Fenêtre : Catalogue d'images

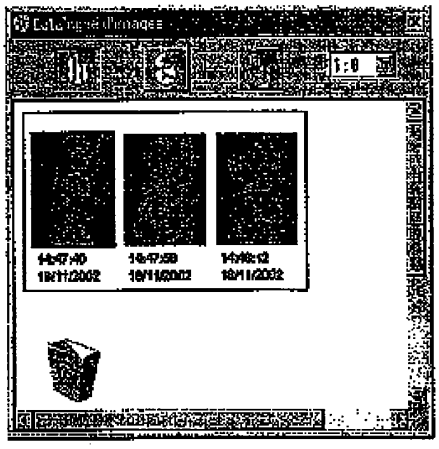


Fig. 3-61 Fenêtre : Catalogue d'images

Vous pouvez afficher/masquer le Catalogue d'images via ***Fenêtre/Catalogue d'images.***

Dans la fenêtre Catalogue d'images, vous pouvez gérer les champs d'images de la préparation, de l'occlusion et des antagonistes (voir „Catalogue d'images" page 64).

Fenêtre : Curseur



Fig. 3-62 Fenêtre : Curseur

La fenêtre ***Curseur*** affiche sous forme de valeur absolue la position actuelle du curseur (pointe de la flèche) dans la fenêtre active. Le zéro se situe dans l'angle supérieur gauche de la fenêtre active.

La première ligne (Fig. 3-62) indique la valeur x, y au niveau de la position du curseur.

La deuxième ligne indique la hauteur au niveau de la position du curseur.

La troisième ligne (Fig. 3-62) indique la valeur x, y de la fissure.

La quatrième ligne indique le point de la fissure présentant la plus faible distance par rapport au plancher de la cavité.

- Vous pouvez prendre la fenêtre ***Curseur*** avec la souris au niveau du bandeau supérieur et la positionner à volonté sur l'écran.

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Fenêtre : Distance



Fig. 3-63 Fenêtre : Distance

Lorsque vous sélectionnez la fonction ***Fenêtre/Distance*** (Fig. 3-59), l'écran affiche la fenêtre ***Distance*** (Fig. 3-63).

1. Avec le bouton gauche de la souris, cliquez sur le point de départ voulu du trajet à mesurer.
2. Déplacez la souris au niveau du point d'extrémité voulu.
3. Cliquez avec la touche gauche de la souris pour définir le point d'extrémité.

Vous pouvez modifier de la manière suivante la position de la ligne bleue :

4. Tout en maintenant enfoncée la touche gauche de la souris, tirer un crayon rouge à l'extrémité de la ligne bleue et le relâcher à l'endroit voulu.

La première ligne (Fig. 3-63) indique la distance tridimensionnelle entre le point de départ et le point d'extrémité de la ligne bleue.

La deuxième ligne (Fig. 3-63) indique la différence de hauteur entre le point de départ et le point d'extrémité de la ligne bleue.

Vous pouvez prendre la fenêtre ***Distance*** avec la souris au niveau du bandeau supérieur et la positionner à volonté sur l'écran.

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3.13 Menu "?"

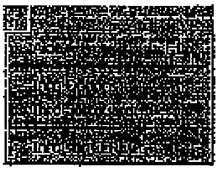


Fig. 3-54 Menu "?"

Le menu "?" permet ...

- d'appeler la Aide (Aide en ligne)
  ?/Aide... ou touche de fonction *F1*
- de demander des informations sur la restauration ouverte
  ?/Info Options...
- d'appeler une information sur la clé électronique raccordée (clé d'activation)
  ?/Info Softguard...
- d'appeler une information sur la version actuelle du programme
  ?/A propos de CEREC...

Aide (Aide en ligne)

L'aide en ligne vous donne des instructions sur les étapes de travail à effectuer.

Si vous souhaitez utiliser l'aide en ligne, le système d'aide doit être installé à partir du CD de documentation joint.

Pour démarrer l'aide, appelez l'option de menu *?/Aide...* ou actionnez la touche *F1*.

L'écran affiche une boîte de dialogue avec une sélection de sujets d'aide que vous pouvez sélectionner et faire afficher.

Info Options

La fenêtre *Options* vous donne des informations sur la restauration ouverte.

Info Softguard

La fenêtre *Softguard* vous donne des informations sur la clé électronique d'activation raccordée (Softguard).

Identification 0	= unité d'usinage CEREC 3 / *Scan* (n° de série <5000)
Identification 1	= unité d'usinage CEREC InLab (n° de série ≥5000)
Identification 2	= unité d'usinage CEREC 3 / *Scan* (n° de série ≥5000)
Identification ??	= aucune unité d'usinage raccordée

A propos de CEREC

Dans la fenêtre *A propos de CEREC*, vous obtenez des informations sur la version actuelle du programme.

Si vous avez installé un accès à Internet, vous pouvez accéder directement à la page Internet de CEREC en cliquant sur le logo Sirona ou sur le bandeau *Homepage*.

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4 Empreinte optique

Il est possible de réaliser une empreinte optique soit avec la caméra 3D, soit avec le scanner.

Dans ce chapitre

Ce chapitre est subdivisé en plusieurs paragraphes :

- „Prises d'empreintes avec la caméra 3D" page 55
- „Enregistrements avec le scanner" page 62
- „Champs d'images" page 63
- „Catalogue d'images" page 64

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4.1 Prises d'empreintes avec la caméra 3D

Dans ce paragraphe

Le présent paragraphe traite des sujets suivants :

- „Commande de prise d'empreinte caméra 3D" page 55
- „Enregistrement unique" page 56
- „Enregistrements complémentaires" page 58
- „Enregistrements angulaires" page 59
- „Enregistrements complémentaires et enregistrements angulaires" page 59
- „Enregistrements pour l'assainissement de l'arcade dentaire" page 60
- „Enregistrement de dents d'extrémité" page 60
- „Enregistrement de l'antagoniste" page 61

4.1.1 Commande de prise d'empreinte caméra 3D

Déclencher la prise d'empreinte

La commande de prise d'empreinte de la caméra 3D fonctionne comme suit :



1. Positionnez le curseur sur l'icône Enregistrer (p. ex. *Enregistrer préparation*).

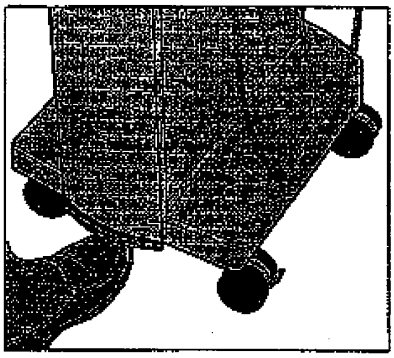


Fig. 4-1 Pédale

2. Avec le pied, poussez la pédale vers le haut et maintenez-la dans cette position.
   Une image vidéo live apparaît (voir Fig. 4-4).
3. Relâchez la pédale.
   L'image vidéo se transforme en une image fixe.
4. Par un bref clic, l'image fixe entre dans le catalogue d'images (p. ex. champ d'image *Préparation*).

Il suffit de répéter les étapes 1.- 4. pour effectuer des prises d'empreintes supplémentaires.

En positionnant le curseur sur une autre icône d'enregistrement (p. ex. *Enregistrer occlusion* ou *Enregistrer antagoniste*) et en répétant les étapes 2.- 4., il est possible de réaliser des prises d'empreintes supplémentaires dans les champs d'image *Occlusion* ou *Antagoniste*.



5. Pour quitter le processus de prise d'empreinte, cliquez sur l'icône *Suite*.

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4.1.2 Enregistrement unique

Enregistrement de référence

Pour des restaurations de dents isolées, un enregistrement unique suffit généralement. Il doit être réalisé dans le sens occlusal (Axe d'introduction). Il est appelé enregistrement de référence.



Une fois que vous avez sélectionné une dent et le procédé de construction, l'icône *Enregistrer préparation* dans la barre d'icônes devient active. Le curseur vient se positionner sur cette icône.

ATTENTION

La caméra 3D est un instrument de mesure opto-électronique ultraprécis devant être manipulé avec précaution. Tout traitement incorrect (chocs, chutes) provoque la défaillance de la caméra 3D.

– N'appuyez pas la tête de la caméra (prisme) sur une dent. Pour cela, utilisez le support de caméra.

Support de caméra

REMARQUE

L'utilisation du support de caméra présente les avantages suivants :

– vous obtenez des enregistrements non-bougés,

– vous évitez une détérioration du prisme,

– vous évitez le contact avec la dent préparée.

ATTENTION

Désinfectez en essuyant ou en pulvérisant avant utilisation. Destiné à un usage unique.

Réalisez l'enregistrement

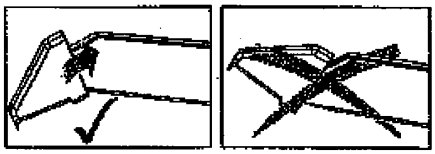


Fig. 4-2 Emmanchez le support de caméra

1. Emmanchez le support de caméra sur la caméra comme indiqué sur la figure.

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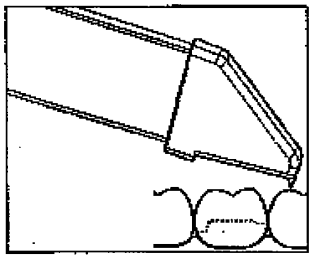


Fig. 4-3 Appuyez la caméra 3D

2. Positionnez la caméra 3D au-dessus de la préparation poudrée (poudrage, voir Notice d'utilisation de l'unité de prise d'empreinte).
3. Appuyez la caméra 3D à l'aide de la partie avant du support de caméra sur une dent afin de pouvoir la tenir sans bouger pendant la phase de mesure.

REMARQUE

Si le prisme entre en contact avec des surfaces poudrées, de la poudre reste généralement collée sur la surface du prisme, ce qui provoque des taches sombres sur l'image.
La poudre peut être essuyée au niveau du prisme avec un chiffon doux.

4. Actionnez la **pédale et maintenez-la enfoncée (Fig. 4-1).**

   Tant que vous maintenez la pédale enfoncée, vous voyez sur l'écran une image vidéo Live de la préparation à mesurer.

   La luminosité de l'image lors de l'enregistrement est automatiquement réglée, de sorte qu'une luminosité optimale est toujours garantie, et ce pratiquement indépendamment de la distance entre la caméra 3D et la dent.
   L'environnement de la dent à enregistrer doit être aussi faiblement éclairé que possible. Evitez tout type d'éclairage étranger. Eteignez la lampe dentaire et l'éclairage de la pièce, si nécessaire.

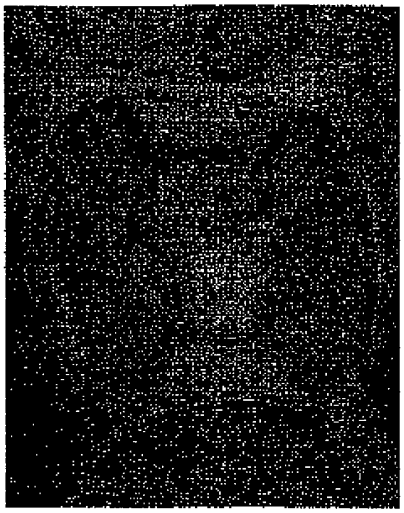


Fig. 4-4 Image vidéo Live

5. Tenez compte de la présence de contre-dépouilles au niveau de toutes les arêtes occlusales latérales de la préparation.
6. Si vous êtes satisfait de l'axe d'introduction sélectionné par le positionnement de la caméra 3D, vous pouvez relâcher la pédale pour déclencher la mesure tridimensionnelle de la préparation.

Pour éviter les prises d'empreintes floues provoquées par un retrait prématuré de la caméra 3D, un signal acoustique[1] retentit dès que l'enregistrement est terminé.

7. Contrôlez ensuite une nouvelle fois les points précités. Veillez à ce que l'enregistrement de mesure soit suffisamment clair, net et sans zones floues. Le non respect de l'un de ces points peut avoir des conséquences négatives pour la suite de la construction.

1. Veillez à ce que le volume du potentiomètre Windows ne soit pas trop faible et à ce que le réglage "son coupé" ne soit pas activé.

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8. Pour quitter le processus de prise d'empreinte, cliquez sur l'icône *Suite*.

4.1.3 Enregistrements complémentaires

Enregistrer également les dents voisines



Fig. 4-5 Zone de chevauchement : 8mm

Si les dents voisines doivent être représentées au complet, il est possible d'étendre le champ d'image par des enregistrements supplémentaires de ces dents. La zone de chevauchement de deux enregistrements voisins doit être de l'ordre de 8mm.

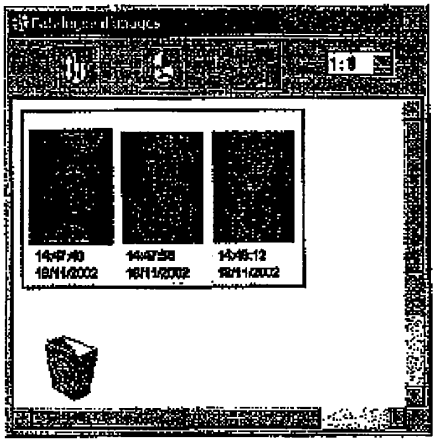


Fig. 4-6 Catalogue d'images

1. Prenez l'Enregistrement de référence (voir „Enregistrement unique" page 56, étapes 1- 7.).

REMARQUE

L'enregistrement de référence définit au départ l'axe d'introduction, lequel peut être modifié ultérieurement en cas de besoin (voir „Redéfinition de l'axe d'introduction" page 71).

2. Cliquez brièvement pour enregistrer l'enregistrement de référence dans le catalogue d'images.
3. Répétez les étapes 4.- 7. (voir „Enregistrement unique" page 56) pour le contour mésial.
4. Cliquez brièvement pour enregistrer le contour mésial dans le catalogue d'images.
5. Répétez les étapes 4.- 7. (voir „Enregistrement unique" page 56) pour le contour distal.
6. Cliquez brièvement pour enregistrer le contour distal dans le catalogue d'images.



7. Pour quitter le processus de prise d'empreinte, cliquez sur l'icône *Suite*.

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4.1.4 Enregistrements angulaires

REMARQUE
L'enregistrement de référence définit au départ l'axe d'introduction, lequel peut être modifié ultérieurement en cas de besoin (voir „Redéfinition de l'axe d'introduction" page 71).

Enregistrements angulaires supplémentaires

Il est possible de réaliser des enregistrements angulaires supplémentaires pour la préparation. Ils peuvent être utilisés pour enregistrer des zones qui sont masquées sur l'Enregistrement de référence ou pour enregistrer des parois verticales sous des angles plus favorables.

ATTENTION
La présence de délaminages proximaux peut empêcher la mise en place d'un Inlay.

L'angle de basculement maximal pour la réalisation d'un enregistrement supplémentaire de la même zone est de 20°.

4.1.5 Enregistrements complémentaires et enregistrements angulaires

REMARQUE
L'enregistrement de référence définit au départ l'axe d'introduction, lequel peut être modifié ultérieurement en cas de besoin (voir „Redéfinition de l'axe d'introduction" page 71).

Enregistrements complémentaires et enregistrements angulaires supplémentaires

Outre l'Enregistrement de référence, il est possible de réaliser des enregistrements complémentaires et des enregistrements angulaires supplémentaires.

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4.1.6 Enregistrements pour l'assainissement de l'arcade dentaire

REMARQUE

L'enregistrement de référence définit au départ l'axe d'introduction, lequel peut être modifié ultérieurement en cas de besoin (voir „Redéfinition de l'axe d'introduction" page 71).

Enregistrer un champ d'image avec 5 dents

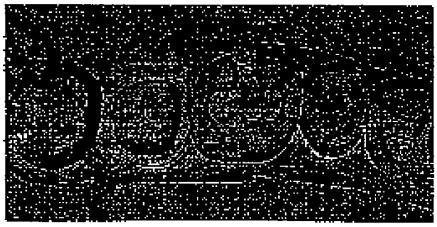


Fig. 4-7 Assainissement de l'arcade dentaire

Pour l'assainissement de l'arcade dentaire, il est recommandé de réaliser un champ d'image avec 5 dents. Ce champ peut être couvert de plusieurs enregistrements complémentaires et angulaires.

4.1.7 Enregistrement de dents d'extrémité

Dent d'extrémité au bord distal

Dans le cas du traitement de dents d'extrémité, la dent extrême doit se trouver au bord distal du champ d'image.

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4.1.8 Enregistrement de l'antagoniste

Enregistrement centré de l'occlusion

L'enregistrement de l'occlusion permet de voir la relation interocclusale entre la dent préparée et l'antagoniste sur la mâchoire opposée.

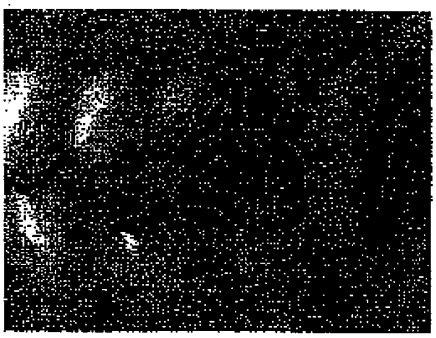


Fig. 4-8 Enregistrement centré de l'occlusion

1. Déposez le matériau de prise d'empreinte sur la préparation.
2. Demandez au patient de serrer les dents (sans mouvement fonctionnel).
3. Après le durcissement, travaillez le matériau de prise d'empreinte de sorte que les surfaces proximales mésiales et distales soient visibles.



4. Enregistrez l'antagoniste (voir „Enregistrement unique" page 56, étapes 1.- 7.).

REMARQUE

Le champ d'image des antagonistes doit coïncider dans la zone mésiale et distale avec le champ d'image de la préparation.



Fig. 4-9 Antagoniste affiché

5. Supprimez les informations de bordure gênantes via *Corriger Construction/Enregistrements* (voir „Effacer et corriger des zones d'images de champs d'images" page 72).



6. Pour quitter le processus de prise d'empreinte, cliquez sur l'icône *Suite*.

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4.2 Enregistrements avec le scanner

(uniquement CEREC *Scan*)

Remarques générales

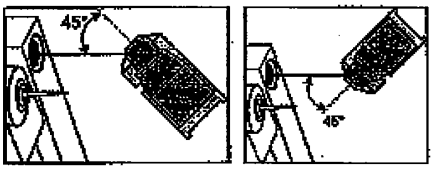
REMARQUE

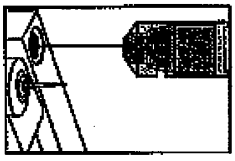
L'utilisation du scanner exclut la possibilité de réalisation d'enregistrements complémentaires et d'enregistrements angulaires.

L'exploration du modèle s'effectue depuis plusieurs directions. Après l'exploration, plusieurs images individuelles apparaissent dans le catalogue d'images. Ces images ne peuvent pas être effacées dans le catalogue d'images ou affectées à un autre champ d'image.

Les enregistrements de référence ne peuvent pas être modifiés par un double clic.

Procédé de balayage





Vue occlusale

Fig. 4-10 Procédé de balayage

Ce procédé de balayage consiste en deux balayages sous un angle de 45° plus un balayage en vue occlusale. A partir de ces trois images, le logiciel calcule une image finale.

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4.3 Champs d'images

Un Champs d'images peut être constitué d'un ou de plusieurs enregistrements.

Dans CEREC 3D, on distingue les types de champs d'images suivants :



- Champ d'images de la préparation



- Champ d'images de l'occlusion



- Champ d'images des antagonistes

REMARQUE

L'utilisation d'un nombre très élevé d'enregistrements (>10) peut entraîner des temps d'attente importants lors du calcul du modèle 3D. Les fichiers deviennent très volumineux.
Règle générale : Limitez-vous au nombre d'enregistrements nécessaires.

4.3.1 Champ d'images de la préparation

Le champ d'images de la préparation peut contenir des enregistrements de la dent préparée (ou des dents préparées). La présence d'enregistrements angulaires est également recommandée dans ce cas.

4.3.2 Champ d'images de l'occlusion

Le champ d'images de l'occlusion peut contenir des enregistrements d'une occlusion préexistante ou du wax-up d'une occlusion.

Le champ d'image de l'occlusion doit coïncider dans la zone mésiale et distale avec le champ d'image de la préparation.

4.3.3 Champ d'images des antagonistes

Le champ d'images des antagonistes peut contenir des empreintes d'un enregistrement centrés de l'occlusion.

Le champ d'image des antagonistes doit coïncider dans la zone mésiale et distale avec le champ d'image de la préparation.

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4.4 Catalogue d'images

Remarques générales

Dans l'état de traitement *Empreinte optique*[1], vous pouvez exécuter les actions suivantes :

- définir une autre image comme enregistrement de référence (voir „Redéfinir l'enregistrement de référence" page 65)
- affecter une image à un autre champ d'image (voir „Modifier l'affectation" page 65)
- effacer des enregistrements (voir „Effacer enregistrement" page 65)

REMARQUE

Si la restauration en est un à stade de traitement plus avancé, vous pouvez actionner l'icône Annuler aussi souvent que nécessaire pour retourner à l'état de traitement Empreinte optique. Pour ce faire, vous devez effacer la restauration (si nécessaire).

ATTENTION

Pour les enregistrements qui ont été réalisés avec le scanner (option), vous ne pouvez pas exécuter les actions décrites précédemment.

Ouvrir le catalogue d'images

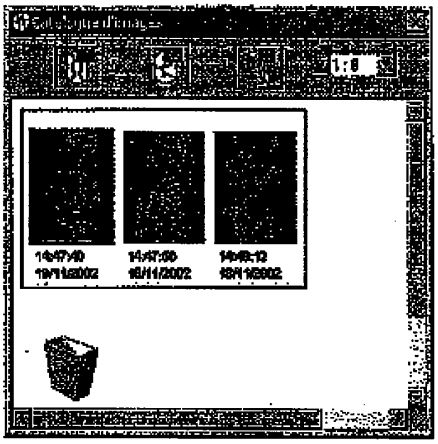


Fig. 4-11 Catalogue d'images

Le catalogue d'images Fig. 4-11) s'ouvre automatiquement si vous avez réalisé plus d'un enregistrement (ou via le menu *Fenêtre/Catalogue d'images*).

Chaque enregistrement est affichée sous une taille réduite (prévisualisation) dans le catalogue d'images.

Vous pouvez sélectionner la taille de la prévisualisation entre 1:10 et 1:4.

Le premier enregistrement d'un champ d'image est appelé Enregistrement de référence ; il est représenté par un encadrement rouge. Il doit être réalisé dans le sens occlusal (Axe d'introduction).

1. visible dans la barre d'état (en bas à gauche).

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Redéfinir l'enregistrement de référence

Pour définir une autre image comme enregistrement de référence, vous devez double-cliquer sur l'image voulue.

Agrandir l'image

Si vous pointez sur une image avec le pointeur de la souris, l'image est représentée en taille originale.

Modifier l'affectation

1. Tout en maintenant enfoncée la touche droite de la souris, tirez l'image que vous voulez déplacer sur le symbole de "l'autre" champ d'image.
2. Relâchez la touche gauche de la souris.

L'image est affectée à "l'autre" champ d'image.

Effacer enregistrement

1. Tout en maintenant enfoncée la touche droite de la souris, tirez l'image que vous voulez effacer sur le symbole de la corbeille à papier.
2. Relâchez la touche de gauche de la souris.

L'enregistrement est effacé.

Afficher l'image de hauteur

Cliquez avec la touche de droite de la souris sur l'enregistrement en taille réduite dans le catalogue d'images. L'image de hauteur est affichée. Pour quitter l'image de hauteur, cliquez à nouveau avec la touche droite de la souris sur l'image de hauteur.

Fermer le catalogue d'images



Le catalogue d'images se ferme automatiquement si vous cliquez sur l'icône *Suite* (ou via le menu *Fenêtre/ Catalogue d'images*).

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5 Construction

Dans ce chapitre

Ce chapitre est subdivisé en plusieurs paragraphes :

- „Masquage de zones d'image" page 67
- „Indication du bord de la préparation" page 68
- „Redéfinition de l'axe d'introduction" page 71
- „Effacer et corriger des zones d'images de champs d'images" page 72

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5.1 Masquage de zones d'image

Une fois que le champ d'image de la préparation est affiché dans le Viewer et avant d'indiquer le bord de la préparation, vous pouvez masquer des zones d'image de la préparation, p. ex. le contour mésial et distal.

Masquer des zones d'image

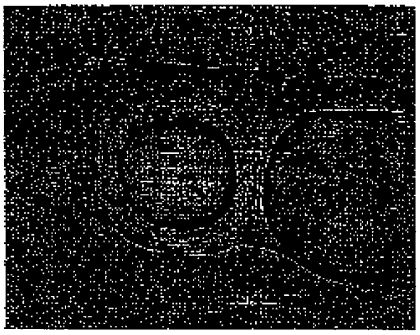


Fig. 5-1 Contour distal masqué

1. Tracez une ligne ouverte en double-cliquant au début de la ligne sur le champ d'image/objet.
2. Cliquez pour placer d'autres points de la ligne, p. ex. dans la zone inter-dentaire.
3. Double-cliquez sur le champ d'image/objet pour terminer la ligne.

La zone d'image le long de la ligne est masquée. S'il ne s'agit pas de la bonne zone d'image, vous pouvez passer à l'autre zone d'image en double-cliquant sur la zone masquée.

Vous pouvez masquer autant de zones d'image que vous le souhaitez.



4. Pour quitter ce processus, cliquez sur l'icône *Suite*.



Fig. 5-2 Bouton Trim

Un clic sur le bouton *Trim* permet de masquer ou d'afficher ensemble toutes les zones d'images.

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5.2 Indication du bord de la préparation

Dans ce paragraphe

Le présent paragraphe traite des sujets suivants :

- „Remarques générales" page 68
- „Inlay à plusieurs surfaces" page 69
- „Inlay occlusal et couronne" page 70
- „Indication du bord de la préparation en cas de préparations floues" page 70

5.2.1 Remarques générales

Vous pouvez indiquer le bord de la préparation dans le Viewer dans la représentation tridimensionnelle (3D) de la préparation.

ATTENTION

***AVANT** d'indiquer le bord de la préparation, vous pouvez si nécessaire redéfinir l'axe d'introduction ou effacer et corriger des zones d'image (voir Page 72 et Page 71).*

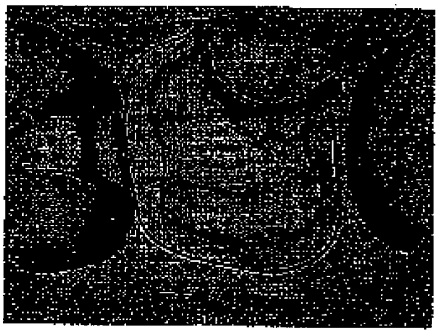


Fig. 5-8 Bord de la préparation

Une rotation de la représentation en 3D de la préparation est possible pendant l'indication du bord de la préparation.

Le bord de la préparation doit toujours être une ligne fermée et peut se composer d'un ou de plusieurs segments.

- Dans le cas d'un d'inlay à plusieurs surfaces, le bord de la préparation se compose de plusieurs segments.

  Les transitions entre zone de plancher et zone de bordure (limites des segments) doivent être marquées par un double-clic.
- Dans le cas d'un d'inlay occlusal ou d'une couronne, le bord de la préparation se compose d'un segment.

Il est possible d'éditer le bord de la préparation directement après avoir été indiqué.

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Indiquer le bord de la préparation

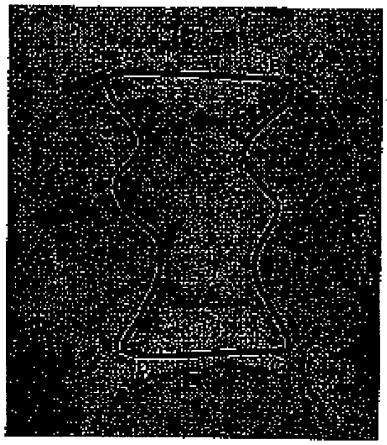


Fig. 5-4 Limites du segment

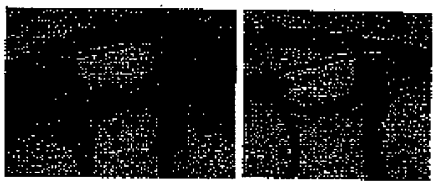


Fig. 5-5 Détection automatique d'arêtes

5.2.2 Inlay à plusieurs surfaces

1. Démarrez le tracé par un double-clic sur le sommet d'un segment cervical (A, Fig. 5-4).

REMARQUE

Vous devez d'abord fermer un segment ouvert par un double-clic (B) (point rouge) avant d'entrer un nouveau segment.

2. Déplacez le curseur le long du bord de la préparation vers B.

   Entre la position actuelle du curseur et le dernier clic, la recherche du bord de la préparation s'effectue à l'aide d'un procédé de détection d'arêtes.

REMARQUE

Pour déclencher la détection automatique d'arêtes, cliquez sur le côté surélevé à proximité de l'arête (Fig. 5-5). Une correction automatique intervient lors du positionnement du point suivant.

   *double-cliquez aux limites des segments (Fig. 5-4, flèches).

3. Poursuivez le procédé jusqu'à ce que vous soyez à nouveau arrivé au point de départ.
   (p. ex. A -> B -> C -> D -> A, Fig. 5-4).

4. Terminez la saisie par un double-clic sur le point de départ (A, Fig. 5-4).

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5.2.3 Inlay occlusal et couronne

Indiquer le bord de la préparation

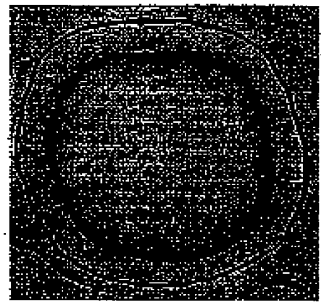


Fig. 5-6 Bord de la préparation Couronne

1. Démarrez l'introduction par un double-clic à un endroit quelconque du bord de la préparation.
2. Déplacez le curseur le long du bord de la préparation.

REMARQUE

Pour déclencher la détection automatique d'arêtes, cliquez sur le côté surélevé à proximité de l'arête. Une correction automatique intervient lors du positionnement du point suivant.

3. Poursuivez le procédé jusqu'à ce que vous soyez à nouveau arrivé au point de départ.
4. Terminez l'introduction par un double-clic sur le point de départ.

5.2.4 Indication du bord de la préparation en cas de préparations floues

Fenêtre : Image intensité

Lorsque des préparations ne présentent pas d'arêtes de préparation nettes, vous pouvez appeler la fenêtre *Image intensité*.

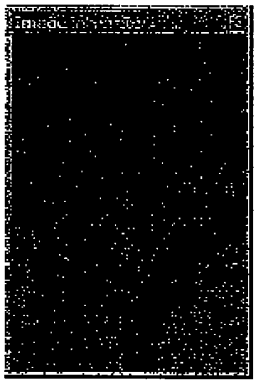




Fig. 5-7 Image intensité

Si vous actionnez la barre d'espacement (A, Fig. 5-7) lors de l'indication du bord de la préparation, la fenêtre avec la croix au milieu apparaît en haut à gauche. Dans cette fenêtre, vous pouvez dessiner le bord de la préparation exactement sur l'arête. Le programme passe au procédé d'interpolation (fonction Spline) et vous pouvez placer différents points en cliquant avec la souris.

ATTENTION

Placez les points exactement sur l'arête et proches les uns des autres.

Lorsque vous actionnez une nouvelle fois la barre d'espacement, la fenêtre se ferme et le programme repasse au procédé de détection d'arêtes.

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5.3 Redéfinition de l'axe d'Introduction

Une fois que le champ d'image de la préparation est affiché dans le Viewer et avant d'indiquer le bord de la préparation, vous pouvez redéfinir l'axe d'introduction.

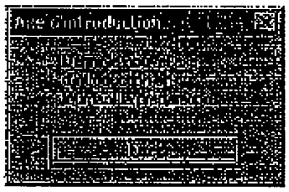


Fig. 5-8 Axe d'introduction

1. Sélectionnez *Construction/Axe d'introduction*. La fenêtre *Axe d'introduction* s'ouvre.
2. Tournez la préparation de sorte que le sens de vision corresponde au nouvel axe d'introduction.
3. Cliquez sur le bouton *Fixer* (Fig. 5-8).

Le système de coordonnées de référence est modifié pour toutes les étapes de la construction.

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5.4 Effacer et corriger des zones d'images de champs d'images

Avant d'indiquer le bord de la préparation, vous pouvez effacer et corriger des zones d'images de tous les champs d'images (préparation, occlusion, antagoniste).

1. Sélectionnez ***Construction/Corriger la prise d'empreinte***. La fenêtre ***Corriger la prise d'empreinte*** s'ouvre.
2. Sélectionnez le type de champ d'image (***Empreinte***) et ***Procédé*** et valider avec ***OK***.

   * Au niveau du ***Procédé***, vous pouvez décider si vous voulez découper en dehors ou à l'intérieur d'une ligne fermée ou lisser à l'intérieur de la ligne.

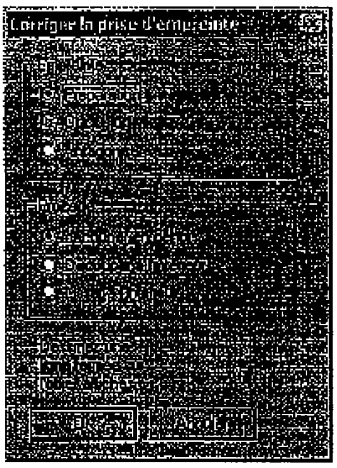


Fig. 5-9 Corriger la prise d'empreinte

Exemple 1 : Eliminer une tache de poudre

1. Pour corriger une tache de poudre sur une surface plane, sélectionnez sous ***Empreinte*** le type de champ d'image correspondant (Fig. 5-9).
2. Dans ***Procédé***, cliquez sur ***lisser à l'intérieur***.
3. Confirmez avec ***OK***.
4. Dessinez une ligne fermée (Fig. 5-10) :
   - Positionnez le point de départ par un double-clic
   - Cliquez pour placer d'autres points.
   - Terminez la ligne par un double-clic sur le point de départ.

La surface est lissée.

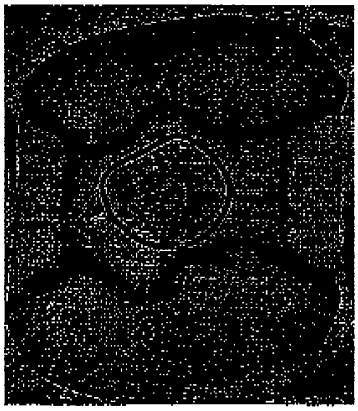


Fig. 5-10 Tracez une ligne fermée

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Exemple 2 : Effacer des zones d'image gênantes

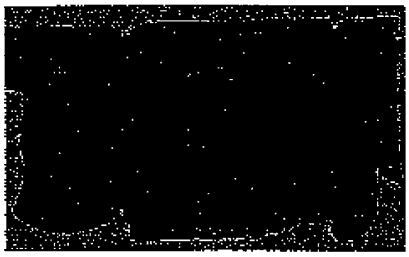


Fig. 5-11 Tracez une ligne fermée

1. Pour effacer des zones gênantes de l'enregistrement de l'occlusion dans le champ d'image de l'antagoniste, sélectionnez sous ***Empreinte*** le type de champ d'image ***Antagonist*** (Fig. 5-9).
2. Dans ***Procédé***, cliquez sur ***découper en dehors***.
3. Confirmez avec ***OK***.
4. Dessinez une ligne fermée (p. ex. tout autour de l'empreinte de l'antagoniste / de l'enregistrement de l'occlusion) :
   - Positionnez le point de départ par un double-clic
   - Cliquez pour placer d'autres points
   - Terminez la ligne par un double-clic sur le point de départ.

La surface à l'extérieur de la ligne est effacée.

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6 Usinage

Dans ce chapitre

Ce chapitre est subdivisé en plusieurs paragraphes :

- „Prévisualisation Simulation d'usinage" page 75
- „Démarrer le processus d'usinage" page 76

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6.1 Prévisualisation Simulation d'usinage

Une fois que la construction de la restauration est terminée, vous pouvez activer la simulation d'usinage en cliquant sur l'icône ***Suite***.

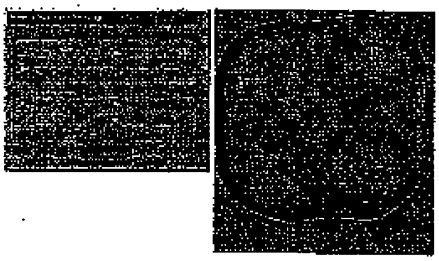


Fig. 6-1 Prévisualisation d'usinage

La restauration est affichée dans le Viewer telle qu'elle sera usinée à l'aide de l'unité d'usinage. Vous pouvez analyser la surface de collage ainsi que le point de séparation.

Il est possible de sélectionner la simulation d'usinage même lorsqu'il n'y a pas d'unité d'usinage raccordée.

Dans la fenêtre ***Prévisualisation d'usinage***, vous pouvez modifier le mode d'usinage et/ou le point de séparation. Lorsque vous cliquez sur le bouton ***Prévisualisation***, ces modifications sont actualisées dans le Viewer.

Les endroits trop minces de la restauration sont représentés en rouge (voir „Paramètre : Affichage épaisseur minimale" page 45).

Si la restauration doit être corrigée, vous pouvez cliquer sur l'icône ***Annuler*** pour retourner au mode construction.

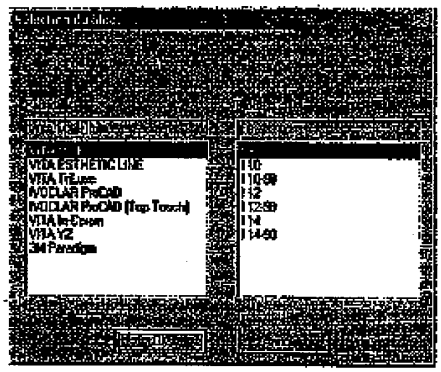
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6.2 Démarrer le processus d'usinage

Une fois que la construction est terminée et que vous avez examiné la restauration dans la simulation d'usinage, vous pouvez démarrer l'usinage de la restauration :

1. Cliquez sur l'icône *Usiner*.

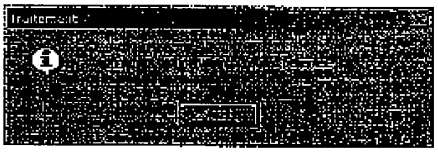


Le programme vous demande de sélectionner une taille de bloc donnée. Le système propose toujours le bloc le plus petit possible.

Les blocs portant la désignation I 10-90, I 12-90 et I 14-90, sont de la même taille que I 10, I 12 et I 14. La désignation -90 signifie que ces blocs sont placés verticalement (tournés à 90°) afin d'y loger une construction plus haute (p. ex. couronnes de dents frontales).

2. Sélectionnez un bloc et confirmez avec *OK*.

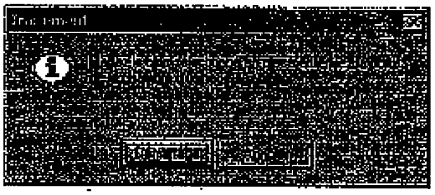
Fig. 6-2 Sélection du bloc



3. Attendez que la broche se trouve en position zéro.

⚠ATTENTION
La porte de la chambre d'usinage doit être fermée.

Fig. 6-3 Attendre la position zéro



4. Ouvrez la porte de la chambre d'usinage.
5. Placez un bloc céramique de taille et de couleur adéquate dans la broche et fixez-le à l'aide de la tige filetée (voir aussi la notice d'utilisation de l'unité d'usinage/unité d'usinage *Scan*).
6. Fermez la porte de la chambre d'usinage et démarrez le processus d'usinage (cliquez sur *Démarrage*, Fig. 6-4).

⚠ATTENTION
La mise en veille ne doit pas être activée lors du processus d'usinage.

Fig. 6-4 Démarrer le processus d'usinage

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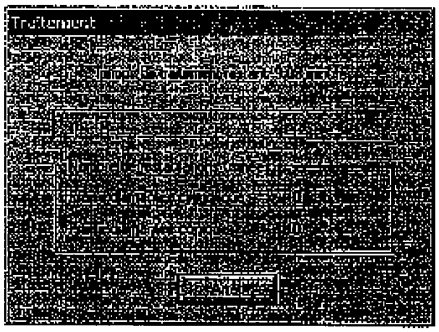


Fig. 6-5 Démarrer le processus d'usinage

Les instruments sont automatiquement calibrés et l'usinage démarre.

Le temps de traitement restant est affiché en permanence.

Le nombre de restaurations usinées est indiqué afin de permettre une estimation de la durée de vie restante des instruments (fraises diamantées).

ATTENTION

L'actionnement du bouton Arrêt permet d'interrompre à tout moment le processus d'usinage.

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7 Gérer/archiver les données

Enregistrer régulièrement

Pour créer une archive de toutes le restaurations usinées, les données doivent être régulièrement enregistrées.

Sous ***Réglages / Configuration / Enregistrer***, vous pouvez activer ou désactiver trois options (Voir „Configuration : Enregistrer" à partir de la page 47.).

Comprimer les fichiers

Lorsque cette option est activée, un seul fichier de restauration comprimé est enregistré dans chaque répertoire dentaire (réglage recommandé !).

Lorsqu'elle est désactivée, toutes les images (enregistrements de mesure, images de hauteur, images de restauration) et un fichier de tracés sont enregistrés sous forme de fichiers séparés sur le disque dur.

Créer un fichier TIF

Lorsque cette option est activée, l'empreinte de la préparation est enregistrée en supplément sous forme d'une image TIF. Ce fichier peut être ouvert dans des applications graphiques courantes.

Connecter la base de données

Si une base de données SIRONA est installée sur le système, le choix de cette option permet de l'utiliser pour l'archivage et la gestion des patients. Lorsque la base de données est connectée, l'application connaît tous les patients de la base de données. Vous devez entrer les nouveaux noms de patients dans la base de données. L'enregistrement et le chargement de restaurations doivent également s'effectuer via la base de données.

Si vous utilisez l'option "Connecter la base de données", toutes les restaurations CEREC sont stockées dans un sous-répertoire *CEREC*, dans le répertoire Pdata de la base de données. Ce répertoire se trouve d'habitude sur un serveur accessible depuis tous les PC et unités de prise d'empreinte CEREC raccordés dans le réseau.

S(V)IDEXIS utilise également cette base de données. Lorsque la base de données est connectée, les restaurations CEREC sont également visibles dans S(V)IDEXIS, dans le filtre d'images *Toutes*. Elles y sont présentées sous forme de prévisualisation et peuvent être ouvertes. Il s'agit d'une image représentative de la restauration (en général, l'empreinte de la préparation) au format TIF.

Les images CEREC reçoivent l'identification *VC* (Vidéo CEREC) dans la base de données SIRONA.

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Importation base de données

Lorsque l'option "Connecter la base de données" est activée, tous les patients et toutes les restaurations stockées localement sont transférés (importés) dans la base de données SIRONA. La réussite de l'importation de la base de données est ensuite signalée.

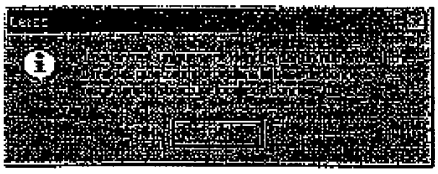


Fig. 7-1 Importation base de données

Les patients (et leurs restaurations) qui ne sont identifiés que par un numéro de fiche dans la structure locale de données CEREC ne peuvent pas être importés dans la base de données SIRONA. Ceci est signalé lors de l'importation dans la base de données.

Exportation base de données

Lors de la désactivation de l'option "Connecter la base de données", une boîte de dialogue apparaît dans laquelle vous pouvez choisir si les restaurations CEREC présentes dans la base de données doivent être copiées (exportées) dans la structure locale de données CEREC.

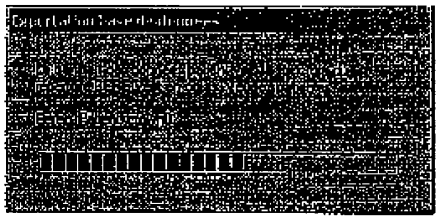


Fig. 7-2 Exportation base de données

Les informations sur les patients sont systématiquement transmises puisqu'un répertoire de patient est créé dans la structure de données CEREC pour chaque patient de la base de données. Une barre de défilement vous informe de l'avancement de la procédure d'exportation de la base de données.

La réussite de l'exportation de la base de données est ensuite signalée.

