose quality, as evaluated in step Cl., is the highest, i.e. whose addition is most likely to improve the result of the test in step C2.

Discriminant information can be removed, for example, if the last result is worse than the previous one. In particular, the discriminant information added in the previous cycle can be deleted and further discriminant information added, as described above.

Determining the discriminant information to be added and/or removed can be random. Preferably, however, it results from the implementation of a metaheuristics method, preferably evolutionary, preferably simulated annealing, preferably of the type described above.

Example

By way of example, figure 11 shows a reference map superimposed on the acquired image, relating to reflection information (discriminant information).

The acquired image, preferably acquired by means of an acquisition kit according to the invention, is a photograph taken in a particular position and orientation of the camera. photo. This position and orientation constitute the actual acquisition conditions for the acquired image.

A person of skill in the art knows that, in the acquired image, the higher the brightness of a point, the higher the probability that this point belongs to a reflection zone. Brightness can therefore be used as an indicator of the “quality” of the reflection information.

Filtering in step Cl. can consist of retaining only those areas of the acquired image which have a brightness above a quality threshold, for example 70%.

The acquired map shows these areas, which constitute the discriminant information to be tested.

In step C2, steps 01) to 06) are used to test whether the selected zones are consistent with the observation of the reference model.

In step 01), the acquired image is analyzed to roughly evaluate the actual acquisition conditions by virtual acquisition conditions. This evaluation preferably results from an analysis of the position and/or shape of the representation, on the acquired image, of markers of a retractor used during acquisition.

Roughly estimated virtual acquisition conditions may constitute the “virtual acquisition conditions to be tested” in step 02).

In step 03), by observing the reference model from the virtual acquisition conditions to be tested, a reference image is obtained.

In step 04), as shown in figure 11, vectors (black dashes 20) of equal length, perpendicular to the faces of the reference model, can be projected onto the reference image. Circles 22 represent these vectors when viewed along their length. The reference map is thus formed by these black lines 20 and circles 22.

A person of skill in the art will know that the circles 22 normally correspond to areas of the image corresponding to reflections. On the reference map, the discriminant information, i.e. the reflection information, is represented by the black lines 20 and by the circles 22, the inverse of the length of the black lines being used as an indicator of the “quality” of the reflection information on the reference map, one circle corresponding to zero length, and done to maximum quality.

In step 05), a comparison of the acquired and reference maps may consist, for example, in checking whether the lines 20 and circles 22 are inside areas of the acquired map (which initially correspond to a brightness of over 70%). The evaluation function may be, for example, the ratio R between

- the difference between the number of circles 22 and the number of dashes that are within areas of the acquired image, and
- the total number of circles 22.

The decision may be to continue the search by modifying the virtual acquisition conditions to be tested until a maximum is reached for the acquisition function.

In step 06), if this maximum is considered to have been reached, we exit the loop of steps 03) a 06). Alternatively, a modification to the virtual acquisition conditions to be tested is determined, preferably by means of a metaheuristic method, preferably evolutionary, and step 03) is repeated.

Upon completion of steps 03) to 06), the R ratio is therefore maximized, for this acquired image, for example, at 95%. This ratio R then represents the result of the match test performed in step C2.

In step C3, this result is evaluated using an assessment function.

This assessment function determines whether the result is optimal or not. If the result is considered optimal, for example because no better result can be obtained after several cycles of steps C2.-C3, the areas of the corresponding acquired map are deemed to provide optimal discriminant information.

Alternatively, the acquired map is modified, for example by adding points from the acquired image, e.g. by adding points with a brightness greater than 71%. This addition leads to the addition of circles in areas of the acquired map, which improves the R ratio, but also to the addition of black lines, which degrades the R ratio. Reciprocally, it is possible to remove points with a brightness greater than 69%. This deletion leads to the deletion of circles in the acquired map areas, which

degrades the R ratio, but also results in the removal of black lines, which improves the R ratio.

The change to be made is preferably guided by a metaheuristic method, preferably evolutionary. Based on the newly acquired map, which defines the discriminant information to be tested, we resume step C2.
The cycling of steps C2. and C3. can be continued until an optimum result is determined. The discriminant information to be tested is then considered optimal.