Fichiers de restaurations

Dans le répertoire *Programmes / CEREC / Données* (si vous avez installé le programme selon *Programmes / CEREC*) figure pour chaque patient un sous-répertoire portant son nom. Chaque répertoire de patient contient un ou plusieurs répertoires dans lesquels se trouvent les différents fichiers de restauration.

Si vous utilisez l'option "Connecter la base de données", le répertoire *PDATA* (créé lors de l'installation de la base de données SIRONA) contient alors un sous-répertoire *CEREC*. Comme un numéro univoque est affecté à chaque patient dans la base de données, ce ne sont pas des noms de patients qui figurent sous *CEREC*, mais des répertoires numérotés (p. ex. "P_000001"). Ils contiennent les répertoires dentaires et les fichiers de restauration.

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Contrôle de cohérence

Lorsque la base de données est connectée, un contrôle de cohérence est réalisé lors du démarrage de l'application CEREC. Le système contrôle la base de données pour rechercher des entrées d'images de versions CEREC antérieures. Si la base de données contient des entrées anciennes, ces dernières sont alors actualisées. L'avancement de l'opération est indiqué par une barre de défilement.

Lorsque la liste des restaurations d'un patient est affichée en vue de son chargement ou de son effacement, les fichiers de restauration défectueux sont détectés et le système propose de les effacer.
Ce mécanisme est toujours actif, que la base de données soit connectée ou non.

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8 Types de restaurations et procédés de construction

Dans ce chapitre

Ce chapitre est subdivisé en plusieurs paragraphes :

- „Créer nouvelle restauration" page 82
- „Vue d'ensemble des types de restaurations et des procédés de construction" page 83
- „Procédé de construction Base de données dentaire" page 84
- „Procédé de construction Corrélation" page 86
- „Assainissement de l'arcade dentaire" page 89

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8.1 Créer nouvelle restauration

1. Sélectionnez *Restauration/Nouveau...* ou cliquez sur l'icône *Nouveau*.

   La fenêtre de dialogue suivante apparaît (voir Fig. 8-1).



Fig. 8-1 Sélectionner un patient pour une nouvelle restauration

2. Sélectionnez un patient existant :
   - double-cliquez sur un patient ou
   - sélectionnez un patient et cliquez sur *OK*.

   Le dialogue Nouveau apparaît (voir Fig. 8-3).

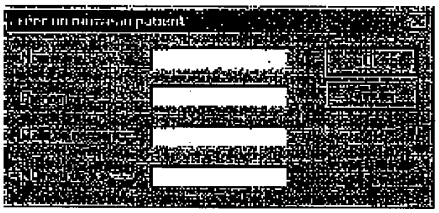


Fig. 8-2 Créer un nouveau patient

3. Un masque de saisie apparaît lorsque que vous cliquez sur le bouton *Nouveau*.

REMARQUE

Il est possible de sélectionner le type de masque de saisie. Le type de masque de saisie affiché n'est pas le même selon que la case dans Réglages/Configuration/Gestion patients labo est cochée ou non (Voir „Configuration : Gestion des patients Labo" à partir de la page 48.)

4. Tapez le *nom*, *le prénom*, *la date de naissance** et/ou un *numéro de fiche*.

   * La *date de naissance* doit être indiquée conformément à la convention de saisie nationale réglée dans Windows : au format "JJ.MM.AAAA" (p. ex. : 27.03.1964) ou "MM/JJ/AAAA" (p. ex. : 03/27/1964).

Dans la structure des données CEREC, un patient est clairement identifié par l'une des deux entrées suivantes :

- *nom, prénom* et *date de naissance*

ou

- *numéro de s.s.*

Si la base de données est connectée, *le nom, le prénom* et *la date de naissance* doivent être mentionnés ; l'indication du *numéro de s.s.* est optionnelle.

Lorsque vous cliquez sur le bouton *OK* à la fin de la saisie des données, le dialogue Nouveau apparaît (voir Fig. 8-3).

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8.2 Vue d'ensemble des types de restaurations et des procédés de construction

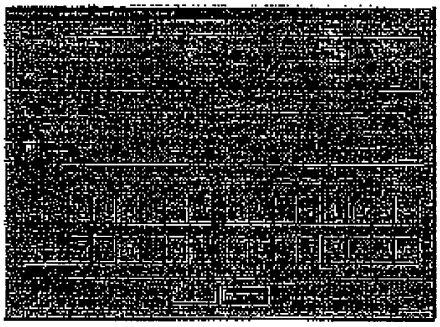


Fig. 8-3 Dialogue Nouveau

Dans le dialogue Nouveau, vous pouvez sélectionner les points suivants et les valider avec ***OK*** :

- Restauration
  - Inlay, onlay, couronne partielle
  - Couronne
  - Inlay occlusal
  - Facette
- Procédé de construction
  - Base de données dentaire
  - Corrélation
- Dent

REMARQUE

Les inlays à une seule surface (pas seulement occlusaux) doivent être sélectionnés en tant que "Inlay occlusal".

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8.3 Procédé de construction Base de données dentaire

Exemple de construction Couronne

Créer nouvelle restauration

1. Après avoir sélectionné un patient dans la base de données ou après avoir créé un nouveau patient, sélectionnez dans le dialogue Nouveau le type de restauration : ***Couronne***, le procédé de construction : ***Base de données dentaire*** et une ***Dent*** (p. ex. 47).
2. Cliquez sur ***OK***.



La flèche du curseur vient se placer automatiquement sur l'icône ***Enregistrer préparation***.

Réaliser l'enregistrement

1. Sortez la caméra 3D de son support et positionnez-la au-dessus de la zone de travail poudrée.
2. Enregistrez la préparation („Prises d'empreintes avec la caméra 3D" page 55).
3. Enregistrez ensuite l'antagoniste / l'enregistrement de l'occlusion.



4. Cliquez sur l'icône ***Suite***.

Le programme calcule la représentation en 3D de la préparation. Cette représentation en 3D sera ensuite affichée dans le Viewer.

Masquer des zones d'image

1. Découpez le contour distal et le contour mésial en traçant respectivement une ligne ouverte (voir „Masquage de zones d'image" page 67).



2. Cliquez sur l'icône ***Suite***.

Indiquer le bord de la préparation

1. Indiquez le bord de la préparation (voir „Indiquer le bord de la préparation" page 70).



2. Cliquez sur l'icône ***Suite***.

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Réaliser la construction

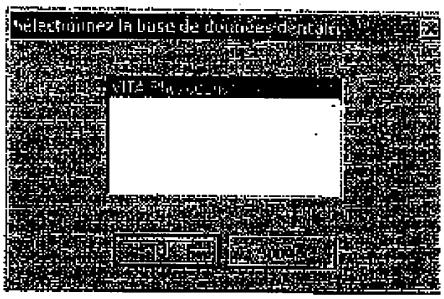


Fig. 8-4 Sélectionnez la base de données dentaire

1. Sélectionnez la base de données dentaire et confirmez avec ***OK***.
   La restauration (couronne) est affichée.
2. Les outils ***Position*** et ***Rotate*** permettent d'orienter la restauration si nécessaire.
3. Les outils ***Design Scale***, ***Edit***, ***Shape*** et ***Drop*** permettent d'effectuer des modifications afin que la restauration puisse s'intégrer de manière optimale dans la situation globale.
4. Le bouton ***Antagoniste*** permet d'afficher le dialogue Antagoniste (voir „Afficher/Masquer antagoniste" page 20) et à l'aide des outils ***Design***, vous pouvez adapter la surface de mastication à l'antagoniste .



5. Une fois que la construction est terminée, cliquez sur l'icône ***Suite***.

Evaluer la simulation d'usinage

La simulation d'usinage est représentée (voir „Prévisualisation Simulation d'usinage" page 75). Vous pouvez ici examiner et évaluer la restauration.

Usinage d'une couronne



1. Si vous êtes satisfait de la restauration, cliquez sur l'icône ***Usiner*** (voir „Usinage" page 74).
2. Démarrez le processus d'usinage (voir aussi notice d'utilisation de l'unité d'usinage).

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8.4 Procédé de construction Corrélation

Exemple de construction Couronne partielle

Créer nouvelle restauration

1. Après avoir sélectionné un patient dans la base de données ou après avoir créé un nouveau patient, sélectionnez dans le dialogue Nouveau le type de restauration : ***Inlay, onlay, couronne partielle***, le procédé de restauration : ***Corrélation*** et une ***Dent*** (p. ex. 26).
2. Cliquez sur ***OK***.

Prendre l'empreinte de l'occlusion



1. Amenez la flèche du curseur sur l'icône ***Enregistrer occlusion***.
2. Sortez la caméra 3D de son support et positionnez-la au-dessus de la zone de travail poudrée.
3. Enregistrez l'occlusion („Prises d'empreintes avec la caméra 3D" page 55).

REMARQUE
Lors de l'enregistrement, l'occlusion de la dent à traiter doit se trouver au centre de l'image.

Prendre l'empreinte de la préparation

1. Enregistrez la préparation.

REMARQUE
Lors de l'enregistrement, la dent préparée doit se trouver au centre de l'image.



2. Cliquez sur l'icône *Suite*.
   Le programme calcule la représentation en 3D de la préparation. Cette représentation en 3D sera ensuite affichée dans le Viewer.

Masquer des zones d'image

1. Découpez le contour distal et le contour mésial en traçant respectivement une ligne ouverte (voir „Masquage de zones d'image" page 67).



2. Cliquez sur l'icône *Suite*.

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Indiquer le bord de la préparation

1. Indiquez le bord de la préparation (voir „Indiquer le bord de la préparation" page 70) et contrôlez-le en faisant tourner la préparation.



2. Cliquez sur l'icône ***Suite***.

Adapter la proposition d'équateur

Le programme vous propose un tracé d'équateur (ligne rose).

1. Contrôlez la position de l'équateur dans les zones proximales et modifiez-la si nécessaire à l'aide de l'outil ***Design Edit*** (voir „Editer ligne de construction" page 23).
2. Activez l'enregistrement de l'occlusion en cliquant sur le bouton ***Occlusion***.
3. Adaptez l'équateur en fonction de l'occlusion à l'aide de l'outil ***Design Edit*** (voir „Editer ligne de construction" page 23).



4. Cliquez sur l'icône ***Suite***.

Adapter la ligne de copie

Le programme propose une ligne de copie (ligne verte). Les points d'extrémité sont représentés sous forme de points rouges.

1. Si nécessaire, déplacez les points d'extrémité rouges sur le bord de la préparation.
2. Si nécessaire, modifiez la ligne de copie avec l'outil ***Design Edit*** (voir „Editer ligne de construction" page 23).



3. Au terme de l'adaptation de la ligne de copie, cliquez sur l'icône ***Suite***. Le programme calcule la restauration.

Traiter la restauration

1. Evaluez la restauration sous tous les angles.
2. Masquez les dents voisines en cliquant sur le bouton ***Trim***.
3. Activez les surfaces de contact en cliquant sur le bouton ***Contact*** (voir „Afficher/Masquer les contact avec la dent voisine (Contact)" page 19).
4. Si nécessaire, adaptez les surfaces de contact avec les outils ***Design***.

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5. Une fois que la construction est terminée, cliquez sur l'icône *Suite*.

Evaluer la simulation d'usinage

La simulation d'usinage est représentée (voir „Prévisualisation Simulation d'usinage" page 75). Vous pouvez ici examiner et évaluer la restauration.

Usiner une couronne partielle



1. Si vous êtes satisfait de la restauration, cliquez sur l'icône *Usiner* (voir „Usinage" page 74).
2. Démarrez le processus d'usinage (voir notice d'utilisation de l'unité d'usinage).

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8.5 Assainissement de l'arcade dentaire

Exemple de construction sur les dents 14 à 17

Enregistrer les dents 14 à 17

1. Après avoir sélectionné un patient dans la base de données ou après avoir créé un nouveau patient, sélectionnez dans le dialogue Nouveau le type de restauration, le procédé de construction et une dent (p. ex. 16).
2. Cliquez sur *OK*.



La flèche du curseur vient se placer automatiquement sur l'icône *Enregistrer préparation*.

3. Enregistrez successivement les dents 14 à 17.

Créer la restauration (dent 16)

1. Définissez la dent 16 comme étant le centre (voir „Construction : Centrer..." page 40).
2. Redéfinissez l'Axe d'introduction pour la dent 16 (voir „Redéfinition de l'axe d'introduction" page 71).
3. Créez une restauration (voir „Exemple de construction Couronne" page 84).

Utiliser la restauration de manière virtuelle (dent 16)

1. Sélectionnez *Construction/Changer*. La fenêtre *Changement de construction* s'ouvre.
2. Cliquez sur *Utiliser restauration de manière virtuelle* et confirmez par *OK*.
3. Sélectionnez le patient correspondant, le type de restauration, le procédé de construction et une nouvelle dent (p. ex. 15).

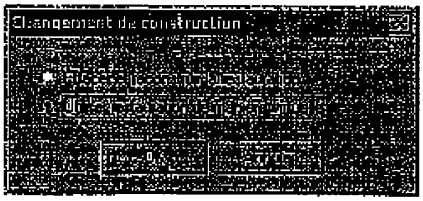


Fig. 8-5 Utiliser restauration de manière virtuelle

La construction finie (dent 16) est utilisée de manière virtuelle et apparaît en tant que dent dans la nouvelle représentation.

Dent 15

1. Définissez la dent 15 comme étant le nouveau centre (voir „Construction : Centrer..." page 40).
2. Redéfinissez l'Axe d'introduction pour la dent 15 (voir „Redéfinition de l'axe d'introduction" page 71).
3. Créez une restauration (voir „Exemple de construction Couronne" page 84).

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9 Fixation adhésive de restaurations CEREC

Préparatifs



Fig. 9-1 Retirer le tenon

Avant de mettre en place la restauration, meulez le tenon restant au terme du processus d'usinage.

Fixer la restauration conformément aux règles générales de la technique adhésive.

Vous pouvez fixer les restaurations CEREC selon les règles généralement admises de la technique adhésive.

Respectez les instructions du fabricant du matériau adhésif.

ALN121512

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10 CEREC 3D Messages

Différents types

Dans le CEREC 3D, on distingue trois types de messages.

- Informations
- Avertissements
- Messages de défaut

ALN121513

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10.1 Informations

Description



Ces messages servent à vous demander d'effectuer une manipulation ou à vous indiquer qu'une action donnée n'est actuellement pas possible.

Exemple

Exemple : le système signale qu'une fraise devrait être changée ou que l'unité d'usinage est occupée.

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10.2 Avertissements

Description



Ce type de message est également utilisé pour indiquer des manipulations importantes ou des problèmes.

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10.3 Messages de défaut

Description

Un message de défaut signifie qu'une action n'a pas pu être exécutée. Le programme et les données sont, en générale, dans le même état qu'avant l'action.

Différentes variantes

Les messages de défaut peuvent se présenter de différentes manières. Il existe les variantes suivantes :

- Messages de défaut auto-explicatifs
- Autres types de défauts (Défauts à deux niveaux)
  - Défauts lors de la détermination ou de la gestion des lignes de construction
  - Erreur lors du calcul de la restauration
  - Erreur système
  - Erreur d'allocation de mémoire

10.3.1 Messages de défaut auto-explicatifs

Ce type de message de défaut est systématiquement utilisé lorsque la cause de l'erreur survenue est parfaitement claire. Suivant les possibilités, vous obtenez une information détaillée sur les actions nécessaires.

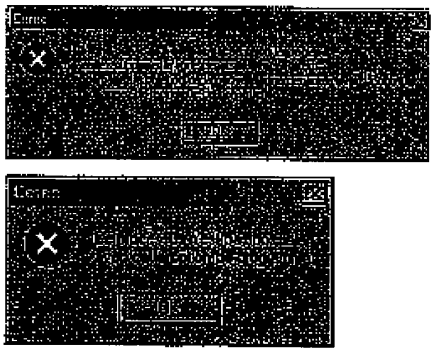


Fig. 10-1 Messages de défaut auto-explicatifs

10.3.2 Autres types de défauts

Défauts à deux niveaux

D'autres messages de défaut interviennent en deux temps. Le système affiche tout d'abord le défaut fondamental.

Vous pouvez ensuite demander l'affichage de détails supplémentaires. En cas d'apparition répétée de tels messages de défaut lors d'une construction, il conviendrait d'envoyer à Sirona Dental Systems la construction accompagnée d'une description de la procédure utilisée.

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A l'exception de l'Erreur d'allocation de mémoire vous pouvez normalement valider le message de défaut qui vient de s'afficher et continuer à travailler.

Défauts lors de la détermination ou de la gestion des lignes de construction

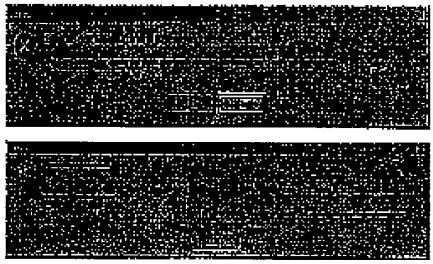


Fig. 10-2 Défauts à deux niveaux

Ce type de défaut apparaît de manière typique lorsque les lignes de construction sont inadaptées. Il peut aussi s'agir d'une erreur du programme.

Si vous cliquez sur *Oui*, le système affiche une boîte de dialogue avec des détails et des indications supplémentaires.

La description du défaut, c'est-à-dire l'ID, sert à l'assistance technique CEREC ou à l'équipe de développement pour analyser et éliminer le problème.

Normalement, vous pouvez continuer à travailler avec les données de restauration après avoir validé le message de défaut. A titre de sécurité, vous pouvez faire une copie et travailler avec cette copie. Vous êtes ainsi certain de disposer encore de l'enregistrement original en cas de problèmes.

Erreur lors du calcul de la restauration

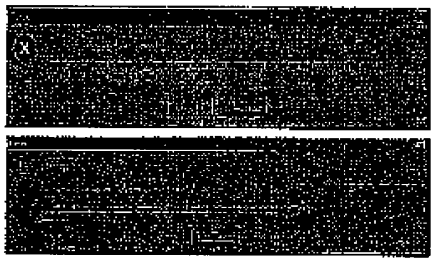


Fig. 10-3 Erreur lors du calcul de la restauration

Ce défaut peut apparaître lorsqu'il faut usiner la restauration. Dans ce cas, il n'est pas possible de procéder au calcul de l'objet à usiner avec les lignes de construction existantes.

Dans ce cas aussi, vous pouvez normalement continuer à travailler avec les données de restauration après avoir validé le message de défaut. A titre de sécurité, vous pouvez également travailler ici avec une copie.

Contrôlez et corrigez, si nécessaire, toutes les lignes de construction.

Erreur système



Fig. 10-4 Erreur système

Une erreur dans le programme peut entraîner une erreur système.

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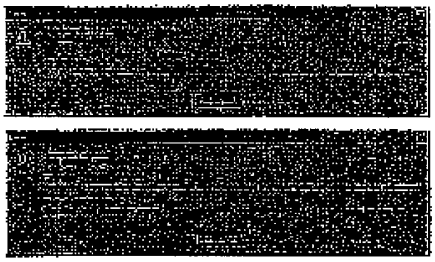


Fig. 10-5 Informations détaillées

Une information détaillée peut se présenter sous deux formes.

Même dans le cas de ces messages d'erreur, vous pouvez continuer à travailler avec les données de construction éventuellement existantes, mais en utilisant systématiquement une copie pour des raisons de sécurité.

Erreur d'allocation de mémoire



Fig. 10-6 Erreur d'allocation de mémoire

L'apparition de l'erreur d'allocation de mémoire signifie que le programme ou le système d'exploitation sont dans un état critique.

1. Quittez le programme.
2. Enregistrez les éventuelles données de construction existantes sous un autre nom.
3. Si ce défaut devait réapparaître, quittez tous les programmes en cours et redémarrez le système d'exploitation.

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11 Liaison à la gestion du cabinet

REMARQUE

En cas de liaison à un programme de gestion du cabinet, il convient de saisir les données du patient dans le programme de gestion du cabinet et de les modifier en cas de besoin.

Dans ce chapitre

Le présent chapitre décrit les possibilités dellaison aux systèmes de gestion du cabinet.

- „Interface de paramètres" page 98
- „Interface SLIDA" page 100
- „Interface OpenDenta" page 101

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11.1 Interface de paramètres

Données patient sous forme de liste de paramètres

Il est possible de configurer certains programmes de gestion de cabinets dentaires de sorte que les données des patients puissent être transmises sous forme d'une liste de paramètres.

Interface de paramètres *CerPI.exe*

Tableau 4:
Cette interface de paramètres vous permet de réaliser de manière simple les tâches suivantes :

créer de nouveaux patients dans la structure de données :	présélectionner des patients existants dans les dialogues suivants :
avec base de données connectée	Charger
sans base de données connectée	Effacer
-	Nouveau

Créer ou présélectionner un patient

Appelez le programme *CerPI.exe* en indiquant les données suivantes :

- *CerPI.exe*
- Signe moins (-)
- *N° de fiche*
- *Prénom*
- *Nom de famille*
- *Date de naissance*

La *date de naissance* doit être indiquée conformément à la convention de saisie nationale réglée dans Windows : au format *JJ.MM.AAAA* (p. ex. : 27.03.1964) ou *MM/JJ/AAAA* p. ex. : 03/27/1964).

ATTENTION
Après le numéro de fiche, le prénom, le nom de famille et la date de naissance, vous DEVEZ taper un "point virgule";).

Exemple

CerPI.exe -0815;prénom;nom de famille;15.11.2000;

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Résultat

Tableau 5: Liaison à la base de données

CEREC avec base de données connectée	CEREC sans base de données connectée
Le patient est inscrit dans la base de données SIRONA.	Le patient est créé dans la structure locale de données CEREC.

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11.2 Interface SLIDA

Uniquement avec base de données connectée

Si la base de données est connectée, il est possible d'envoyer des données patient à CEREC via l'interface SLIDA.

Modifier les données patient via l'interface SLIDA

Vous pouvez créer de nouveaux patients, modifier des données patient et activer des patients. Le mailslot pour l'interface SLIDA est créé lors de l'installation de la base de données.

Ne pas modifier les données patient dans CEREC

Des patients qui ont été entrés dans la base de données SIRONA via l'interface SLIDA peuvent être effacés dans l'application CEREC, mais pas modifiés, car la base de données SIRONA ne contient que des copies et pas les données originales.

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11.3 Interface OpenDenta

Uniquement avec base de données connectée

Une autre possibilité de communication avec différents programmes de gestion de cabinet consiste à utiliser l'interface OpenDenta lorsque la base de données est connectée. L'installation de l'interface OpenDenta dans le cabinet est réalisée par un technicien OpenDenta. En plus de la base de données SIRONA, le serveur SIRONA-OpenDenta doit être installé. Dans l'application CEREC, il suffit de connecter la base de données SIRONA.

Données patients visibles

Lorsque l'environnement OpenDenta (automate OpenDenta, serveur SIRONA OpenDenta) est installé et que la base de données SIRONA est connectée, toutes les données patient qui ont été communiquées par un système de gestion conforme au standard OpenDenta via l'interface OpenDenta sont également visibles dans l'application CEREC. Si le système de gestion du cabinet peut également demander des images via OpenDenta, toutes les images représentatives des restaurations CEREC (généralement la prise d'empreinte de la préparation) y sont également visibles.

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12 Conseils et astuces

Dans ce chapitre

Dans ce chapitre, vous trouverez des indications précieuses qui vous faciliteront le travail avec CEREC 3D :

- „Screenshot (Photo d'écran) / Image TIF" page 103
- „Indications techniques" page 104
- „Questions fréquentes" page 107

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12.1 Screenshot (Photo d'écran) / Image TIF

L'application SIROCAM convient parfaitement pour exporter les images TIF de préparation de restaurations ou pour la transmission de ces images à un programme graphique en vue de leur traitement ultérieur.

Générer une photo d'écran

Comme les lignes de construction ne sont pas représentées sur les images TIF de préparations, il peut être nécessaire de générer une photo d'écran :



1. Lorsque le contenu souhaité est visible sur l'écran, appuyez sur la touche *Imecran*.
   Dans le même temps, sur l'unité de prise d'empreinte CEREC, appuyez sur la touche indiquée à gauche.
2. Ouvrez le programme graphique de votre choix (p. ex. Paint).
3. Dans ce programme, sélectionnez *Edition/Insérer*.

La photo d'écran apparaît et peut être traitée et enregistrée.

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12.2 Indications techniques

Aucune prise d'empreinte n'est possible durant la lecture d'un film sur DVD.

Durant la lecture d'un film sur DVD, il n'est pas possible de réaliser de prises d'empreintes (caméra 3D ou SIROCAM). Avant la réalisation d'une nouvelle prise d'empreinte, le logiciel de lecture de DVD doit être mis à l'arrêt.

Le déclenchement d'une prise d'empreinte pendant la lecture d'un DVD provoque des erreurs graphiques. Dans ce cas, quittez à la fois l'application CEREC (ou SIROCAM) et le logiciel de lecture de DVD et redémarrez l'application CEREC (ou SIROCAM).

Clé électronique

Le raccordement d'un appareil supplémentaire (imprimante, lecteur externe) sur la clé électronique peut nuire à son bon fonctionnement.

1. Débrancher l'appareil concerné.
2. Dans le BIOS Setup du PC, contrôlez que l'interface parallèle est réglée sur EPP. Pour ce faire, consultez le manuel de la carte mère.

L'unité de prise d'empreinte est correctement réglée en usine !

Problèmes lors de la communication avec l'unité d'usinage

S'il n'est pas possible d'établir la communication avec l'unité d'usinage, l'interface et la vitesse de transmission doivent être contrôlées via l'option de menu *Réglages/Configuration/Communication*.

Des conditions radio défavorables peuvent entraîner des problèmes de communication avec l'unité d'usinage. Débranchez le module radio de l'unité d'usinage (débrancher la fiche), rebranchez-le et refaites un essai.

Exemples pour unité de prise d'empreinte CEREC 3 raccordée :

Liaison par câble	Interface=COM2	Vitesse de transmission=115200
Liaison par câble long	Interface=COM2	Vitesse de transmission=19200
Liaison radio EU	Interface=COM1	Vitesse de transmission=115200

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Liaison radio USA (Hôfl&Wessel)	Interface=COM1	Vitesse de transmission=115200
Liaison radio USA (Futaba)	Interface=COM1	Vitesse de transmission=19200
Liaison radio Japon (Futaba)	Interface=COM1	Vitesse de transmission=19200

Pour PC/Notebook

Contrôlez le *port de communication* (interface).

1. Sélectionnez *Démarrer/Paramètres/Panneau de configuration.*
2. Double-cliquez sur *Système.*
3. Dans *Propriétés système* (Fig. 12-1) sélectionnez l'onglet *Matériel* et cliquez sur *Gestionnaire de périphériques.*

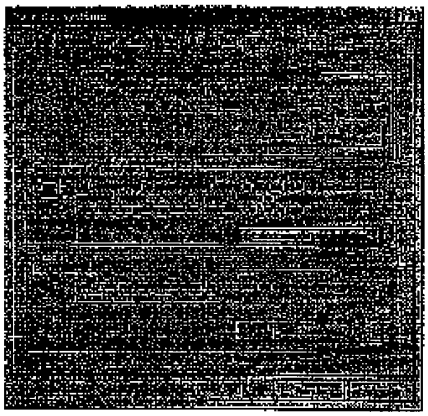


Fig. 12-1 Caractéristiques système

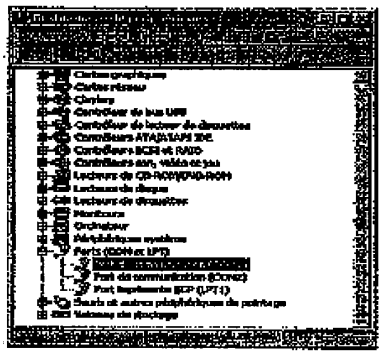


Fig. 12-2 Gestionnaire de périphériques

4. Double-cliquez sur *Ports.* Vous voyez ici quel *port de communication* est disponible (p. ex. COM1, COM2).
5. Réglez l'interface ici indiquée via l'option de menu *Paramètres/Configuration/Communication* (voir „Configuration : Communication" page 46).

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Pas de mise en veille pendant le processus d'usinage

⚠ *ATTENTION*
La mise en veille ne doit pas être activée durant le processus d'usinage.

Régler l'option d'alimentation sur "jamais".

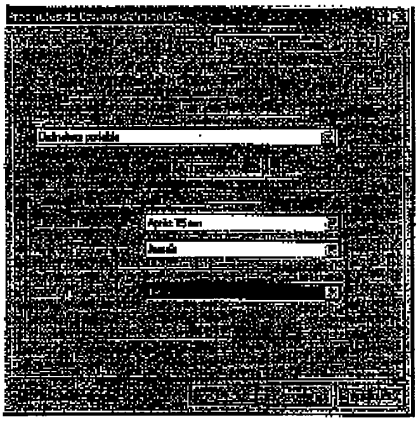


Fig. 12-9 Options de gestion de l'alimentation

1. Sélectionnez ***Démarrer/Paramètres/Panneau de configuration.***
2. Double-cliquez sur ***Gestion de l'alimentation.***

Dans les options de gestion de l'alimentation pour ***Arrêt des disques durs, Mode Standby*** et ***Mise en veille*** il faut régler ***"jamais"*** (Fig. 12-9).

Modifier la taille de la police

Si le texte d'une boîte de dialogue n'est pas totalement visible, le mode d'affichage réglé est : ***Propriétés de l'affichage -> Grandes polices.*** En cliquant avec la touche droite de la souris sur l'arrière-plan, vous pouvez basculer dans la fenêtre ***Propriétés de Affichage/Paramètres/Taille de la police*** sur le réglage ***Petites polices*** .

Economiseur d'écran

L'activation de l'économiseur d'écran peut provoquer des erreurs de représentation. Dans ce cas, désactivez l'économiseur d'écran.

Gestionnaire de tâches

L'activation du gestionnaire de tâches (Ctrl.+Alt+Suppr) peut provoquer des erreurs de représentation. Dans ce cas, fermez le CEREC 3D programme et redémarrez-le.

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12.3 Questions fréquentes

Liaison à la base de données

L'indication de numéro de dent des entrées CEREC (identification "VC") n'est pas convertie dans S(V)IDEXIS en cas d'utilisation du schéma dentaire USA.

Réduction de l'application

Durant l'usinage, il n'est pas possible de réduire l'applicationCEREC 3D.

Prises d'empreintes floues

Les prises d'empreintes floues sont reconnaissables à la présence d'ondulations (préparation ou occlusion) De même, des taches claires ou sombres sur l'image de hauteur (préparation ou occlusion) sont des indices d'une prise d'empreinte floue.

Une prise d'empreinte floue peut également entraîner un résultat d'usinage défectueux (trous dans la restauration). La caméra 3D doit être maintenue de façon immobile jusqu'au "clic" audible.

Textes en allemand pour versions internationales de Windows

Dans de rares cas, des textes en allemand peuvent apparaître dans des installations Windows et CEREC 3D internationales ou dans d'autres applications (p. ex. Photoshop). Dans ce cas, le fichier "MFC42LOC.DLL" en "MFC42LOC.BCK" doit être renommé.

Pour ce faire, exécutez l'application "RenameLog.exe" sur le CD de programme CEREC 3D (dans le répertoire "Misc\RenameMFC42LOC").

Logiciel supplémentaire sur le CD CEREC 3D

- En plus du logiciel CEREC 3D, le programme Freeware "Zoomer" est également installé dans le groupe de programmes CEREC. Ce programme comprend une fonction de loupe servant d'aide au dessin. Un clic avec la touche droite de la souris dans la fenêtre de loupe permet de réaliser divers réglages.
- Dans le répertoire "Misc/CSA" se trouve un programme qui permet de participer au projet de documentation CEREC de la "Deutsche Gesellschaft für computergestützte Zahnheilkunde" (DGCZ) et de l'"International Society of Computerized Dentistry" (ISCD). Pour de plus amples informations, veuillez lire le fichier "Readme.txt" dans le même répertoire.

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13 Glossaire

Axe d'introduction	Le sens de vision de la caméra 3D doit coïncider avec l'axe d'introduction de la restauration.
Barre d'état	Barre située au niveau du bord inférieur de l'écran et qui affiche des informations actuelles.
Barre d'icônes	Symboles (icônes) permettant d'appeler des fonctions importantes du programme.
Catalogue d'images	Fenêtre pour la gestion des champs d'images (préparation, occlusion et antagoniste)
Champs d'images	Une ou plusieurs prises d'empreinte de la préparation, de l'occlusion ou de l'empreinte des antagonistes.
Clé électronique	Fiche qui se monte sur l'interface parallèle de l'unité de prise d'empreinte (PC) et qui valide différentes options d'usinage.
Contact	Outil (bouton) pour l'affichage/le masquage de la surface de contact par rapport à la dent voisine.
Cut	Outil/fenêtre de coupe permettant de tracer un plan de coupe à travers la restauration/la préparation.
Design	Fenêtre avec outils de construction utilisés pour le traitement de la restauration.
Drop	Outil (bouton) pour l'activation/désactivation de la fonction "gouttes de cire" qui permet de déposer du matériau goutte à goutte et de le lisser. Activation/Désactivation à l'aide de la barre d'espacement.
Edit	Outil (bouton) pour l'activation/désactivation de la fonction d'édition qui permet de modifier les lignes de la construction.
Enregistrement de référence	Le premier enregistrement qui définit au départ l'axe d'introduction. Une modification ultérieure est possible.

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Enregistrement d'occlusion	Enregistrement d'une occlusion existante ou du wax-up d'une occlusion.
Enregistrement unique	Enregistrement unique devant être réalisé dans le sens occlusal (axe d'introduction).
Enregistrements angulaires	Enregistrements supplémentaires de la même zone sous un angle d'inclinaison maximal de 20°.
Enregistrements complémentaires	Plusieurs enregistrements qui illustrent le contour mésial et le contour distal.
Image Intensité	Fenêtre permettant de tracer de manière plus précise les segments cervicaux du bord de la préparation aux endroits épigingivaux. L'image intensité peut être activée/désactivée à l'aide de la barre d'espacement durant l'introduction du bord de la préparation.
Occlusion	Outil (bouton) pour l'affichage/le masquage d'un champ d'images existant de l'occlusion.
Position	Outil de positionnement permettant de décaler l'ensemble de la restauration dans différentes directions.
Prise d'empreinte de l'antagoniste	Empreinte optique de l'enregistrement centré de l'occlusion
Rotate	Outil de rotation permettant de faire tourner l'ensemble de la restauration autour de différents axes.
Scale	Outil (bouton) pour l'activation/désactivation de la fonction de mise à l'échelle qui permet de déformer des zones sélectionnées.
Shape	Outil (bouton) pour l'activation/désactivation de la fonction de surfaces de forme libre permet de déposer du matériau, d'en enlever et de le lisser.
Trim	Outil (bouton) permettant l'affichage/le masquage de zones préalablement définies.

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View	**Fenêtre de visualisation avec boutons et outils permettant d'afficher/de masquer différentes vues.**
Viewer 3D	**Fenêtre principale pour la visualisation et la construction d'un restauration en représentation 3D.**

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Sous réserve de modifications dues au progrès technique.

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Translation into English of the article by

R. Stoll, V. Stachniss

Computer-aided technologies in dentistry

With the introduction and mass production of the Cerec© system, a method of computer-controlled manufacturing of single tooth prostheses with modern milling methods first gained current significance. Entirely new techniques, such as the optical impression, "modeling" on the computer with CAD programs and manufacturing with CNC machines are here introduced for the first time from the industrial production into dentistry. The CEREC ® method is presently still limited to the indication of the inlay fillings and this currently available technology is still very distant from the vision of the computer-manufactured crown including okklusal surface design. Whether this technological leap can occur in the foreseeable future, is not yet clear.

1 Introduction

In this decade, dentistry is also confronted with the instruments and the techniques of a new industrial revolution. The computer, which was recently voted "man of the year" by a renowned American magazine, now also finds its place in dentistry and also affects various surrounding professions. Where EDP in the dental office had previously only purely administrative duties in management and accounting, it now penetrates into the workflow of the dentist including treatment of patients: this time from the direction of industrial manufacturing with computer-controlled methods for manufacturing fillings and single tooth prostheses [3]. These new methods and future images were debated in the dental media spontaneously and as intense as no other topic for some time. While the assistant was mainly the one apparently concerned when the computer first appeared, now the dental technicians see their jobs endangered by computer technology [8, 9]. However, just like the statement "IT cuts labor" in most cases turned out to be merely a sales promotion tale, computer technology falls far short of making a dental technician obsolete and will if at all only lead to a change in work flows [9]. This article will explain the basics of this new technology from its origins and give an overview of the currently available technology.

2 Why computer technologies in the industry?

Modern computer technologies in industrial production are often referred to as C-technologies. Here, the C stands for the computer, which is not difficult to guess. Industrial manufacturing of products made of various materials has been influenced by automation for 150 years. The initial way of craft manufacturing was transferred more and more to

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R. Stoll, V. Stachniss[1]

Computerunterstützte Technologien in der Zahnheilkunde

Mit der Vorstellung und Serienproduktion des Cerec®-Systems erlangte erstmals ein Verfahren zur computergesteuerten Fertigung von Einzelzahnersatz mit modernen Fräsverfahren eine aktuelle Bedeutung. Völlig neue Techniken, wie der optische Abdruck, die »Modellation« am Computer mit CAD-Programmen und die Fertigung mit CNC-Maschinen werden hier erstmals aus der industriellen Produktion in die Zahnheilkunde eingeführt. Zur Zeit ist das Cerec®-Verfahren noch auf die Indikation der Einlagefüllung begrenzt und der aktuelle Stand dieser Technik noch weit von der Zielvorstellung der computergefertigten Krone inklusive Kauflächengestaltung entfernt. Ob dieser Technologiesprung in absehbarer Zukunft stattfinden kann, ist noch nicht erkennbar.

1 Vorwort

In diesem Jahrzehnt wird auch die Zahnmedizin mit dem Instrumentarium und den Techniken einer neuen industriellen Revolution konfrontiert. Der Computer, der vor kurzem von einer renommierten amerikanischen Zeitschrift zum »Mann des Jahres« gewählt wurde, findet nun auch seinen Platz in der Zahnheilkunde und berührt auch die verschiedenen Berufe im Umfeld. Hatte die EDV in der zahnärztlichen Praxis bislang nur rein administrative Aufgaben in der Verwaltung und Abrechnung erledigt, so dringt sie jetzt in die Arbeitsabläufe des Zahnarztes bis zur Behandlung am Patienten vor; diesmal aus der Richtung der industriellen Fertigung mit computergesteuerten Methoden zur Anfertigung von Füllungen und Einzelzahnersatz [3]. Diese neuen Methoden und Zukunftsbilder wurden spontan und so intensiv wie lange kein anderes zahnmedizinisches Thema in den Medien diskutiert. War beim ersten Erscheinen des Computers hauptsächlich die Helferin die scheinbar Betroffene, so mögen nun die Zahntechniker ihre Arbeitsplätze durch die Computertechnologie in Gefahr sehen [8, 9]. Ebenso wie sich jedoch die Aussage »EDV spart Arbeitskräfte« in den meisten Fällen als lediglich verkaufsförderndes Märchen herausstellte, wird auch die Computertechnologie noch lange keinen Zahntechniker überflüssig machen und allenfalls zu einer Veränderung der Arbeitsabläufe führen [9]. Dieser Artikel soll die Grundlagen dieser neuen Technologie aus ihren Ursprüngen heraus erklären und einen Überblick über den aktuellen Stand der Technik geben.

2 Warum Computer-Technologien in der Industrie?

Moderne Computertechnologien in der industriellen Produktion werden häufig als C-Technologien bezeichnet. Hierbei steht das C für den Computer, wie unschwer zu erraten ist. Die industrielle Herstellung von Produkten aus verschiedensten Werkstoffen steht bereits seit 150 Jahren im Zeichen der Automation. Dabei wurde die intial handwerkliche Fertigungsweise immer mehr auf Maschinen übertragen und die zunehmend komplexeren Arbeitsabläufe zusammengefaßt und automatisiert. Dies hat den Vorteil, daß die Produkte in kürzerer Zeit, billiger, fehlerfreier und in größeren Serien hergestellt werden können. Mußte zunächst noch die Maschine durch den Menschen bedient werden (Beispiel: Arbeiter an einer Drehbank), so versuchte man bald, die Arbeitsabläufe der Maschine durch ein Programm zu steuern. In den Anfängen wurde dieses Programm durch eine einfallsreiche Mechanik realisiert, z. B. wurde der erste programmgesteuerte Webstuhl 1808 mit einer Lochkartensteuerung gebaut. Es lag somit nahe, den Computer als universelles Instrument zur Steuerung einzusetzen, was zum ersten Mal 1948 durch *J. Pearson* realisiert wurde. Diese Technik wird mit dem Kürzel CNC bezeichnet, was als Abkürzung for *C*omputer *N*umeric *C*ontrol steht. Werkzeugmaschinen, die sich lediglich durch Eingabe von Zahlenwerten steuern lassen, werden dagegen lediglich als NC-Systeme bezeichnet (NC = *N*umeric *C*ontrol).

Computergesteuerte Fräsmaschinen oder Drehbänke können jedoch zunächst nur geometrisch genau definierte Körper herstellen, was bei der industriellen Produktion von Maschinenteilen ja die Regel ist. Die höheren Kosten für solche komplizierteren Maschinen werden leicht durch die Kostenvorteile der großen Stückzahl, der niedrigeren Produktionszeiten und der besseren und reproduzierbaren Qualität wieder ausgeglichen. Durch die gestiegenen Anforderungen an diese Programmsteuerung wandelten sich jedoch auch die Werkzeugmaschinen, die an die besonderen Vorzüge dieses Verfahrens angepaßt wurden. Die Bewegungsmöglichkeiten der Werkzeuge werden dabei ausgeweitet und ermöglichen es, mit der Maschine immer kompliziertere Werkstücke herzustellen.

Einer Wandlung wurde aber auch der Prozeß der Planung und Konstruktion unterzogen. Das Reißbrett wird immer mehr vom Computer als Zeichenhilfe (CAD = *C*omputer *A*ided *D*esign) abgelöst. Dadurch können Änderungen schnell vorgenommen werden, und mit den gespeicherten Konstruktionsdaten kann ein NC-Fräsprogramm zur Herstellung der konstruierten Teile (CAM = *C*omputer *A*ided *M*anufacturing) erzeugt werden, welches von einer CNC-Maschine ausgeführt wird.

3 Die industrielle Fertigung im CAD/CAM-Verfahren

Das CAD/CAM-Verfahren ist in der industriellen Produktion mittlerweile zum Standardverfahren geworden. Hierbei ist die konventionelle Arbeitsweise durch Einsatz des Computers vereinfacht und automatisiert worden. Ein typischer Arbeitsgang erfordert folgende Stufen:

3.1 Computerunterstützte Konstruktion – CAD

Industrielle Werkstücke werden in der Regel aus geometrisch definierten Grundformen in bestimmten Lagebeziehungen aufgebaut. Diese Objekte lassen sich beispielsweise durch Kreise, Strecken, Kanten und geometrische Körper wie Kugeln oder

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Kopie von subito e.V., geliefert für Michalski Hüttermann Patentanwälte (COM09X01091)

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Polyeder beschreiben. An dieser Aufzählung kann man bereits erkennen, daß hier von verschiedendimensionalen Grundstrukturen die Rede ist. Die zu konstruierende Produktform ist selbstverständlich immer ein dreidimensionaler Körper. Dieser kann jedoch mit einfachen Elementen gezeichnet werden. Bei der konventionellen Konstruktion am Reißbrett werden diese einfachen Elemente vom Zeichner mit Zirkel und Lineal aufgebaut. Ein solches Vorgehen ist jedoch auch mit einem Computer möglich. Mit modernen Eingabetabletts kann ein Zeichner auf dem Monitor die gleichen Zeichenarbeiten ausführen, wie auf dem Reißbrett. Er hat jedoch beim Computer die Vorteile, daß er Details leicht verändern und beliebige Details in einer Vergrößerung bearbeiten kann. Der Computer ist mit einer geeigneten Software sogar in der Lage, aus einfachen zweidimensionalen Zeichenobjekten dreidimensionale Strukturen zu erzeugen und in einer beliebigen Ansicht darzustellen. Die fertige Konstruktionszeichnung muß nun nur noch auf Datenträger gespeichert werden, um sie der Weiterverarbeitung zugänglich zu machen.
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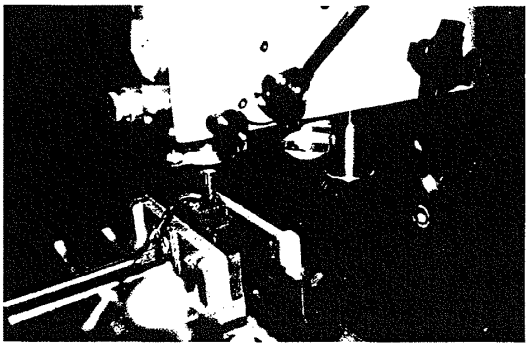


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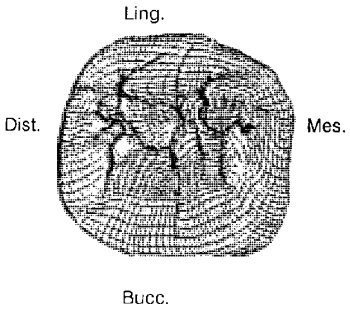


Abb. 2 Optisch abgetastete Molarenkrone als Beispiel für eine Netzgrafik. Entnommen aus [14]

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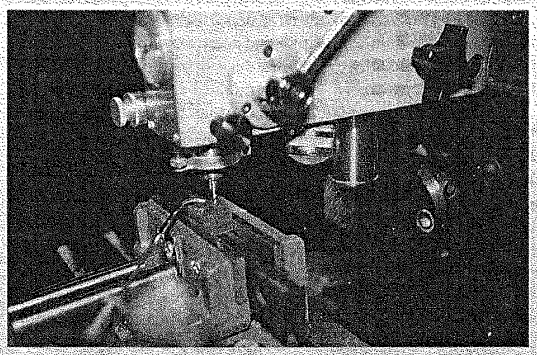


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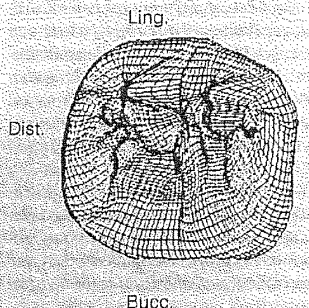


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Dies gilt für Designartikel oder beispielsweise für Formen, die im Windkanal als Modell optimiert werden müssen. Solche Modellformen müssen mit geeigneten Abtastsystemen in das CAD-Programm übernommen werden. Auch hierfür gibt es in der Industrie fertige Lösungen. Hierbei wird die Oberfläche der Form mit einem Meßtaster oder einem Laserstrahl Punkt für Punkt abgefahren und vermessen. Die einfachen Punktinformationen können mit geraden Linien verbunden werden, was eine netzartige Darstellung auf dem Computermonitor ergibt (Abb. 2). Komplexere Auswertungsprogramme verwenden statt der etwas kantigen Linie gekrümmte Ausgleichskurven (Splineinterpolation), was zu stetigen und glatten Oberflächen führt [14]. Ein Programm kann die so erstellte Netzgrafik in ein für das CAD-Konstruktionsverfahren geeignetes Datenformat umrechnen.

4 Computer-Technologien in der Zahnmedizin

Nach dieser etwas längeren Einführung soll nun der Kreis zur Zahnmedizin wieder geschlossen werden, indem zunächst festgestellt wird, daß mit den nachfolgend genannten Verfahren lediglich ein industriell gut entwickeltes Produktionsverfahren an den Zahnarztstuhl herangeholt wird. Leider treten im Vergleich zur Industrie Unterschiede und Probleme auf, die eine einfache Übernahme der bestehenden Technologie fast unmöglich machen.

4.1 Argumente für C-Techniken

Die Vision der CNC-Fertigung von Zahnersatz beginnt da, wo der Zahnarzt die Präparation einer Krone beendet hat:

Im Jahre 2000 entscheidet sich ein Zahnarzt bei einem Patienten zur Anfertigung einer Einzelkrone im Seitenzahnbereich. Nach konventioneller Präparation mit rotierenden Instrumenten steht nun der rein technische Teil der Behandlung bevor. Statt eines konventionellen Abdruckes wird mit einer kleinen Kamera der Stumpf aufgenommen, wobei die Präparationsränder selbstverständlich deutlich erkennbar dargestellt sein müssen. Nachdem auch noch die übrigen Zähne des Quadranten sowie die Zähne des Gegenkiefers solcherart optisch abgeformt wurden, beginnt ein Computer mit seiner Arbeit. Die Bilddaten werden in dreidimensionale Daten umgewandelt und in ein CAD-System übernommen. Die Relation des Stumpfes zum Antagonisten wird hergestellt, anhand der Geometrie der übrigen Zähne werden die Kaubewegungen simuliert und in einem Bewegungsfeld dargestellt. In diese Umgebung wird nun ein Musterzahn aus einer Datenbank hineinprojiziert und an die Stumpfform und die Form des Antagonisten durch leichte Formverzerrung angepaßt. Hierbei werden automatisch kleine Präparationsfehler ausgeglichen und gleichzeitig wird die Außenform noch parodontologisch optimiert. Nachdem der Computer beim Zahnarzt nachgefragt hat, welcher Werkstoff aus einer Palette von verschiedenen Keramiken, hochfesten und abrasionsbeständigen Kunststoffen oder den unterschiedlichsten Metallen ausgewählt werden soll (hier hat er sich gerade für Reintitan entschieden, da der Patient keine besonderen Anforderungen an die Ästhetik stellt), erarbeitet der Computer ein Programm für eine kleine Fräsmaschine, welche die Krone in wenigen Minuten aus einem Materialblock herausfräst. Das Einzementieren der vorzüglich passenden Krone und die anschließende obligate Okklusionskontrolle (die jedoch selten ein Nachschleifen erforderlich macht) kann der Zahnarzt in der gleichen Sitzung vornehmen. Lediglich der Zahntechniker hat das Nachsehen.

Mit diesem kleinen ›Science-fiction‹-Exkurs soll aufgezeigt werden, was der Zahnarzt sich von den neuen Technologien versprecht. Sinnvoll ist sicher das Argument der hohen Materialunabhängigkeit. Mit einem CNC-Fräsverfahren könnten Werkstücke auch aus vielen bislang schwer vergießbaren Materialien oder Halbzeug gefertigt werden, ohne daß die Qualität des Werkstoffes durch einen Gießprozeß in Mitleidenschaft gezogen würde. Werkstoffschädigungen oder Porenbildung wären ausgeschlossen. Die Paßgenauigkeit einer solchen Krone würde unter der Annahme, daß das Verfahren hinreichend genau arbeitet, nicht von schwer kalkulierbaren Werkstoffeigenschaften (Abdruckmasse, Modellmasse, Wachs, Einbettmasse etc.) abhängen. Menschliches Versagen wäre ebenso im Prinzip ausgeschlossen. Das fertige Werkstück könnte in der gleichen Sitzung eingesetzt werden, womit Kosten für Provisorien entfallen. Ob und wie diese Verfahren schon realisierbar sind, und welche Probleme und Nachteile sich hierbei auftun, soll im folgenden untersucht werden.

4.2 Erstes Problem: Der optische Abdruck

Im bisherigen indirekten Arbeitsverfahren wird von den zu behandelnden Zähnen oder den zu rekonstruierenden Kieferabschnitten eine Abformung und im nächsten Arbeitsschritt ein Modell gewonnen. Bereits dieser Schritt enthält durch Werkstoff und Methodik verursachte Fehler, welche eine Auswirkung auf die Paßgenauigkeit der späteren Rekonstruktion haben. Es ist daher anzustreben, solche fehlerträchtigen Positiv-/Negativumwandlungen so präzise wie möglich zu machen oder einfach zu vermeiden. Bei CNC-basierten Verfahren besteht die Möglichkeit, das Modell mit einem geeigneten Abtastverfahren direkt zu digitalisieren, d. h. dem Computer zuzuführen. Für den Zahnarzt bedeutet dies, daß eine Digitalisierung der anatomischen Situation mit einem geeigneten Verfahren direkt im Munde des Patienten anzustreben ist. Für ein solches Verfahren kann man zunächst die Anforderungen formulieren. Es muß in der Lage sein, die gewünschten Informationen mit hinreichender Genauigkeit, d. h. einer Auflösung im Mikrometerbereich zu gewinnen und darf gleichzeitig nur eine relativ kurze Zeit für den Meßvorgang benötigen. Sollte die Abtastzeit zu groß werden, kann man Fehler durch Verwackelung nicht ausschließen, es sei denn, daß Aufnahmeapparatur und Kiefer starr verbunden wären. Als Kompromiß ist denkbar, die Digitalisierung nicht im Munde, sondern nach herkömmlicher Modellherstellung in Ruhe am Stumpf vorzunehmen.

Als Digitalisierverfahren kommen mehrere Konzepte in Frage. Die einfachste Möglichkeit ist das Abtasten mit einer Meßsonde. Hierbei wird das Objekt in eine Apparatur eingebracht, die die Oberfläche des Objektes nach einer speziellen Strategie abtastet und für jeden Punkt die Koordinatenwerte bestimmt. Dieser Taster kann ein einfacher Schalter oder ein induktiver Wegaufnehmer sein. Ein etwas fortgeschritteneres Konzept ersetzt einen solchen harten Tastkopf durch einen Laserstrahl, mit welchem die Oberfläche berührungslos abgetastet werden kann [12]. Dieses Verfahren bezeichnet man als Lasertriangulation. Nachteil dieser Verfahren ist die Abtastzeit, die bei hinreichend dichter Meßpunktlage erheblich ist. Als Abtastmechanismus kommt eine Maschine zum Einsatz, die den Meßsensor an jeden Punkt des Objektes plazieren kann. Hierzu ist im Idealfall auch eine CNC-Maschine mit hoher Achsenzahl (> 3) erforderlich, die den Meßsensor überall möglichst senkrecht zur Objektoberfläche führen kann. Aus diesem Grund bedarf es zusätzlich einer sehr ausgeklügelten Meßstrategie, die nicht ohne Computerprogramme zu realisieren ist. Der Vorteil dieses Verfahrens ist jedoch die hohe Meßgenauigkeit, die hierbei zu erzielen ist. Für einen Einsatz im Munde ist dieses Verfahren wegen der langen Meßdauer nicht geeignet, dafür wird es im Labor mit Erfolg eingesetzt. Durch die Meßdauer auf teuren Maschinen ist jedoch die Wirtschaftlichkeit dieses Verfahrens eher zweifelhaft.

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Für eine intraorale Abtastung kommen hauptsächlich fotografische Verfahren zur Anwendung. Hierbei wird analog zur bisherigen Abdrucknahme vom optischen Abdruck [24] oder Videoabdruck [7] gesprochen. Leider gewinnt man auf einem normalen Foto nur eine zweidimensionale perspektivische Ansicht des Objektes. Bei bekanntem Maßstab lassen sich hieraus nur zweidimensionale Informationen gewinnen, die Tiefeninformation fehlt. Es bedarf also für eine dreidimensionale Auswertung zusätzlicher Information. Die einfachste Möglichkeit, diese Information zu gewinnen, ist die Anfertigung einer zweiten Aufnahme aus einem anderen Blickwinkel. Bei bekanntem Abstand kann aus diesen beiden Bildern die Tiefeninformation (analog zum räumlichen Sehen beim Menschen) zurückgerechnet werden. Für dieses Verfahren der stereoskopischen Photogrammetrie können einerseits herkömmliche Filmaufnahmen herangezogen werden, die später durch optische Scanner digitalisiert werden, andererseits kann der Film wieder durch eine kleine Video-Kamera ersetzt werden. Als Miniatur-Videokameras werden heutzutage kleine Chipkameras eingesetzt, bei denen der Film durch einen kleinen Siliziumchip ersetzt wird. Diese sog. CCD-Kameras (CCD = Charge Coupled Device) können sehr klein hergestellt werden und geben das Bild sofort an eine Auswertungselektronik weiter. Der Nachteil dieser Kameras ist, daß sie nur eine begrenzte Anzahl von Bildpunkten auswerten [26]. Herkömmliche CCD-Chips haben ein Auflösungsvermögen von 256 × 256 Bildpunkten, werden jedoch mittlerweile durch eine neue Generation von Bausteinen mit einer Auflösung von 512 × 512 oder sogar 1024 × 1024 Punkten ersetzt. Je weniger Bildpunkte verarbeitet werden, desto ungenauer ist die anschließende Auswertung. Die beiden Teilbilder können später im Computer zu einer dreidimensionalen Darstellung zusammengesetzt werden. Durch automatische Erkennung von Kanten können relevante Bereiche, wie z. B. die Präparationsgrenze, ermittelt und ihrer Bedeutung entsprechend dichter digitalisiert werden [26]. Probleme gibt es jedoch, wenn einzelne Teile des Objekts nicht einsehbar sind bzw. sich überdecken. In diesem Fall sind weitere Ansichtsbilder aus günstigerem Blickwinkel notwendig. Ein komplexes dreidimensionales Bild aus mehreren Ansichtsaufnahmen zusammenzusetzen, ist mit geeigneten Rechenverfahren jedoch ein lösbares Problem.

Während die stereoskopische Photogrammetrie die Tiefeninformation aus zwei verschiedenen Ansichten gewinnt, gibt es noch ein weiteres Verfahren, um die Tiefeninformation aus nur einer Aufnahme zu erhalten. Hierbei wird ein Streifenmuster mit gleichbleibendem, definiertem Streifenabstand auf die Oberfläche des Objekts projiziert. Aus der entfernungsbedingten Verzerrung dieses Streifenmusters durch die Objektgeometrie, bei Aufsicht unter einem kleinen Parallaxwinkel, kann nun die Tiefeninformation zurückgerechnet werden. Diese, der Moiré-Topografie sehr ähnliche Verfahren, eignen sich bei einfachen Objekten, die eine klare Geometrie und eine gut reflektierende Oberfläche haben. Eine Zahnoberfläche reflektiert zwar schlecht, jedoch kann hier mit einem farbgebenden Pulver nachgeholfen werden [21].

Weitere denkbare Verfahren, wie z. B. die Holografie [30] sind in der Mundhöhle schwer realisierbar und setzen auch im Labor bei der geforderten Präzision und Übertragbarkeit in den Computer erheblichen apparativen Aufwand voraus.

Der hier beschriebene optische Abdruck ist für die zahnärztliche Anwendung des CAD/CAM-Verfahrens eine Schlüsseltechnologie, da diese Fragestellung im industriellen Bereich nicht routinemäßig auftritt.

4.3 Zweites Problem: Computer und Software

Die beschriebenen Verfahren setzen eine dreidimensionale Struktur in eine Menge von Punktdaten um. Diese können nun als sog. Netzgrafik für ein CAD-Programm lesbar gemacht werden. Der Raum zwischen den Punkten wird hierbei durch ebene oder gekrümmte Flächen interpoliert.

Aufgabe des CAD-Systems ist es nun, den beschliffenen Stumpf zu einem kompletten Zahn zu vervollständigen und die so konstruierte Krone/Inlay als dreidimensionale Daten zur Weiterbearbeitung aufzubereiten. Dies klingt einfacher als es zunächst erscheint. Für die Rekonstruktion eines Zahnes benötigt man eine Menge von verschiedenen Informationen. Man benötigt Wissen um die anatomische Form des Originalzahnes, über das Verhältnis zum Antagonisten, zur parodontalen Situation, über die Form der Nachbarzähne, über die Bewegung des Zahnes in Funktion und damit auch über die Kiefergelenke und das gesamte stomatognathe System. Ein CAD-System, das die Rekonstruktion einer oder mehrerer Kronen leisten soll, muß also in diesen Bezichungen Wissen und Intelligenz (im Sinne einer intelligenten und umfassenden Programmierung) beinhalten. Auch müssen die notwendigen Daten zu diesen Parametern erhoben sein. Dies könnten beispielsweise dreidimensionale Daten zu den Antagonisten und den Nachbarzähnen sein. Informationen zur Gelenkfunktion können als Mittelwerte vorliegen oder in Form einer elektronischen Pantografie direkt eingegeben werden. Die anatomische Struktur des Originalzahnes kann vor dem Beschleifen digitalisiert worden sein oder einer Datenbank mit Musterzähnen entnommen werden [5, 15, 27]. Durch Verzerrung, Drehung oder Vergrößerung dieses Musterzahnes kann er nun sowohl an die Präparationsgrenze, als auch an den Antagonisten angepaßt werden. Bei diesem Vorgang kann gleichzeitig ein Zementspalt eingearbeitet werden, und die approximalen Kontaktzonen können parodontal optimiert werden. Die dreidimensionale Form der so erzeugten Krone (Inlay oder Brücke) wird nun umgewandelt in ein Fräsprogramm für eine Werkzeugmaschine. Hierbei werden Informationen über den Werkstoff, das Werkzeug und die Werkzeugmaschine benötigt und eingearbeitet. Ebenso werden Informationen über die geforderte Genauigkeit benötigt. Je nach Komplexitätsgrad benötigt selbst ein leistungsfähiger Computer an dieser Stelle hohe Rechenzeiten. Diese Arbeitsschritte sind auf modernen Grafikrechnern (sog. Workstations) heute jedoch prinzipiell kein Problem mehr und können teilweise mit standardisierten Softwarepaketen durchgeführt werden [27]. Der übrige Teil der Software stellt jedoch ein wesentliches Problem dar, da diese speziell zu erstellen ist. Die Entwicklungszeit für ein Softwareprodukt dieser Komplexität kann auf einen zweistelligen Betrag an Mannjahren (1 Mannjahr = 1 Jahr Arbeitszeit für einen Programmierer) geschätzt werden.

4.4 Drittes Problem: Werkstoff, Werkzeug und Maschine

Eine universelle Maschine zur CNC-Fertigung von Zahnrekonstruktionen sollte in der Lage sein, unterschiedliche Materialien zu bearbeiten. So unterschiedliche Materialien wie Kunststoff, Keramik oder verschiedene Metalle benötigen jedoch Bearbeitungsinstrumente, die an die verschiedenartigen Werkstoffeigenschaften angepaßt sind. Es ist daher nicht möglich, alle Werkstoffe mit einem Instrument oder einer speziellen Instrumentenform zu bearbeiten. Da das Werkstück gekrümmte Flächen aufweist, muß auch das Fräswerkzeug gekrümmte Flächen haben [10]. Der Fräser muß wiederum in seiner Form der Werkstückgeometrie angepaßt sein. Kleine Instrumente sind für die Kroneninnenform (extremes Beispiel: Kronen für die untere Front) und das komplexe Kauflächenrelief (Fissuren und Grübchen) notwendig, gröbere Formen können für die Glattflächen verwendet werden. Die Schneidengeometrie ist dem Werkstoff und der angestrebten Oberflächenqualität anzupassen. Es ist daher bereits absehbar, daß eine Werkzeugmaschine für zahnärztliche Zwecke mit wechselbaren Instrumenten ausgestattet sein muß. Verschiedene Größen und Schneidengeometrien müssen daher

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auch wieder der steuernden Software bekannt sein, welche die Fräswege an diese Eigenschaften anpassen muß. Diese Anforderungen erhöhen den Komplexitätsgrad der Software und der Werkzeugmaschine beträchtlich. Die weitere Entwicklung für die Zukunft ist hierbei noch nicht absehbar. Andere, in der Industrie bereits eingesetzte Verfahren werden bislang noch nicht für CNC-Systeme im zahnärztlichen Bereich diskutiert. Hierzu zählen z. B. die Funkenerosion, die Ultraschallerosion (Keramik) oder die Materialabtragung mittels Laserstrahl.

4.5 Viertes Problem: Kosten

Die oben dargelegten Anforderungen an Aufnahmetechnik, Computer, Software und Werkzeugmaschine lassen die voraussichtlichen Entwicklungs- und Produktionskosten sehr schnell auf Millionenbeträge ansteigen. Ein so ausgestattetes Gerät wäre im Preis auch für eine überdurchschnittliche Praxis schon nicht mehr tragbar und nicht wirtschaftlich.
Um ein solches System also zu bauen und finanzierbar zu halten, muß das Problem auf einen geeigneten, ggf. minimalen Aufwand reduziert werden, wobei man von Grundideen und -forderungen abweichen muß.

4.6 Aktuelle Lösungsmöglichkeiten durch Problemreduktion

Bei der optischen Bildgewinnung für das anschließende Digitalisieren entsteht das Problem der untersichgehenden Stellen und projektionsbedingter Schattenzonen. Dieses Problem kann bei komplexen Objekten nur durch Mehrfachaufnahmen gelöst werden, welche gemeinsame Bezugspunkte aufweisen müssen. Durch die besonderen Schwierigkeiten in der Mundhöhle wird das Aufnahmeverfahren weiterhin behindert. Eine Lösung zur Vereinfachung stellt hier die Datenaufnahme vom herkömmlichen Gipsmodell dar [11–16, 28], die im Labor nach optischer Kontrolle der Präparation durchgeführt werden kann. Hierzu ist jedoch ein Abdruck nach herkömmlichem Verfahren notwendig, der zwar alle Nachteile der Werkstoffe mit sich bringt, aber auch alle Vorteile bei gingivanahen Präparationsgrenzen.
Ein Abtasten des Modells im Labor kann daher zunächst ein gangbarer Weg sein, der auch andere Optionen offenläßt. Zum Beispiel würde hierbei keine komplexe Software zur Kauflächengestaltung benötigt. Nach Abtasten der Stumpfoberfläche kann auf normalem Weg eine Krone in Wachs modelliert werden, wobei die Gestaltung vom Zahntechniker in herkömmlicher Weise übernommen wird. Diese Wachsmodellation kann in einem zweiten Schritt von der gleichen Meßanordnung digitalisiert werden. Mit einem solchen Vorgehen erübrigt sich die CAD-Software und die problematische Einbeziehung von schwer erfaßbaren Daten (Gegenkiefer, anteriore und posteriore Führung, etc.) und Okklusionstheorien, die noch nicht mathematisch bis in die letzte Konsequenz beschrieben sind.
Nachdem nun an der Datenaufnahme gespart wurde, kann dies auch im Hinblick auf die Fräsmaschine geschehen. Wenn für die Paßgenauigkeit größere Werte als 50 µm zugelassen werden und möglicherweise eine Einschränkung der geforderten Materialien auf ein einziges Material oder eine Materialgruppe zugelassen wird, kann der Komplexitätsgrad und die Anzahl der Achsen, reduziert werden. Lösungen mit weniger als fünf Achsen werden dann denkbar, die bei geringerer Präzision auch nicht in übermäßiger Stabilität ausgeführt sein müssen. Ebenso entfallen Einrichtungen für den Instrumentenwechsel und damit auch die Anforderungen an die Steuersoftware.
Ansätze zur Problemreduktion gibt es daher an vielen Punkten und sind mit diesen wenigen Beispielen sicher noch nicht erschöpfend behandelt. Um eine CAD/CAM-Zahnheilkunde heute schon zu realisieren, sind sie sicher notwendig.

5 Real existierende CAD/CAM-Systeme

Über CAD/CAM-Techniken wird im zahnmedizinischen Bereich nicht nur diskutiert und geforscht, es gibt bereits seit einigen Jahren konkrete Bestrebungen, diese Idee in die Praxis umzusetzen.

5.1 CNC-gesteuerte Geschiebeherstellung

Bereits seit einiger Zeit bestehen von Seiten der Zahntechnik Bemühungen, die herkömmliche Frästechnik für individuelle Geschiebeteile durch NC- oder CNC-gesteuerte Fräsmaschinen durchführen zu lassen. Sowohl die Firma Degussa, als auch ein italienischer Erfinder stellten solche Maschinen vor, die jedoch nur als Prototypen realisiert wurden und nicht in Serie gingen. Das Gerät der Firma Degussa wurde 1986 auf der IDS in Köln der Fachwelt vorgestellt, während der italienische Erfinder *Menecki* seine Fräsmaschine auf der Expodental in Genua im gleichen Jahr präsentierte. Das Problem beider Geräte ist der individuelle Charakter der Geschiebeform zum individuellen Zahnstumpf und dem individuellen Metallgerüst. Die Einrichtzeit zum Justieren dieser Geräte auf die individuelle Patientensituation ist so groß, daß der Fräsvorgang im Vergleich zur Handarbeit unwirtschaftlich wird. Erst der Einsatz von bildaufnehmenden, intelligenten Computersystemen könnte diese innovative Idee weiterbringen, wobei derzeit immer noch an der Wirtschaftlichkeit gezweifelt werden darf.

5.2 Grundlagenforschung zur Datenaufnahme

Das Problem der Datenaufnahme vom Modell beschäftigt mehrere Forschergruppen. Hat man sich bislang nur auf die dreidimensionale Erfassung von bestimmten Arealen (z. B. Füllungsrand) oder definierter Probekörper beschränkt, so gehen mehrere Forschergruppen mittlerweile mit mechanischen Abtastern oder Lasersensoren zur Erfassung eines kompletten Zahnstumpfes und ganzer Kieferabschnitte über (Abb. 3). Hierzu zählen unter anderem die japanische Gruppe um Prof. *Kimura* an der Universität Osaka [11–16] und die Arbeitsgruppe um Prof. *Rekow* in Minnesota [25–28], über die weiter unten noch mehr berichtet werden kann. Über eine holografische Methode zur Digitalisierung und computergesteuerten Reproduktion von Kauflächen wurde bereits 1977 von der Arbeitsgruppe *Young* und *Altschuler* [30] berichtet, die jedoch mangels verfeinerter Technologie auf ein rein experimentelles Niveau beschränkt blieb. Optische Methoden mittels Streifenmusterprojektion werden bereits mit Erfolg in den Systemen von *Mörmann* und *Brandestini* [2, 19–24], sowie im System von *Duret* [5, 6, 29] angewandt. Ein stereophotogrammetrisches Verfahren wird von *Rekow* et al.

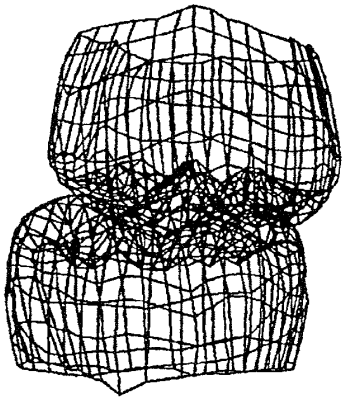


Abb. 3 Zwei digitalisierte Molaren, mit dem CAD-System in Okklusion gebracht. Netzgrafik entnommen aus [15]

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[25–28] als Alternative zur mechanisch/optischen Modellabtastung beschrieben.

5.3 Mechanische Ideen aus Schweden

Die mechanische Abtastung kann im einfachsten Fall direkt und ohne Computer an eine Fräsmaschine gekoppelt sein. Eine solche Anordnung wird als Kopierfräsverfahren bezeichnet und wird hauptsächlich in der Feinmechanik angewendet. Ein in Schweden von *Anderson* an der Universität Umeå [1] realisiertes Verfahren fräst die Außenkontur eines Kronenersatzes mittels Kopierfräsen aus reinem Titan. Die problematischere Innenkontur wird hierbei durch Funkenerosion aus dem Vollen herausgearbeitet. Die hierzu notwendigen Elektroden werden ebenfalls mittels Kopierfrästechnik angefertigt. Die Entwicklung dieses Verfahrens wurde staatlich unterstützt, und mittlerweile soll bereits eine klinische Studie mit 200 Kronen laufen.

5.4 Das Cerec®-System

Das erste CAD/CAM-System, das am Patienten funktionstüchtig war, ist das Cerec®-System von *Mörmann* und *Brandestini* [2, 19–24], das in einer Zusammenarbeit zwischen der Universität Zürich und der Firma Brains (Brandestini Instruments of Switzerland) entwickelt wurde und mittlerweile von der Firma Siemens vertrieben wird. Dieses System zeigt, daß durch geradezu geniale Problemreduktion bereits mit den heute verfügbaren Mitteln ein CAD/CAM-System realisierbar ist.

Im Cerec®-System wird zunächst der Anwendungsbereich auf Inlays und Verblendschalen beschränkt. Als Werkstoff wird lediglich Keramik oder Glaskeramik zugelassen. Fernerhin werden die Restaurationen adhäsiv zementiert, so daß die Anforderungen an die Paßgenauigkeit sinken. Mit diesen Ansätzen gelang es, eine CNC-Maschine zu entwickeln, welche die Anfertigung von Inlays am Behandlungsstuhl in wenigen Minuten ermöglicht (Abb. 4).

Die Kavität zur Aufnahme des Inlays wird ohne Unterschnitte und Federränder präpariert und für den optischen Abdruck mit einem weißen Kontrastpuder bestäubt. Die Aufnahme der Kavität erfolgt mit einer kleinen CCD-Kamera mit 256 × 256 Bildpunkten, wobei während der Aufnahme ein Streifenmuster auf die Kavität projiziert wird. Die Tiefeninformation kann nun aus der tiefenabhängigen Verzerrung dieses Streifenmusters zurückgerechnet werden, ein Verfahren, welches als aktive Triangulation bezeichnet wird [24]. Um alle Bildpunkte entsprechend auszuwerten, wird das Streifenmuster während vier aufeinanderfolgenden Messungen jeweils um einen kleinen Betrag verschoben, der Meßvorgang erfolgt jedoch innerhalb von 0,2 Sekunden und kann vom geübten Behandler verwacklungsfrei intraoral durchgeführt werden (Abb. 5). Die theoretische Genauigkeit dieses Verfahrens wird mit etwa 55 µm in allen drei Richtungen angegeben [17, 24]. Die Daten werden nun von einem Rechner aufgenommen und vom Zahnarzt interaktiv am Bildschirm zur gewünschten Inlayform ergänzt (Abb. 6 und 7). Hierbei werden die approximalen Konturen ausgeformt, auf eine Konstruktion der Kauflächenanatomie wird jedoch absichtlich verzichtet, die gegenüberliegenden okklusalen Präparationsgrenzen werden lediglich geradlinig verbunden [24]. Das okklusale Relief muß später vom Behandler mit rotierenden Instrumenten gestaltet werden. Die fertige Inlaykontur wird nun von einer dreiachsigen Schleifmaschine aus einem Keramikblock herausgeschliffen. Als Arbeitsinstrument dient eine diamantierte Schleifscheibe mit einem Durchmesser von 30 mm und einer Breite von 0,5 mm. Diese wird mittels einer Hochgeschwindigkeitsturbine angetrieben und auf eine Umlaufgeschwindigkeit von unbelastet 35 m/s an der Arbeitsfläche gebracht (Abb. 8). Während des Schleifvor-

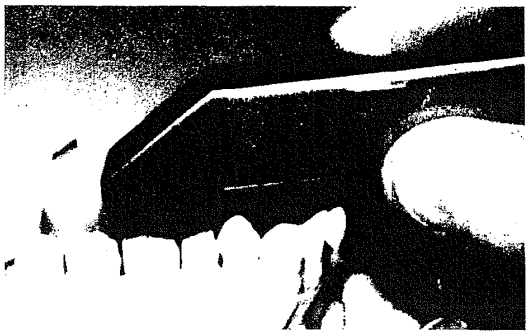


Abb. 5 Der optische Abdruck mittels Miniaturkamera. (Cerec®-System)

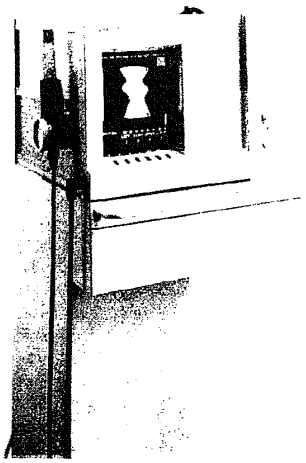


Abb. 4 Die fahrbare Cerec®-Einheit

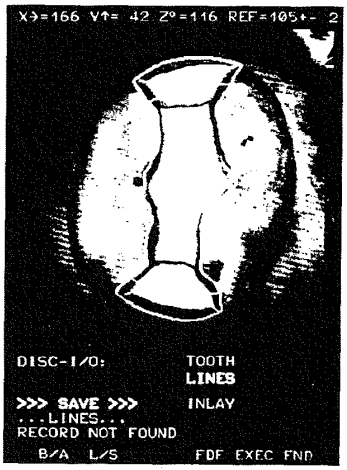


Abb. 6 Aufgenommene Kavität mit eingezeichneter Inlaykonstruktion auf dem Monitor des Cerec®-Systems

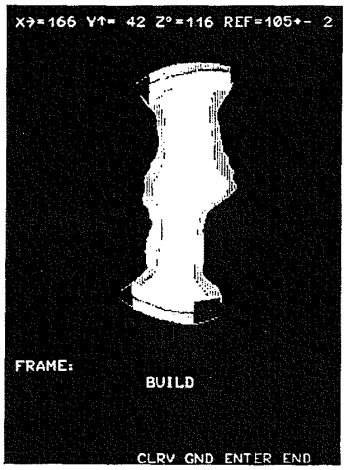


Abb. 7 Das konstruierte Inlay vor dem Fräsvorgang. (Cerec®-System)

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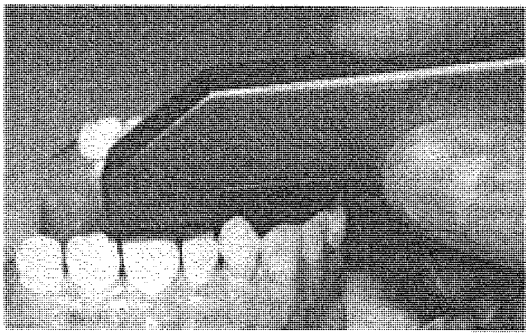


Abb. 5 Der optische Abdruck mittels Miniaturkamera. (Cerec®-System)



Abb. 4 Die fahrbare Cerec®-Einheit

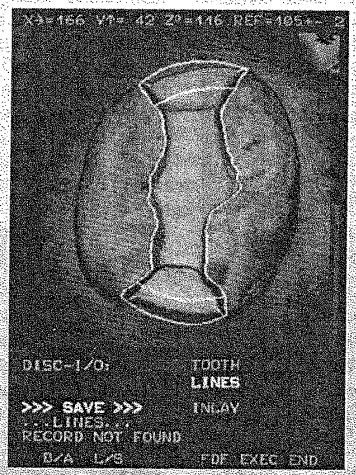


Abb. 6 Aufgenommene Kavität mit eingezeichneter Inlaykonstruktion auf dem Monitor des Cerec®-Systems

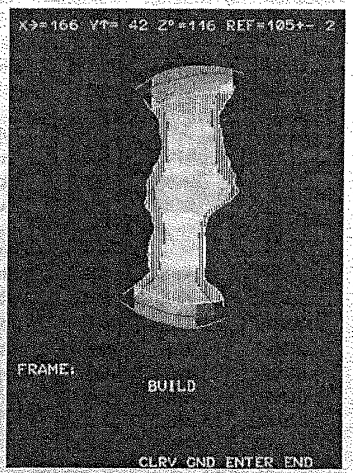


Abb. 7 Das konstruierte Inlay vor dem Fräsvorgang. (Cerec®-System)

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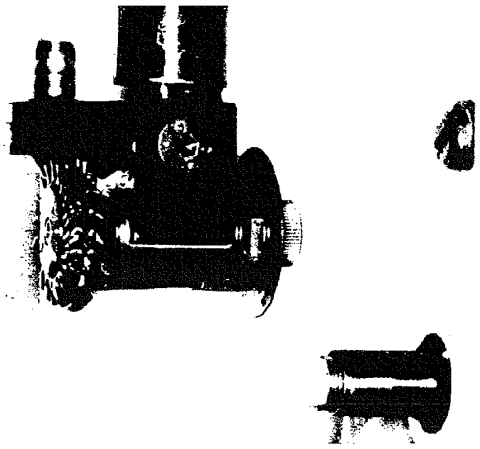


Abb. 8 Die Schleifeinheit des Cerec®-Systems. Links das Turbinenrad, rechts die Schleifscheibe, darunter der Materialblock

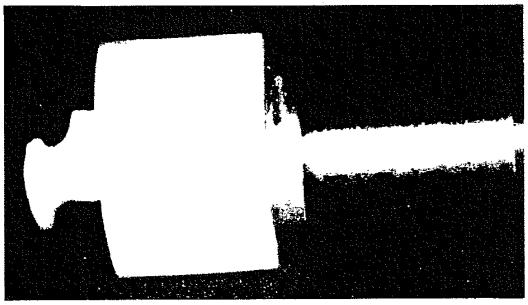


Abb. 9 Teilausgeschliffene Inlaykontur. (Cerec®-System)

ganges wird der Keramikblock um seine Achse gedreht und kontinuierlich in dieser Achsrichtung vorgeschoben. Die Schleifscheibe trägt das Material von der Seite her in unterschiedlichen Tiefen ab. So wird die Kontur des Inlays in mesiodistaler Richtung plastisch herausgearbeitet (Abb. 9). Im letzten Arbeitsgang wird das fertige Inlay vom Keramikblock abgetrennt und kann der Schleifkammer entnommen werden. Durch diese einfache Schleifmechanik wird der Komplexitätsgrad der CNC-Maschine auf ein Minimum reduziert, und gleichzeitig werden die Anforderungen an die Steuersoftware gering, da keine komplizierten Fräsbahnen berechnet werden müssen. Rechner und Schleifmaschine sind hierbei in einem kompakten, fahrbaren Gehäuse untergebracht, das gut neben einer Behandlungseinheit plaziert werden kann. Das fertige Inlay wird nach einer Einprobe (Abb. 10)mit einem speziellen Befestigungskomposit adhäsiv zementiert. Als letzter Arbeitsgang wird die Okklusion mit rotierenden Diamantinstrumenten manuell herausgearbeitet. Die Paßgenauigkeit dieser Inlays ist deutlich schlechter als die konventionell gegossener Restaurationen. Randspalten von bis zu 250 µm treten auf [18], werden jedoch durch das Befestigungskomposit ausgefüllt, so daß eine dichtschließende Restauration resultiert [21]. Welcher klinische Erfolg hiermit zu erreichen ist, muß sich jedoch erst in klinischen Langzeitstudien zeigen.

5.5 Die Probleme des Monsieur Duret

Eine weitergehende Lösung wurde vom Grenobler Zahnarzt Dr. *Duret* in Zusammenarbeit mit der französischen Firma Hennson Int. im Jahre 1985 erstmals vorgestellt [5, 6, 29]. Diese ermöglicht die Herstellung von Kronen und kleinen Brücken. Hier ist die Datenaufnahme getrennt von der eigentlichen Fräsmaschine, die mit dreieinhalb Achsen etwas komplexer ausgestattet wurde. Dadurch wird in der Praxis nur noch die Datenaufnahmeeinrichtung für den optischen Abdruck benötigt. Die digitalisierten Daten können dann über Datenleitung oder Telefon an die eigentliche CAD/CAM-Maschine übertragen werden, so daß mehrere Zahnärzte diese Einrichtung nutzen können. Die Datenaufnahme erfolgt hier ebenfalls mit einer kleinen CCD-Kamera. Da hier mit größeren Präparationsformen gearbeitet wird, reicht eine einzige Aufnahme in der Regel nicht aus, es werden pro Präparation vier Aufnahmen angefertigt. Der präparierte Stumpf wird also aus verschiedenen Blickwinkeln aufgenommen und im Computer rekonstruiert. Zur besseren Kontrastgebung wird der Zahn auch hier mit Titandioxidpulver eingefärbt. Die Tiefeninformation wird hier ebenso über ein Linienmuster gewonnen. Damit die verschiedenen Aufnahmen zusammengesetzt werden können, wird über einen Nachbarzahn eine modifizierte Cofferdamklammer gelegt, die drei Drähte mit kleinen Kugeln als Bezugspunkte trägt. Die Kamera ist hier mit einer Auflösung von 512 × 512 Bildpunkten besser ausgestattet und erlaubt eine Punktauflösung von etwa 20 µm. Auf dem fertigen CAD-Computerbild wird nun der Präparationsrand manuell markiert, was hohe Anforderungen an den Behandler stellt. Die Originalzahnform wurde vor der Präparation aufgenommen und kann nun direkt als Ausgangsbasis für die Restauration dienen. Stehen diese Daten nicht zur Verfügung, wird die Zahnform einer Beispieldatenbank entnommen und an den Stumpf angepaßt. Als CAD-Software wird das Euclid-System (Firma Matra Datavision) auf einer Micro VAX II (Digital Equipment Corp.) eingesetzt [27]. Die innere Form der Krone wird nun an den Stumpf angepaßt, wobei ein Zementspalt mit eingearbeitet wird. Die äußere Form wird an den Antagonisten und die Nachbarzähne angeglichen, wobei Zusatzinformationen über einen elektronischen Gesichtsbogen eingearbeitet werden können.

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Leider existieren über dieses System keine detaillierteren Veröffentlichungen und abgesehen von einzelnen Demonstrationen hält sich der Entwickler bislang sehr bedeckt. Die Aufnahme der Serienproduktion war zwar für 1987 angekündigt, ist jedoch bis heute (Anfang 1990) nicht erfolgt. Von dritter Seite werden hier hauptsächlich konstruktionsbedingte Probleme der Fräsmaschine gesehen, die mit einer zu niedrigen Achsenzahl ausgestattet sein

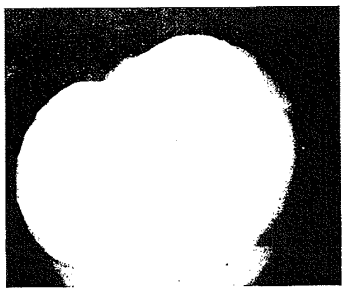


Abb. 10 Das fertige Inlay in situ

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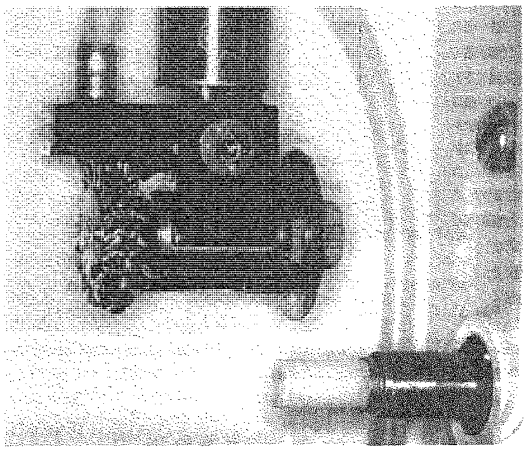


Abb. 8 Die Schleifeinheit des Cerec®-Systems. Links das Turbinenrad, rechts die Schleifscheibe, darunter der Materialblock

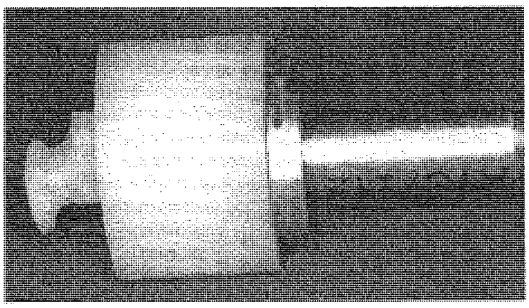


Abb. 9 Teilausgeschliffene Inlaykontur. (Cerec®-System)

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soll. Fernerhin sind die Probleme der Werkzeugauswahl und der jeweiligen Werkzeugstandzeiten wohl schwer zu lösen [10]. Klinische Erfahrungswerte fehlen für das *Duret*sche Verfahren bisher ebenso wie Untersuchungen über die reale Paßgenauigkeit der hiermit angefertigten Rekonstruktionen.

5.6 Das Minnesota-System

Beim Minnesota-System, bekannt auch unter der Bezeichnung DentiCAD [25–28], wird beim Zahnarzt lediglich der optische Abdruck gewonnen. Die Fertigung wird auch hier von einer zentralen Stelle (evtl. Dental-Labor) übernommen. Damit sollen die Anschaffungskosten für den Zahnarzt unter 5000 $ für die Datenerfassung gehalten werden. Das System wurde von der Arbeitsgruppe *Rekow* et al. an der Universität Minnesota mit Unterstützung des US National Institute of Dental Research entwickelt.

Die Datenaufnahme erfolgt mit einem stereophotogrammetrischen Verfahren, wobei eine normale 35-mm-Kamera mehrere Aufnahmen über einen speziellen Lichtleiter macht. Die Aufnahme erfolgt auf konventionelles Filmmaterial, da hierbei größere Auflösungen erzielt werden können. Das Fotomaterial wird anschließend mit einer Auflösung von 4096 × 4096 Bildpunkten digitalisiert, was bei einem Objektfeld von 10 mm Kantenlänge einer rechnerischen Auflösung von 2,44 µm pro Bildpunkt entspricht. Diese Genauigkeit ist nach Argumentation der Entwickler nicht über eine Videokamera zu erzielen.