As is now clear, a method for optimizing discriminant information according to the invention enables discriminant information of good quality and abundance to be constructed. In particular, it enables a partial but good-quality initial contour to be progressively built up into a more complete but still good-quality contour.
Of course, the invention is not limited to the embodiments described and presented above.

In particular, unless otherwise indicated, the optional features described in the context of a step of a first process according to the invention are applicable in the context of an analogous or identically referenced step of a second process according to the invention.

The method for checking tooth position and/or shape can be used successively for each of the two arches, or simultaneously for both arches. In addition, several different devices can be used for these procedures. For example, acquisition can be carried out using a cell phone and the subsequent steps using a fixed computer.

Lastly, the patient is not limited to a human being. In particular, a tooth positioning control method according to the invention can be used for any other animal.

# CLAIMS

1. A method for monitoring the appearance of a patient's teeth, comprising the following successive steps:
   A. acquisition, by means of a first acquisition apparatus, of at least a first two-dimensional image of said teeth and of a first reference gauge, referred to as the “initial image”;
   A. acquisition, by means of a second acquisition apparatus, of at least a second two-dimensional image of said teeth and a second reference gauge with the same appearance as the first reference gauge, the “updated image”;
   B. standardization of the initial and updated images so that the representations of the first and second reference gauges on the normalized initial and updated images have the same appearance;
   D. before or after step C., identification of the same tooth region on the initial and updated images;
   E. comparison of the appearance of said region on the initial and updated normalized images.

2. A process according to the preceding claim, in which the time interval between steps A and B is greater than 1 week.

3. A process according to any of the preceding claims, wherein the first and/or second acquisition apparatuses are cameras and/or mobile telephones, the acquisitions in steps A. and/or B. being carried out under the illumination of a flash.

4. A process according to any one of the preceding claims, wherein the acquisitions in steps A. and/or B. are carried out by means of an acquisition kit comprising:
   - a dental retractor designed to be placed in a patient's mouth, and having a registration mark;
   - an image acquisition apparatus with
     - a display screen,

- a computer memory containing information on target acquisition conditions,
- a computer program comprising program code instructions for simultaneously displaying an image on said screen and a reference, said reference being in a position such that, when the registration mark corresponds to the reference on the screen, the acquisition apparatus complies with the target acquisition conditions.

5. A process according to the immediately preceding claim, in which the target acquisition conditions are determined as a function of the teeth whose appearance property is to be checked.

6. A process according to any one of the two immediately preceding claims, in which the acquisitions in steps A. and B. are carried out by means of acquisition kits in which the target acquisition conditions are identical.

7. A process according to any one of the three immediately preceding claims, wherein the first and/or second acquisition apparatus includes a computer program comprising program code instructions for locating, in real time, the registration mark(s) on the retractor, analyzing its position(s) or dimensions and, as a result, providing information.

8. A process according to any one of the preceding claims, wherein, in step D., the spotting comprises a comparison of discriminant information common to both the initial and updated images, and then an identification of said region with respect to said common discriminant information.

9. A process according to any one of the preceding claims, wherein, in step D., the identification of said region on the initial and/or updated images comprises a search for virtual acquisition conditions in which the first acquisition apparatus and/or the second acquisition apparatus, respectively, would have acquired said initial and/or updated image by observing a digital three-dimensional reference model of at least part of a patient's arch.

10. A process according to any one of the preceding claims, in which, in step D., the marking of the region on the initial and/or updated image, known as the “acquired image”,

comprises the implementation of a method for assessing the actual acquisition conditions of the acquired image, said method comprising the following steps:

001) creating a three-dimensional digital reference model of at least part of a patient's arch;

002) analysis of the acquired image and production of a map relating to a discriminant information, known as the “acquired map”;

003) search for virtual acquisition conditions that optimally approximate said real acquisition conditions, according to the following steps 01) to 05):

01) optionally, determination of approximate virtual acquisition conditions approximating said real acquisition conditions, preferably by analyzing the representation of a retractor used during acquisition of the acquired image;

02) determination of virtual acquisition conditions to be tested;