Die Aufnahmen werden als Graustufenbilder abgespeichert und in dreidimensionale Koordinaten übersetzt, indem spezielle Kantensuchalgorithmen zur Konturensuche eingesetzt werden, um korrespondierende Punkte in den Stereobildpaaren zu suchen.

Aufnahmen von Stumpf und Antagonist in der angestrebten Okklusion sowie in anteriorer und lateralen Exkursionspositionen geben Daten für die okklusale Gestaltung der Rekonstruktion. Ein Kronenmodell wird nun aus einer anatomischen Beispieldatenbank entnommen und durch Verzerrung der Konturen okklusal an das errechnete Bewegungsfeld angeglichen. Ebenso wird die Außenkontur an die Kontaktbereiche der Nachbarzähne und an die Präparationsgrenze angepaßt. Aufgrund dieser Daten errechnet ein Standard-Softwarepaket (ICEM-DDN, Control-Data Corp.) die Fräsbahnen für eine Fünfachsen-CNC-Maschine. Die Genauigkeit dieses Systems wird von den Autoren auf unter 20 µm für einen Randspalt angegeben. Obgleich erste Demonstrationskronen in einer Videovorführung gezeigt wurden, liegen noch keine Untersuchungen über die reale Paßgenauigkeit und keine klinischen Erfahrungen vor.

6 Ausblick und Bewertung

Die CAD/CAM-Fertigung von Zahnersatzteilen steckt auch heute noch in den Kinderschuhen. Zwar gelingt es jetzt mit dem Cerec®-Verfahren, unter strengen Voraussetzungen Keramikinlays anzufertigen, der Quantensprung zur Vollkrone ist jedoch noch nicht vollzogen worden. Dies liegt daran, daß hier ein kaum vorstellbarer Mehraufwand auf mechanischer Seite und auf der Seite der Computerintelligenz (Software und Rechenleistung) notwendig ist. Die bislang gezeigten Verfahren versuchen, dieses Problem anzugehen, sind jedoch von einer Anwendbarkeit in der Praxis noch weit entfernt. Die heutzutage geforderte Paßgenauigkeit (Randspalten unter 50 µm) muß zunächst noch erreicht bzw. nachgewiesen werden. Ebenso muß eine fehlerfreie okklusale Gestaltung, die nur eine minimale Nacharbeitung am Patienten notwendig macht, erst erzielt werden. Die Wirtschaftlichkeit einer so hergestellten Vollkrone im Vergleich zum Guß ist ebenso noch nicht gegeben.

Die weitere Entwicklung ist noch nicht absehbar. Der Sprung von der Vollkrone zur Brücke ist wiederum eine Hürde, da hierzu noch mehr Patientendaten einbezogen werden müssen. So komplizierte Gebilde wie Prothesenbasen werden dann im nächsten Schritt angegangen, wobei die praktische Realisation hier eher in ferner Zukunft liegen wird. Ob eine CAD/CAM-Fertigung von Zahnersatzteilen wirtschaftlicher sein wird als die herkömmliche Qualitätsarbeit des Zahntechnikers, ist wegen dieses hohen Aufwandes fraglich. Auch wird der Zahntechniker durch eine Maschine nicht ersetzt werden können, denn hohe Anforderungen an Ästhetik sind mit einer Krone, die aus einem gleichmäßig eingefärbten Keramikblock geschliffen wurde, sicher nicht zu befriedigen. Hier ist immer noch die künstlerische Handarbeit der freien Schichttechnik gefragt. Damit bleibt die computergestützte Fertigung von Zahnersatz auch in der nächsten Zeit noch eine Wunschvorstellung aus dem Umfeld der ›Science-fiction‹.

Summary

The introduction and production of the Cerec®-System was the first time, when a method of computer-aided design and manufacturing (CAD/CAM) of dental restorations moves to the chairside. New technologies like optical impression, solid modelling of crown shapes by CAD-Programs or computer controlled milling were aquired from the field of industrial production. Nevertheless, the Cerec®-Systems is indicated only in a limited range of clinical situations, and the production of a well fitting computer-designed full crown is not yet possible at this stage of development. It can only be guessed whether these advancements will be achieved in the near future.

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Inlays/Onlays – Ein praktisches Arbeitskonzept

Th. Schmidt, quintessenz bibliothek, Quintessenz Berlin, 1989, 108 S. 187 Abb., DM 178,–

Zahntechnikermeister *Thomas Schmidt* stellt mit diesem Buch sein »praktisches Arbeitskonzept« der Labortechnik von Inlays, Onlays und Pindledges aus Goldlegierungen vor. Dieses Buch wird dem Untertitel auch vollauf gerecht. Die verschiedenen Arbeitsgänge werden Schritt für Schritt sehr gut beschrieben und mit hervorragenden Abbildungen dargestellt: Herstellung und Vorbereitung der Modelle, Wachsmodellation und Gußkanalsysteme, Einbetten, Vorwärmen, Gießen und Ausarbeiten. Auch werkstoffkundliche Aspekte werden kurz diskutiert: Modellmaterialien, Einbettmassen und Probleme der Gußtechnik sowie geeignete Legierungen. Die Abbildungen betreffen zum großen Teil klinische Patientenfälle und sind deshalb absolut realistisch. Dem schwierigsten Arbeitsgang, der Herstellung der Wachsmodelle, wird besonders viel Platz eingeräumt. Der Begriff »Onlay« sollte allerdings entsprechend den Absprachen nicht mehr benutzt werden; richtig wäre der Begriff »Teilkrone bzw. Stufenteilkrone«. Auch sind viele Gedanken und Verfahren der einschlägigen Literatur entnommen, die in diesem Buch jedoch nicht zitiert wird. Für ein »praktisches Arbeitskonzept« ist dies auch nicht erforderlich; dies müßte jedoch im Vorwort begründet werden. Insgesamt ist diese Arbeitsanleitung didaktisch hervorragend aufgebaut und überzeugend, so daß jeder Schritt der Herstellung einer Gußrestauration nachvollzogen werden kann. In Text und Bild ist dieses Buch hervorragend ausgestattet und kann jedem Zahntechniker und jedem, der Gußtechnik selbst praktiziert, wärmstens empfohlen werden.

A. Motsch, Göttingen

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machines and the increasingly complex work processes were combined and automated. This has the advantage that the products can be produced in larger series at less time, be less expensive, have fewer faults. While the machine initially needed to be operated by humans (example: workers at a lathe), one soon tried to control machine work procedures by means of a program. In the early days, this program was realized by an ingenious mechanism, for example, the first program-controlled weaving loom was built in 1808 with a punch card system. It was therefore logical to use the computer as a universal control tool, which was realized for the first time in 1948 by J. Pearson. This technology is referred to in short as CNC, which is an abbreviation for Computer Numeric Control. Machine tools that can be controlled merely by entering numerical values, however, are simply referred to as NC systems (= Numeric Control NC).

Computer-controlled milling machines or lathes, however, were initially only able to produce geometrically well-defined bodies, which in the industrial production of machine parts is indeed the rule. The higher costs of such complicated machines are easily balanced by the cost advantages of large quantities, lower production times and improved quality and reproducibility. Due to the increased demands on this program control, tools that were adapted to the particular advantages of this method were likewise adapted. Movability of the tools was here expanded, allowing for production of more complex parts with the machine.

The process of planning and design was also subjected to change. The drawing board is being successively replaced by the computer as a drawing aid (CAD = Computer Aided Design). This allows changes to be made quickly, and with the recorded design data structure, an NC milling program for fabricating the designed parts (CAM = Computer / Aided Manufacturing) can be generated, which is executed by a CNC machine.

3. Industrial production in CAD/CAM processes

The CAD/CAM process has meanwhile become a standard process in industrial production. The conventional mode of operation has here been simplified and automated by the use of computers. A typical operation cycle requires the following steps:

3.1 Computer-aided design – CAD

Industrial workpieces are normally composed of geometrically defined basic shapes in specific positional relationships. These objects can be described e.g. by circles, distances, edges and geometric bodies such as balls or polyhedrons. This enumeration already shows that basic structures having different dimensions are here referred to. The product shape to be designed is, of course, always a three-dimensional body. This three-dimensional body

can, however, be drawn with simple elements. In the case of conventional designing on the drawing board these simple elements are drawn in a compass and straight-edge construction mode by the designer. This course of action is, however, also possible by means of a computer. Making use of modern input tablets, a designer can carry out on the monitor the same drawing operations as on the drawing board. The use of a computer, however, offers the advantages that the designer can easily modify details and work on arbitrary details in magnification. On the basis of a suitable software, the computer is even able to produce three-dimensional structures from simple two-dimensional drawing objects and to display them in an arbitrary view. The finished design drawing only has to be stored on data carriers so as to make them suitable for further processing.

To this end, various data formats can be used. The drawing may e.g. be stored as an amount of lines representing the boundary edges of the workpiece (edge model). In addition, the data format may consist of a mathematical description of the boundary surfaces (area model), and in the case of more recent programs mathematical descriptions of basic bodies (volume models) are used. The data obtained in this way must now be drawn as a diagram for conventional production, and this, in turn, is done by means of an electronic drawing device (plotter). For controlling a CNC machine, these data must, however, be processed still further.

3.2 Computer-controlled production – CNC

A CNC machine is basically an NC machine with a computer connection. This means that the functions of the machine are controlled by simple commands. The workpiece is fixed in the machine at a defined position and also a tool is mounted at a defined procession (Fig 1). The machine can now move the tool freely in a coordinate system in specific directions. The coordinate system used is often a Cartesian system with three axes that extend at right angles to one another. A simple command for the machine may now read as follows: X 150, which means that the tool is to be displaced by 150 distance units in the X direction. Many parameters of the machine, such as the rotary speed of the tool or the feed rate can be controlled with similar commands. The task which is here to be fulfilled by the program corresponds to that which a human being has to do in conventional production processes when the design drawing is being evaluated, viz. subdividing the production into meaningful substeps and taking into account material and tool-dependent characteristics.



Fig. 1: CNC machine tool with fixed block of material
(University of Minnesota)

A particularly problematic aspect is here the continuous path control of the working tool [8]. In order to cut out complex bodies from a block of material, the paths of the milling cutter must be controlled such that the cutter will not have applied thereto excessive loads, get blunt, let alone break. Furthermore, the cutting geometries and the ideal attack angle as well as the outer shape of the milling cutter, which may perhaps have to be replaced several times during operation, have to be taken into account. A cylinder cutter, for example, may contact the workpiece at several points and thus remove material at locations where this is not desired. In view of these problems the movement possibilities of the machine and the "intelligence" of the computer and of its programs (software) have to satisfy high requirements. The more complex the shapes to be produced are, the more movement possibilities the respective machine tool must have. This number of degrees of freedom is normally indicated in the form of movement axes [4]. Translatory motions in the individual directions of the coordinate system are regarded as "axes", and also possible rotary motions thereabout are regarded as separate "axes". The term "axis" has here intentionally been put in quotation marks, since a conceptual overlap with the axis of the coordinate system is given. Machine tools for complicated shapes need, as a standard, at least five such axes. The higher the number of axes and the more complex the geometry of the workpiece are, the more difficult path control of the tool will be, since it does not suffice when the tool moves in individual isolated directions of movement, but it has to follow free paths in the three-dimensional space.

In order to create a program for such a complex machine, the design drawing from the CAD system must be processed and translated by means of a computer. The design data are first converted into an area model which describes the surfaces with mathematical functions. A special computer program creates from this, with substantial computational effort, a milling program for a specific CNC machine. When the shapes in question are simple geometrical shapes, this process is still comparatively uncomplicated. The situation

becomes more difficult, when the shape to be produced has three-dimensionally curved surfaces. This necessitates the use of high-performance computers and of "intelligent" software.

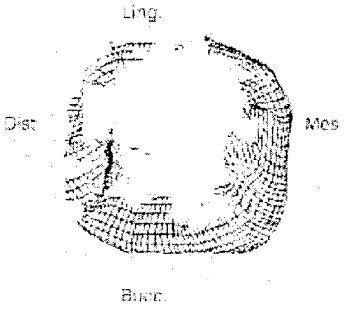


Fig. 2 optically scanned molar crown as an example for a network graphics. Taken from [14]

3.3 Method of 3D scanning

From time to time, shapes are created in industry which cannot be designed primarily in a CAD process. This applies to design articles or e.g. to shapes that have to be optimized as a model in a wind tunnel. Such model shapes must be transferred to the CAD program by means of suitable scanning systems. Also for this purpose, complete industrial solutions exist. According to these solutions the surface of the shape is scanned and measured by a measuring sensor or a laser beam point for point. The simple items of point information can be interconnected by straight lines, whereby a netlike representation is obtained on the computer monitor (Fig. 2). More complex evaluation programs use, instead of the slightly edged line, curvilinear best-fit-curves (spline interpolation), whereby continuous and smooth surfaces are obtained [14]. The network graphics obtained in this way can be converted by a program into a data format suitable for the CAD design process.

4 Computer technologies in dentistry

After this somewhat lengthy introduction, we should like to come back to dentistry by stating first that the processes specified hereinbelow only mean that an industrially well-developed production process is adapted for use at the dental chair. Unfortunately, differences and problems arise in comparison with industry, which make a simple transfer of the existing technology almost impossible.

4.1 Arguments in support of C technologies

The vision of CNC production of dental prostheses begins where the dentist finished the preparation of a crown:

> In 2000, a dentist decides to make an individual crown in the side tooth area of the patient.
> After a conventional preparation by means of rotating instruments, the purely technical part of the treatment now has to be carried out. Instead of a conventional dental cast, a picture of the tooth stump is taken with a small camera; the preparation margins must, of course, be represented such that they are clearly visible. When optical images have also been taken of the other teeth of the quadrant as well as of the teeth of the counter jaw, a computer starts its work. The image data are converted into three-dimensional data and transferred to a CAD system. The relation of the stump to the antagonist is established; on the basis of the geometry of the other teeth, the masticatory movements are simulated and represented in a motion field. A sample tooth from a database is now projected into these surroundings and adapted to the shape of the stump as well as the shape of the antagonist by slight shape distortion. In so doing, small preparation errors are automatically compensated for and the exterior shape is simultaneously optimized from the parodontological point of view. After the computer obtained information from the dentist which material is to be selected from a variety of different ceramic materials, high-strength and abrasion-resistant plastic materials or a great variety of different metals (in the present case the dentist decided to use pure titanium, since the patient's aesthetic demands are not particularly high), the computer creates a program for a small milling machine, which cuts out the crown from a block of material within a few minutes. The dentist can cement the excellently fitting crown in place and carry out the subsequent obligatory occlusion control (which, however, rarely necessitates re-grinding) in the same session. Only the dental technician is left empty-handed.

This short excursion into the science-fiction is intended to show what kind of advantage the dentist expects from the new technologies. A reasonable argument is certainly a high degree of material independence. The use of a CNC milling process allows workpieces to be produced from materials which have hitherto been difficult to cast or from semifinished products, without the quality of the material being impaired by a casting process. Damage to the material in question or a formation of pores would be excluded. Assuming that the method operates in a sufficiently precise manner, the fitting accuracy of such a crown would not depend on material characteristics which are difficult to calculate (impression material,

modelling material, wax, investment compound, etc.). Also human failure would, in principle, be excluded. The finished workpiece could be used in the same session, which means that there will be no costs for transitional prostheses. Whether and in which way these processes are already realizable and which problems and drawbacks are entailed by them will be investigated hereinbelow.

4.2 First problem: The optical Impression

In the previous indirect work processes, an impression of the teeth to be treated or the jaw to be reconstructed is taken and a model is obtained in the next step. Already this step comprises errors caused by materials and methods, which have an impact on the fit of the subsequent reconstruction. It is therefore desirable to make such an error-prone positive / negative transformation as precise as possible or easy to avoid. With CNC-based methods, the possibility exists to have the model directly digitize with a suitable scanning method i.e. performed with the computer. For the dentist, this means that digitization of the anatomical situation with a suitable method directly in the mouth of the patient is desirable. For such a method, the requirements can first be formulated. It must be able to obtain the information with reasonable accuracy, i.e. a resolution in the micrometer range and may simultaneously require only a relatively short time for the measuring procedure. If the scanning time is too long, errors due to shaking can not be avoided unless that recording apparatus and jaws were rigidly connected. As a compromise, it is conceivable to perform digitization not in the mouth, but, according to traditional model fabrication, calmly on the stump.

Several concepts qualify as digitizing methods. The easiest option is with a scanning probe. Here, the object is inserted into an apparatus which scans the surface of the object according to a special strategy and determines the coordinate values for each point. This scanner can be a simple switch or an inductive way displacement transducer. A slightly more advanced concept replaces such a hard scan probe by a laser beam with which the surface can be scanned without being in contact (12]. This procedure is known as laser triangulation. The drawback of this method is the scanning time, which for sufficiently dense measurement point location is substantial. As a scanning mechanism, a machine is used which can place the measuring sensor at each point of the object. For this, also a CNC machine with a high number of axes (> 3) is ideally required, which can direct the measuring sensor anywhere as perpendicular as possible to the object's surface. For this reason, a very sophisticated measurement strategy is necessary that can not be realized without computer programs. The advantage of this method, however, is the high measurement accuracy that can be achieved. Due to the long measuring time, this method is not suitable for use in the mouth, but it is used with success in the laboratory. Due to the measuring time on expensive machines, however, the cost-effectiveness of this method is rather doubtful.

For intra-oral scanning, mainly photographic methods qualify. In analogy to previous methods for obtaining impressions, it is referred to as optical impression [24] or video impression [7]. Unfortunately, one can only obtain a two-dimensional perspective view of the object on a normal photo. With a known scale, only two dimensional information can be obtained, any depth information is lacking. Additional information is therefore needed for three-dimensional evaluation. The easiest way to obtain this information is to produce a second exposure from a different angle. Given a known distance, the depth information (analogous to the spatial vision in humans) can be calculated back from these two images. For this method of stereoscopic photogrammetry, conventional film exposures can be used on the one hand, which are later digitized by optical scanners, on the other hand, the film can again be replaced by a small video camera. Small chip cameras are today used as miniature video cameras, in which the film is replaced by a small silicon chip. These so-called CCD cameras (CCD = Charge Coupled Device) can be manufactured to a very small size and immediately transfer the image to some evaluation electronics. The drawback of these cameras is that they evaluate only a limited number of pixels [26]. Conventional CCD chips have a resolution of 256 x 256 pixels, but are now being replaced with a new generation of devices having a resolution of 512 x 512 or even 1024 X 1024 pixels. The fewer pixels are processed, the less accurate the subsequent evaluation. The two partial images can later be assembled in the computer to a three dimensional representation. By means of automatic detection of edges, relevant areas, such as e.g. the preparation border can be determined and digitized according to their significance [26]. Problems arise, however, when some parts of the object are not visible or overlap. In this case, more images from more favorable angles are required. To assemble a complex three-dimensional image from multiple images, however, is a problem that can be solved using appropriate computing methods.

While stereoscopic photogrammetry obtains information on the depth from two different views, there is yet another method for obtaining the information on depth from only one recording. Here, a stripe pattern having constant, defined stripe spacing is projected onto the surface of the object. From the distance-related distortion of this stripe pattern due to object geometry, the depth information can now be calculated back by viewing from the top at a small parallax angle. These methods, being very similar to Moire topography, are suitable for simple objects that have a clear geometry and a good reflective surface. Though a tooth surface reflects badly, this can be helped with coloring powder [21]

Other possible methods, such as holography [30] are difficult to achieve in the oral cavity and even in the laboratory need substantial means for the required precision and portability to the computer. The visual impression described here is a key technology for the dental

application of the CAD / CAM method, because this issue does not commonly arise in the industrial.

4.3 Second problem: Computer and software

The methods described transform a three-dimensional structure into a set of point data. These can now be made readable as a so-called network diagram for a CAD program. The space between the dots is here interpolated through flat or curved surfaces.

It is now the task of the CAD system to complete the ground stump to a complete tooth and to process the crown / inlay thus designed as three-dimensional data for further processing. This sounds easier than it first appears. Reconstruction of a tooth requires a lot of different information. It requires knowledge about the anatomical shape of the original tooth, about the relationship to the antagonist, about the periodontal situation, about the shape of adjacent teeth, about the movement of the tooth in action and therefore also about the jaw joints and the entire stomatognathic system. A CAD system that is to perform the reconstruction of one or more crowns must therefore comprise knowledge and intelligence in all these relations (in the sense of intelligent and comprehensive programming). In addition, the necessary data on these parameters must be collected. This could, for example, be three-dimensional data on the antagonist and the adjacent teeth. Information about joint function can be given as mean values or directly entered as an electronic pantography. The anatomical structure of the original tooth may have been digitized before grinding or taken from a database with sample teeth [5.15. 27]. By distortion, rotation, or magnification of this sample tooth, it can now be adapted both to the preparation border as well as to the antagonist. In this process, a cement gap can be simultaneously included and the proximal contact areas can be optimized periodontally. The three-dimensional shape of the crown thus produced (inlay or bridge) is now converted into a milling program for a machine tool. In this, information about the material, the tool and the machine tool are required and incorporated. Information on the required accuracy is likewise needed. Depending on the degree of complexity, even a powerful computer at this point requires long computation time. These work steps, however, are basically today no longer a problem with modern graphics computers (so-called workstations) and can be partially performed with standardized software packages [27]. The rest of the software, however, represents a significant problem, especially since this is to be created individually. The development time for a software product of this complexity can be estimated to a two-digit number of man-years (1 man-year = 1 year's work for a programmer).

4.4 Third problem: Material, tools and machines

A universal machine for CNC fabrication of tooth reconstructions should be able to process different materials. Various materials such as plastics, ceramics or metals, however, require different processing instruments adapted to the different material properties. It is therefore not possible to process all materials with one instrument or a special instrument shape. Since the work piece has curved surfaces, the milling tool must also have curved surfaces [10]. The cutter must in turn be adapted in its shape to the work piece geometry. Small instruments are necessary for the inside of the crown shape (extreme example: crowns for the lower front) and the complex occlusal relief (fissures and pits), more course shapes can be used for smooth surfaces. The cutting geometry is to be matched to the material and the desired surface quality. It is therefore already foreseeable that a machine tool for dental purposes must be equipped with exchangeable instruments. Various sizes and cutting geometries must therefore again be known to the control software which adapts the cutting paths to those characteristics. These requirements significantly increase the degree of complexity of the software and the machine tool. Further development for the future is still unclear. Others methods already employed in the industry are not yet being discussed for CNC systems in dentistry. These include, for example, spark erosion, ultrasonic erosion (ceramics) or the removal of material by laser beam.

4.5 Fourth problem: Costs

The requirements outlined above for the recording technology, computer, software and machine tools can quickly elevate the estimated development and production costs to the millions. A device thus equipped would price-wise no longer be viable and economical even for an above-average dental practice.

In order to build such a system and render it affordable, the problem must be reduced to a suitable, possibly minimal effort, making it necessary to deviate from the basic ideas and demands.

4.6 Current solutions options by reducing problems

In optical image acquisition for subsequent digitization, the problem of underlaying areas and projection-related shadow zones arises. This problem can for complex objects be solved only by means of multiple imaging which need to have common reference points. Due to the special difficulties in the oral cavity, the recording process is further impeded. A solution to simplify is here given by data recording from the conventional plaster casts (11. 16. 28] which can be performed in the laboratory following optical control of the preparation. For this, however, an impression according to the conventional methods is necessary, which, although being accompanied by all the drawbacks of the materials, also has all the advantages of preparation borders close to the gingiva.

Scanning the model in the laboratory can therefore initially be a viable option, which also leaves open other options. For example, this would not require any complex software for designing the occlusal surfaces. After scanning the stump surface in the normal manner, a crown can be modeled in wax, where the design is taken over by the dental technician in the conventional manner. This wax modellation can in a second step be digitized from the same measuring arrangement. Such an approach eliminates the CAD software and the problematic inclusion of elusive data (opposing jaw, anterior and posterior guides, etc.) and occlusion theories that are not described mathematically to the last detail.

Following savings in data recording, this can also be achieved regarding the milling machine. When values larger than 50 µm for fitting accuracy are allowed and limitation of the required materials to a single material or group of materials is permitted, then the degree of complexity and the number of axes can be reduced. Solutions with less than five axes are then conceivable which, with less precision, also do not need to be formed excessively stable. Moreover, apparatuses for changing instrument are eliminated and therewith the requirements for the control software.

Approaches to reducing problems are therefore given at many points and with these few examples are certainly not exhaustively addressed. In order to realize CAD / CAM dentistry today, they are certainly necessary.

5 Actually existing CAD / CAM systems

CAD / CAM technology in the field of dentistry is not only discussed and researched, there have for several years been serious efforts to transform this idea into practice.

5.1 CNC attachment production

There have been efforts for some time on the part of dental technology to have conventional milling techniques for individual attachments be performed by NC or CNC-controlled milling machines. Both the Degussa company as well as an Italian inventor introduced such machines, which, however, were only realized as a prototype and never go into production. The device of the Degussa company was presented to the professional world in 1986 at the IDS in Cologne, whereas the Italian inventor Menecki presented his milling machine at the Expodental in Genoa in the same year. The problem of both devices is the individual character of the attachment shape to the individual tooth stump and the individual metal frame. The setup time for adjusting these devices to the individual patient's situation is so long that the milling process is uneconomical compared to manual labor. Only the use of image-recording intelligent computer systems could propel this innovative idea, whereas economic viability is currently still doubtful.

5.2 Basic research on data acquisition

Several research groups are busy with the problem of data acquisition from the model. While previously only the three-dimensional recording of certain areas (e.g. filling edge) or defined specimens was focused on, several research groups are now shifting to mechanical scanners or laser sensors for recording a complete tooth stump and entire jaw sections (Fig. 3). These include inter alia the Japanese group led by Prof. Kimura at the University of Osaka [11-16] and the group led by Prof. Rekow in Minnesota [25-28], about whom more can be reported further below. A holographic method for digitization and computer-controlled reproduction of occlusal surfaces was already reported by the working group Young and Altschuler [30] as early as 1977, which, however, was limited to a purely experimental level due to the lack of sophisticated technology. Optical methods by using stripe projections are already being employed successfully in the systems of Mörmann and Brandestini [2, 19-24], as well as in the system of Duret [5, 6, 29]. A stereo photogrammetric method is described by Rekow et al. [25-28] as an alternative to mechanical / optical model scanning.

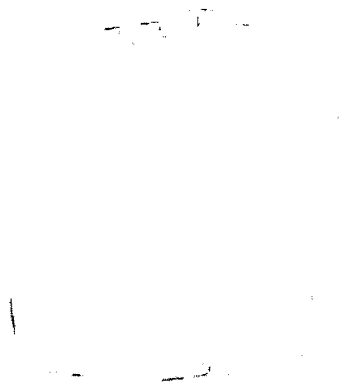


Figure 3 Two digitized molars brought into occlusion
with the CAD system. Network diagram taken from [15]

5.3 Mechanical ideas from Sweden

Mechanical scanning can in the simplest case be coupled directly and without any computer to a milling machine. Such an arrangement is called a copy milling procedure and is mainly used in precision engineering. A method realized in Sweden by Anderson at the University Umcä [1] mills the outer contour of a crown replacement by copy milling from pure titanium. The problematic inner contour is carved out from a solid body by spark erosion. The electrodes required for this are also fabricated by means of copy milling technology. The

development of this method was government sponsored and a clinical study with 200 crowns is supposedly ongoing in the meantime.

5.4 The Cerec® system

The first CAD / CAM system being functional at the patient is the Cerec© system by Mörmann and Brandestini [2 19-24], which was developed in a collaboration between the University of Zurich and the Brains company (Brandestini Instruments of Switzerland) and is now marketed by the Siemens company. This system shows that by means of downright ingenious reduction of problems, a CAD / CAM system can be realized today with currently available means.

In the Cerec® system, the area of use is first restricted to inlays and veneers. Only ceramic or glass ceramic is permitted material. Furthermore, restorations are adhesively cemented so that the requirements for fitting accuracy are reduced. With these approaches, a CNC machine could be developed which enables fabrication of inlays at the dental chair within a few minutes (Fig. 4).

The cavity for receiving the inlay is prepared without underlaying areas and feather edges and for the optical impression is dusted with contrasting white powder. Imaging the cavity is performed with a small CCD camera having 256 x 256 image points, where during imaging, a stripe pattern is projected onto the cavity. The depth information can now be calculated back from the depth-dependent distortion of this stripe pattern, a method which is called active triangulation [24]. In order to evaluate all the image points accordingly, the stripe pattern is shifted for four successive measurements in each case by a small amount. However, the measurement procedure is performed within 0.2 seconds and can be performed by the experienced dentist intraorally without shaking (Fig. 5). The theoretical accuracy of this method is specified with about 55 µm in all three directions [17, 24]. The data is then recorded by a computer and completed by the dentist interactively on-screen to the inlay shape desired (Fig. 6 and 7). In this, the proximal contours are formed, any construction of occlusal surfaces is intentionally omitted, the opposing occlusal preparation borders are merely connected by a straight line [24]. The occlusal relief must be designed later by the practitioner with rotating instruments. The finished inlay contour is then ground out from a ceramic block by a three-axis grinding machine. A diamond grinding wheel having a diameter of 30 mm and a width of 0.5 mm is used as a working instrument. It is driven by means of a high speed turbine and applied to the work surface at a rotational speed of unloaded 35 m / s (Fig. 8). During the grinding process, the ceramic block is rotated about its axis and advanced continuously in this axial direction. The grinding wheel grinds away the material from the side at different depths. The contour of the inlay is thus plastically worked out in the mesiodistal direction (Fig. 9). In the final work step, the finished

inlay is separated from the ceramic block and can be removed from the grinding chamber. By means of this simple grinding mechanics, the degree of complexity of the CNC machine is reduced to a minimum, while simultaneously requirements for the control software are low, since no complicated milling paths must be calculated. The computer and the grinding machine are presently accommodated in a compact, mobile housing, which can fit well next to a treatment unit. Following a trial fit (Fig. 10), the finished inlay is adhesively cemented with special fastening composite. As a finale work stage, occlusion is manually worked out using rotating diamond instruments. The fit accuracy of these inlays is significantly worse than the conventionally cast restorations. Edge gaps of up to 250 μm occur [18], but are filled by the fastening composite so that a tight fitting restoration results [21]. It needs to be proven in long-term clinical trials what clinical success is achievable herewith.

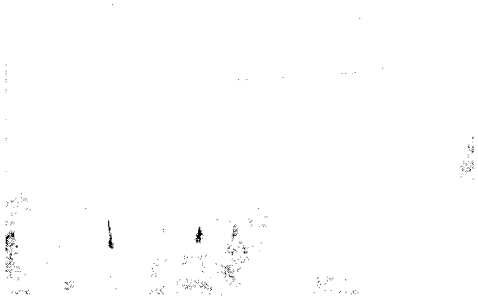


Fig. 5 The optical impression by means of a miniature camera (Cerec® system)

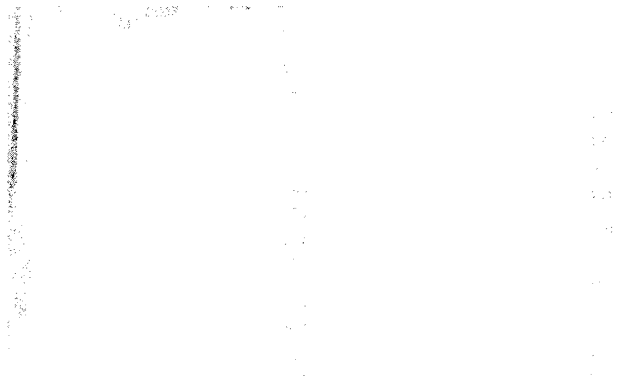


Fig. 4 Mobile Cerec® unit

Fig. 6 Imaged cavity with inlay structure drawn-in on the monitor of the Cerec® system

Fig. 7 The constructed inlay prior to the milling procedure (Cerec® system)

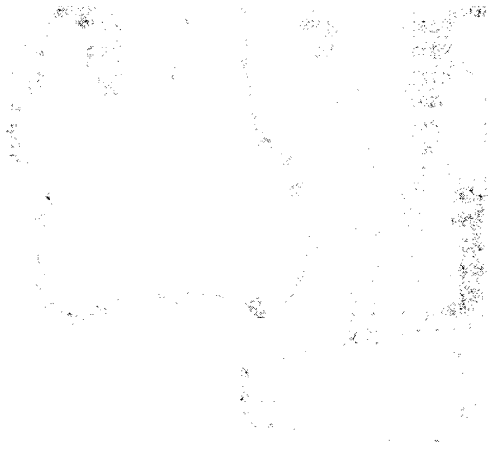


Fig. 8 The grinding unit of the Cerec® system. On the left, the turbine wheel on the right, the grinding wheel, underneath is the material block



Fig. 9 Partially ground out inlay contour (Cerec® system)

5.5 The problems of Monsieur Duret

A further developed solution was first presented in 1985 by the Grenoble dentist Dr. Duret in cooperation with the French company Hennson Int. [5, 6. 29]. It allowed the production of crowns and small bridges. Here, data collection is separate from the actual milling machine, which being equipped with three and a half axes was a bit more complex. In practice, only the data recording device for the optical impression is needed. The digitized data can then be transmitted via data line or telephone to the actual CAD / CAM machine, so that several dentists can use this facility. Data recording is here also performed with a small CCD camera. Since larger preparation forms are presently worked with, a single image is generally not sufficient, four images per preparation are recorded. The prepared stump is thus imaged from different angles and reconstructed in the computer. For improved contrasting, the tooth is here also colored with titanium dioxide powder. The depth information is here likewise collected via a line pattern. In order to be able to assemble the different images, a modified cofferdam clamp carrying three wires with small balls as reference points is superimposed on an adjacent tooth. The camera is here better equipped

with a resolution of 512 x 512 pixels and allows a point resolution of about 20 μm. On the final CAD computer image, a preparation edge is now marked manually, which sets high demands on the practitioner. The original tooth is recorded prior to preparation and can now be used directly as a basis for the restoration. If this data is not available, then the shape of the tooth is collected from a template data base and adapted to the stump. The Euclid system (Matra Datavision company) on a Micro Vax II (Digital Equipment Corp.) is used as CAD software [27]. The inner shape of the crown is now adapted to the stump, where a cement gap is included. The outer shape is matched to the antagonist and the adjacent teeth, where additional information can be incorporated via an electronic face bow.

The finished restoration is fabricated using a small three and a half-axis machine [10]. Ceramics, composites or metal composites are to be used, from which inlays, onlays, crowns, full crowns, small bridges and even entire prostheses are to be fabricated.

Unfortunately, there are no detailed publications on this system and apart from individual demonstrations, the developer has very much contained himself. The start of series production had been announced for 1987, but until now (early 1990) did not occur. Third parties here mainly see construction-related problems for the milling machine, which is supposedly equipped with too low a number of axes. Furthermore the problems of tool selection and the respective tool life are probably hard to solve [10]. Clinical experience for the Duret method is so far lacking as much as studies on the actual fit accuracy of the reconstructions manufactured herewith.

Fig. 10 The completed inlay in situ

5.6 The Minnesota System

With the Minnesota system, also known under the name DentiCAD [25 - 28] merely the optical impression is recorded at the dentist. Manufacturing is here as well performed by a central office (possibly dental laboratory). This is to keep the dentist's purchase costs for data collection under $ 5,000. The system was developed by the Working Group Rekow et al. at the University of Minnesota with support from the U.S. National Institute of Dental Research.

Data acquisition is performed by means of a stereo photogrammetric method, wherein a normal 35-mm camera takes several images via a special light guide. The image is recorded on conventional film, since this enables larger resolutions. The photographic material is then digitized with a resolution of 4096 x 4096 pixels, which for an object field of 10 mm edge length corresponds to a calculated resolution of 2.44 µm per pixel. This accuracy is not to be achieved with a video camera according to the arguments of the developer.

The images are saved as grayscale images and transformed into three-dimensional coordinates in that special edge searching algorithms are used for contour search in order to search for corresponding points in stereo image pairs.

Images of the stump and the antagonist in the intended occlusion as well as in the anterior and lateral excursion position provide data for the occlusal design of the reconstruction. A crown model is now taken from an anatomical template data base and by means of distortion of the contours adapted occlusally to the calculated field of motion. Similarly, the outer contour is adapted to the contact areas of the adjacent teeth and to the preparation border. Based on this data, a standard software package (ICEM DDN, Control Data Corp.) computes the milling paths for a five-axis CNC machine. The accuracy of this system is specified by the authors to below 20µm for a given edge gap. Although first demonstration crowns were shown in a video presentation, there are still no studies on the actual fitting accuracy and no clinical experience.

6 Outlook and Evaluation

CAD / CAM production of dental prostheses elements is today still in its infancy. Although it is now possible to manufacture ceramic inlays under strict conditions using the Cerec® method, the quantum leap to full crowns, however, has not yet been completed. This is because an unimaginable additional effort on the mechanical side and on the side of computer intelligence (software and computing power) is necessary. The previously presented methods attempt to address the problem, however, the are still far away from any applicability in practice. The fitting accuracy required nowadays (edge gaps of less than 50 µm) must still be achieved or demonstrated, respectively. Similarly, faultless occlusal design requiring only minimal reworking on the patient remains to be achieved. The cost effectiveness of a full crown thus produced compared to casting is likewise not yet given.

The further development remains unclear. The leap from the full crown to the bridge is again a hurdle, since even more patient data must be included. These complicated structures such as denture bases are then tackled in the next step, the practical realization thereof being well into the distant future. Whether CAD / CAM manufacturing of dental

prostheses will be more economical than traditional quality work of the dental technician is questionable because of this high complexity. In addition, the dental technician will not be able to be replaced by a machine because high demands for aesthetics are certainly not satisfiable with a crown that was cut from a uniformly colored ceramic block. This still requires the artistic handicraft of free layer technology. Therefore, computer-aided manufacturing of dental prostheses shall also in the time to come be wishful thinking from the world of >Science-Fiction<

Summary

The introduction and production of the Cerec®-System was the first time, when a method of computer-aided design and manufacturing (CAD/CAM) of dental restorations moves to the chairside. New technologies like optical impression, solid modeling of crown shapes by CAD-Programs or Computer controlled milling were acquired from the field of industrial production. Nevertheless, the Cerec®-Systems is indicated only in a limited range of clinical situations, and the production of a well-fitting computer-designed full crown is not yet possible at this stage of development. It can only be guessed whether these advancements will be achieved in the near future.

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Interactive Keyframe Animation of 3-D Articulated Models

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Abstract

This paper discusses some of the issues concerned with keyframed computer animation of 3-D articulated models and the problems in designing interactive systems for this type of animation. Examples are taken from the four years of keyframe animation of articulated models done at the NYIT Computer Graphics Lab, and from our recent attempts to refine our original keyframe animation system, *BBOP*. This paper also addresses the importance of the interaction of animators with keyframe animation systems as an element in the design of such systems.

Résumé

Cet article aborde certains des aspects de l'animation par ordinateur traitée par images intermédiaires de modeles 3-D articulés et des problemes de la conception de systemes interactifs appliqués à ce genre d'animation. Des examples décrits sont extraits de nos quatre ans d'expérience en animation par images intermédiaires de modeles articulés au sein du NYIT Computer Graphics Laboratory et de nos récentes tentatives d'améliorer notre systeme d'animation par images intermédiaires, BBOP. Cet article souligne aussi l'importance de l'interaction des animateurs avec des systemes d'animation par images intermédiaires comme un élement de la conception de tels systemes.

KEYWORDS: Animation, articulated model, keyframe, interactive, user-friendly.

Introduction

Animation for film and video has traditionally been a long and tedious task, with many animators drawing and painting each frame by hand. With the advent of computers, animators turned toward these machines to take the drudgery out of the animation process. Early systems worked with two–dimensional images, automating the tedious inbetweening task. Animators specified the correspondence between lines in successive key frames by tracing them in a fixed order. The computer would generate the frames in between by interpolating corresponding lines from the keyframes [1,2]. This technique has been refined and is still very popular in modern animation systems like the TWEEN system produced by CGL, Inc. [3]

As three dimensional animation became possible with faster machines and better display hardware, keyframing was adapted to 3-D animation. Instead of interpolating corresponding 2-D line segments, 3-D animation systems interpolate transformations at joints in a three-dimensionally represented model. Key frames consist not of 2-D images, but of 3-D positions of a model.

Because the models were represented in 3-space and projected on the image plane by the computer, these systems tend to produce more realistic-looking images, than those produced by an animator who approximates a 3-D representation with a 2-D drawing.

This paper discusses some of the techniques and problems in the design of 3-D keyframe animation systems, stressing the importance of animator interaction. It draws heavily on the NYIT Graphics Lab's keyframe animation system BBOP[4,5], and a more recent NYIT animation system, EM[6].

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Models

The information stored in a model is an important aspect of any animation system. One simple way to define models is as a set of rigid objects jointed at nodes, organized hierarchically into an articulated body. At each node or joint, a 3-D transformation matrix controls the position of the portion of the body below that joint. Transformation matrices are nested in accordance with the body structure. The position of the model at any one instant is determined solely by the transformation matrices. The only intelligence contained in the model is the topology of the body parts and the degrees of freedom at each joint. Alone, the model is a static entity. To make the model move, the animator uses the animation system to control the 3-D transformation values at each joint. The "rigid object" stipulation allows scaling of the body parts (using the joint matrices) but not flexing or changing their basic geometries. These are the types of models used by the animation systems BBOP and GRAMPS[7]. The particular model structure was motivated by the Evans & Sutherland Multi-Picture System (MPS), on which the systems are based. The MPS manages nested transformations easily: performing real-time transformation, clipping, and display of lines.

Like BBOP, EM uses models constructed of parts connected at joint nodes. However, EM uses a geometric modeling language which allows parametric control over the transformations at each joint and over the geometry of the individual body parts. The set of parameters define the model's final position, shape, and characteristics. Parameters can be constrained and coordinated with respect to constants or other parameters in order to give the model intelligence in the way it moves. For instance, the motion of a ball can be dependent on the slope of the floor it rolls across, or swinging arms can be made to swing opposite to each other.

Scripted systems [8,9,10,11] use procedural models [12], which embed the possible motions of the model in the model description itself, leaving some parameters for external control.

Regardless of the implementation of its models, an animation system should allow animators to easily modify model structure and movement. Interaction and visual feedback are important. Systems like BBOP, EM, and GRAMPS are significant in this regard because the animator can immediately view his changes.

Positioning models

Because keyframed animation is based on key "still" frames, the method of creating these frames is a vital component of the system. The animator must be able to easily set up all the parameters necessary to define a keyframe. One basic method of positioning a model in a keyframe is to type in a joint identifier, the parameter to be changed at that joint, and the value for that parameter. Although functional, this method is not easy to use.

In BBOP the animator selects a joint using a joystick to traverse the transformation tree of the model. With a set of function keys, the animator specifies that he wants to modify the translation, rotation, or scaling parameters at that joint. Each parameter set has three elements, one for each of the x, y, and z axes. Using a three-axis joystick, the animator can modify these three values and watch the model move on the screen. BBOP provides no constraints or rules about moving the model, except that it follows the x, y, z movements of the joystick. When manipulating a human body model, for instance, limbs can disconnect from the body structure and joints can be bent at unrealistic angles, even causing a limb to enter the body itself. At each joint, the interaction is the same: the x, y, and z, translation, rotation, and scaling parameters are controlled by the three outputs of the joystick. This makes the system simple to use, and an inexperienced person can learn to manipulate a model in just a few minutes.

GRAMPS, which has a similar interactive input method, takes a step beyond BBOP by allowing several devices for input. By means of simple functional assignment statements, values from eight dials, a data tablet, and a joystick can be used to modify the model's parameters. For instance, the animator can assign the inverse value of a dial to the rotation of a character and set bounds on the values the rotation can assume. EM builds on BBOP and GRAMPS, allowing input modes to be defined dynamically with complicated dependency expressions including other parameters and multiple input devices.

We noticed an interesting phenomena in systems which have user configurable inputs. In BBOP, the interaction modes are predefined and remain the same from joint to joint and model to model. An animator can sit down with a new model and immediately begin to manipulate it. In EM, the interaction modes can be configured specific to each parameter and joint in the model's tree structure, and by each user. Each

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model and each user can have different input modes. Thus, it is difficult to sit down with a new model and animate it right away. It takes time for the animator to get used to the model's control characteristics. Once familiar with a model's movement, however, configurable inputs have proven to be very effective. Especially useful has been the ability to interactively control parameters of several joints of the model at the same time. For instance, the animator can rotate the shoulder, wrist, and waist of a model simultaneously. This was not possible with BBOP.

Modeling camera movement is also an important part of an animation system. There are many ways to move the camera interactively. We first must define the coordinate axes in which the camera can be moved. We define the pivoting of a camera on its own axes, i.e. tilting, panning, and rolling the camera, as rotation in the camera's local coordinate system. Camera movement around an external center point is movement in a global coordinate system. This is exemplified by a camera mounted on a crane that moves around the space of the "animation studio." In BBOP, the center of global camera movements is always the center of world space and cannot be changed. Movement along arbitrary coordinate axes would be an important enhancement to the camera model. This would aid in tracking a movement of the model or moving the camera along a particular trajectory while maintaining a constant object of interest.

The second aspect of camera movement is how the camera moves relative to the model or scene. One approach to interactive camera movement is to have the joystick (or other interactive device) operate as if it were attached to the camera. This is the local or "airplane" method of camera control, because the joystick models the pitch, yaw, and roll of an airplane joystick. Pushing the joystick forward causes the camera to tilt down; pulling the stick to the side causes the camera to tilt to that side. The second method is to model the input as if the animator were controlling the world. In this "global" mode, joystick control creates just the opposite effect of the "airplane" method. Pushing the joystick forward causes the camera to tilt up (or apparently, the world tilt to down, away from the eye). The two methods are computationally equal since moving the camera to the left is indistinguishable from moving the world to the right. Different people favor different approaches; however, the majority prefer the "move the world" approach because the picture they see moves in the same direction as the joystick. BBOP and EM also can simulate multiple cameras, enabling an animator to display the same animation as seen from several viewpoints.

In addition to camera movement, there is local and global movement at the joints of the model. That is to say, transformations at a joint can take place in the coordinate system local to the joint or in the coordinate system of the next higher, or "parent," joint. (In an ideal implementation the animator would be able to effect transformations in any coordinate system. This would aid, for instance, in making a figure walk so that it rotates over the balls of the feet, not around the center of the body.) Because BBOP has just one interaction mode – joystick x, y, z controlling model parameters x, y, z, – the joystick's motion often has little physical relation to the motion of the model on the screen. To get around this problem, the animator can display the local coordinate axes as they move with the current joint. EM fosters more natural interaction because the animator designs the input modes, adapting each to a particular manipulation of the model. An example of this is to set the tablet x/y to be the model x/z position on a floor, and the joystick x, y, z to the model's rotation around its z, x, y axes respectively. Pushing the joystick away from you would make the model tilt away from you.

The most natural input method perhaps would allow the animator to point directly to a joint and "drag" it around on the screen. Thus the animator would manipulate the model by pushing and pulling it into position. There are, however, implementation problems in trying to manage 3-D control from a 2-D view. For instance, determining the coefficient of movement along the axis perpendicular to the screen can be quite complicated. A typical solution would be to set that "z" coefficient to zero, but a more sophisticated solution would be better.

Finally there are non-kinetic parameters such as color, reflectance, elasticity, etc. which the animator may need to control. These qualities may be required if a raster version of the animation is desired, and sometimes are perceptible only in a fully rendered scene. The time it takes to render scenes is usually prohibitive to display the actual property to the user in an interactive fashion. An alternative form of viewing these values is necessary. In EM, the animator can learn the current value of any parameter by typing its name. With color vector devices, part of this problem can be solved by coding various properties with different colors.

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Keyframing

A frame in an animation is basically a description of the particular state of the world at a particular instant in time. In a keyframe system, the animator need not describe each frame. Instead he describes a set of "key frames" from which the animation system can interpolate the frames in between. Interpolation of intermediate values can be linear, cubic spline, cosine, etc.

The information stored at a keyframe may vary from a total description of the scene and animation to the value of a single parameter used in the generation of a frame. In scripted systems, the "key" information is more like a cue to a stage performer [9]. The cues tell the models (or actors) to start, stop, and in some cases to modify or switch their behavior to some other pre-programmed mode. In goal-oriented systems, the animator describes a goal state and the model moves towards that state using its knowledge of itself and the world [11,13]. Goal states can be considered the keys with the model itself generating the inbetween movements.

To set up keyframes in BBOP or EM, the animator positions the model on the display screen. Then he can record the position of the whole model, a subset of the model, or just the value of a single parameter as a keyed position in a particular numbered frame. In 3-D systems, each parameter has its own set of keys, unlike 2-D systems which key a whole image. In BBOP, every value at every joint for every frame is saved. Those values to be used as keys have a note to that effect. This is a simple but storage-intensive implementation. When an animator specifies a position as a key in EM, the system saves only the values of keyed parameters, the frame number, and interpolation information about the interval between that key and the next. EM has been implemented in a way that eliminates the need to maintain values at the inbetween frames. This scheme is more complicated than BBOP's, but more space-efficient. EM also can save key positions by name, separate from the interpolated sequence of numbered keyframes. Numbered keyframes can contain references to named keys, thus providing a sort of macro facility to the keyframe process. For example, if the same position is needed in multiple keyframes, the position can be described once and then referenced by each key. If the position needs to be changed, modification of the original copy modifies it in the other keys.

An animator often uses the same key many times. Copying keyframes from one position to another at first seems to be conceptually simple, but when looked at carefully a number of issues become apparent. Frequently, an animator copies (or moves) keys forward or backward in a sequence to change the pace or timing of an animation. Moving a keyframe forward to expand a sequence can be done by moving the key to the new location, pushing subsequent keys forward in the process. This expands the particular key interval but also lengthens the entire animation. For modification of the timing of an entire animation, or non-synchronized motions, this is a valid approach. However, moving a key for a motion that is, at some point, synchronized or cued to other motions will push the subsequent keys out of synchronization. Clearly the subsequent keys cannot be moved forward with any integrity unless corresponding keys for the entire animation are also moved forward. Thus, lengthening a keyframe interval for a subset of a model's parameters requires a corresponding contraction of another keyframe interval. The reverse is also true.

In expanding or contracting an interval, an animator may wish to preserve the characteristics of the original motion in the interval. For the most part, interpolating functions take care of that. However, there are cases in which the modified timing of the intervals produces a motion with undesirable characteristics. This is especially true with cubic spline interpolation where keyframe spacing affects the shape of the interpolating curve.

Creating motion cycles is another technique that requires copying keyframes. Repeated motions are common in animation, as in the cycle of a walk or swing. To generate a cycle, an animator can manually copy keyframes of the basic motion to multiple locations, one for each repetition of the cycle. This method is tedious and error-prone. Often the original keys contain information unnecessary to the cycle and need to be trimmed down. Additionally, if the motion is to be repeated many times, the keyframe copy process is unwieldy. Ideally, some form of cycle operator or interpolation should exist in the animation system.

An alternative approach to modifying animation pacing or cycle generation is to manipulate the sequence of frame playback. An animator might draw a curve as a function of time to indicate to the animation system the frame playback sequence he wants. This curve could be saved and later used to control frame playback. A ramp function might be used to produce linear playback of frames at a speed

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dependent on the slope of the ramp. Cosine curves would create cyclical animation. Acceleration and deceleration could all be described in terms of this function. With further refinement, different parts of a model or animation could become subject to different pacing functions.

As well as being able to key motions, the animation system should make it possible for the animator to key attributes such as color, reflectance, etc. A flexible database is necessary if these attributes, varied in number, are to be added to a model without destroying previous animation.

Using keyframe systems, an animator must manage scores of joints across hundreds of frames; perhaps hundreds of individual keys. Several systems have successfully tackled the problem of giving such control to the animator. One such system, MUTAN[14], divides a model or group of models into tracks – separate entities that can be keyed individually. For each track, the system displays a sort of ruler that spans the range of frames. Tick marks indicate keys and include notations about the action at that key. Animators manipulate the tick marks to change key positions. MUTAN also has a mode which the animator can use to deal with the set of keys at a particular frame. Another system, DIAL[15], employs a specialized notation that the animator edits on a regular alphanumeric terminal. It displays frames horizontally and tracks vertically on the screen. The animator can view parallel tracks at once to facilitate coordination of keys. BBOP and EM have a special motion editor to manipulate keys along a single track (or parameter), and a command that prints the list of key frames for a particular parameter.

Interpolation

The interpolation process has been given little attention in many animation systems. Usually they only support linear and cubic spline interpolation. Some systems allow cosine interpolation and acceleration or deceleration functions. Animators' experiences with BBOP indicate that control of the inbetween frames is very important. There are cases in which the animator only needs linear or cubic spline interpolation, but there are also cases in which a more sophisticated motion is desired. One way to accomplish this is to add more keyframes. With this method, however, the animator quickly gets lost in a forest of keys, and the efficiency of the computer inbetweening is lost. Another solution is to offer a variety of interpolation types which can be selected for the intervals between keyframes. This scheme is better but the interface must give the animator a clear picture of the various interpolation types and the motions they produce. Limiting the animator to typing in keyframes and interpolation information may not be sufficient.

BBOP addresses this problem by providing a motion editor. The animator uses the motion editor to view the values of a parameter across the span of the animation. Key frames are clearly marked along the curve. The animator can add or delete keys and specify one of several functions to interpolate values in individual keyframe intervals. In addition, the animator can hand draw the desired motion between keyframes to achieve unique movement.

With more than one type of interpolation possible, especially across the path of a single parameter, it is important how curves of different interpolation types are joined. To control the continuity of the overall animation, the animator must be able to determine the degree of continuity across keyframes. Also, the interpolant's behavior at key boundaries is an important factor in its behavior between keys. ASAS solves this problem by using piecewise cubic curves with a selectable degree of continuity at the joints. MUTAN lets the animator specify acceleration or deceleration functions at keys. The BBOP motion editor supports an ease-in/ease-out function to match slopes at key boundaries. Using BBOP, an animator usually positions models at key frames, previews the motion generated by the default cubic interpolation of the inbetween frames, and then fine-tunes the movement in the motion editor. The motion editor allows an animator to give characters idiosyncratic motions, limps, jerkyness, and human-like qualities that linear and cubic interpolation would not provide.

Conclusions

The art of 3-D animation goes beyond positioning models, setting keyframes, and interpolating the inbetweens. Although many animations can be made with these methods, a wide range of situations require more. Scripted animation systems provide one set of solutions. They tend to allow a high level of control over an animation, simplifying many types of motion control, and are often used to model algorithmic or functionally-defined motions. These systems are well suited to goal-directed animation and the simulation of mechanical processes. However, scripted systems

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are not good at producing the idiosyncratic and non-algorithmic "natural" motions that professional animators favor in their productions. In addition, they do not provide immediate feedback – an important element in animation systems geared towards animators. Clearly, some combination of scripted and interactive keyframe animation is desirable.

The combining of the two approaches has been researched over the past year at NYIT, primarily by Pat Hanrahan. The animation system, EM, that has grown out of this research, is more clearly detailed in a paper submitted to the ACM SIGGRAPH '84 conference.

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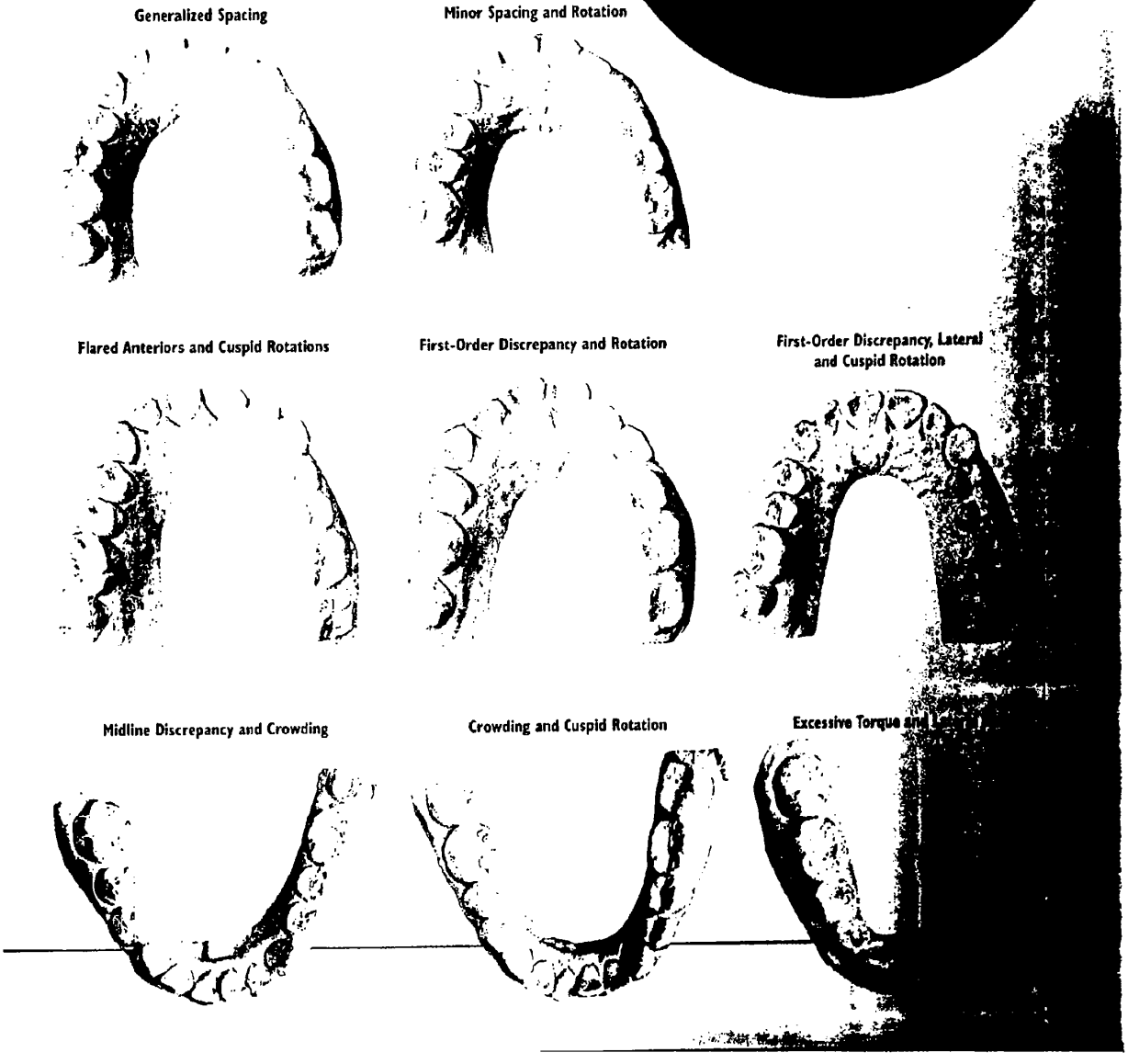
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Step 1: Conduct the initial examination to determine if your patient is a candidate for Red, White & Blue.

Step 2: Make a quality impression of your patient's teeth. *Note: If you use polyvinyl siloxane (e.g., Take 1 Super Fast Medium/Monophase from Kerr), you don't need to pour a model. Just be sure the impression doesn't have any bubbles or missing margins. If you use alginate (e.g., Basis from Ormco) for your impressions, we ask that you pour and trim a model.*

Step 3: Select the anterior teeth that you want corrected. *Note: If you have elected to reposition cuspids, we suggest that you maintain one or more incisors in their current position.*

Step 4: Mark the information on the prescription form. *Note: Select where you want a retention dimple placed and mark it on the prescription form as well. (See explanation on following page.)*

Step 5: Send the prescription and impression or model to AOA/Pro.

Step 6: Receive the Red, White & Blue system.

Step 7: For the most reappointment flexibility, deliver all the Red, White & Blue appliances at one time.

You may choose to reappoint your patients in approximately 8 weeks when they should be ready to begin wearing the Blue appliance. At that point, you can then perform any additional recontouring before the patient

Creating the Active Appliances

Our technicians will use the model you sent or will use your impressions to build one. The teeth you've selected will be cut from this model and progressively corrected. After each correction, a lab technician will create a corresponding appliance for a total of 3 active appliances.

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Doctors follow different protocols for interproximal reduction or recontouring. You may choose to:

- Recontour prior to taking the impression (which AOA/Pro will take into consideration when creating the appliance), then recontour again (if needed) prior to having the patient wear the Blue appliance.
- Recontour when you're delivering the White appliance, then again (if needed) prior to having the patient wear the Blue appliance.
- If you choose to recontour when you deliver the White appliance, we will have provided you with an information card indicating the amount of reduction we performed per tooth to make the appliances, which can serve as a template for your reductions.

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If you have any questions about whether a case you're considering is applicable, simply contact any AOA/Pro Red, White & Blue specialist at (800) 262-5221 in Sturtevant, Wisconsin, or at (800) 826-2224 at the Enfield, Connecticut, facility. Together, you can determine if the patient is an appropriate candidate for this treatment

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When 3 Appliances Will Not Achieve the Desired Result

Some cases may require more than three active retainers to reach the desired result. If so, one of the AOA/Pro Red, White & Blue technicians will call you to discuss the case and the alternative to achieve the result you want.

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For cases with short clinical crowns or where you feel additional retention is indicated, you can specify Crown Contour™ retention dimples.* Simply select where you want each retention dimple placed and mark it on the prescription form. AOA/Pro will affix specifically contoured shapes onto the model, which will transfer as a dimple in exactly the same position on each appliance. When we send the appliances, we'll also send an indirect bonding matrix for each molar. When you're delivering the appliances, you'll pack the recess of the bonding matrix with light-cure adhesive or dental composite and follow your normal bonding procedures, using the matrix as your guide. Since the matrix is a clear vinyl, you can easily light cure the adhesive/composite through it. The resulting dimple will fit and retain each appliance.

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– Stephen G. Tracey, DDS, MS, Upland, CA

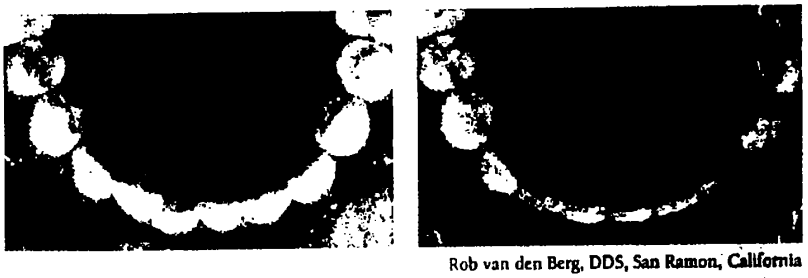
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Randall C. Moles, DDS, MS, Racine, Wisconsin



Ross Stryker, DDS, Lebanon, Missouri



Rob van den Berg, DDS, San Ramon, California

"Red, White & Blue is an appropriately simple technology for simple cases and it's the perfect option for patients who would otherwise do nothing. All I have to do is send in an impression and AOA/Pro does the rest."

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"How many times have you had to tell a patient's parent who [illegible] about fixing mild crowding, rotations or spacing that the only alternative was braces or another aligner alternative that involves considerable time and monetary commitments? With Red, White & Blue, I've got a treatment option that's simple and affordable for these types of cases and [illegible] of income by satisfying an unfulfilled niche."

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- The model used to create the Blue (final) appliance
- An indirect bonding matrix for creating retention dimples, if prescribed
- An information card indicating the specific amount of interproximal reduction (per tooth) performed to create the final appliance
- Patient information about cleaning and wearing the appliance

*Cope Plastic is a licensed product of Cope Plastics, Inc.

To order, contact AOA/Pro in Sturtevant, Wisconsin at (800) 262-5221 or the Enfield, Connecticut, facility at (800) 826-2224.

Keeping Your Preferences on File

We will be pleased to keep preferences you have for your Red, White & Blue cases on file to be used each time we fabricate the appliances for you. Such preferences may be:

- When possible, overcorrect rotations
- Always make the Blue appliance from DuraClear
- Always make an additional Blue retainer in .040 Cope material (Red, White & Blue²)
- Always include Crown Contour retention dimples

Patient Marketing Support



Complimentary Counter Display with Pocket (MATER100RWB)

Complimentary Patient Brochures (Packs of 50) (MATER102RWB)



Consultation Model Kit (MATER101RWB)

AOA/Pro
ALLESEE ORTHODONTIC APPLIANCES • PRO LAB

13931 Spring Street, Sturtevant, WI 53177 • 800-262-5221 • 262-886-1050 • Fax 262-886-6879 • www.aoa-pro.com
P.O. Box 200, 6 Niblick Road, Enfield, CT 06083 • 800-826-2224 • 860-741-3745 • Fax 860-741-7655
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NEXT ▸

THE CHOICE IS CLEAR

Red, White & Blue...
The Simple, Affordable, No-Braces Treatment

Now you've got a simple, cost-effective alternative for those prospective patients who would like minor adjustments made to their incisors but who don't want braces. It's the AOA/Pro Red, White & Blue system of three active, nearly invisible, custom-made retainers worn in the easy-to-remember red, white and blue sequence. Made of clear, lightweight plastic, each retainer works to coax your patients' teeth in small incremental movements, getting them progressively closer to the desired result – their new smile. They're comfortable for patients to wear and easy to talk with. Whether your patients are in school, on the go with a family, a professional in the public eye or active in sports, Red White & Blue fits easily into their busy lives. With little chair time, flexible appointments and impressive results, you'll discover the benefits of Red, White & Blue. Since Red, White & Blue is much simpler and less expensive than comparable treatment systems, it offers an affordable option for patients who otherwise would probably never have treatment.

Red, White and Blue Prescription Form	
Get Acrobat	Adobe Acrobat Reader [illegible] you will need the Acrobat Reader [illegible] Windows, Macintosh and many UNIX platforms.

The Prefect Candidate

The perfect candidate for Red, White & Blue is an adult or fully grown teenager who...

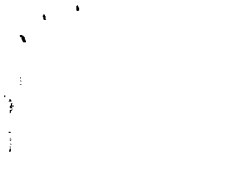
- Exhibits minor anterior overlapping or spacing
- Has had braces or other appliances and doesn't want braces
- May be a candidate for positive overjet
- Presents with a stable pre-treatment relationship and no TMJ symptoms
- Does not want to wear [illegible] your busy life



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Typical Red, White & Blue Candidates

Generalized Spacing



Minor Spacing and Rotation



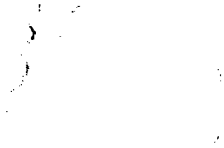
Flared Anterior and Cuspid Rotations



First-Order Discrepancy and Rotation



First-Order Discrepancy, Lateral and Cuspid Rotation



Midline Discrepancy and Crowding



Crowding and Cuspid Rotation



Excessive Torque and Lateral Rotation

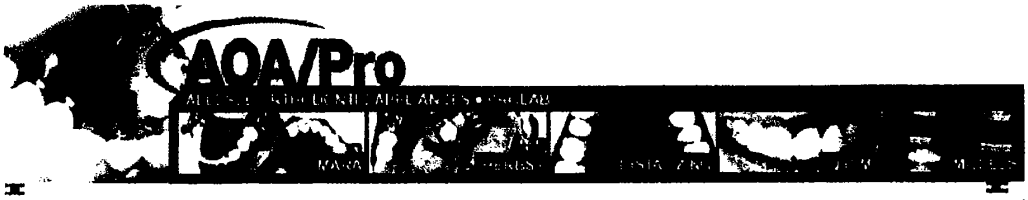


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Here's How it Works

The Red, White & Blue system is designed to treat minor rotations, torque, tip and spacing problems in the social six anteriors by using a series of three active appliances, each working to move the teeth progressively closer to the desired result. Most patients wear each retainer for two to four weeks in the easy-to-remember sequence transitioning from the red to the white to the blue appliances with the blue serving as the final appliance and retainer. Each appliance is clearly marked with color-coded dots for easy identification.

Step 1: Conduct the initial examination to determine if your patient is a candidate for Red, White & Blue.	**Step 2**: Make a quality impression of your patient s teeth. Note: If you use polyvinyl siloxane (e.g., Take 1 Super Fast Medium/Monophase from Kerr) you don't need to pour a model. Just be sure the impression doesn't have any bubbles or missing margins. If you use alginate (e.g., Basis from Ormco) for your impressions, we ask that you pour and trim a model
Step 3: Select the anterior teeth that you want corrected. Note: If you have elected to reposition cuspids, we suggest that you maintain one or more incisors in their current position.	**Step 4**: Mark the information on the prescription form. Note: Select where you want a retention dimple placed and mark it on the prescription form as well. (See explanation on following page.)
Step 5. Send the prescription and impression or model to AOA/Pro.	**Step 6**: Receive the Red, White & Blue system.
Step 7. For the most reappointment flexibility, deliver all the Red, White & Blue appliances at one time.	
You may choose to reappoint your patients in approximately 8 weeks when they should be ready to begin wearing the Blue appliance. At that point, you can then perform any additional recontouring before the patient begins the final phase of treatment.	

Creating the Active Appliances

AOA000133

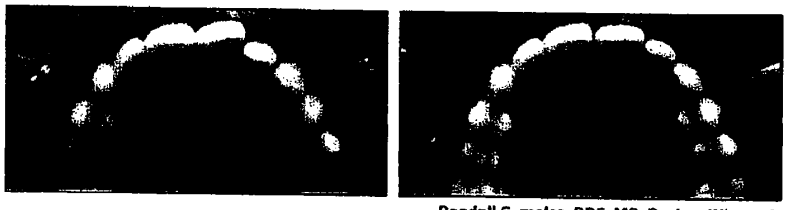
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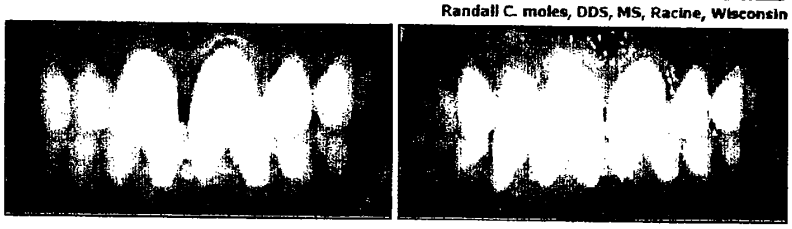
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Randall C. moles, DDS, MS, Racine, Wisconsin



Ross Stryker, DDS, Lebanon, Missouri



Rob van den Berg, DDS, San Rafael, California

"Red, White & Blue is an appropriately simple technology for simple cases and it's the perfect option for patients who would otherwise do nothing. All I have to do is send in an impression and AOA/Pro does the rest."
– **Randall C. Moles, DDS, MS, Racine, Wisconsin**

"How many times have you had to tell a patient's parent who asked about fixing mild crowding, rotations or spacing that the only alternative was braces or another aligner alternative that involves considerable time and monetary commitment. Finally, with Red, White & Blue, I've got a treatment option that's simple and affordable for these types of cases and a new source of income by satisfying an unfulfilled niche."
– **Ross Stryker, DDS, Lebanon, Missouri**

AOA000134

dramatically outpacing the rest of the market. Red, White & Blue lets you easily capitalize on this trend without much overhead with very little clinician and staff time involved. And the display with patient brochures markets the appliance for you."
– Stephen G. Tracey, DDS, MS, Upland, CA

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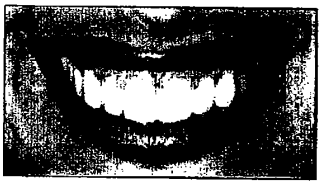
DOCTOR INFORMATION



If all you need is a little cosmetic improvement for a great smile and you'd prefer not to have braces, the nearly invisible Red, White and Blue no-braces system may be the treatment for you. A quick evaluation will tell if you're a candidate for this convenient treatment and, if so, you can have a dazzling new smile in just a few months

Here's How It Works

If your doctor determines that you're a candidate for the system, we'll take an impression of your teeth and send it to the laboratory where they'll create a series of active aligners, custom-made for you. Each appliance is a tray made of lightweight plastic with an impression of your teeth in the shape of your arches.



You'll wear each appliance approximately 2-4 weeks in the easy-to-remember Red, White and Blue sequence. The nearly invisible appliances are so easy to wear and talk with, few people will even know you have them on. And in just a few months, you'll be enjoying your beautiful new smile. Whether you're in school, on the go with a family, a professional in the public eye or active in sports, Red White and Blue fits easily into your busy life.

It's So Convenient

Red, White and Blue is simple to follow. Start with the Red, transition to the White and end with the Blue. Your doctor will give you more explicit directions. Each aligner is clearly marked with color-coded dots for easy identification. Each one works to coax your teeth in small incremental movements, each getting you progressively closer to your new smile. In some cases, the doctor will slenderize your front teeth to make room for tooth movement.

When you begin wearing the aligners, you may experience minor discomfort, but they'll soon loosen and become comfortable. The final Blue appliance is designed with all the desired correction and can be worn at night as a long-term retainer. It couldn't be any easier!

Ask Your Doctor

Red, White and Blue is not for everyone. Your doctor will be [illegible] if you're a candidate. Make your consultation appointment today. After all, your dazzling new smile is simple.

affordable and convenient...may be just three dots away.



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AOA000139



Red, White & Blue is not for everyone. Many patients do require more traditional means of treatment. Your doctor is the best source for your particular needs.

MKT-211



The Red, White & Blue way to improve your smile!

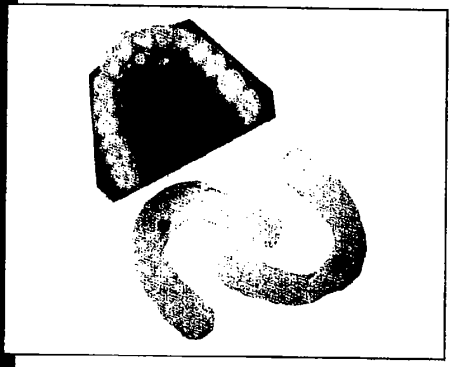
Ask our staff if you are a candidate - and improve your smile in just a few months ...it's simple and nearly invisible!

AOA/Pro

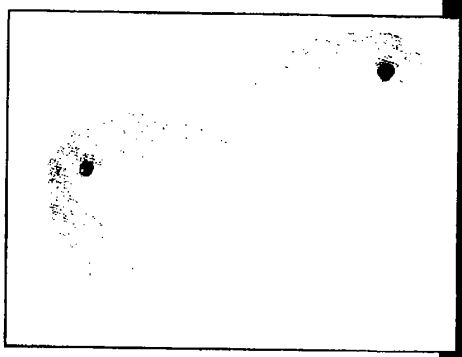
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AOA000092

The doctor's staff will take an accurate impression of your teeth. They will then pour the impression with plaster and after the plaster hardens, send the model to the laboratory. At the laboratory the models are evaluated for accuracy and the potential to correct the positioning of your front teeth. The front teeth are then removed from the plaster model and reset into either a more corrected or ideal position. This is done in very small incremental movements for each retainer, therefore, the reason for a group of retainers. Often, your Doctor will slenderize the crowded front teeth, which will enhance the retainers' tooth moving ability.



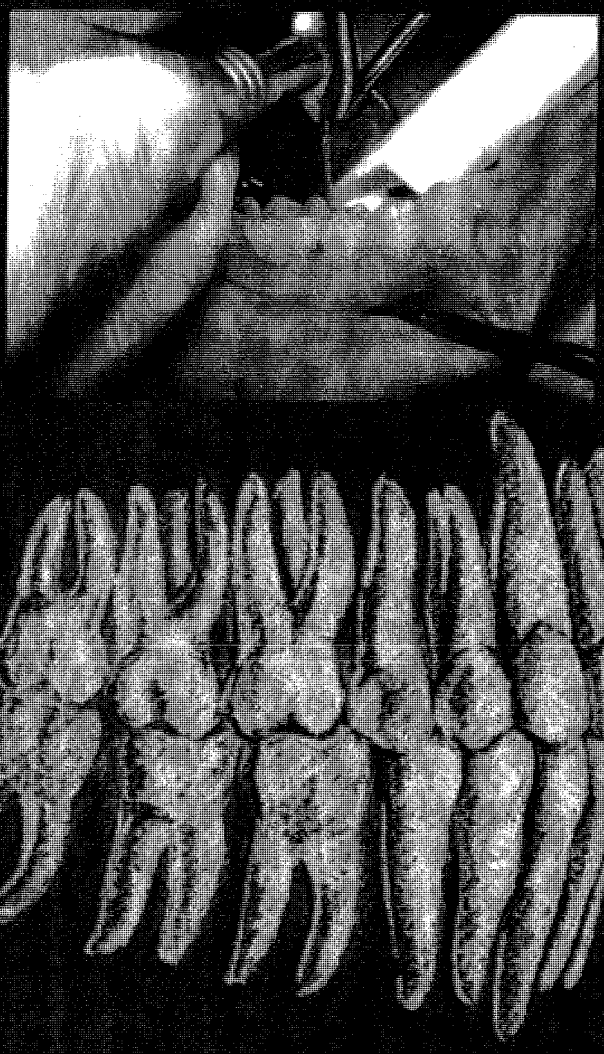
The final "blue" retainer is designed with all or nearly all the wanted correction.



You simply wear each retainer approximately 2-4 weeks or as directed by your doctor. Start with the Red, transition to the White and end with the Blue. Each retainer is clearly marked with dots to indicate which is which.

The appliances are activated each time you firmly seat them over your teeth. The special material has been preprogrammed to coax your teeth toward a more ideal and pleasing position. While the amount of movement each appliance can produce is measured in fractions of millimeters, the force will be noticeable and may result in some temporary minor discomfort. As you progress with your retainers, the appliance will feel looser and you will experience less discomfort.

THE FUNCTIONAL ORTHODONTIST
A JOURNAL OF FUNCTIONAL JAW ORTHOPEDICS
VOLUME 9, NUMBER 5
SEPTEMBER/OCTOBER 1992



Recontouring Teeth for Excellence in Orthodontic Case Finishing

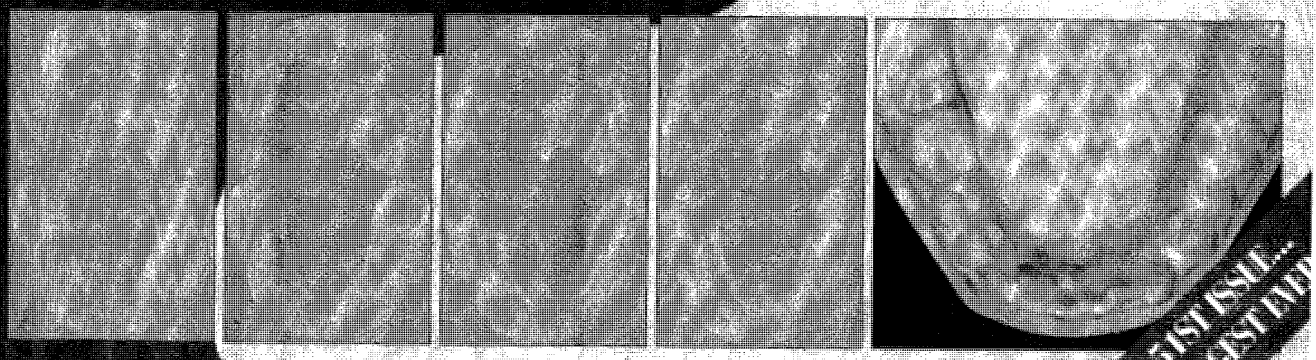
by Dr. James M. Broadbent

Truax CLASP-LESS™ Appliance System
by Dr. Lloyd H. Truax

The Twin Block Technique
by Dr. William J. Clark

The Bicuspid Buildup as an Alternative in Phase II Treatment of Craniomandibular Dysfunction
by Dr. Walter Niemann

Maintaining a Positive Cash Flow in an Orthodontic Practice
by Dr. Ronald J. Mackley



PLUS...Down the Salmon River for the AAFO Mini Conference

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TRUAX CLASP-LESS™ APPLIANCE SYSTEM

ABSTRACT:

This new simplified appliance system is a breakthrough in orthodontic treatment. Advantages of this system:

1. **Mixed dentition treatment made easier.**
2. **Removable appliances without wires.**
3. **Patients love these appliances and you will, too.**
4. **Results are superb.**

Many different types of clasps have been made to hold removable orthodontic appliances in place (Figure 1). In 1986 we began designing and field testing a device we called a Crown Contour (Figure 2). These plastic Crown Contours are bonded on two to four teeth in each arch on which an appliance is to be placed (Figure 3).

We have observed that it is not necessary to place Crown Contours for every CLASP-LESS™ appliance. Many adult dentitions have enough undercut areas to hold a CLASP-LESS™ appliance in place. However, Crown Contours may be indicated in cases of mixed dentition, vertical pull elastics, and reverse-pull headgear.

The same acid etch technique for plastic brackets is used to bond these Crown Contours to the facial surface of a tooth crown. This Crown Contour changes the facial surface of the tooth, thus providing better retention.

A simple "C" clasp (Figure 4) is now able to hold a removable appliance in place much better. The multitude of more complicated clasps are no longer necessary. It is also unnecessary to consider cutting a groove in the facial surface of a deciduous tooth to gain an area of retention for a clasp.

Since 1987, we have used the Crown Contours to secure a Serial Truax Appliance Rains System (STARS) thermoplastic appliance. With Crown Contours on, anterior teeth may be slenderized to provide space for rotations and alignment (Figure 5). Impressions are taken and these teeth are reset in the laboratory; three clear Tru-Tain plastic trays are made of various thicknesses. The thinnest tray snaps into place first for three to four weeks; this is followed by the other two trays at three-to-four week intervals. These appliances are taken out only to eat and brush. For patients who have considerable crowding and do not want to have brackets placed, a second set of impressions and another setup may be necessary (Figure 6; note Crown Contours on first and second bicuspids).

An offshoot of this technique was to start making more complicated removable appliances that contain screws. Using this new method, most removable appliances can now be made without clasps.

Appliances with clasps become loose as the screws are turned; therefore, the screws and and clasps need readjustment. One of the biggest problems, loose removable appliances, has been solved. Readjustment is not necessary with these CLASP-LESS™ appliances. This not only pleases the patient, but also reduces the length of treatment time, which has been another big problem with removable appliances. Treatment time is reduced, whether or not the patient has temporomandibular joint dysfunction.

With these removable appliances, as with all removable appliances, patient cooperation is essential. Appliances should be removed only to brush their teeth, if the mouth is sore, or to place a mouth guard for sports. Patients who have worn clasp appliances really appreciate the CLASP-LESS™ varieties because these new appliances are

KEY WORDS:
Crown Contours, Clasp-Less™, Aesthetic, Better Retention, Efficient

by Dr. Lloyd H. Truax

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Figure 1

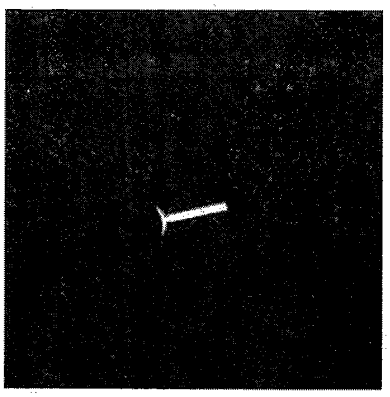


Figure 2

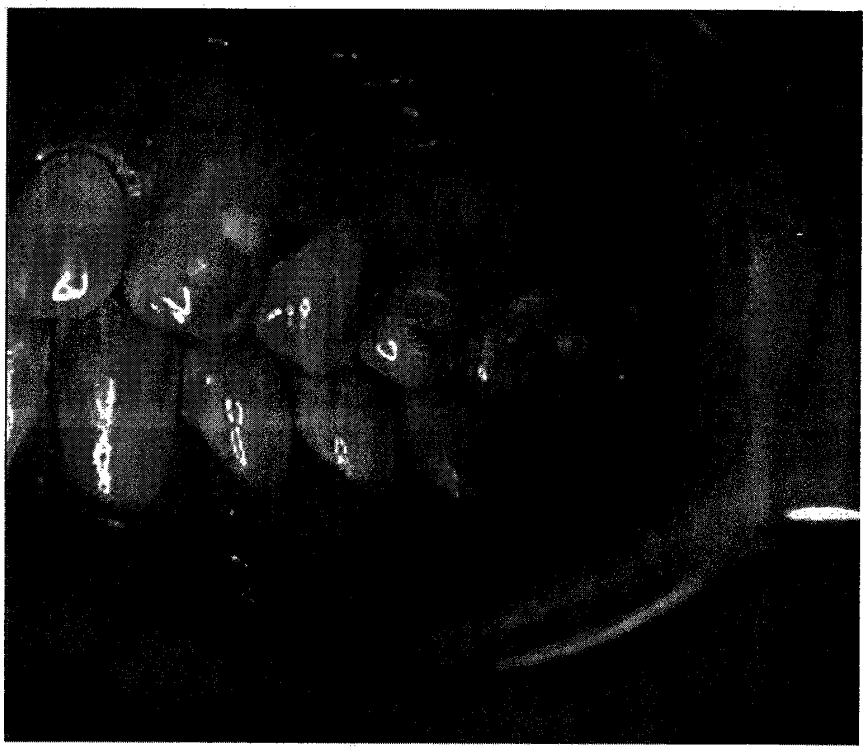


Figure 3

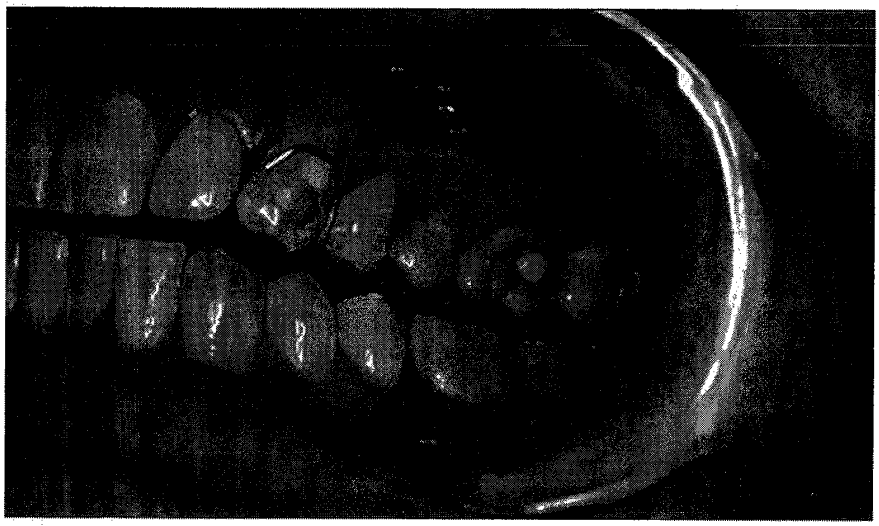


Figure 4

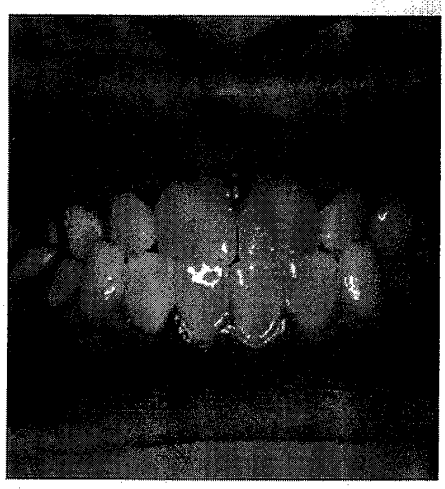


Figure 7

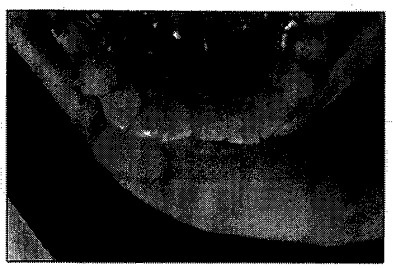


Figure 5



Figure 6



Figure 8

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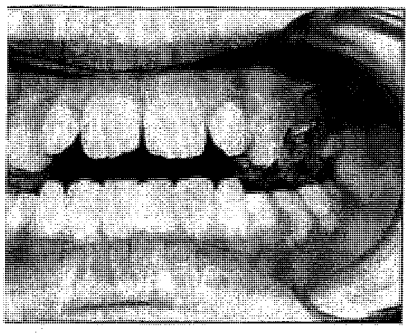


Figure 9

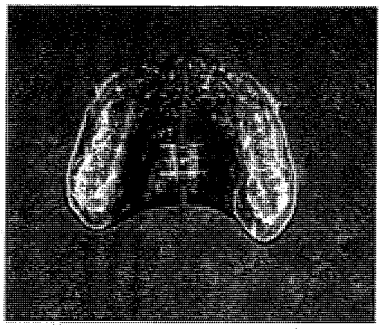


Figure 10

very aesthetic and comfortable. With good retention, children can be treated earlier, allowing faster and greater changes during growth and development. Early treatment also reduces the probability of future TMJ dysfunction by eliminating the traumatic occlusion.