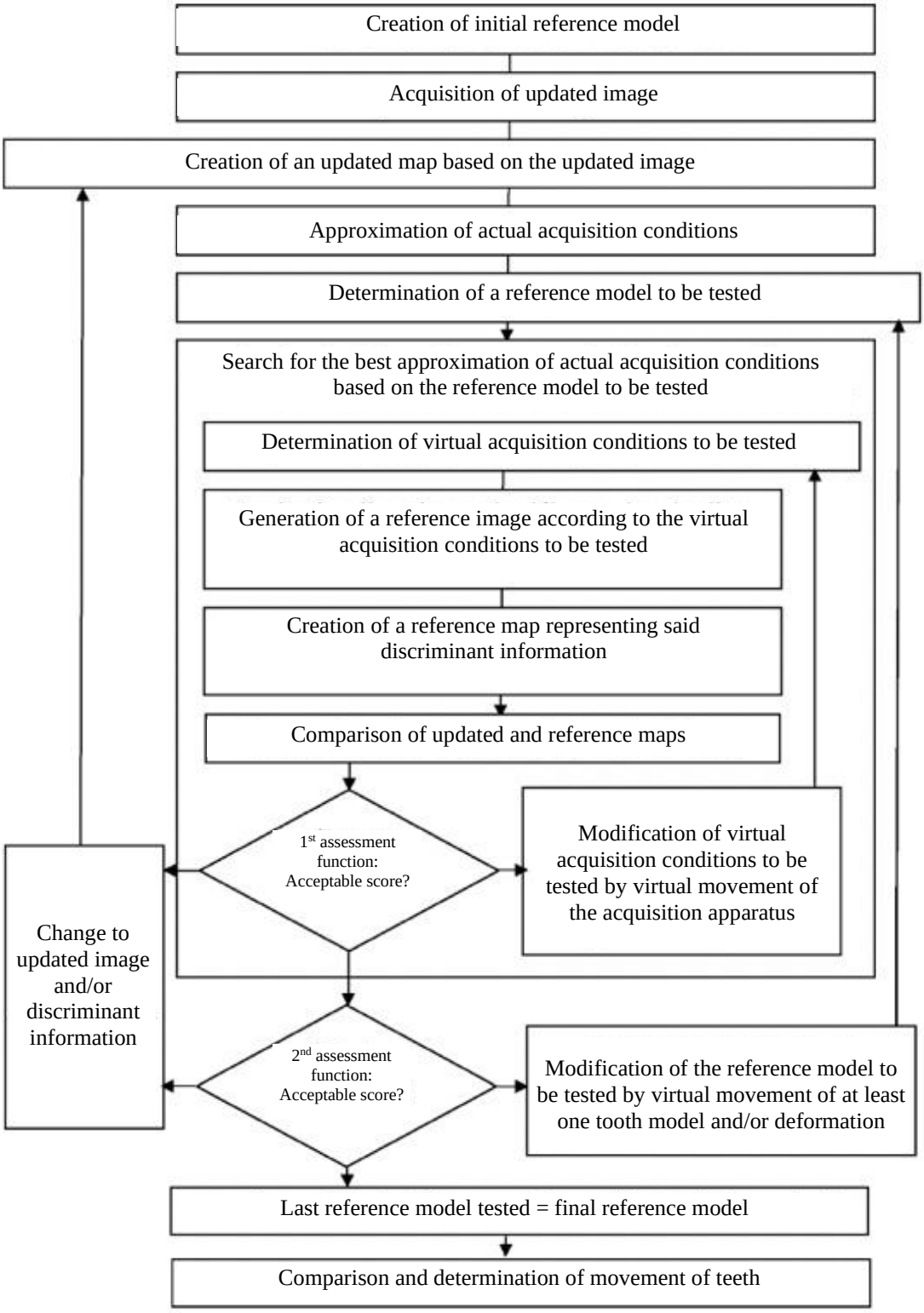
03) production of a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;

04) reference image processing to produce at least one reference map representing said discriminant information;

05) comparison of acquired and reference maps to determine a value for an assessment function, with said value for the assessment function depending on differences between said acquired and reference maps and corresponding to a decision to continue or halt the search for virtual acquisition conditions that approximate real acquisition conditions more accurately than said conditions with greater precision than said virtual acquisition conditions to be tested;

06) if said value for the assessment function corresponds to a decision to continue said search, modifying said virtual acquisition conditions to be tested, then resuming step 03);

if not, assessment of the actual acquisition conditions by said virtual acquisition conditions to be tested.


Creation of initial reference model
Acquisition of updated image
Creation of an updated map based on the updated image
Approximation of actual acquisition conditions
Determination of a reference model to be tested
Search for the best approximation of actual acquisition conditions based on the reference model to be tested
Determination of virtual acquisition conditions to be tested
Generation of a reference image according to the virtual acquisition conditions to be tested
Creation of a reference map representing said discriminant information
Comparison of updated and reference maps
1st assessment function: Acceptable score?
Modification of virtual acquisition conditions to be tested by virtual movement of the acquisition apparatus
Change to updated image and/or discriminant information
2nd assessment function: Acceptable score?
Modification of the reference model to be tested by virtual movement of at least one tooth model and/or deformation
Last reference model tested = final reference model
Comparison and determination of movement of teeth

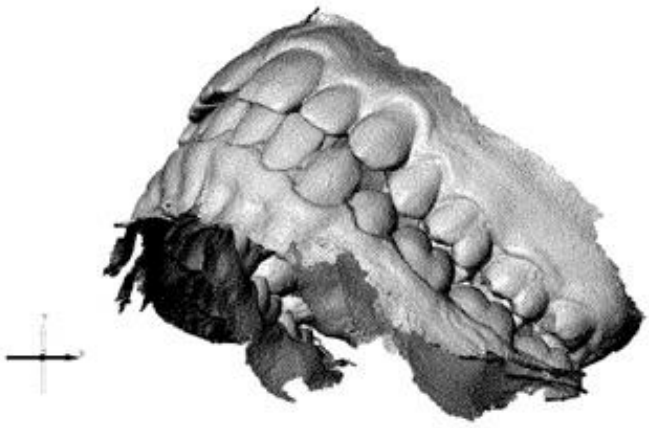


Fig.2

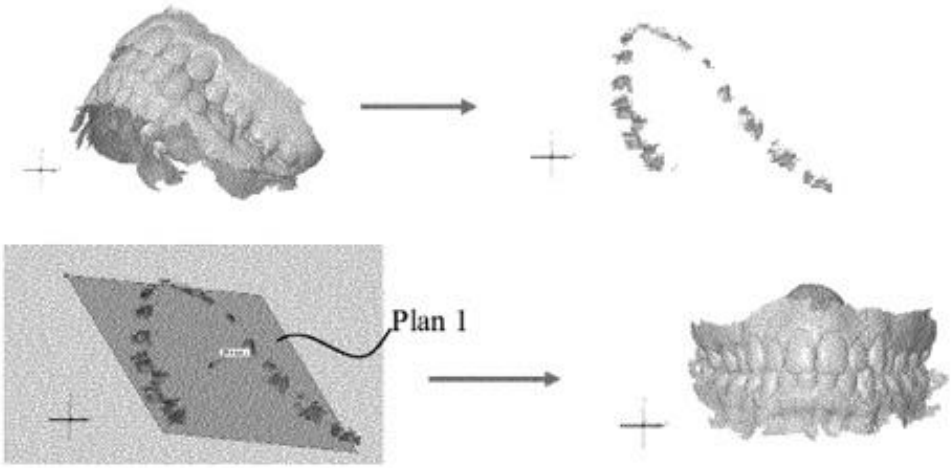



Fig.3

Fig. 4a

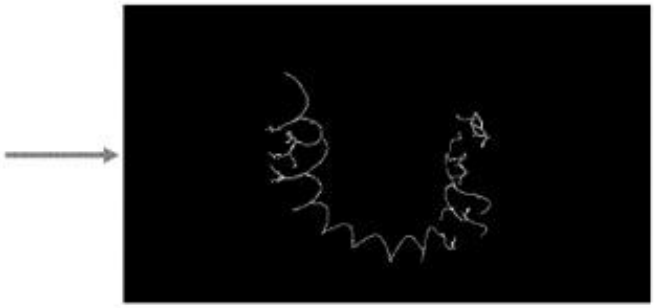


Fig. 4b

Fig. 4c

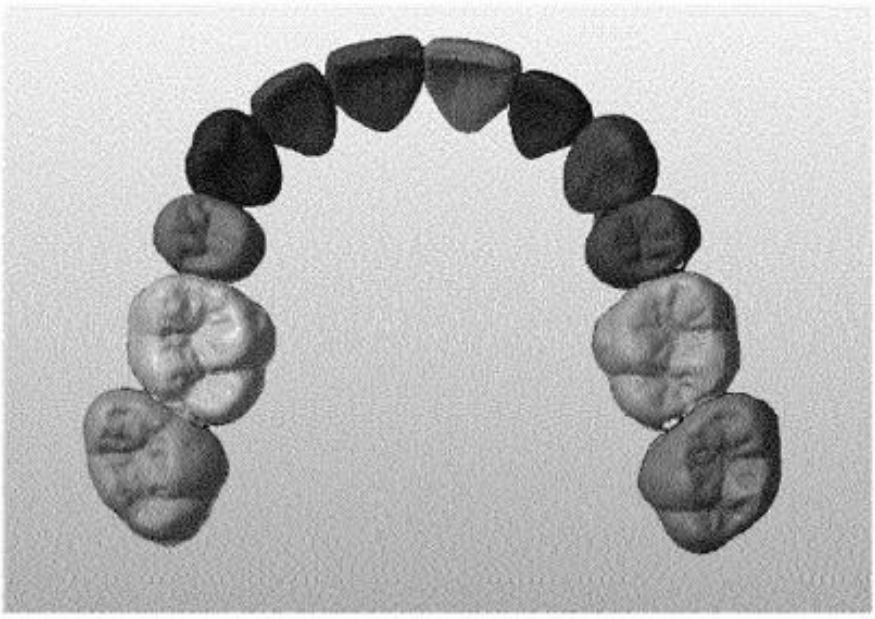


Fig. 4d

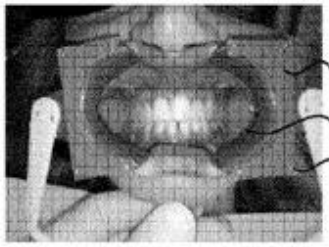



Fig. 5a

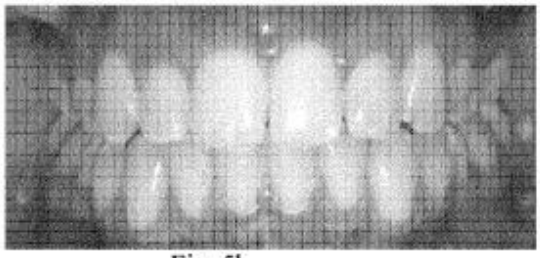


Fig. 5b

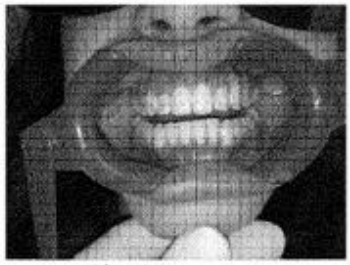


Fig. 5c

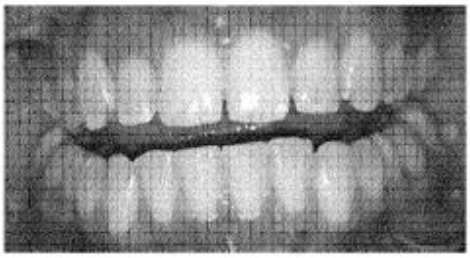


Fig. 5d

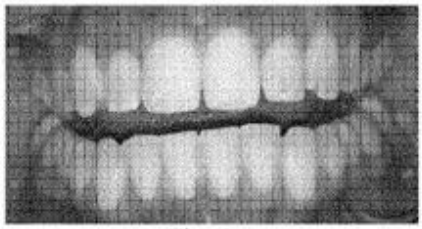


Fig. 6a

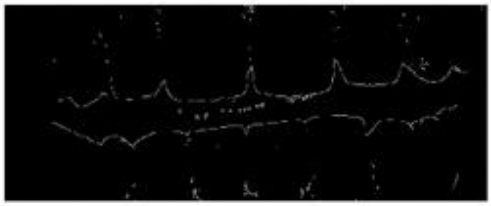


Fig. 6b

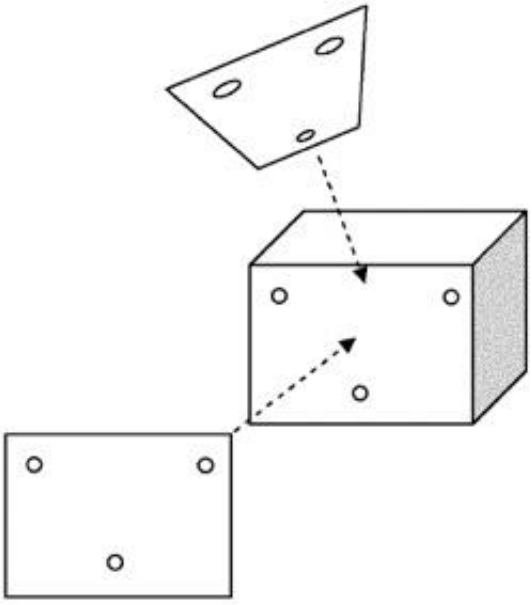


Fig. 7

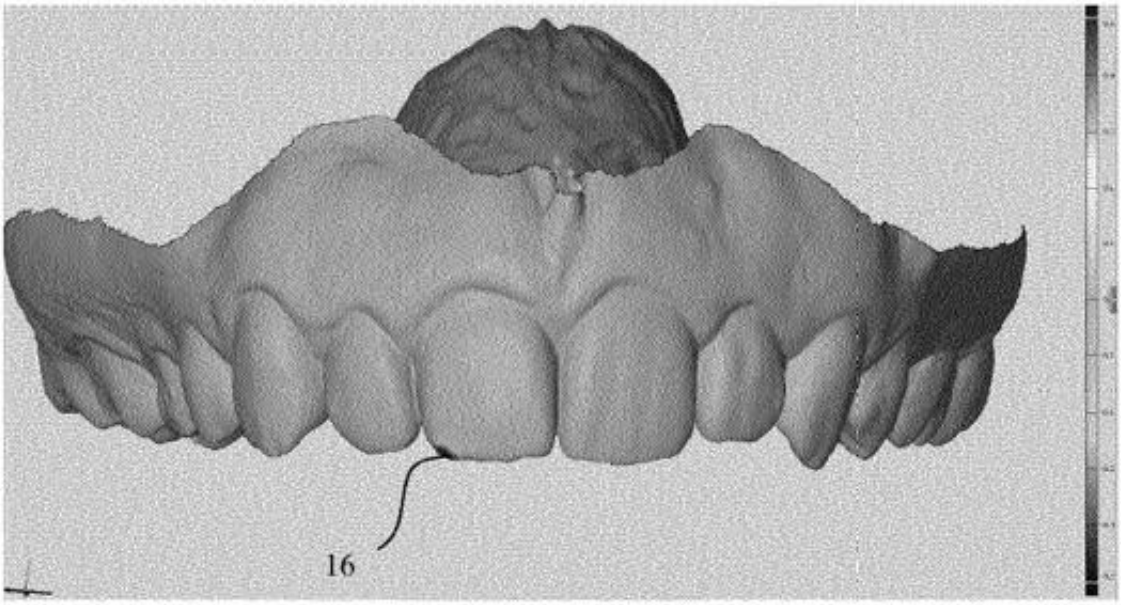



Fig. 8

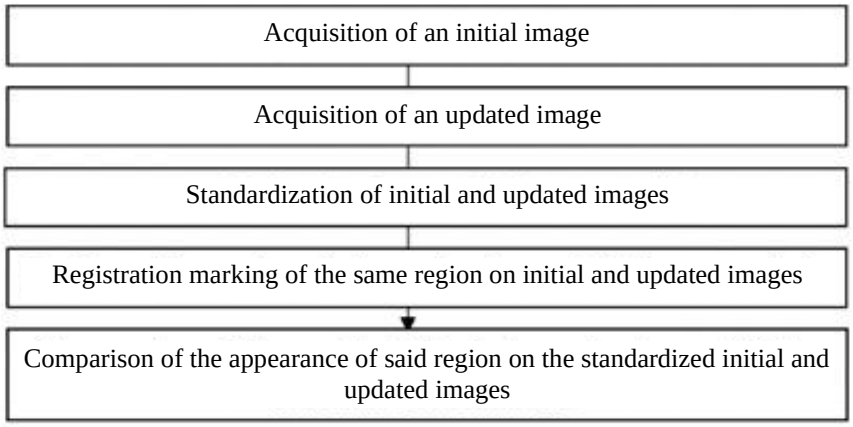



Fig. 9

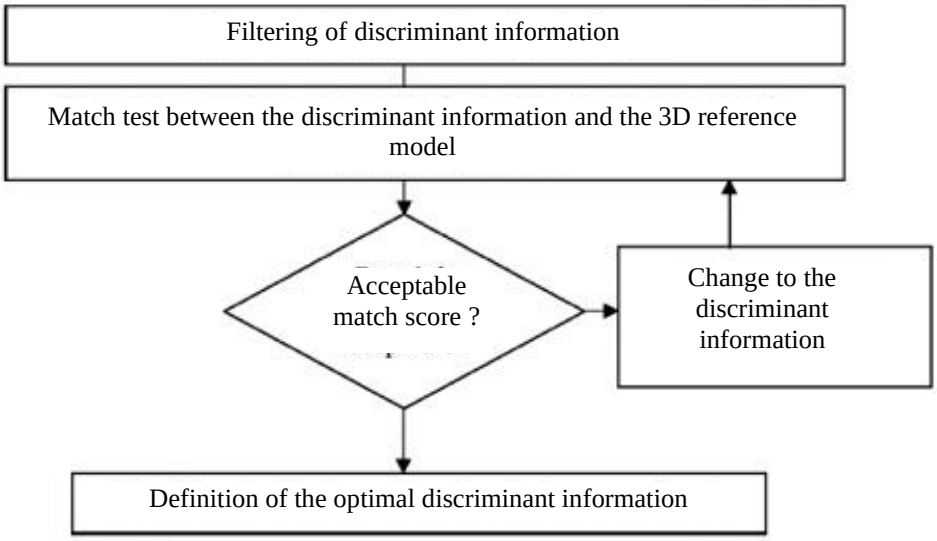



Fig. 10

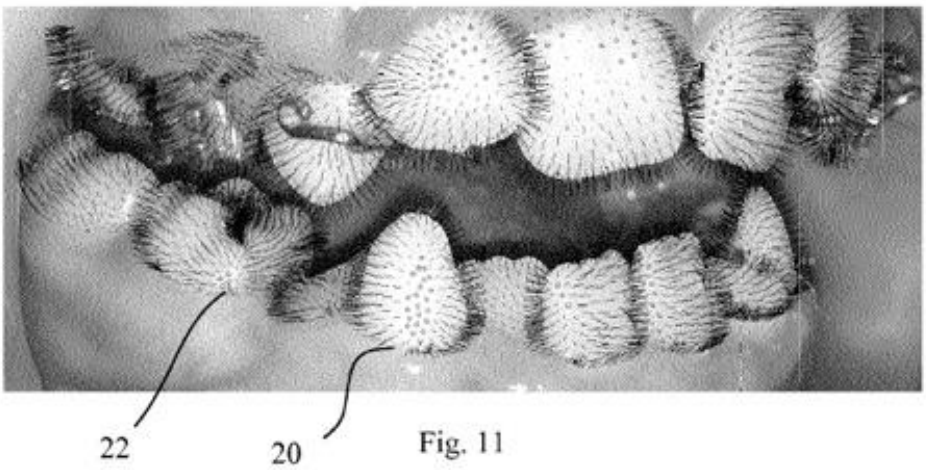



Fig. 11

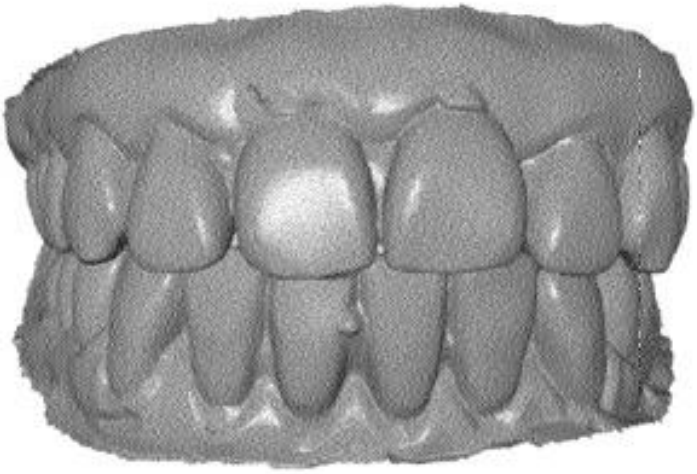


Fig. 12a

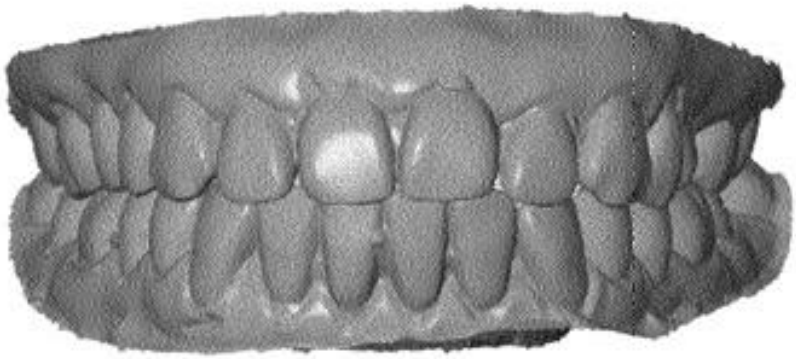


Fig. 12b

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/074896

A. CLASSIFICATION OF SUBJECT MATTER
INV. C07D471/04 A61K31/437 A01N43/40 A61P31/10 G06T7/00