Patient K.P.
Age 9 years, 8 months
Class III (centric relation)
Overjet –1 1/2 to –2 mm
Overbite 1 1/2 to 2 mm
ROM 49/9/9/9

Maxilla is in total crossbite (Figures 7 and 8), maxillary anteriors need 2 1/2 to 3 mm for alignment, some soreness of joints when chewing hard food, no clicking of TM joints.

Interceptive, or Phase I, treatment is indicated to allow for normal growth and development, better eruption of maxillary teeth, and to reduce the stress on temporomandibular joints.

Treatment: Crown Contours and a CLASP-LESS™ transverse, removable appliance with reverse-pull headgear hooks (Figures 9 and 10) were placed. This CLASP-LESS™ appliance is so

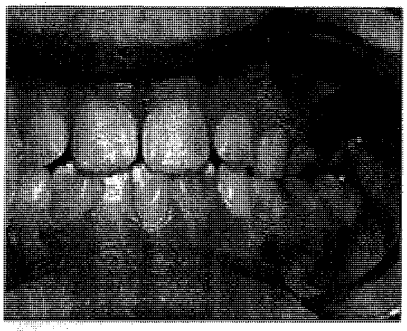


Figure 11

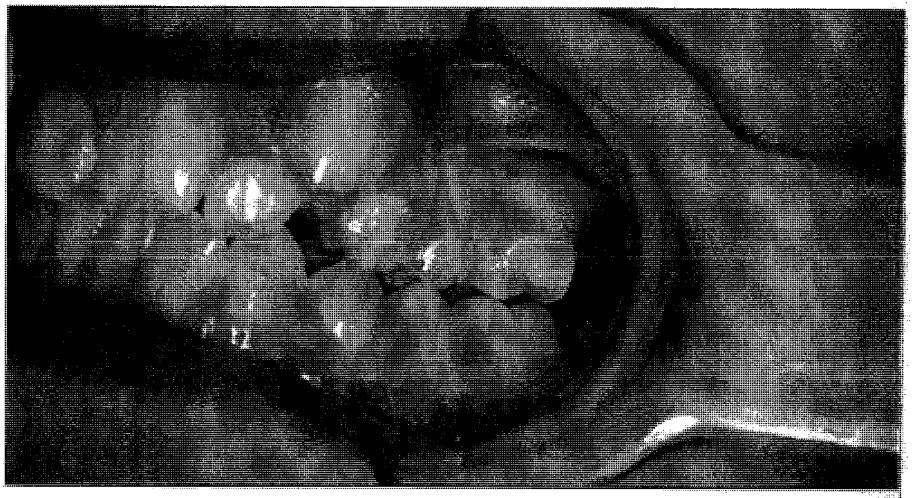


Figure 12



Figure 13

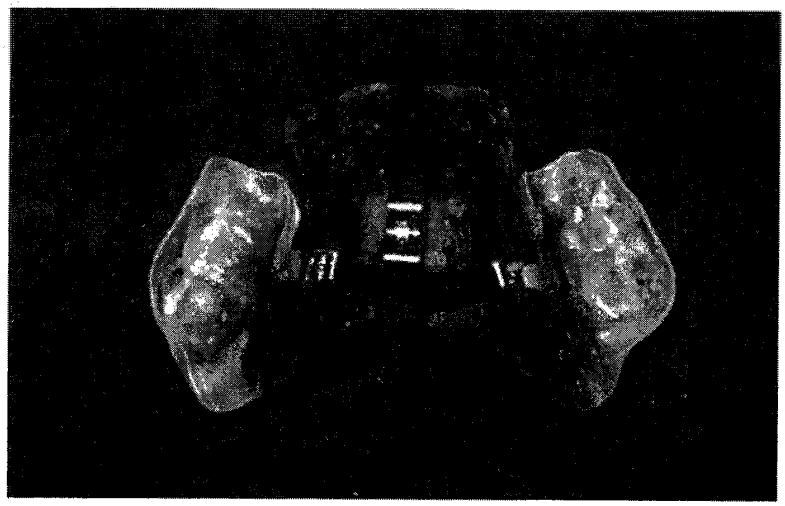


Figure 15

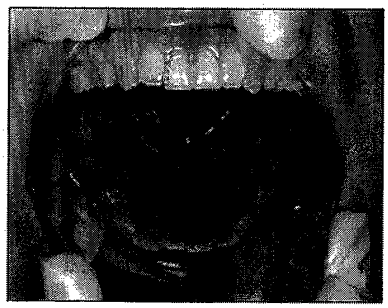
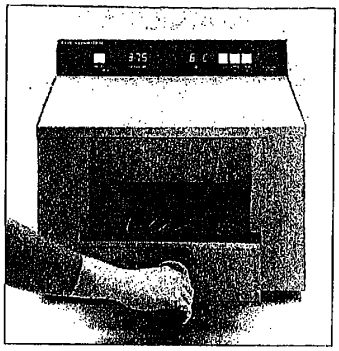


Figure 14

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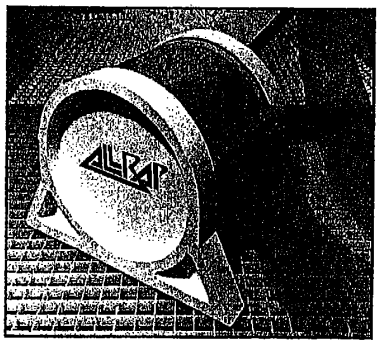
The Cox rapid transfer method uses no steam or chemicals to dull, rust or corrode your instruments. Quick cycle time, means you can substantially reduce instrument inventory!

Includes: 2 Drawers, 1 Plier Rack, 1 Bur Holder, and 1 Cooling Fan.

Cat. No. 0789 Cox Sterilizer **Super Low $2,500!**

Cat. No. 0789 New! 2-minute Handpiece Disinfection Kit **Just $249!**

(Includes 1 Handpiece drawer, 1 electronic timer, 1 set of instructions)



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Cat. No. 4185 Allrap Dispenser **Only $31.95!**

Cat. No. 4185-C Allrap Film - Clear Roll **Only $19.95!**

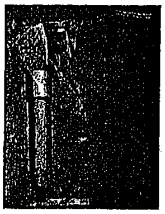
Cat. No. 4185-B Allrap Film - Blue Roll **Only $19.95!**



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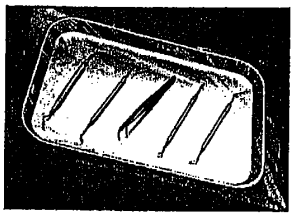
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4060105	5 Gallon w/dispensing spigot	$90.00
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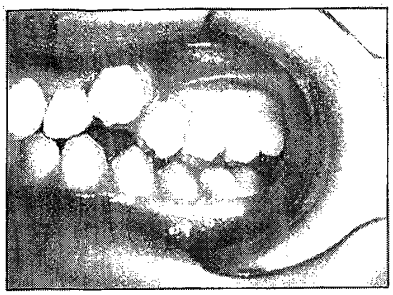


Figure 16



Figure 17

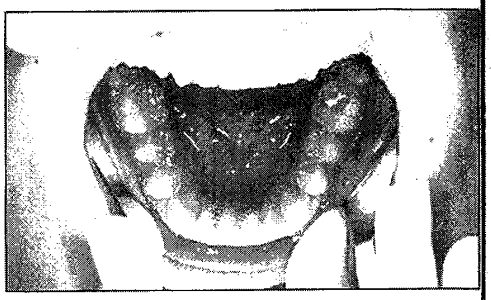


Figure 18



Figure 19



Figure 20

ORTHODONTIC LABORATORY

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secure that it remains in place when reverse-pull headgear is utilized. The force was applied to the entire maxilla (not just the maxillary teeth) approximately twelve hours per day. The transverse screw was turned one-quarter turn (1/2 mm) twice per week. After four and a half months (Figure 11) the transverse appliance and the reverse-pull headgear were discontinued. For three months a full palate Tru-Tain retainer was worn day and night, except while eating and brushing. This interceptive treatment is stable and the patient is being observed on tooth guidance. She will perhaps need a second phase of treatment. However, the chances of surgery are greatly reduced in patients who receive interceptive treatment and tooth guidance.

Patient D.T.
Age 13 years, 8 months
Class II, Division I
Overjet 0—1 mm
Overbite 1 1/2—2 mm
ROM 52/9/9/9

Maxillary cuspids were blocked out of alignment and minor crowding in the mandibular arch (Figures 12, 13, and 14). He had signs and symptoms of temporomandibular joint dysfunction: occasional clicking of both joints, muscle tenderness in the TMJ areas, pain when chewing hard food, and headaches nearly every day.

Crown Contours and a Class II CLASP-LESS™ trans-sagittal appliance with a flat posterior bite plane was placed (Figure 15). No appliance was placed in the mandibular arch. After one month his symptoms were greatly diminished and had completely disappeared after eleven months. Space was provided for the maxillary cuspids (Figures 16 and 17). With the occlusion unlocked, his mandible migrated forward and the anteriors self aligned. This could only be possible if the untreated maxillary anteriors were putting pressure on the mandibular anteriors, thus holding the mandible back causing TMJ dysfunction, and crowding of the mandibular anteriors (Figure 18).

Patient E.C.
Age 10 years, 10 months
Class II, Division I mixed (Figure 19, panorex x-ray)
Overjet 9—10 mm (Figure 20, cephalometric x-ray)
Overbite 5 1/2—6 mm

Begin treatment with Crown Contours and a CLASP-LESS™ Clark Twin Block with space blocked out for eruption of the second bicuspids. The mesial 4 mm of the mandubular first molars are included in this block and the incline is still placed distal to the second bicuspid space. With the space blockout areas, we are able to begin treatment earlier, thus taking advantage of growth and development (Figures 21 and 22).

The maxillary block has a transverse screw to widen the maxilla, as the mandible comes forward (Figure 23). This provides the maxillary arch with the proper width when the 0 occlusion is Class I.

Patient R.L.
Age 23 years, 8 months
TMJ dysfunction patient

Using a CLASP-LESS™ verticalizer after Twin Block therapy (Figures 24 and 25).

CONCLUSION

The Truax CLASP-LESS™ Appli-

BNS-40 — *THE* ALTERNATIVE TO DRUG-THERAPY

In-Home Ultra-Low Frequency Electrical Muscle Stimulation



The BNS-40 provides:

- Relaxation of Muscle Spasm
- Increased Local Blood Circulation
- Increased Range of Motion
- Simplified Occlusal Procedures

The BNS-40 is a compact, portable instrument specifically designed for in-home use. It provides **safe**, effective simultaneous bilateral stimulation of paired masticatory muscles. Prescribe the BNS-40 for muscle spasm associated with TMJ, pain or locking following long dental procedures, or post-op pain and edema associated with TMJ or third molar surgery. It is **extremely effective** in conditions when muscle spasm is involved and is an excellent alternative to long term use of potent pain control medications.

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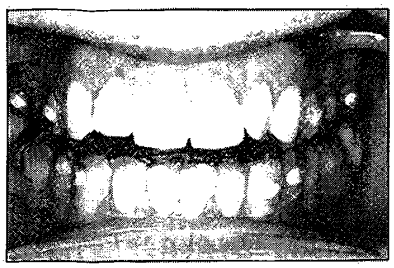


Figure 21

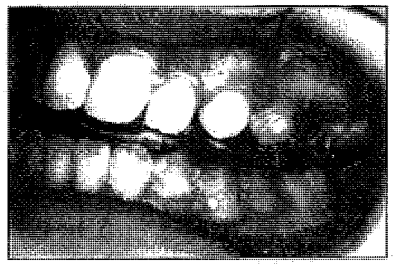


Figure 22

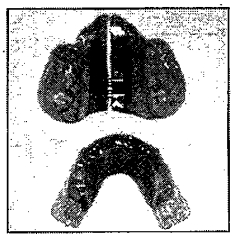


Figure 23

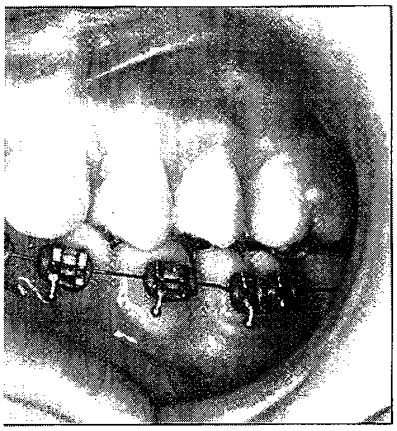


Figure 24

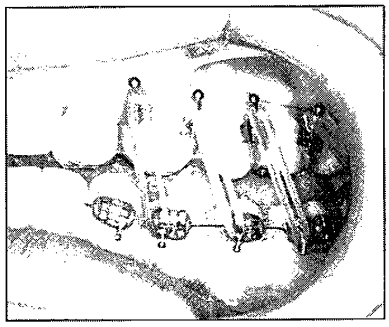


Figure 25

ance System is the future of removable orthodontic appliances.

ACKNOWLEDGMENTS

The author is indebted to Kevin L. Truax for several years of persistence in working with engineers of various injection molding companies and techniques, and to Aliese Erickson for 22 years of innovative skills regarding her laboratory techniques.



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Retention without Clasps.

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- Appliances are comfortable to wear. Clasp-Less cases snap in. The retention is crisp, comfortable and transparent.
- Patients look good wearing Clasp-Less appliances. This means more cooperation and quicker treatment results.
- Your patients will be happier and so will you.

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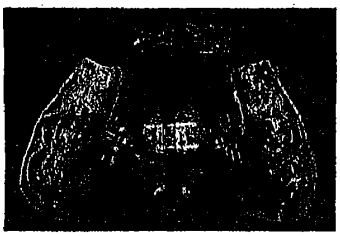
Introducing The Future of Removable Orthodontic Appliances---

THE TRUAX CLASP-LESS APPLIANCE SYSTEM ™

(Patent Pending)



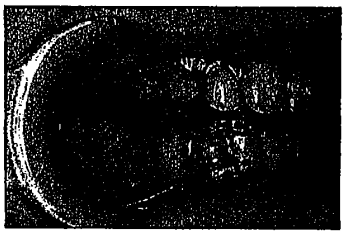
CLASP-LESS Appliance in the Mouth



Upper CLASP-LESS Appliance



Lower CLASP-LESS Appliance



Crown Contours on Teeth

This new technique allows most every type of removable orthodontic appliance to be made without wire clasps.

Advantages of **THE CLASP-LESS APPLIANCE SYSTEM** ™ (Pat. Pend.) are:

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For more information on this revolutionary new system, contact any of the exclusively licensed laboratories listed below:

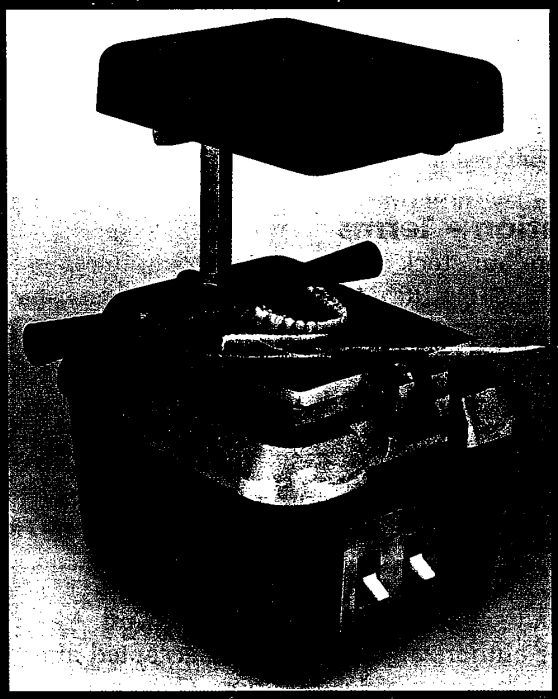
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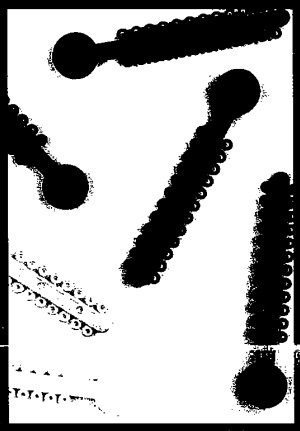
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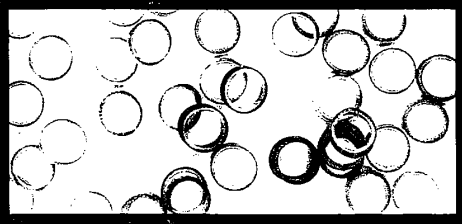
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We accept Visa and Mastercard. First time orders must be payed by C.O.D., Visa or Mastercard to establish account. Established accounts are billed on 30-day net terms, with 1.5% monthly interest or 18% annual rate.

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Returns must be made within 30 days for a full refund. After 30 days you will need to call for authorization. No returns accepted after 90 days. All items returned must be in sellable condition. *(15% re-stocking charges on returns after 30 days.)*

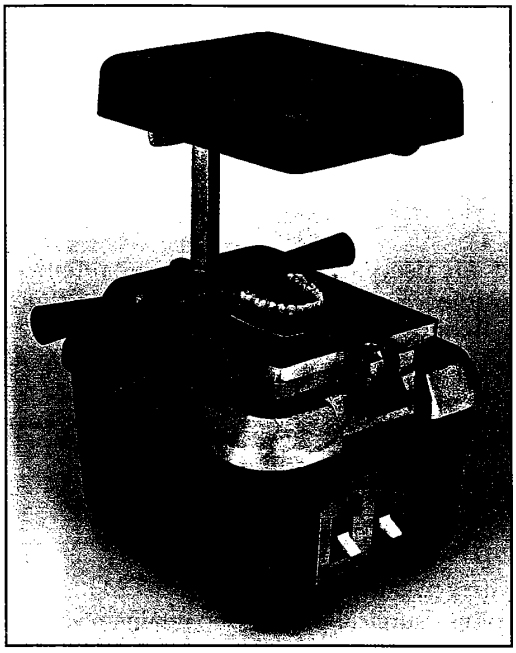
Satisfaction Guaranteed

All of our products and materials have an unconditional warranty/guarantee. If for any reason you are not completely satisfied with your purchase, Tru-Tain will replace or refund your money, whichever you prefer, if the materials are returned within 30 days.

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TRU-FORM Vacuum Machine



Basic Machine Package
Includes a technique manual and sample pack of plastics.
Item No. TFB-110 .....$285.00

Standard Machine Package
Includes above, plus one pack .030 Tru-Tain Retainer plastic.
Item No. TF-110 .....$300.00

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Includes all of the above, plus one pack of Pro-Form laminates, Miltex scissors, crown and bridge scissors, wheel saw.
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Features:
- All aluminum construction—no rusting
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- Made in the United States

Applications	Material Used
Clear Orthodontic Retainers	TRU-TAIN Retainer Material .030 (Type A); .040 Splint; .030, .040 Coping (Type C)
Athletic Mouthguard	PRO-FORM Mouthguard, .150 Mouthguard
Protective Care Guard	PRO-FORM Mouthguard
Ortho Re-Positioner	PRO-FORM Niteguard
Space Maintainer	PRO-FORM Niteguard
Periodontal Splints	PRO-FORM Niteguard, .040, .060, .080 Splint
Custom Fluoride Trays	PRO-FORM Niteguard, .120, .150 Mouthguard
Pressure Guard	PRO-FORM Niteguard
Soft Bruxism Splint	PRO-FORM Niteguard, .120, .150 Mouthguard
Hard/Soft Bruxism Splints	PRO-FORM Dual Laminate
Temporary Bridges	020 Temp Splint Material–Crown & Bridge, 020 Coping Material
Denture Bases	060, 080 Base Plate Material, 100
Custom Trays	125 Tray Material, 150 Tray Material
Copings	020 Coping Material, 030 Coping Material
Indirect Bonding	.080 Mouthguard–EVA
Bleaching	Bleaching Laminate, .040, .060 Mouthguard–EVA

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Thermoforming Dental Materials

(F.D.A. Approved)

Vacuum formers use a variety of plastics for the production of different dental and orthodontic appliances. These materials are known as thermoplastics. We offer a large array of these materials to fit every need, as well as technical information on making all appliances. **Standard size of all materials listed are 5 in. x 5 in. square sheets. We also offer 125 MM x 125 MM in squares and circles for pressure forming machines.** ***(Please Specify)***

Retainer Materials A variety of plastics are used to make orthodontic retainers. The most popular for making clear invisible vacuum formed retainers is the .030 TRU-TAIN retainer plastic. A copolyester material *that will bond with acrylic,* forms easily and provides stable retention. Flexible so it works great for minor tooth movement.

TRU-TAIN Retainer Plastic (Type-A Material)

Item No.	Thickness INCHES	MM	Cost
	(25 sheets per pack)		
TT-30	.030	.7	$16.00
	(economy pack of 100 sheets)		
TT-30E	.030	.7	$55.00

Other popular materials for making retainers are .040 splint, .030 & .040 coping, (Type-C Material). These are listed below.

Splint Materials

These plastics are used for hard T.M.J. splints, surgical trays, ortho retainers, etc. *These materials will bond with acrylic.*

Item No.	Thickness INCHES	MM	Cost
	(25 sheets per pack)		
SS-20	.020	.5	$13.50
SS-40	.040	1.0	$17.50
SS-60	.060	1.5	$18.50
SS-80	.080	2.0	$21.50
SS-100	.100	3.0	$23.50

New Night & Date Retention System

Item No. NDRS

25 sheets of .030 TRU-TAIN Retainer plastic, (Type-A Material) for daytime use and 25 sheets .030 Coping, (Type-C Material) for night use. One combination pack of both materials.

50 sheets per pack $26.00

Temporary Splint-Crown & Bridge Material

This plastic is used for quick production of crown forms and temporary bridge applications. *This material will not adhere to acrylic.*

Item No.	Thickness INCHES	MM	Cost
	(50 sheets per pack)		
TS-20	.020	.5	$13.50

Order 5 packs of any material for 10% discount

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Thermoforming Dental Materials

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Mouthguard-E.V.A. Materials

These materials have a variety of uses which include athletic sports guards, bleaching trays, soft splints, indirect bonding and model duplication.

Item No.	Thickness INCHES	MM	Cost
	(25 sheets per pack)		
MG-40	.040	1.0	$18.00
MG-60	.060	1.5	$22.00
MG-80	.080	2.0	$24.00
MG-120	.120	3.0	$27.00
MG-150	.150	3.8	$27.00
MGC-150*	.150	3.8	$28.00

* *Available colors: blue, red, green, yellow, orange, black, white & assorted color packages*



Bleaching Laminates

The bleaching of teeth has become a popular and acceptable dental technique. The bleaching laminate is ideal for making bleaching trays—a thin splint material with a foam liner that helps absorb the bleaching agent and reduce the bleaching time for the patient. Soft and comfortable to wear.

Item No.	Cost
(25 sheets per package)	
BL	$33.00

Base & Tray Materials

These materials are used for making denture bases for try in of dentures and custom fabrication of impression trays.

Item No.	Thickness INCHES	MM	Cost
(25 sheets per package, or 100 sheet package)			
BP-60	.060	1.5	$8.50
BP-80	.080	2.0	$10.50
BP-100	.100	2.5	$12.50
BP-125	.125	3.2	$14.50
BP-150	.150	3.8	$16.50

Coping Materials

These plastics are used for temporary crown & bridge forms, bleach trays and retainers in .030 & .040 thickness. *These materials will not bond with acrylic.*

Item No.	Thickness INCHES	MM	Cost
	(50 sheets per pack)		
CBP-20	.020	.5	$13.00
CBP-30	.030	.7	$20.00
CBP-40	.040	1.0	$25.00

Sample Pack

A sample of all the various thermoplastics presently used in the dental industry. It contains the Pro-Form laminates, base plates, tray materials, retainers, crown & bridge materials and much more. These materials are all labeled with name and various applications that they may be used for. A technique booklet with step-by-step instructions on all applications is also included.

Item No.	Cost
	$25.00

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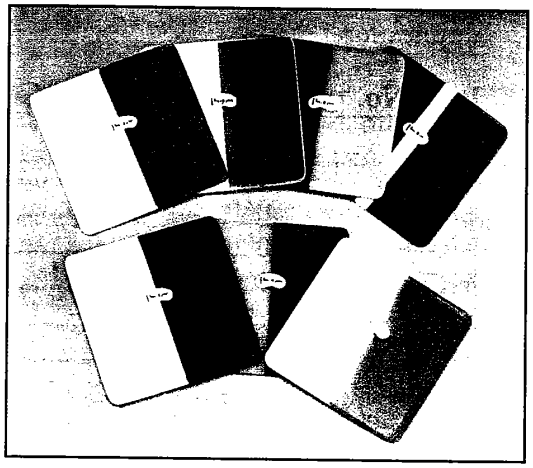
PRO-FORM Laminates

These are the finest materials available. Each laminate is injection molded for thickness control, cross layered to assure reinforcement and laminated for strength. Three types of laminates: mouthguards, niteguards and dual hard/soft splints.

Mouthguard Laminates

The best mouthguard protection available. Pro-Form laminates are made of the highest quality, energy absorbing vinyl. It is the only mouthguard that has two layers for strong resistance against broken teeth and fractures. Choose from a variety of colors: red, blue, green, yellow, orange, black, white, purple, maroon and clear. Or, for fun try the new "Multi-colored" mouthguards. Match your team colors, kids love them. Of the colors listed, you can combine any combination in two tone or three tone on a single sheet of material.

Item No.	Thickness INCHES	MM	Cost
	(12 sheets per pack)		
PFMG	.160	4.0	$51.00



Buy 3 packs of any laminates at $45.00 per pack, or 8 packs at $39.00 per pack

Niteguard Laminates

This material was developed for a soft bruxism splint, but proved to be ideal for a variety of uses. These include orthodontic repositioners, fluoride trays and periodontal stints. The top layer of this laminate is a dense vinyl that has excellent plastic memory and abrasion resistance. This provides a finished appliance that is soft and pliable, yet very durable to withstand high tooth abrasion and still be comfortable.

Item No.	Thickness INCHES	MM	Cost
	(12 sheets per pack)		
[illegible]G	.150	3.8	$51.00

Dual Laminates

A hard/soft laminate used as functional splint in T.M.J. cases or for fast flipper production. The combination of hard and soft material provides a number of excellent features. The top surface is hard to withstand the jaw's tremendous closing pressures, plus cold cure acrylic as well as light cure material can be added to make occlusal adjustments. Also, the addition of teeth for flipper production. The soft bottom surface gives the appliance great retention, yet is soft for gingival tissue comfort.

Item No.	Thickness INCHES	MM	Cost
	(12 sheets per pack)		
[illegible]L	.150	3.8	$51.00

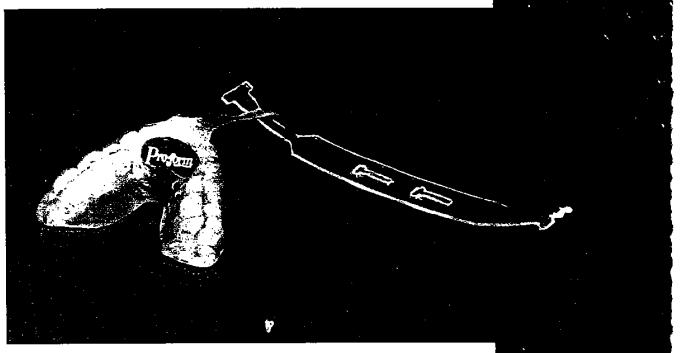
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PRO-FORM Laminates

Mouthguard Straps

Easy to attach helmet strap for custom made mouthguards. Safety release feature allows mouthguard to break away under 12 pounds of pressure. Available in the same stock colors as the mouthguard material.

Item No.	Cost
(12 straps per pack)	
MGS-1	$8.00
(25 straps per pack)	
MGS-2	$15.00



Mouthguard Programs

We have two kits to help the dental professional with a custom made mouthguard program.



Kit 1

A starter kit to promote professionally made mouthguards. It includes: 3 sheets of Pro-Form mouthguard, a strap for helmet attachment, a folder of various clinical studies, an educational video, patient brochures and poster. An excellent way to convey the importance of custom made mouthguards to parents and coaches.

Item No.	Cost
	$20.00

Kit 2

This is a production kit for dental offices and labs who want to make professionally made mouthguards. It contains a complete package of 24 Pro-Form mouthguards *(must specify colors)*, 24 helmet straps, and 24 storage boxes. This kit is a great practice builder.

Item No.	Cost
	$99.50

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Anti-Snoring Kits

The Pro-Form Anti-Snoring Device is a patented, custom made dental appliance that gently protrudes the lower jaw forward. Due to its unique design, the device increases air flow during sleep, is comfortable to wear, and can be easily made and adjusted. The kits allow the dental professional to make an anti-snoring device that has been successful in treating 80% of snoring patients.

The hard/soft base is first vacuum formed onto the upper arch. Next a repositioning ramp is chosen that fits in the lingual of the lower anteriors. There are six different sized ramps to choose from. The ramp is positioned and attached to the upper, vacuum formed, hard/soft splint with acrylic. Then this appliance can be further adjusted or modified by grinding or adding more acrylic.

To get started, we recommend one of the kits listed below. All come with promotional materials. So start making more profit today with the Pro-Form Anti-Snoring Device.

Intro Kit

This is an easy starter kit. It contains enough materials to make two ASD appliances. Promotional materials for the dental office included.

Item No.	Cost
P500-000	$39.00

Production Kit

A slightly larger kit for offices or laboratories who are presently making ASD devices. Kit includes: 6 base hard/soft splints, 6 different ramps, appliance storage boxes and promotional materials.

Item No.	Cost
P500-Kit 1	$75.00

Lab (Bulk) Kit

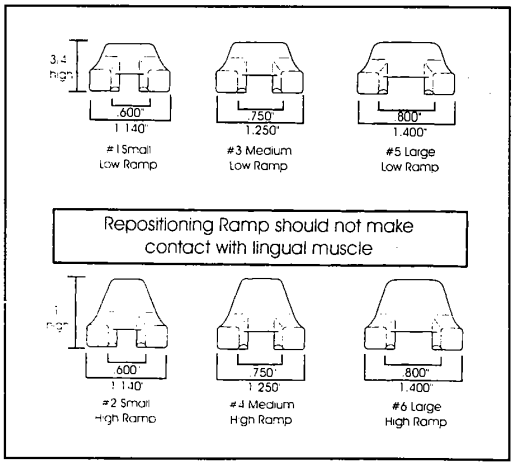
A kit developed for the larger laboratories who are fabricating a lot of anti-snoring devices. Kit includes: 24 base hard/soft splints, 24 assorted ramps of various sizes, storage boxes and promotional material.

Item No.	Cost
[illegible]	$250.00

Repositioning Ramps

Ideally the ASD appliance should have a downward sloping ramp that slides up and down on the lingual portion of the lower cuspids. To accomplish this, the ASD ramps come in various sizes. **Cost $20.00** (6 ramps per pack)

Part No.	Description
P500-AST	6 ea. Assorted Ramps
P500-SL6	(size #1) 6 ea. Small Low Ramps
P500-SH6	(size #2) 6 ea. Small High Ramps
P500-ML6	(size #3) 6 ea. Medium Low Ramps
P500-MH6	(size #4) 6 ea. Medium High Ramps
P500-LL6	(size #5) 6 ea. Large Low Ramps
P500-LH6	(size #6) 6 ea. Large High Ramps



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Ortho Appliance Boxes

Economy Retainer Cases

(¾ in. deep) Item No. OB

Ideal for retainers, splints, bleach trays, etc.

Quantity	Cost
100 cases (.38 ea.)	$38.00
200 cases (.36 ea.)	$72.00
500 cases (.34 ea.)	$170.00
1000 cases (.31 ea.)	$310.00

NEW "Ortho-Gard" Retainer Cases

(1 in. deep) Item No. OG-1

A new case designed for durability and protection for all orthodontic and dental appliances. It features a strong living hinge, vent holes and a top cover that can hold adjustment key for expansion screws.

Quantity	Cost
100 cases (.42 ea.)	$42.00
200 cases (.40 ea.)	$80.00
500 cases (.38 ea.)	$190.00
1000 cases (.36 ea.)	$360.00

NEW "Ortho-Gard Plus" Appliance Cases

(1½ in. deep) Item No. OGP

For larger functional appliances.

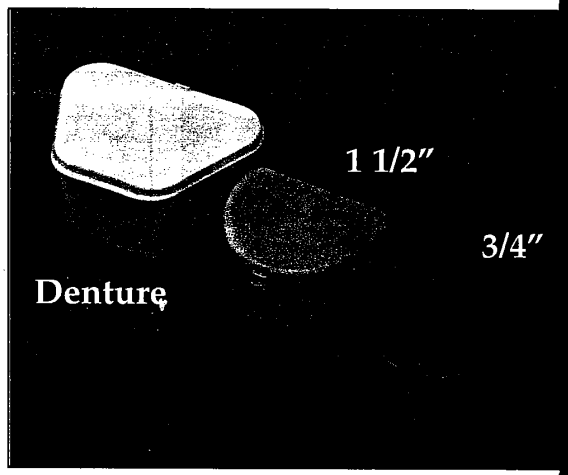
Quantity	Cost
100 cases (.44 ea.)	$44.00
200 cases (.42 ea.)	$84.00
500 cases (.40 ea.)	$200.00
1000 cases (.38 ea.)	$380.00

Denture Storage Boxes

Item No. [illegible]

Large enough to hold a full set of dentures. Colors: light blue, yellow, rose, cream.

Quantity	Cost
25 boxes (.52 ea.)	$13.00
50 boxes (.50 ea.)	$25.00
100 boxes (.48 ea.)	$48.00
200 boxes (.45 ea.)	$92.00



Stock colors for all appliance cases

8 different colors to choose from: red, blue, green, yellow, pink, black, purple, and white.

Custom imprinting available on all cases!

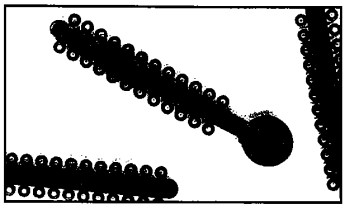
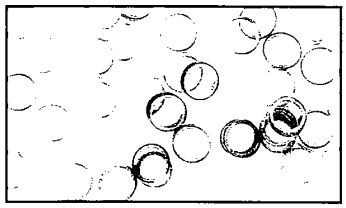
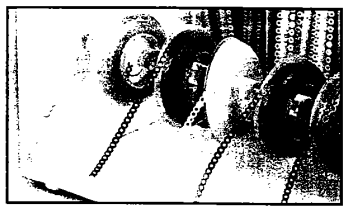
This is a great practice builder, promote your office with an imprint of your name, address, phone number or custom logo.

Call today for details and pricing.

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Elastomerics: Ligature Ties & Chain

Now you can have the highest quality elastomeric ligature ties and chain in 25 matching colors. Our ties have unmatched streach and rebound. The vibrant colors last longer, making them a patient favorite. *ORDER YOURS TODAY!*

Molded Ties-Mini Sticks

42 sticks/24 ties each. (1008 per pack)
Item No. EMS - (size/color)

Quantity	Cost/pkg.
1-4 packs	$13.00
5-9 packs	$11.00
10 or more	$10.00

Intraoral Elastics

Latex Elastics - 50 bags of 100 elastics/5000 total. *Item No. EL - (size/color)*

Natural - *Amber* ..... **$18.00/pkg.**
(5 or more packs of 50 bags - $15.00/pkg.)
Assorted Colors ..... **$19.00/pkg.**
(5 or more packs of 50 bags - $16.00/pkg.)

All of our elastics are coated with Oat Powder, not cornstarch. Oats have a healing effect and are easily absorbed in the body. It does not absorb the proteins from latex.

NEW Non-Latex Elastics

Designed for patients who are sensitive to latex. This new elastomeric material has consistant gram force and elasticity. Available in natural clear, assorted colors and glow-in-the-dark.

Price..... **$18.00/pkg.**
(5 or more packs of 50 bags - $15.00/pkg.)

Sizes 1/8 Med, 1/8 Heavy, 3/16 Med, 3/16 Heavy, 1/4 Med, 1/4 Hevy, 5/16 Med, 5/16, Heavy (Medium= 4.5 oz. force, Heavy= 6.5 oz. force. Light force elastics 2.5 oz. in natural only. All bags are colored coded and marked for easy patient identification.

Elastomeric Power Chain

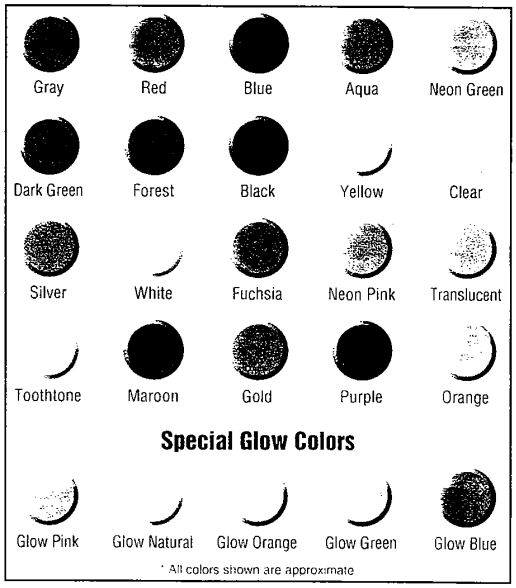
(15 ft. spools) Available in short (*Item: ECS*), continuous (*Item: ECC*), and long (*Item: ECL*)

Quantity	Cost/pkg.
1-4 spools	$13.00
5-9 spools	$11.00
10 or more	$10.00

NEW: Glow-in-the-Dark, Ties Chains & Elastics

Glo-Ties add $3.00 extra per pkg.
Glo-Chains add $3.00 extra per spool

Elastomeric Color Chart



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Helpful Items

Pro-Form Procedure Video

A video containing a complete treatise on thermoplastics and vacuum former uses in dentistry. This is a 75-minute tape that covers everything from basic vacuum forming techniques, model preparation, thermoplastic selection to more complicated issues of actual appliance fabrication.

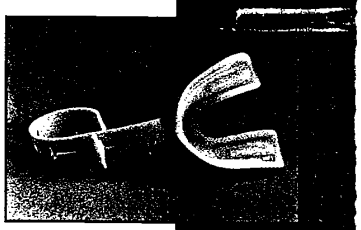
Item No.	Cost
P107-Tape	$39.95

Plasterless Articulator

This is perfect for appliance production or review, especially for those cases where occlusal surface adjustments are necessary. Articulator will firmly hold any size model with a set of expanding screws. Eliminates the need for plaster mounting. Has a complete set of anatomical movements, making the articulator ideal for study models, denture work, reproducing centric relationships, and anti-snoring devices.

Item No.	Cost
P300-000	$140.00

Boil & Bite Mouthguards



For the dental professional that wants to be involved with mouthguard production, but time and cost constraints do not allow for a custom made mouthguard. It has a unique occlusal surface "Crush Zone" design that allows for good protection and excellent air-intake. Sold in packages of 12. Comes in Small, Medium, and Large sizes and a variety of colors.

Item No.	Cost
P170-XXX	$20.00

Blockout Compound

A specially formulated, high heat resistant compound ideal for blocking out undercuts before vacuum forming. Will not run or stick to models. Reusable.

Item No.	Cost
P400-000	$12.00

Micro Torch



A small 150 gram micro torch capable of generating temperatures of 1,300°C. Useful for soldering orthodontic wires, denture repairs, mouthguard strap attachments, and softening of bite waxes, and much more. Uses regular Butane fuel found in any hardware or drug store, which is purchased separately.

Item No.	Cost
Torch P340-000	$49.00

VISA

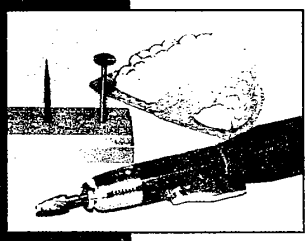
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Helpful Items

Mouthguard Finishing Kit

Pro-Form has put together these helpful items for the final finishing of professionally made mouthguards. The kit contains a 8 in. utility scissor, a C&B scissor for final trimming, an abrasive wheel for smoothing of edges and a cone point for final smoothing of edges and strap attachment.

Item No.	Cost
P106-010	$20.00



Wheel Saw

High quality cutting wheel useful for hard sheet resin and dual laminate trimming.

Item No.	Cost
P380-000WS	$12.95

Acrylic Bur

A handpiece bur designed to quickly cut through plastics and acrylics.

Item No.	Cost
P390-000AB	$9.95

Silicone Lubricant

Helps eliminate the plastic/frame sticking problems often associated with vacuum forming processes. Simply spray frame and model. Comes in 16 oz. aerosol spray can.

Item No.	Cost
C060-001	$8.00

Tray Handles

An aluminum handle ideal for quick custom impression tray production. Package of 50 each.

Item No.	Cost
P370-000	$8.50



8 in. Utility Scissor

These universal shears are excellent for bulk trimming of thermoplastics from models. Easy gripping handles with a heavy duty stainless steel construction in shears.

Item No.	Cost
P360-007	$9.95

Technique Booklet

This booklet is a complete review of the vacuum forming techniques now being used in the dental field. It discusses the plastics, the vacuum machines, various clinical applications, plus the techniques used for the best results. The booklet also contains step-by-step production methods for each appliance plus photos for easy interpretation.

Item No.	Cost
	$6.00

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Helpful Items

The Crown Contour™ *(Patented)* Item No. CR

Bondable undercut for retention of removable appliances. For use with vacuum formed or clasp appliances.
Sizes: 4.5MM x 2.5MM & 5.0MM x 2.0MM



Quantity	Cost
(56 Contours per package)	
1 Pack	$18.50
5 Packs	$16.50
10 Packs or More	$14.50

Retention Wedges™ *(Patented)* Item No. RW

Similar to the Crown Contour except the Retention Wedge has a center groove for stable retention of wire clasps.

Quantity	Cost
(56 per pack)	
1 Pack	$18.50
5 Packs	$16.50
10 Packs or More	$14.50

Asepto-Sol™

ASEPSIS SYSTEM FOR IMPRESSIONS AND GYPSUM CASTS

- Effectively eliminates all pathogens
- Compatible with all types of impression materials
- No effect on physical properties
- University tested and proven (data on file)
- Can be sprayed and incorporated into impression cast
- Eliminates the need to use a wetting agent
- Ensures accurate, clean, smooth casts
- Conveniently packaged in tablet form

Quantity	Cost
(Includes 1 gal. jug & 1 qt. spray bottle. Each 5 gram tablet yields 1 liter/quart of disinfecting solution)	
20 tablet jar	$40.00
60 tablet jar	$90.00

The Solution to all problems associated with impression disinfecting

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Accessories

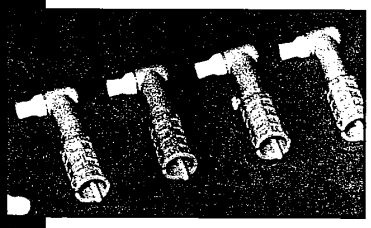


Alginate Flavors

A few drops adds great taste to impressions. Flavors: Bubblegum, Cherry, Strawberry, Raspberry, Orange, Grape, Mint, Cola, Pineapple, Banana, Punch, Cinnamon, Rootbeer, Lemon, Blueberry, Pina-Colada. **Size: 2 oz. bottle.**

Item No.	Cost
AF	$6.75

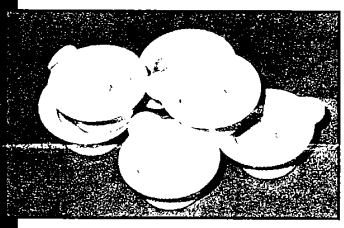
Buy 5—get one free, 10—get two free



Disposable Prophy Angles

Item No. PA

Quantity	Cost
Pack of 100	$38.00
Pack of 500	$180.00
Pack of 1000	$340.00

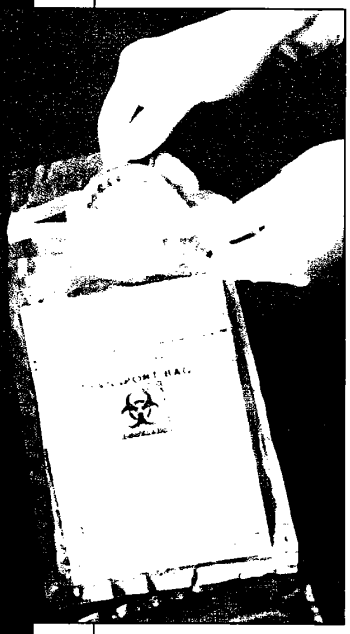


Prophy Paste

Item No. PP

Individual patient application size. Available in fluoridated and non-fluoridated for ortho use.