A61C7/00 A61C9/00
ADD.
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)
C07D A61K A61N A61P G06T 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 practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | WO 01/51005 A2 (BRITESMILE INC [US])<br>19 July 2001 (2001-07-19)<br>page 4, line 1 - page 6, line 10<br>page 21, lines 7-19<br>page 22, lines 1-3<br>----- | 1-10 |
| A | WO 2006/065955 A2 (ORTHOCLEAR HOLDINGS INC; WEN HUAFENG [US])<br>22 June 2006 (2006-06-22)<br>paragraphs [0032], [0034], [0057], [0058], [0060], [0061]<br>----- | 1-10 |

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"P" document published prior to the international filing date but later than the priority date claimed

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 17 December 2015 | 12/01/2016 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Kerner, Bodo |

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/074896

| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
|---|---|---|---|---|---|---|
| WO 0151005 | A2 | 19-07-2001 | AU | 4900601 | A | 24-07-2001 |
| | | | BR | 0016969 | A | 15-07-2003 |
| | | | CA | 2396913 | A1 | 19-07-2001 |
| | | | EP | 1250105 | A2 | 23-10-2002 |
| | | | JP | 2003523232 | A | 05-08-2003 |
| | | | MX | PA02006862 | A | 05-04-2004 |
| | | | NO | 20023369 | A | 09-09-2002 |
| | | | PL | 364876 | A1 | 27-12-2004 |
| | | | US | 2005084826 | A1 | 21-04-2005 |
| | | | WO | 0151005 | A2 | 19-07-2001 |
| WO 2006065955 | A2 | 22-06-2006 | NONE | | | |

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/074896

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. C07D471/04 A61K31/437 A01N43/40 A61P31/10 G06T7/00
A61C7/00 A61C9/00
ADD.

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)

C07D A61K A61N A61P G06T 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 practicable, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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| A | WO 01/51005 A2 (BRITESMILE INC [US])<br>19 July 2001 (2001-07-19)<br>page 4, line 1 - page 6, line 10<br>page 21, lines 7-19<br>page 22, lines 1-3<br>----- | 1-10 |
| A | WO 2006/065955 A2 (ORTHOCLEAR HOLDINGS INC; WEN HUAFENG [US])<br>22 June 2006 (2006-06-22)<br>paragraphs [0032], [0034], [0057], [0058], [0060], [0061]<br>----- | 1-10 |

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 17 December 2015 | 12/01/2016 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Kerner, Bodo |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/074896

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 0151005 A2 | 19-07-2001 | AU 4900601 A | 24-07-2001 |
| | | BR 0016969 A | 15-07-2003 |
| | | CA 2396913 A1 | 19-07-2001 |
| | | EP 1250105 A2 | 23-10-2002 |
| | | JP 2003523232 A | 05-08-2003 |
| | | MX PA02006862 A | 05-04-2004 |
| | | NO 20023369 A | 09-09-2002 |
| | | PL 364876 A1 | 27-12-2004 |
| | | US 2005084826 A1 | 21-04-2005 |
| | | WO 0151005 A2 | 19-07-2001 |
| WO 2006065955 A2 | 22-06-2006 | NONE | |

County of Denver
State of Colorado } SS.

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Date: August 16, 2023

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