Quantity	Cost
200 per package	$22.00
2 packages or more	$20.00



FACT: It must be....

SAFE-SEAL

REALITY: OSHA says... It must prevent leakage

(Xiii) "Specimens of blood or other potentially infectious materials shall be placed in a container which prevents leakage during collection, handling, processing, storage, transport, or shipping" Federal Register - Vol. 56, No. 235. Dated December 6, 1991.

"SAFE-SEAL" TRANSPORT BAGS MEET ALL OSHA REQUIREMENTS

Safe-Seal Transport Bags

Item No. ST/002

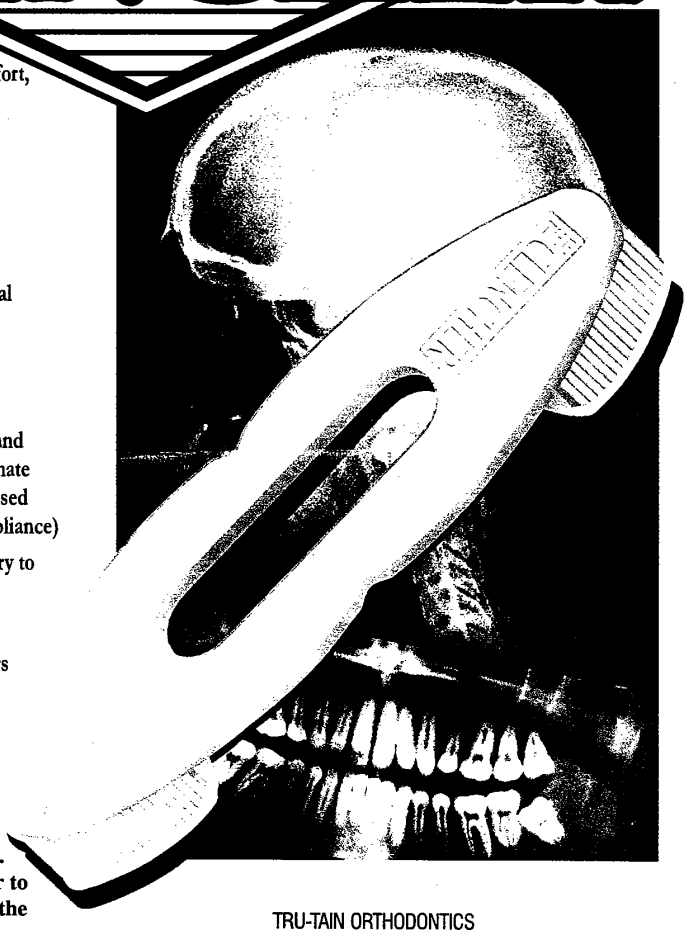
Meets all of OSHA's requirements.

Quantity	Cost
100 bags	$25.00
500 bags	$90.00
1000 bags	$170.00

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Now Available For TMJ Sufferers!

The CLENCHER



- Greatly reduces or eliminates the discomfort, clicking and popping common to TMJ
- Effective for individuals suffering from "limited opening"
- Tones and smoothes facial muscles during ordinary activity
- Strengthens muscles weakened by habitual clenching-ideal for therapeutic regimens
- Maintains sufficient airway for rest or active exertion
- Ideal for patients currently using splints and snoring appliances-could reduce or eliminate the need for daytime splints or could be used in concert with a "light" splint (RCM appliance)
- Develops the "holding strength" necessary to keep nighttime splints in place
- The perfect exercise accessory for TMJ sufferers and excessive clenchers/grinders (Directions for how and when to wear The Clencher found on package back).

The Clencher is a revolutionary muscle-strengthening mouthpiece developed by a dentist from Minnesota. Extensive research shows The Clencher to be an effective means of strengthening the jaw and related muscles (lips, tongue, masseters, etc.) almost immediately. Originally developed as an accessory for weight=lifters, The Clencher has proven highly effective as a means of reducing and eliminating TMJ pain and discomfort.

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LOCAL 507-288-3067

Fax Orders
507-288-9385
Pat. # 5,582,560

Item No. TC-01	Quantity *(one per pack)*	Cost
	1 pack	$12.00 ea.
	5 or more packs	$10.00 ea.

VISA MasterCard

Call Toll-Free (800) 343-0904

AAOF

CASE PARTNER

TRU-TAIN

225 Fifth Avenue Southwest
Rochester, Minnesota 55902
(800) 843-0904
FAX (507) 288-9385

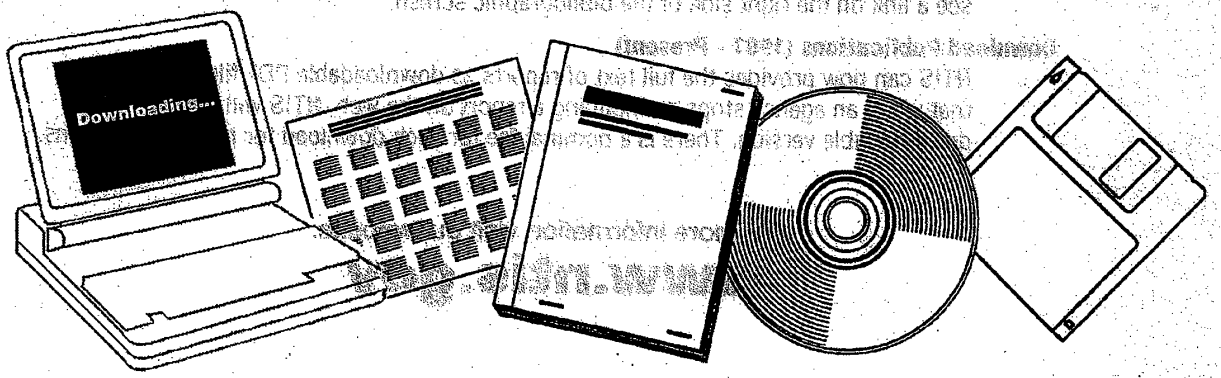
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AUTOMATED CROWN REPLICATION USING SOLID PHOTOGRAPHY SM

SOLID PHOTOGRAPHY INC MELVILLE NY

OCT 1977



U.S. Department of Commerce
National Technical Information Service

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AD

DY–809R

AUTOMATED CROWN REPLICATION USING SOLID PHOTOGRAPHY[SM] (FINAL REPORT)

R. Schmidt
L. Waszak
R. Rongo
R. Segnini

October 1977

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Washington, D.C. 20314

Contract No. DAMD 17–77–C–7041

Solid Photography Inc.
536 Broadhollow Road
Melville, N.Y. 11746

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Solid Photography, Measurement, Three-Dimensional, Dental Crown, Replication, Optical Measurement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A feasibility study applying Solid Photography, an optical, three-dimensional technology, to automatic replication of dental crowns out of inexpensive, non-strategic material. This study demonstrated that the interior and exterior surfaces of a dental crown pattern can be measured by Solid Photography to an accuracy on the order of ±0.002 inch. The interior surface was obtained by measuring the tooth post upon which the crown pattern was formed. A

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numerically-controlled end milling machine carved a replica of the crown in stainless steel based on the measured data.

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AUTOMATED CROWN REPLICATION USING SOLID PHOTOGRAPHY[SM]

SUMMARY

The purpose of this study contract was to determine if Solid Photography[SM] could be used to obtain a digital data base accurately enough to enable a numerically-controlled machine to cut dental crowns. Solid Photography is a new optical, three-dimensional measuring technology developed by Solid Photography, Inc. The object of automatically milling crowns instead of casting crowns, as is conventionally done, is to obviate the need for using costly strategic casting materials as well as to reduce the labor cost and time involved in producing crowns. Further, it was envisioned that other benefits would accrue by virtue of the fact that the Solid Photography technology inherently produces a three-dimensional digital data base that can be transmitted over conventional communications circuits and used by the many digital resources presently available.

A tooth post and wax crown pattern were supplied to Solid Photography Inc. to photograph and produce a digital data base describing the inner and outer crown surfaces to an accuracy on the order of ±0.002 inch. The data base was then used to program the cutting profile of a four-axis milling machine to directly cut a replica of the crown out of stainless steel. Two surface data acquisition approaches were investigated: a three-view measurement and a two-view measurement.

Calibration of the Solid Photography equipment showed it to be capable of measuring surfaces within a cubic volume 0.5 inch on a side to an average error of ±0.001 inch plus a random error of ±0.001 inch around the local average values. Registration of data taken in each of two views was generally within ±0.004 inch. The wax crown pattern and plastic tooth post were very thinly coated with white paint to produce a satisfactory reflective surface for optical measurement. A crown of satisfactory detail and accuracy was milled out of stainless steel from the data base measured from three views.

Three-view processing was more easily accomplished but requires the extra cost of processing the third view. Based on preliminary results obtained in this study, it is believed that a satisfactory procedure can be used for replication of a crown from two views and it is recommended that this principle be used for lowest cost replication.

A steeper milling angle will be required for the interior cut to assure access to interior side surfaces. Modificiation of the measurement system configuration is recommended as described within this report to enable measurement of the two sides not in view with the present equipment. Surface finish can be improved by developing smoothing functions. Going to a five-axis milling machine will enable automatic removal of residual material not accessible by a four-axis machine.

It is believed that ultimately Solid Photography can be adapted to obtain the data base for crowns directly from the surfaces in a patient's mouth. For now, feasibility of automated crown replication has been demonstrated and could be developed as a cost-effective alternative to conventional casting procedures.

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FOREWORD

Solid Photography[SM] provides an economical approach to obtaining the large digital data base necessary to describe a complex surface. This data base is required when a numerically-controlled machine is used to replicate the surface out of a block of material. The desire to eliminate dependance on limited supplies of castable strategic materials and the ever-present need to reduce the cost and time to produce a crown leads inevitably to the use of direct machining. This study has shown that it is feasible to use Solid Photography to generate the digital data base from a wax pattern and post. The data accuracy is on the order of ±0.002 inch which is considered to be satisfactory.

It was found that an opaque, diffuse reflective surface was necessary for high quality measurement. Surfaces not measurable by the present equipment can be measured by modification of the system. Similarly, modification of the data processing and addition of another axis to the milling machine will provide a system capable of producing excellent quality crowns on an economical basis.

1.0 INTRODUCTION

Crowns are presently cast from expensive, strategic materials. The casting process is labor intensive and automation could potentially lower production costs. Numerically-controlled machines could directly replicate a crown from suitable non-strategic and low-cost materials which possess desireable hardness and non-corrosive properties. The key problem confronting this approach has been the inability to obtain the three-dimensional digital data base describing the crown surface rapidly and economically. The crown surface is not easily described by mathematical functions that computers could convert into machine orders. Since each tooth is different, a customized approach was necessary for acquiring the surface data for each one. A rapid, accurate surface measurement system was required.

This feasibility study was initiated to determine whether a newly announced technology, Solid Photography, could be adapted to measure and directly replicate crown patterns accurately enough to eliminate the standard casting process for producing crowns. No attempt was made to modify the existing experimental Solid Photography equipment known to be capable of measuring objects the size of a dental crown with a 0.001-inch resolution. However, careful calibration of the equipment was necessary to attain the accuracy required for crown replication. An accurate holding fixture was required to enable the measurements taken from various angles to be joined together with little relative error. Surface reflectance of the crown and tooth post had to be modified to enable photographic recording of the surface measurements. Software procedures had to be developed to invert the exterior tooth post measurements to form the crown interior. A physical support had to be added by software to hold the crown while surrounding material was stripped away. Finally, special tools had to be made to cut the stainless steel from which the crown was to be carved. Further development in machining methods should provide economic benefit.

This report provides some background on Solid Photography, a description of the steps followed in acquiring and processing the data, and a summary of machining considerations. The positive results of the study demonstrated the feasibility of the Solid Photography process in the replication of dental crowns.

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2.0 BACKGROUND

A new technology for rapid generation of digital data bases representative of surface locations was announced by the Company in June 1976. In a process called Solid Photography a person sits in the center of a studio with eight cameras aimed at him from various angles to view all surfaces of his head. Then four projectors illuminate him and the cameras record the light patterns cast by the projectors. After developing the film, the film is read by an automatic film reader which generates digital numbers representative of the patterns on the film. A digital computer then interprets these numbers as surface measurements which a numerically-controlled milling machine is programmed to follow. The result produces amazingly accurate and low-cost portrait sculptures.

At the same time that Solid Photography portrait sculpture was announced, the Company announced that experimental Macro and Micro Studios were also in existence based on the same technology. The Macro Studio showed that it was possible to scale the measurement volume up in size, with resolution proportional to size. One subject of the Macro Studio that was demonstrated was the front of a Volkswagen car measured with a resolution of 0.3 inch. The Micro Studio showed that as the measurement volume was scaled down, resolution was retained. A grasshopper's head was measured with a resolution of 0.001 inch.

3.0 DATA ACQUISITION

The three-dimensional data for the crown were obtained in the Solid Photography Inc. experimental Micro Studio version of the three-dimensional replication process. The Micro Studio consists of a projector, two cameras and a mounting fixture to hold the object to be replicated. Figure 1 is a photograph showing the crown and post mounted in position. Also seen in the photograph are the

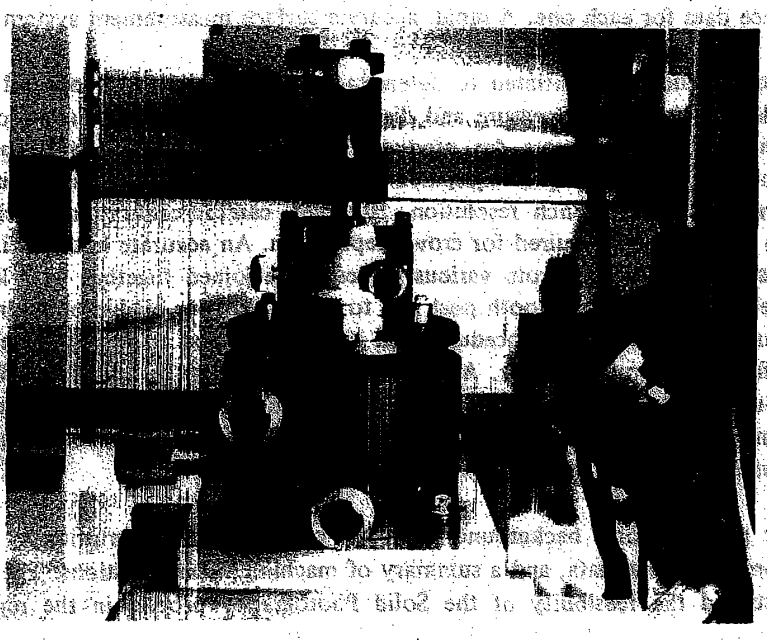


Figure 1. Crown and Post Mounted in Position

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projection lens and one (lower) camera lens. Three-dimensional data are acquired through a process of projecting and photographing a series of light patterns on the object. Each camera acquires three-dimensional data within its field of view. Several cameras and projectors are required to adequately cover a typical three-dimensional object if all surfaces must be measured simultaneously. When inanimate objects are copied by the Micro Studio, the full field coverage may, however, be implemented by re-orienting the object in front of a fewer number of cameras and taking a succession of measurements. In the Micro Studio one projector and two cameras are used. These cameras are at ±45° from the projector optical axis. To obtain sufficient data for the crown replication, three views were measured by rotating the crown ±90° in addition to the first position. Rotational accuracy was ±0.25 degree. These three views were used to generate the outside surface of the crown.

Since the inside of the crown matches the post, three-dimensional data on the post can be used (with suitable software inversions) to generate the inside of the crown; hence, three views of the post were also measured.

3.1 Measurement Procedure

The procedure can be explained with the aid of figures 2A and 2B.

1. The post was mounted in the fixture as shown. In general, the position of the tooth is not critical as long as it is within the viewing volume (0.5-inch cube). However, when using this three-view procedure, some care must be taken in mounting the post such that the sides of the post are aligned symmetrically with respect to the optical axis. This is to insure that the taper of the sides of the post match the tool taper angle of the cutting tool. A gross misalignment of this angle would require additional processing and cutting.
2. A sequence of pictures was taken with each camera at this angle (reference 0°).
3. The rotational stage (see figure 1) was then rotated +90° and a sequence taken.
4. The rotational stage was then rotated −90° (from 0°) and a sequence taken.
5. The crown was next placed on the post and the three sets of picture sequences repeated.
6. The film was unloaded from the cameras, developed, spliced together in proper order and turned over for reading and processing.

3.2 Data Acquisition Problems

Two problems were present in the tooth data acquisition; one photographic, the other mechanical alignment.

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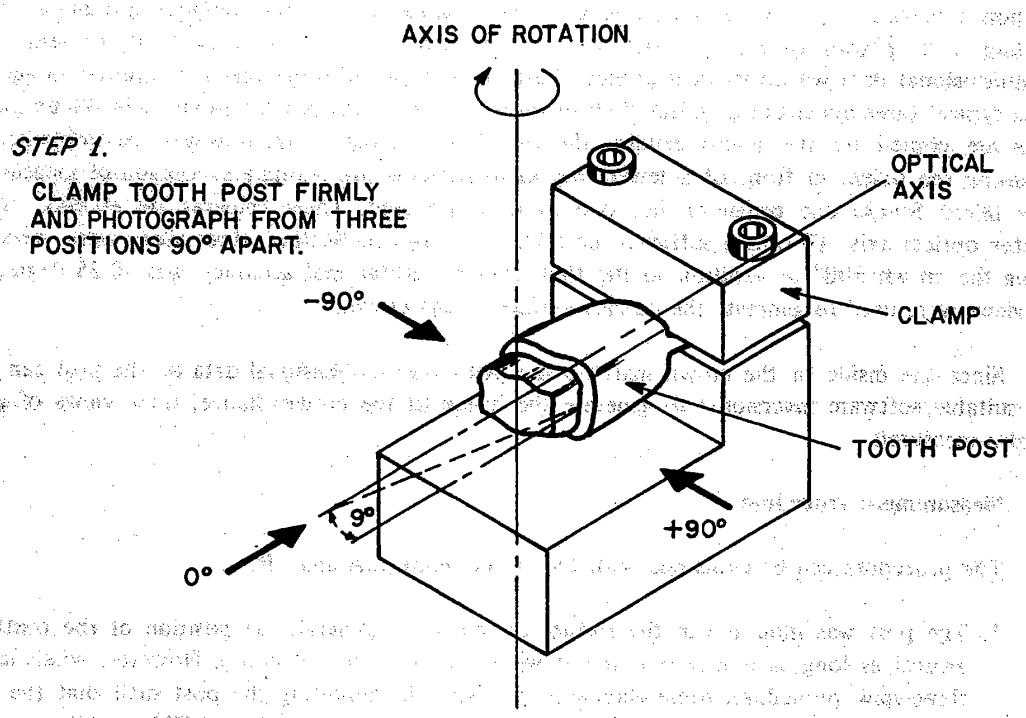


Figure 2A. Tooth Post in Measurement Fixture

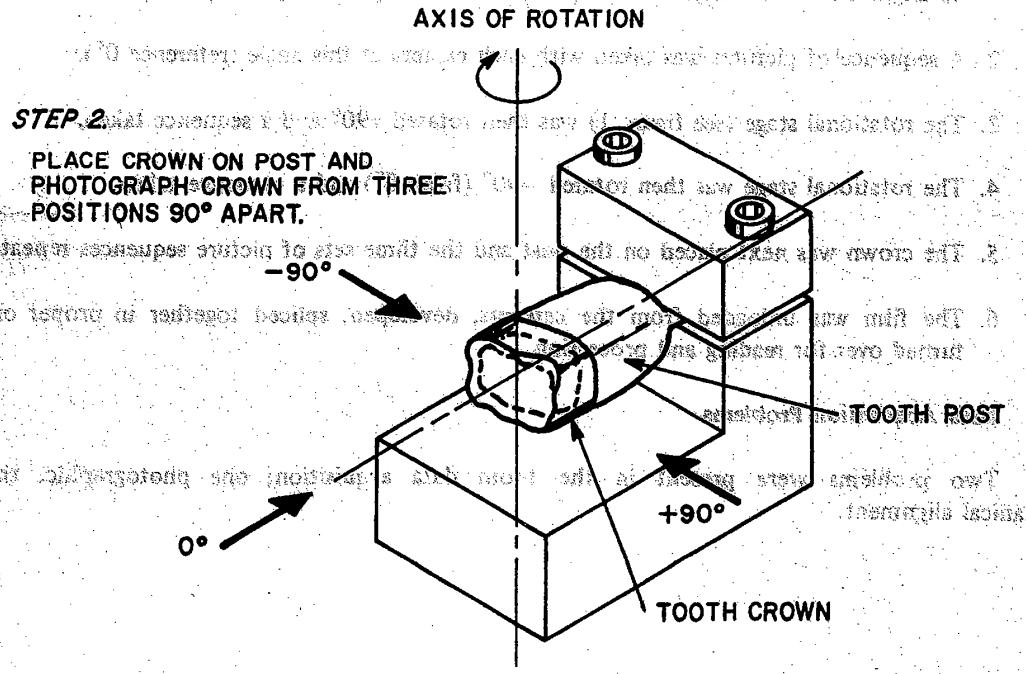


Figure 2B. Tooth Crown Mounted on Post

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A matte diffuse surface is most ideal for photographic reproduction of the projected light patterns. Specular (mirror-like or shiny) surfaces may introduce spurious reflections. Translucent surfaces scatter light from within the volume and obliterate the surface reflection. Examination of the tooth showed that both the post and crown were translucent in addition to having specular components of the smooth surfaces. Trial photographs of the tooth confirmed that the data was washed out from internal scattering of the translucent material. Some surface preparation was necessary. Best results were achieved with sprayed-on flat white acrylic paint. Tests indicate that the thickness of the paint is approximately 0.00075 inch with surface irregularities on the order of 0.0002 inch. Both crown and post were suitably painted. In order that removal of the crown not remove paint from the post, the post data were taken first as outlined above.

The second problem has to do with the mechanical alignment of the rotational axis with respect to the computer-based rotational axis. In the initial setup of the experimental Micro Studio an elaborate procedure was used to determine the relative positions of the projector and camera axes and their point of intersection. This established a computer-based rotational axis. Over the course of time the initial real rotational axis and the computer axis drifted slightly from one another. These drift errors caused discontinuities in the data. Computer processing was used to smooth over the discontinuities. This computer smoothing did not detract from the aesthetics of the replication of previous subjects copied by the Micro Studio. However, in order to make the crown fit the post greater absolute accuracy was required. To this end a means was devised to realign the two axes.

A precise 0.5-inch cube was fabricated, painted and installed in the tooth fixturing. 0°, ±90° photo sequences were then taken and the output data compared to the physical size and position of the cube. Errors in tilt and the position of the axis were indicated. Using 0.0001-inch reading dial indicators and a microscope with 0.00025-inch graduation the rotational axis was adjusted to the computer determined position. (See figure 1 for a picture of the tilt and rotational adjustments.) The cube was then rephotographed and touch-up adjustments were made.

After these axis corrections the final post and crown data acquisition sequences were made.

3.3 Alternate Method

Since it was felt that taking the data from three positions might be an approach that was too conservative, a two-view measurement was made at the same time and processed separately. The post and crown were positioned halfway between the front and right side views and photographed. The post and crown were then rotated 90° to expose the surfaces between the left side and front view.

An additional advantage of using just two views instead of three over the obvious reduction in measurement and processing times is its application toward the ultimate goal of photographing post and crown information in the patient's mouth. It is vital to minimize the number of views in the mouth to keep the instrument size small, keep costs low, and keep the measurement time and effort minimal.

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3.4 Conclusions

The three-dimensional replication process in the present equipment gathers no depth information from any surface which lies in a horizontal plane. In the replication performed under this contract the tooth was rotated on a vertical axis. Hence, surfaces which were approaching horizontal in one view were approaching horizontal in all views. Thus, the top and bottom of the crown contain noisy depth data. It should be pointed out that this is strictly a limitation of the experimental equipment used. If additional views were taken with a rotation of the tooth such that the top and bottom were rotated to the sides as shown on figure 3 this problem would be alleviated. However, this would have required additional costs beyond the scope of this study. It is recommended, further, that the alternate method described in section 3.3 be used in order to decrease the time required for data acquisition, processing and replication. A preliminary investigation indicates that four single camera views each on the post and crown would provide all the data required. The post would be mounted as shown in figure 3. The camera and projector would obtain measurements on each of the four sides with the front surface.

Fixturing would be desired specifically for post-crown data acquisition. Stops would be used to locate angles repeatably rather than vernier scale readings. Increased use of automation would be employed to minimize operator error.

4.0 DATA PROCESSING

In order to process the Micro Studio data obtained on the crown and post with accuracy on the order of ±0.001 inch it was necessary to perform the following tasks:

- Calibrate measurement volume
- Provide correction data for mechanical placement of the Micro Studio mounting fixture
- Merge crown data with reversed post data
- Generate cutting tape with tool offset

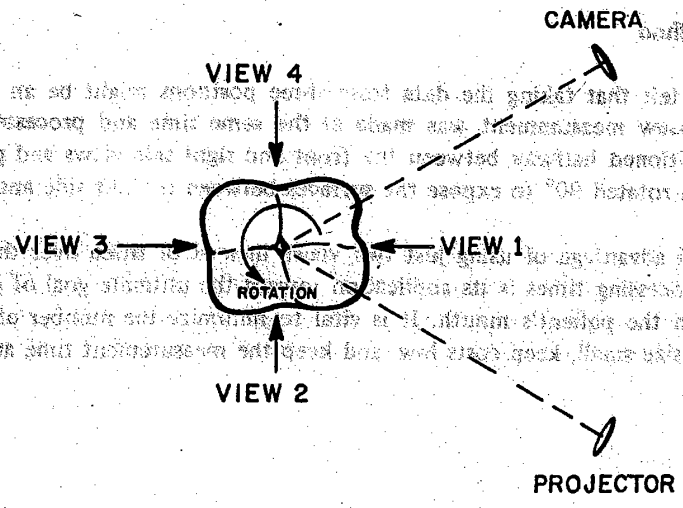


Figure 3. Recommended Measurement Configuration

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4.1 Calibration

A 0.500-inch metal square, painted white, was used to verify the system measurement accuracy. After painting, the square measured 0.5014 inch. Assuming the paint coating on the post and crown would be of comparable thickness, all calibrations assumed the square to be 0.500 inch. In this way the system should tend to compensate for the paint thickness on the post and crown.

The square was placed in three locations and measured. The square was placed at the front of the viewing volume, then at the center and finally at the rear. The average differences measured between the known physical locations and those reported by the Micro Studio ranged from +0.002 to −0.005 in the x dimension (forward-aft), +0.007 to −0.006 in the y dimension (left-right), and +0.0017 to −0.0018 in the z dimension (up-down). A computer program was written to reduce these averaged errors to ±0.001 in most cases. In addition to average errors, random errors occur. For most of the data these additional errors were no greater than ±0.001. Two cameras were used to record data, a camera above and one below the subject. Both simultaneously measured the same surface only from different angles. The above errors were for both cameras individually; averaging the data together, as is done in the processing to produce a final data file further reduces the errors in the file.

4.2 Mechanical Corrections

A 0.500-inch metal cube, also painted white, was used to assure correct merging of data as the subject was rotated ±90° to expose the right and left sides to the cameras after measuring the front of the cube. After painting, the cube measured 0.502 inch wide and 0.501 inch high, so the assumed uniform paint thickness seemed well founded. By noting measured non-parallelism of edges known to be parallel between the right and left cube sides, it was possible to readjust the rotational axis to be parallel to the vertical axis of the measurement volume. Subsequent measurements showed parallel edges to be measured as parallel. By noting displacement of cube sides as measured relative to their correct relationship it was possible to determine how much the rotational axis was displaced from the center of the measurement volume. A correction was made for this displacement and verified by subsequent measurements.

4.3 Merge Crown and Post Data

The crown and post were coated with white paint assumed to be of a thickness comparable to that used in calibration so that compensation would occur automatically. First, the post was mounted horizontally to measure the front and two sides. The crown was then placed on the post and its front and two side surfaces measured. The two data sets were processed independently, then the post data was converted from a convex surface to a concave surface by, in effect, viewing the data from the opposite side. That is, data measured from the front were treated as if measured from the rear. This data supplied one quadrant of the final data. The other three quadrants were taken from the crown data.

A critical check of the data accuracy was possible at this point. The relative positions of the post and crown data sets, where they met at the outer rim of the crown edge, were found to agree within 0.004 inch on a horizontal cut across the center. Both sides gave data that appeared to be shifted 0.004 inch toward the crown front. One side also appeared to be 0.003 inch toward the crown center. This results in cutting away 0.004 inch too much material from the outer side of the crown near the lip

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producing a slightly undersized lip on that side. After undercutting, the residual thickness of the lip was 0.025 inch which was equal to the lip thickness on the other side where no undercutting was obtained.

An interesting measurement occurred when a 0.006-inch crack between the crown and post was measured. The crack was 0.030 inch deep and the two central of six measurement points correctly reported this depth. No data were obtained in the two measurement points on either side of the two reporting points. The crack was in the vertical direction, thus giving line of sight access to the cameras. This demonstrated the system's ability to obtain measurements in very confined areas.

The final processing operation added a data set representative of a mechanical support on the bottom of the crown to provide physical support when machining. Since the crown was photographed on its side, it was cut on its side with this mathematically-generated support under one side to hold the crown in place as the surrounding material was cut away. Undercutting by 0.020 inch in front and rear left a residual support of 0.146 inch. Undercutting by 0.050 inch on each side left a residual width to the support of 0.300 inch. These dimensions were chosen as adequate for the mechanical stresses anticipated during cutting.

4.4 Generate Cutting Tape

The measured surface data were modified to produce a cutting tape containing a three-dimensional locus of points shifted three dimensionally by an amount such that the surface of the cutter (ball end mill of 0.020-inch diameter) coincided with the original data. The data, because of its digital form, represents the surface as discrete changes in depth to be cut by the machine tool. The smallest end mill tool obtainable had a 0.010-inch radius. The tool offset program, therefore, considered where the tip of the tool should be positioned to avoid cutting into the desired surface locations. The relatively large radius therefore must leave a small amount of excess material in interior corners having effective radii less than 0.010 inch. Except for tool taper, exterior surfaces could be milled without leaving any excess material. The computer program automatically added the correct offset values to the measured surface coordinates and recorded the modified values on a magnetic tape to drive the numerically-controlled replicator.

4.5 Alternate Method

The same processing procedures were used to obtain a data base from just two viewing positions 90° apart. A new problem was encountered as a result of capturing data behind the post lip as shown in figure 4. When the data on the post surface were measured in a front view, the lip shadowed the data to the rear. When the data were reversed to obtain the internal crown surface no data existed in front of the lip. This was not the case when viewed 45° from the front since the lip no longer shadowed the rear part of the post. This data became foreground data when the data were reversed to obtain the crown's internal surface. This unwanted data then required a new removal procedure since no software existed to automatically remove it. This was partially accomplished by removing all data more than 0.030 inch in front of the crown lip. The tool was only able to demonstrate the effectiveness of this procedure near the central side area due to the limited software effort. Further effort should satisfactorily resolve this problem.

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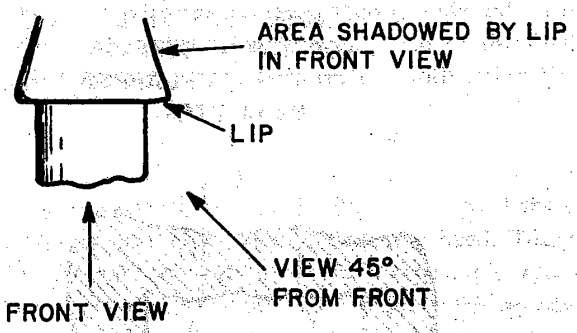


Figure 4. Top View of Post Measurement

Another problem appeared when cutting the inverse post. The problem encountered was due to the physical orientation of the post. The tool could not cut the entire inside surface as illustrated in figure 5.

A solution to this could be to change the ±45° viewing angles to ±22½° or some other value greater than the tool taper angle of 9°. By rotating these two views the cutter limit would be moved closer to the sidewalls as shown in figure 6. This method would allow for more than enough of the required tool overlap.

This could be accomplished by either rotating the tooth post mechanically before the pictures are taken or by rotating the data by computer software.

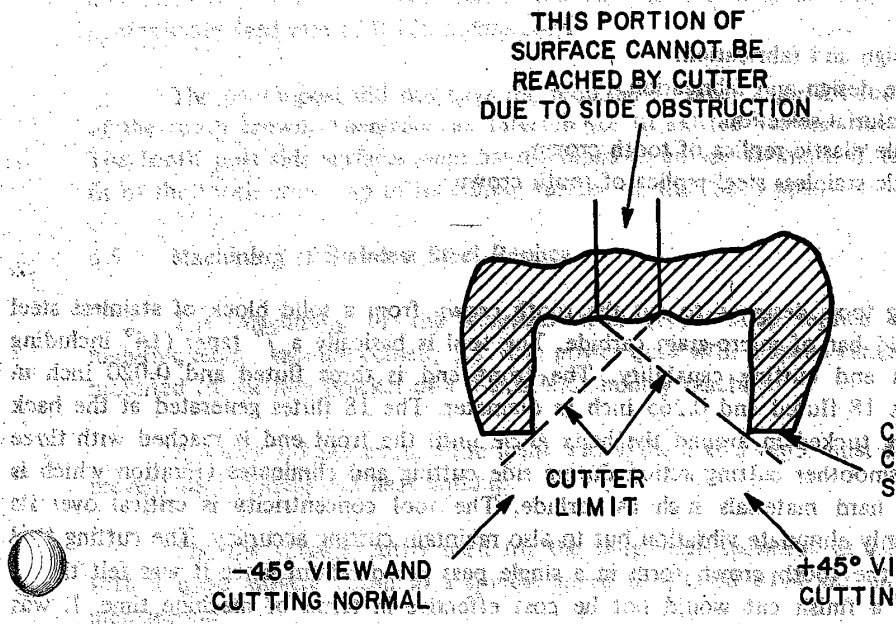


Figure 5. Top Cutaway View of Crown

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After the rough cut the tooth crown had 0.125 inch of material to be removed for a finish cut to the final surface.

During the finish cut operation at 40,000 RPM and approximate feed rate of 0.050 inch/second with the 0.020-inch diameter finishing cutter there was tool breakage on deep plunge cuts. It was determined that the cutter was speed-limited and could not remove material fast enough and several passes per quadrant were required. It is felt that by using a higher spindle speed (approximately 75,000 RPM) it would have been possible to remove the remaining 0.125 inch of material in a single pass per quadrant.

The stainless steel crown, still attached to the steel stock, is shown in figure 7. Air gaps at the interface with the lip of the post were less than 0.003 inch except in a few locations where localized gaps of up to 0.005 inch occured. Figure 8 shows an enlarged view of the interface.

6.0 CONCLUSIONS

The feasibility of automated tooth crown replication has been demonstrated by this study effort. Measurement accuracy on the order of ±0.002 inch has been achieved. Automatic processing from measurement to the generation of a magnetic tape with the machine cutting orders is possible and has in fact been accomplished with minimal operator assistance to call the various processing programs. A steel replica of a wax crown pattern was milled from stainless stock. Although the milling process was quite lengthy, improvement in this area is not expected to be difficult.

The experimental measuring Micro Studio equipment used was not intended for the specific task of measuring crowns nor for accurate measurement. However, it was found to be quite close to fulfilling the requirements, so that a system using essentially the same design with a modified holding mechanism should provide the desired performance. This is a new technology and many avenues of improvement exist. A solid-state sensor could replace the film. Hardware data processing can reduce the processing time as can special purpose programming for crown replication. Direct machining of all surfaces appears possible as does improved surface finish. Faster machining, which is achievable, should make the process economically attractive.

7.0 RECOMMENDATIONS

On the basis of this study it is recommended that a system designed specifically for automatic crown replication be developed using Solid Photography, specialized software, and a specialized replication machine. The measurement sequence should be automated to eliminate human error, and provide a high throughput rate. The same recommendation applies to processing and machining. Preformed metal blanks should enable the maximum machining rate to be achieved.

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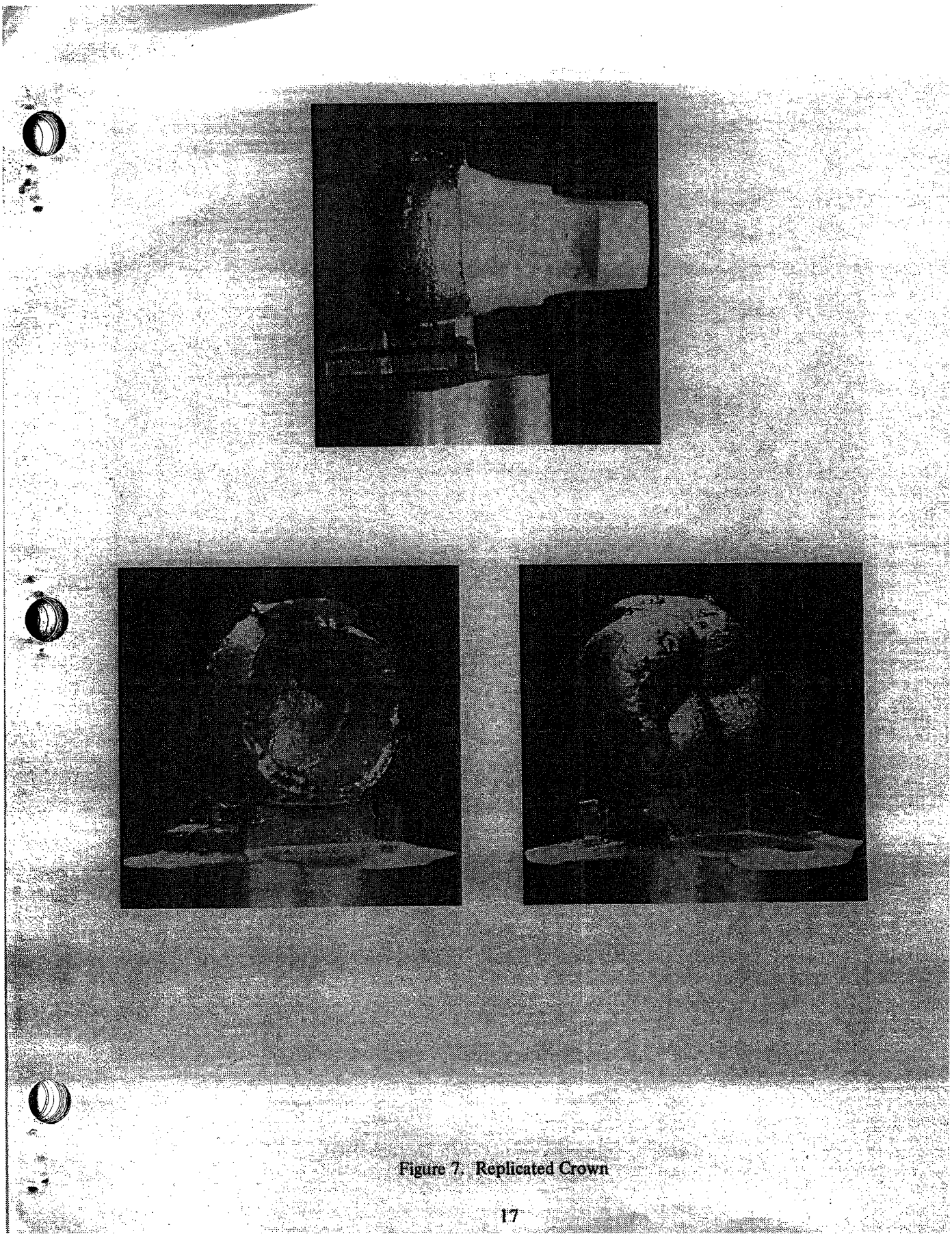


Figure 7. Replicated Crown

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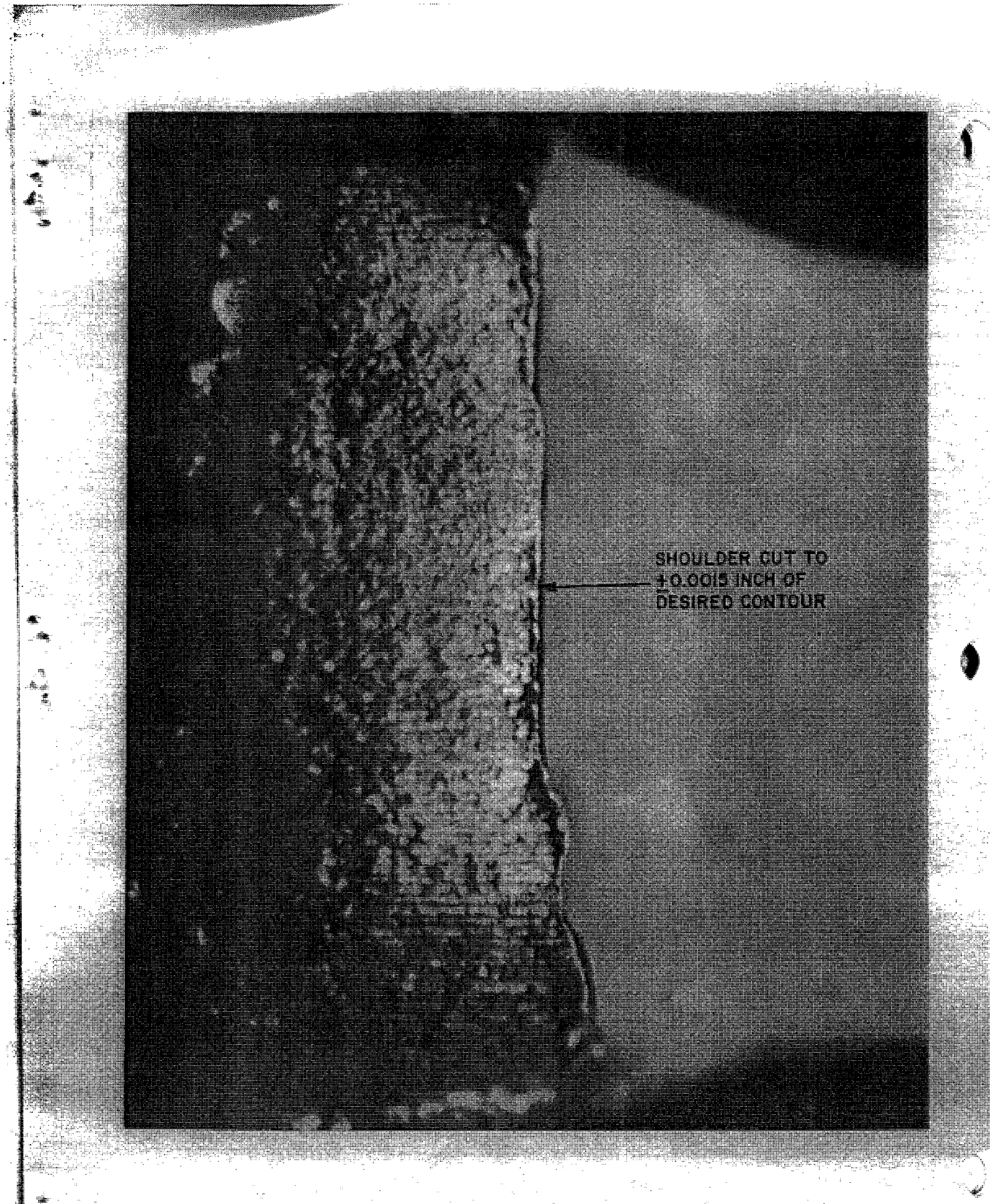


Figure 8. Enlarged View of Crown Lip (Shoulder)
Scale: 0.050" per inch

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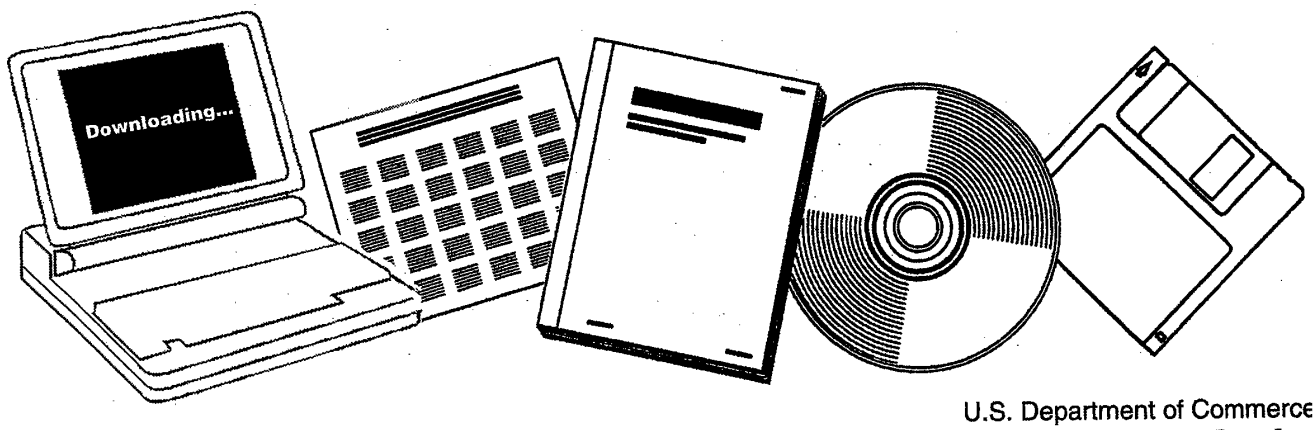
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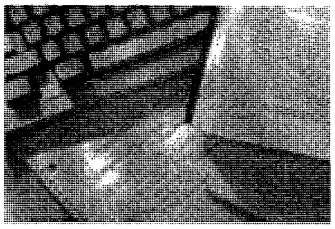


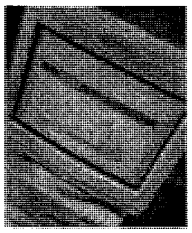
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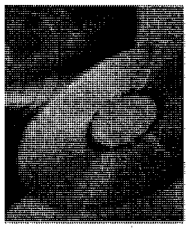
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ABSTRACT

The science of laser holography may significantly change the concepts and procedural techniques of future dentistry. Through the modifying and combining of existing laser, holographic, and computer technology for intraoral use, individual "toothprints" may be computerized. As a result, the dentition of patients may be permanently recorded for use in: dental examination; forensic odontology; oral diagnoses; security identification procedures; and fixed and removable prosthetic applications, including computer milling of crowns from contour holograms. Explained and discussed are the basic concepts and forms of laser holography, holographic interferometry, contour holographic thermography, and stress holography, as well as their possible dental applications. Also presented are techniques developed for holographing such relevant objects as mandibles, skulls, arches, dental casts, prosthetic appliances, and individual teeth.

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HOLODONTOGRAPHY: AN INTRODUCTION TO DENTAL LASER HOLOGRAPHY

I. INTRODUCTION

A hologram is a photographic film, slide, or plate upon which is recorded the interference pattern produced by the reinforcement or cancellation of two different intersecting light wavefronts. Holography is the science of recording the reflected light waves from an object onto a hologram, and the subsequent projection of the stored light-patterns from the developed hologram to reconstruct a three-dimensional phantom virtual image of the object (that will appear in the space where the original object had been). Because holo means "complete," gram means "message," and odont means "tooth," the term "holodontography" is suggested for the science of dental holography which records a "complete tooth message."

The three-dimensional effect of the hologram image is unique. Unlike three-dimensional stereoscopic slides, the hologram, as a single slide, recreates the object's natural parallax effect in the image. Thus the viewer of the hologram, by changing his position, can see objects blocked by foreground objects--an important factor when recording images in an area as severely restricted as the oral cavity.

Because holograms cannot be reproduced in print, black-and-white photographs have been taken of the projected hologram phantom images to illustrate their properties. Figure 1 was exposed closer to the hologram image of a skull and at a lower angle to it than was figure 2. As might be expected if these were photographs of the real skull, the image in figure 1 is larger than that in figure 2, and a greater portion of the palate is visible in figure 1. Moreover, in figure 2 the camera is focused on the foreground anterior teeth, while in figure 1 the camera lens is focused on the palate, thereby indicating a depth of field comparable to photographing a real skull. To the camera lens, the holographic image is identical to the real object.

To produce the hologram and record the interference pattern of two dissimilar wavefronts, a light source is necessary which is free of interference patterns. Thus, laser light, which is monochromatic and coherent (i.e., all the light has the same wavelength and emerges from the laser with the same polarization and amplitude), is used in holography.

An unexposed hologram is an ordinary photographic film plate, and is exposed to laser light for a timed interval determined by an ordinary camera shutter, in nearly the same manner as photographs. If the unexposed hologram plate were exposed to a single beam of laser light, it would not produce a hologram. The single beam, having no interference, would produce a uniform brightness on the plate. As shown in figure 3, a beam splitter is used to divide the single beam in two, forming a reference beam and an object beam. The reference beam proceeds, directed by mirrors, to the unexposed photographic plate. The object beam is directed to the object to be recorded

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NOTE: All figures are grouped at the end of the report.

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(e.g., a skull), and the reflections from the object then proceed to the photographic plate. The hologram plate is positioned so that both beams are equal in length. An interference pattern from the two beams is recorded on the hologram plate and becomes the hologram when the plate is developed and fixed.

As an example of the principle involved, imagine a rectangular pool of water into one end of which a rod is thrown parallel to the pool's shortest side. The rod produces a wave pattern of parallel lines (the reference beam) which travel the length of the pool. A stone is thrown into the other end of the pool at the same time and produces a different wave pattern. In about the middle of the pool the two wavefronts will meet, and will either mutually reinforce or antagonize and cancel each other partially or completely at different points. The hologram plate is in the middle, recording this event for the instant the camera shutter opens. Every object will have a different hologram interference pattern. One such pattern is shown in figure 4.

Ideally, the hologram should be exposed instantaneously; for, during the exposure, the slightest lateral movement of the hologram, or the object, or the reference beam will blur the interference pattern and prevent an image from forming. When a low-powered laser is used, a longer exposure time is needed. All of the apparatus must then be placed on a large concrete slab mounted on shock absorbers, and all mirrors mounted on large heavy bases (fig. 5). To produce holograms in vivo, higher powered lasers must be used which allow exposure times in nanoseconds, thus eliminating vibration problems and the use of heavy apparatus. Finally, the exposed hologram is developed and fixed in the same manner as ordinary photographic film.

Viewing the hologram requires any inexpensive, low-powered laser as a light source. For the hologram to be viewed (fig. 6), a single laser light beam is directed to the plate. The hologram divides the single beam back into its original object and reference beams. The object beam forms or "reconstructs" in space a phantom object--composed of light but with no mass (a hand can pass through the image with no effect)--which appears at the same distance from the hologram plate as the original object. The reconstructed image appears in the monochromatic color of the laser light (in this case, red). In figure 7, a beam from the viewing laser on the right is shining on the hologram in the center. A skull's virtual image is created behind and viewed through the plate. (Some holographic techniques will produce an image appearing in front of the plate; however, none was made in this study.)

Certain unique features differentiate the hologram from ordinary photographic slides. As the hologram records the wave patterns along its entire surface, the holographic plate may be divided into several pieces without loss, each individual segment having the capability to reconstruct the entire image (1). In addition, the angles between the laser, plate, and

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viewer are fairly critical. A number of holograms may be made of different objects by rotating the same hologram plate by several degrees after each exposure. When the plate is developed, each hologram may be viewed in turn by rotating the plate the same number of degrees (2). Thus, a single hologram plate can contain multiple images and can be segmented to provide more than one record.

The basic technique of holography can be expanded to create contour and stress fringes. Any movement of the reference and object beams during a single exposure of the hologram will prevent a clear image from forming. If very slight movement of the object or of the beams occurs between two exposures (i.e., during a double exposure), however, fringes or bands will form in the projected hologram image perpendicular to the object's line of motion (3-6). These fringes can be used to create contour maps of anatomic structures and to record direction of movement produced by stresses on dental prostheses, as will be demonstrated in this paper through the techniques of holographic thermography and of stress holography (7, 8).

A fringe pattern can also be formed by changing, between exposures, the refractive index of the medium surrounding the object through which the object light beam passes (9). Changing the refractive index will cause the beam to bend slightly, altering its course between exposures and thus creating the fringes. This holographic interferometry method can produce contouring when no motion is present or when no motion is desired. Since refractive indices are predictable, this method allows us to determine the distance intervals between contours. A technique discussed in this paper was developed to use this method for dental studies.

Another method uses a laser possessing a double wavelength single pulsed beam (10, 11). Using only a single exposure, the two different wavelengths of the modified laser produce the same fringe pattern achieved in the previous double-exposure techniques. Because the interval between the double exposures in the other techniques introduces the danger of extraneous vibration and movement creating unwanted random fringes, a single exposure technique is more useful for in vivo contour mapping of oral structures. By varying the difference in wavelengths between the beams, this method can produce whatever intervals between contour bands are desired or required. The pioneer holography physicist, E. N. Leith, first made in vitro contour holograms of dental casts through this method (6).

II. MATERIALS AND METHODS

A 50 mw. Spectra-Physics gas laser was used to expose the holograms. Object and reference beams were measured, and their path lengths were equalized by placing mirrors in the path of the reference beam. The mirrors served to lengthen the object beam's path to any desired degree by directing an otherwise straight-line beam along an indirect course to the hologram plate (fig. 5).

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Vibration has been a technical problem in holographing, with low-powered lasers, any inanimate objects resting on mounted surfaces. We found that ordinary dental utility wax was excellent for luting objects to the concrete blocks and also provided excellent shock dampening. All mirrors were secured to heavy metal bases, and the film holder was set in a concrete block (fig. 5). The entire experimental assembly rested on a solid granite block table which, in turn, rested on shock mounts. A timer was used on the shutter to prevent vibration that could result from the experimenter touching the shutter apparatus.

Kodak 4 x 5 in. glass spectroscopic plates (type 649-F), and Agfa-Gefaert Scientia 4 x 5 in. (10E70) glass plates were used for exposing the holograms. Exposure times ranged from 5-20 seconds with Kodak film for single holograms, and 1/15-1/30 second for double exposures with Agfa-Gefaert film. Films were developed according to the manufacturer's specifications. The first two Kodak plates we developed were bleached by the Stanford process (12); but, since significantly better results were not achieved, no other plates were bleached.

The holograms were viewed with a 3 mw. rated Spectra-Physics Helium-Neon (He-Ne) laser with a beam expander which limited the beam output to 1 mw. A wooden film-holder was devised (fig. 7) and mounted on a modified camera stand for viewing. Photographs of the hologram images were taken with a Hasselblad 500C with a 0.5 mm. Proxar closeup lens attachment.

III. EXPERIMENTS

Procedures in initial holographic experiments

A skull was luted to a concrete block with dental utility wax so that the mandible was in a partially depressed position (fig. 5). Holograms of anterior (figs. 1 and 2) and lateral views were exposed. Occlusal and lateral views were taken of a mandible luted to a large square steel plate. Occlusal views were made of maxillary and mandibular dental stone casts of a patient's dentition, and maxillary and mandibular stone casts poured from Colombia Dentoform rubber molds.

Results of initial holographic experiments

Absorption of laser light by translucent portions of the skull created problems in determining correct exposure times. Some areas consistently appeared too light or too dark. The trial and error method was necessary to achieve proper exposures for each object. The stone casts required shorter exposure times than bone material. The holograms project a bright red; and, except for this color change, the holograms appear to the observer exactly like the original object--creating the illusion that they are of solid substance. Irregularities and fractures in the dental arches are readily visible in the hologram image. Fissures, grooves, and carious lesions can also be observed. Anatomic landmarks (figs. 1 and 2) are clearly visible.

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Procedures in contour holographic thermography

A mandibular and a maxillary stone cast of a patient were luted onto a steel plate. A hot-air gun was used to direct a stream of heated air onto the mandibular cast for 1 min. The maxillary cast was not heated. The hot-air gun was removed and a hologram exposed. After 1-1/2 min., as the casts cooled, the hologram plate was double-exposed (fig. 8).

Stone casts poured from a rubber model were positioned in the same manner. The maxillary cast was heated uniformly with heated air. The hot air was then directed into the middle of the mandibular cast for 1 min. The heat gun was removed and a double-exposure hologram (figs. 9 and 10) was made using a 1 min. interval between the exposures.

Using the same procedure, a mandible was heated just posterior to the right mental foramen, and a double-exposure hologram was taken of the right lateral area (fig. 11). A double-exposure hologram was also taken of an occlusal view (fig. 12).

A stone cast, of a full arch secondary impression of prepared teeth for crown abutments to be used for a partial denture, was thermally treated in the same manner; and an occlusal double-exposure hologram was made.

Results of contour holographic thermography

Thermal contraction was used in these experiments to create the internal movement necessary to obtain fringes. The holograms were double exposed as the heated objects cooled, and recorded the resulting contraction. Thermal movement of the object was perpendicular to the fringes. Figure 8 demonstrates the success of this procedure, in this series of experiments; for banding occurred primarily on the heated mandibular cast, while little change was noted on the unheated cast. Motion and banding were thus due to thermal shrinkage or internal movement, and not to vibrational or relative movement. Directing and holding the heat in one area produced the "bull's eye" concentric circle effect of the mandibular cast in figure 9. The cooling contraction was almost uniformly radial. Figure 10 (an enlargement of fig. 9) demonstrates more clearly the contouring created on the molar teeth of the plaster cast. The same concentric motion occurred on a mandible (fig. 11); and a contouring effect of the mandible is not only visible here but is repeated in the occlusal view (fig. 12). The translucency of the natural teeth to laser light did not prevent their being contoured. It was thought that some opaque coating might be necessary, but this was not the case when contour thermography was used. A full arch cast, of prepared teeth for crowns as abutments for a partial denture, produced a fringe pattern similar to the maxillary cast in figure 9.

Procedures in stress holography

Through the use of a stone cast of a patient's mandibular dentition as a model, a removable, bilateral partial prosthesis was fabricated

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which had an acrylic lingual bar and acrylic denture teeth #19 and #30, with Class I metal clasps on #18, #20, #29, and #31. This demonstration prosthesis was not intended for clinical use. The partial denture was placed on the cast. A slight tension in the clasps prevented the partial from completely seating on the cast unless pressure was applied to the occlusal surfaces of the denture teeth.

The cast was rigidly held to a heavy steel base plate with a C-clamp. A modified caliper screw was devised to provide a constant, point stress on the distal buccal cusp of acrylic tooth #19 (fig. 13). The caliper stressor was connected to the same base so that the entire apparatus was rigid, and the metal base was bolted to a concrete block.

A hologram was made with the point stressor just touching the acrylic tooth, and a second exposure was then taken immediately afterwards (fig. 14). A new film plate was used for the next exposure. The caliper screw was then rotated, thus lowering the point stressor and pressing it against the tooth's cusp. A second exposure was then made (fig. 15). This procedure was repeated twice with two new plates, the point stressor being lowered still more each time (figs. 16 and 17).

This series of experiments was then repeated from a lateral aspect. The point stressor was so repositioned that it just contacted the distal buccal cusp, and was not moved between double exposures of the first hologram (fig. 18). The point stressor was then lowered between each subsequent exposure to produce a series of double-exposed holograms (shown subsequently in figs. 19, 20, and 21).

Results of stress holography

Fringes recorded the movement of the partial denture while vertical point stress was placed on it between exposures. Movement was perpendicular to the fringes. No fringes were recorded in figure 14, as the stressor was not moved and the partial denture remained motionless. The arrow in figure 15 points toward the fringes which recorded on the hologram the movement of the partial denture tooth. (Note the fringes on the stressor and on the screw knob, indicating that they were moved between exposures.) Continued apical movement of denture tooth #19 caused the partial's clasps to be stressed. (Note fringes in fig. 16.) All the metal clasps demonstrate fringes indicating shifting or flexing. Denture tooth #30 also moved, as shown by the single band across #30 in figure 16.

Figure 17 shows little movement of tooth #19 which had probably seated completely on the cast. Denture tooth #30 had moved, as had the clasps on that side of the partial. Some independent stressing of the stone cast is also apparent, because fringes are radiating away from the point stressor. Apparently when the partial denture seated completely on the left side, the right side was displaced occlusally.

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This experiment, repeated from a lateral aspect, produced bands indicating that the denture tooth was seating as pressure was applied. Slight banding of the cast (fig. 18) may have been antero-posterior displacement or a temperature effect, because the stressor was not moved. The apical displacement of denture tooth #19 is illustrated in figure 19. With the denture fully seated, the entire cast appears to have been compressed vertically downward (fig. 20) until finally (fig. 21) the acrylic of the denture tooth began to deform elastically, as shown by the curved bands on the buccal surface--indicating a lateral displacement.

The point stressor was intended to duplicate the stress produced on a partial denture by an occlusal prematurity. Further experiments should be made to refine this technique for determining occlusal interferences and for evaluating prosthetic designs, in prosthodontics, in operative dentistry, in orthodontics, and possibly in periodontics.

Procedures in holographic interferometry

Four extracted teeth--a virgin tooth, a tooth with a gold crown, and two teeth with large amalgam restorations--were used as representative samples. They were prepared by embedding the roots of each tooth in molten inlay wax poured into individual cylindrical cup molds of polystyrene. The entire crown portion of each tooth was left exposed, and the molds were not separated from the wax.

To alter the refractive indexes surrounding the teeth in order to produce fine contour fringes on their occlusal surfaces, we decided to immerse the teeth in a solution of methanol and distilled water which would be followed (or superseded) by a solution of distilled water. A tank to hold the teeth was devised (fig. 22) with ports on top and bottom and a clear glass window on one side. The tooth molds were luted to the back of the inside of the tank with dental sticky wax. A solid aluminum cylinder was also luted to the side of the tank to act as a standard, because its geometric contour was known and regular. Liquid solutions were pumped in through the bottom of the tank, and air and excess liquid exited through the top outlet to prevent air bubbles from forming. The ports were closed. After several minutes' wait to allow the liquid to become motionless, the laser's shutter was activated and a hologram exposed. The ports were opened and the liquid was drained. The second liquid of different refractive index was pumped into the tank, and the procedure was then repeated to obtain a double exposure of the hologram plate (fig. 23).

Results of holographic interferometry

Various dilutions of methanol and distilled water were used in our efforts to create the change in refractive index necessary to produce fringes. Extremely fine contour lines were created when distilled water,

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followed by 100% methanol, were used as our solutions. These concentrations produced contour lines which were finer than eye resolution. Thus lines were not discovered in the hologram until optical magnifiers and photographic enlargements were made. A 4:1 solution of methanol and water, replaced by distilled water for the second exposure, was used to create coarser fringes. Good contour lines were produced by using a 10:1 solution of methanol and water, followed by distilled water. The 10:1 dilution produced the contouring of the aluminum cylinder in figure 23. Comparison of lines of contour on the cylinder enabled us to determine definitely that no relative motion and no thermal expansion occurred. Contouring was due entirely to the change in refractive index. Figure 24 is an enlargement of the gold crown closest to the aluminum cylinder. Very fine contour lines may be noted on the crown. The ring around the crown is the plastic cylindrical mold. Note that it, too, has fringes around it.

This series of holograms indicated problems with the reflection from gold and amalgam restorations and also with the translucency of natural tooth surfaces. Both the metal and the enamel surfaces obscured the fringes. The contouring, visible on the aluminum cylinder and the edge of the plastic mold, was not as apparent on the polished metallic surfaces of the restorations because of reflections. Almost no fringes were present on the enamel surfaces. It may be necessary to coat the occlusal surfaces with an opaque film to eliminate both translucent and reflective problems in order to obtain quality fringes through holographic interferometry.

IV. DISCUSSION

The principles of wavefront reconstruction were first introduced by Dr. D. Gabor in 1948 (13-15), but holography did not become practical until Leith and Upatnieks (16, 17) employed the laser beam to expose holograms. Since that time, advances in laser holography and computer technology have created numerous possibilities for utilizing in dentistry the unique properties of the hologram, some of which are reviewed in the following paragraph:

The hologram is a recording device. It permanently stores a 3-D image which resembles the solid object it duplicates. When the angle at which the laser hits the film is varied, several hologram records of objects may be made on the same hologram plate. Any portion of the film records the entire image--in fact, the hologram may be sliced in half and still produce two complete images. Further, the hologram film record consists of a series of concentric and/or interweaving circles (fig. 4) which actually form a "tooth fingerprint" or "toothprint," storable and identifiable by computer. Through the use of various interferometric techniques, fringe lines may be generated to indicate either contour or motion. The contour fringe lines also form a toothprint which can be stored in a computer.

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Modifications and refinements of existing technology may now be all that are necessary to apply laser holography to dentistry. Following are some examples of such possible applications:

Treatment planning and dental patient records. The problems of diagnosing and screening large numbers of patients at one time--in public health clinics, schools, hospitals, the Armed Forces, and group practices--tie up the dentist with routine examinations. Even the training of para-professional personnel to do an initial screening examination is time-consuming and costly. With the use of the laser hologram exactly reproducing, in 3-D, the oral dentition (with frontal, lateral, and occlusal views taken on the same film, then patients, servicemen, or disaster victims could be screened by one para-professional taking holograms with a special laser holographic camera. A dentist could later examine these records for initial charting and treatment planning, thereby making more efficient use of his professional time. Furthermore, the hologram could be used as a permanent dental record--a new hologram taken after completion of each phase of treatment, and thus being available for case history documentation, research, teaching, and legal purposes. Each hologram plate could contain holograms of the patient's dentition, full-face views, radiographs (18), medical and dental history, occlusal studies, and diagnostic models and casts. Also, a holographic plate could be sent to a specialist in another office or city, and his opinion on the advisability of a particular treatment or cast design could be rendered without the patient's presence.

Forensic dentistry and record storage. The problem of identifying the remains of victims in airplane, auto, and other disasters requires the matching of charred teeth (which frequently are all that remain of a victim's body) with existing dental records. This identification is difficult in many cases, even when occlusal photographs of maxillary and mandibular arches are taken. By holographing the occlusal surfaces of teeth, rather than by using conventional photography, we would have the advantages of a 3-D hologram film-record of the teeth. This toothprint could be matched by computer, using pattern recognition of either the concentric circle pattern of the hologram, or the occlusal contour pattern from a contour hologram (19, 20). The holograms taken by the dentist on a single hologram plate would consist of occlusal views of the maxillary and mandibular arches, front and side views of the face, and a hologram of the radiographs. If this film plate were cut in half, one half could be kept as a patient record; the other half could be mailed to a national holographic records repository for forensic, and possibly criminal, identification. The computer would match holographic toothprints in much the same manner as the FBI matches fingerprints; and a single tooth might be enough to identify a person, or to establish that the remains were not those of a supposed victim.

Diagnosis. Contour holographic thermography, as described in this paper, will record changes in size due to temperature variations. It is

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possible that if the entire mouth were cooled with ice water, and a hologram exposed--the mouth allowed to warm, and a second exposure made--then any lesion or infected area would heat and expand more rapidly. A bull's-eye effect (similar to that in fig. 11) is thus created, indicating to the dentist exactly if and where a pathologic condition exists.

Crown and bridge fixed restorative applications. A contour hologram of a prepared tooth for a crown might be used to provide the information to a computer necessary for machining a piece of gold into a dental crown. A dentist would take occlusal and lateral views of the crown and of the adjacent and opposing dentition. The contour hologram would be of the two-frequency type, and contour lines could be spaced to the thousandth of an inch to provide necessary accuracy. A computer would digest the contouring information and direct a precision lathe to machine a precision "casting," thereby eliminating not only the costly laboratory casting procedures and equipment, but also the inaccuracies of impressions and impression material. The lathe would be directed to contour-mill both the internal dimensions of the gold crown and the external occlusal surfaces as well. Information for the correct contouring of the occlusal surfaces would come either from the contoured hologram of the opposing dentition, or from a hologram of a Panky-Mann form of bite registration which records lateral as well as centric interferences. One or two centrally located dental centers could then fabricate all the crowns and bridges for the country. Dentists could mail the necessary holograms without danger of the problems of distortion of impression materials due to time, temperature, and handling. Precision milling of the gold by computer, rather than by present methods, could result in far greater accuracy of fit for dental castings.

Modern computers are now used to direct machines to mill metal for the space industries. The problem of applying such a method to dental work has been the lack of accurate contouring devices to give the computer the required information. Holography may provide this contouring information. This general principle may eventually be used to produce acrylic prosthetic appliances.

Stress analysis of orthodontic, prosthodontic, and periodontic appliances. The stress holography experiments explained in this paper studied the simple seating of a partial denture on a cast with static point stressing of one denture tooth. This process may be somewhat similar to that which occurs when a premature contact acts upon a removable appliance in the mouth. To proceed further with the possibilities of stress analysis--the dentist will now have a simple and dependable means to study and test scientifically the various prosthetic designs which have been improved by largely empirical means. Eventually, intraoral holographic stress research will become possible. Since the slight movement of the teeth may be recorded with holograms, the effects of the dynamic stresses of fixed and removable prosthesis, periodontic splints, and orthodontic appliances on the teeth may be studied and recorded.

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3-D holodonto-roentgenography. Holograms of radiographs have already been made, and the creation of 3-D radiographic images with holography have been attempted (21-23). The future awaits a coherent x-ray source which will allow true holographic oral roentgenograms to be produced. The perfection of holographic radiographs would revolutionize the field of radiology.

Security procedures. A great problem facing our modern security forces is how, simultaneously, to prevent entry to security areas by unauthorized people (who have stolen or forged I.D. cards) and permit entry by authorized personnel, without great inconvenience. For identification purposes, a hologram print of a tooth's occlusal surface would be practically impossible to duplicate. With this method, no authorized personnel would need any identifying cards which could be lost, stolen, changed, forged, or duplicated. A direct reading holographic image on television (24,25), connected to a computer, would be made of the teeth of the person seeking entry into a security area. The computer would instantaneously match the stored record of the hologram with that projected by the toothprints of the respective person and, in this way, verify or reject his identity. No unauthorized person could possibly gain entry under such a system.

V. CONCLUSION

The holograms and holographic techniques described in this paper demonstrate the potential of holodontography as a new dental science. These early experiments have tested various methods of developing contour holograms which may soon be applied as useful tools in research and in dental practice.

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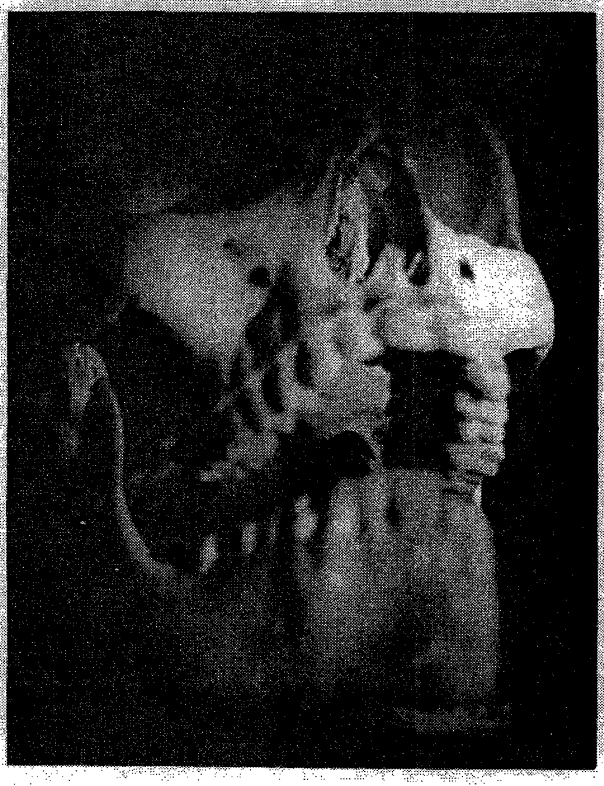


FIGURE 1

Hologram image of skull photographed through the hologram plate.

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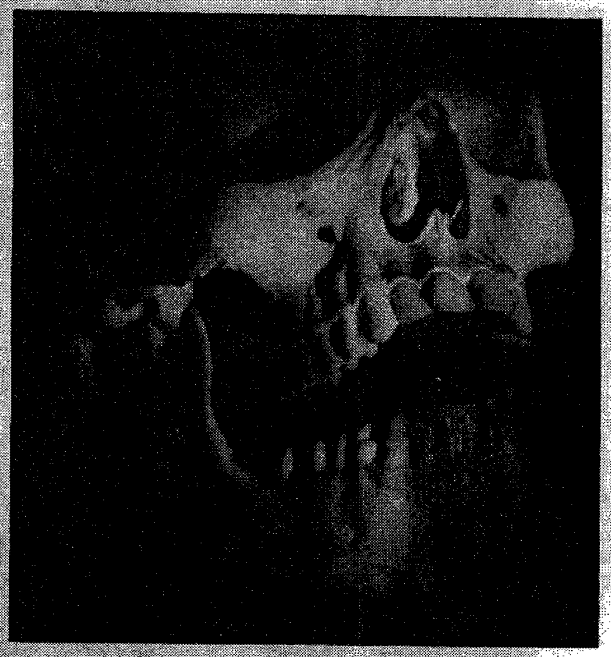


FIGURE 2

The same hologram image as in figure 1, but photographed from a different angle.

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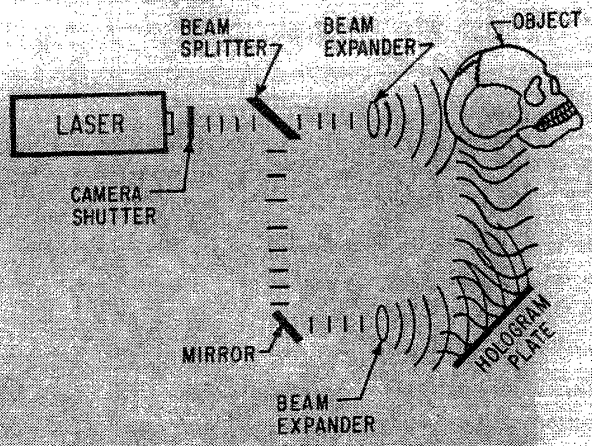


FIGURE 3

Basic arrangement of apparatus for exposing the hologram.

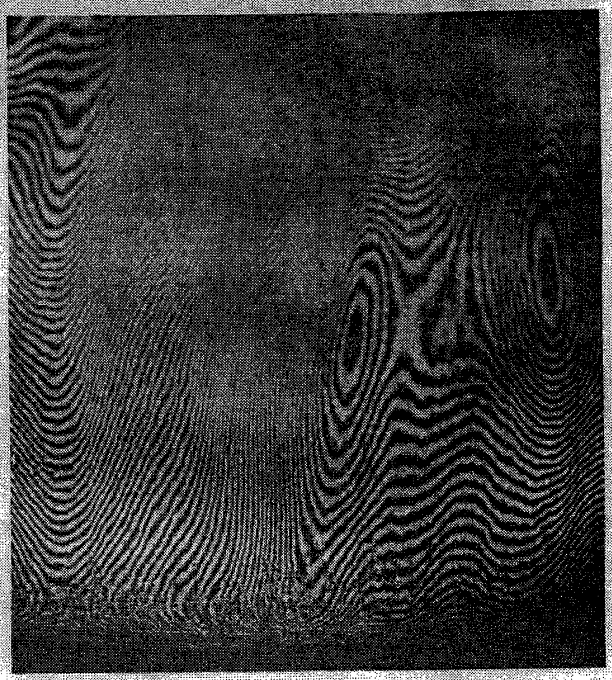


FIGURE 4

One example of a hologram interference pattern stored on a hologram plate.

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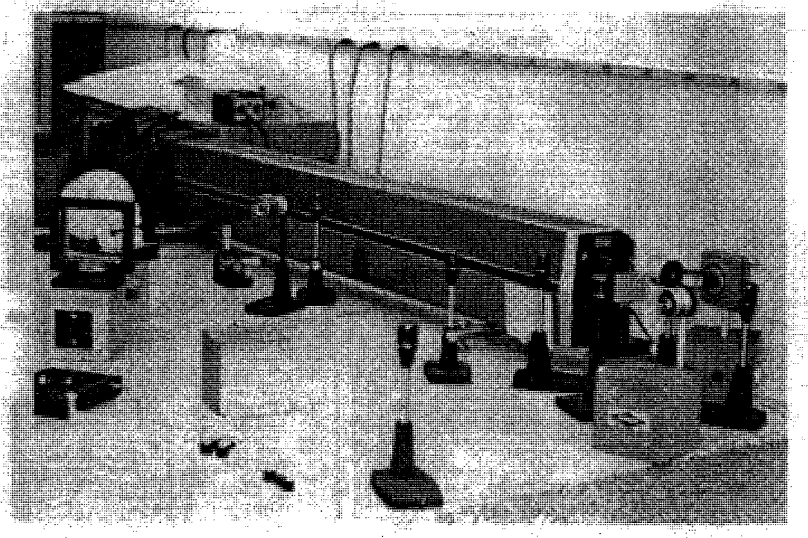


FIGURE 5

Apparatus used to expose holograms. (The laser is the long rectangular tube. Mirrors are mounted on heavy steel bases. Skull and film holder are at left center.)

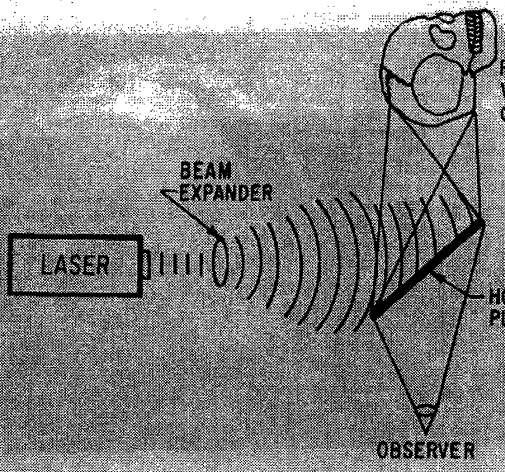


FIGURE 6

Arrangement of apparatus for viewing the hologram image.

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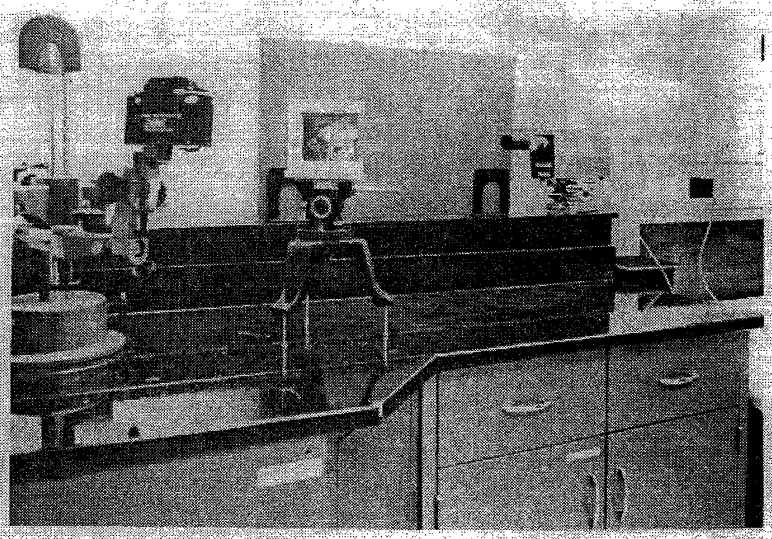


FIGURE 7

Apparatus for viewing the hologram image, as photographed from the observer's position. (Laser is on the right; hologram plate in filmstand is in the center; and the skull image is visible through, and is behind, the plate.)

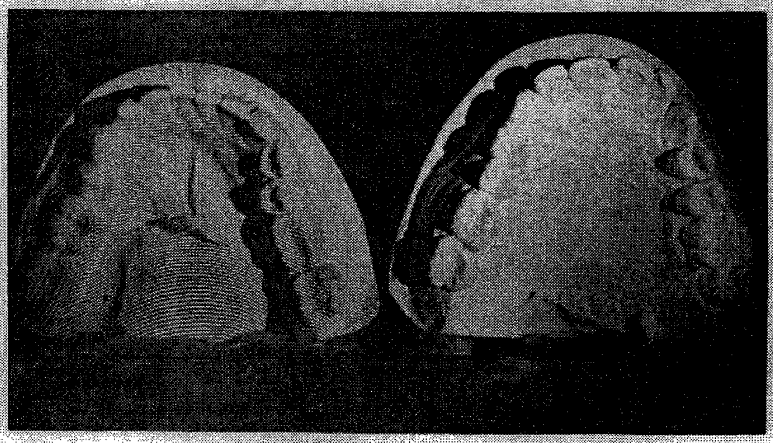


FIGURE 8

Hologram image showing thermal contour bands on heated mandibular cast at left. (Right cast was not heated.)

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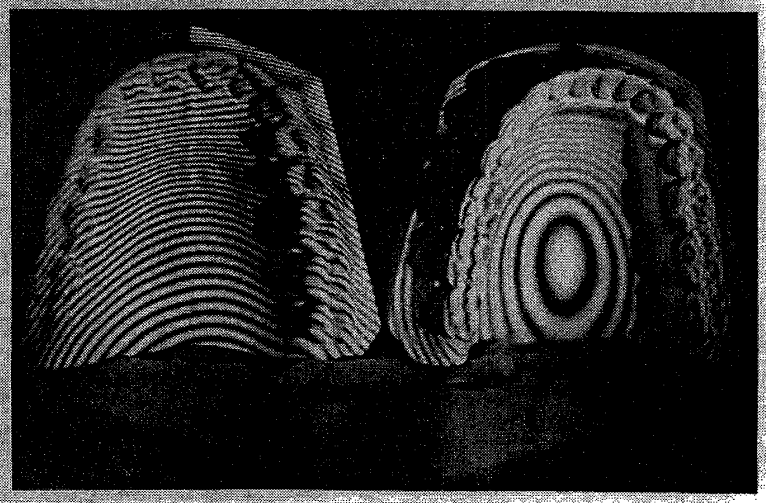


FIGURE 9

Thermal contouring of two casts. (Right cast contracted radially during cooling between double exposures, as indicated by concentric bands.)

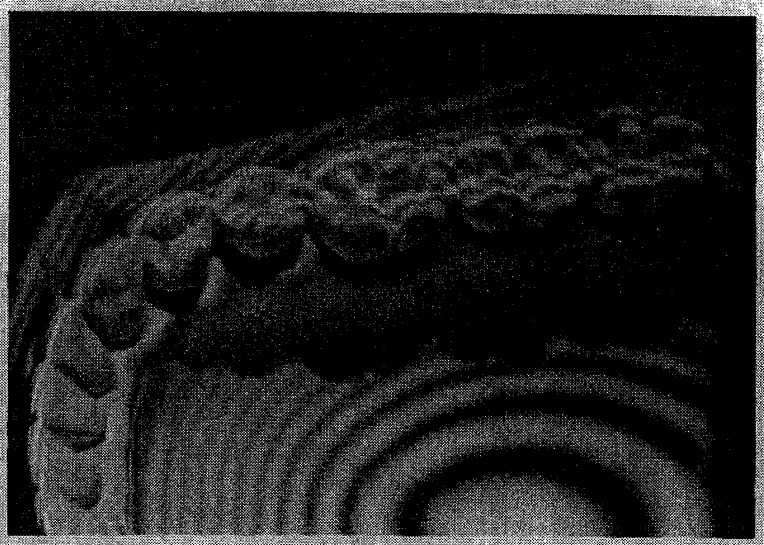


FIGURE 10

Detail of figure 9, thermal contouring of two casts, showing enlarged view of one quadrant. (Note topographic contouring effect on occlusal surfaces of teeth.)

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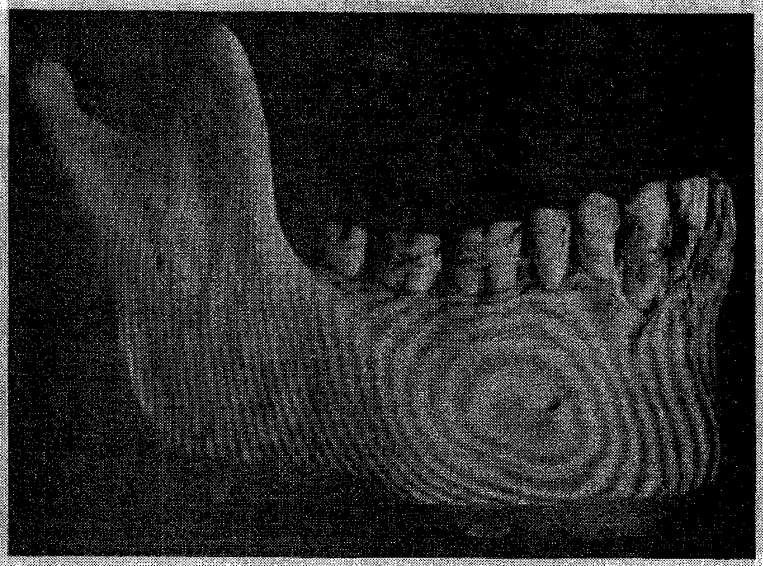


FIGURE 11

Thermal contour hologram of mandible--right lateral view. (Shrinkage of mandible is perpendicular to the fringe bands.)



FIGURE 12

Thermal contour hologram image of occlusal view of the same mandible shown in figure 11.

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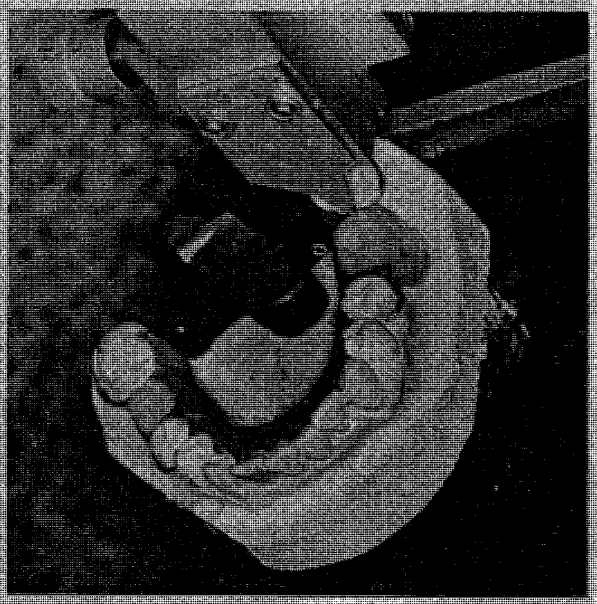


FIGURE 13

Equipment arrangement for stress holography experiments. (Cast is fastened to steel table by C-clamp. Note point stressor resting against denture tooth #19.)

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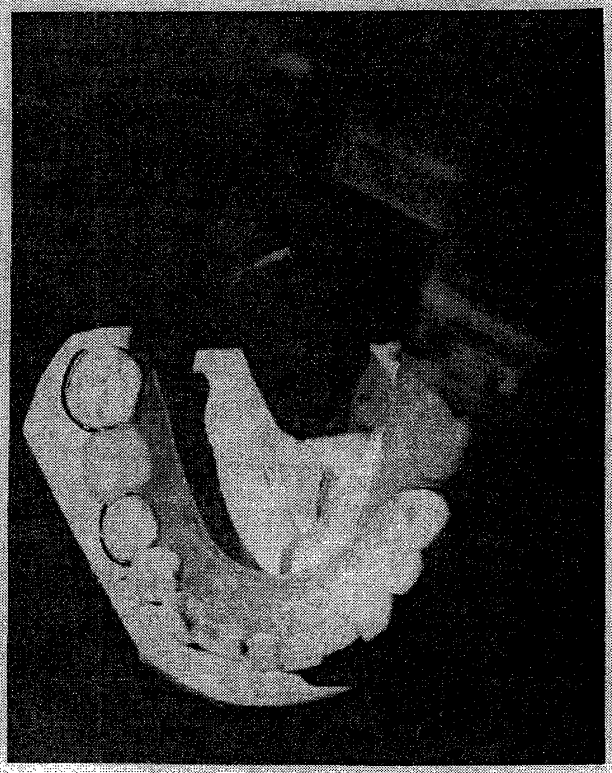


FIGURE 14

Hologram image showing point stressor against #19. (No banding effects are visible, thus indicating no motion occurred between double exposures.)

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FIGURE 15

Double-exposure hologram. (Stressor was moved between exposures. Arrow on photograph is directed toward banding visible on #19 and on stressor. Banding indicates that #19 is seating on cast.)

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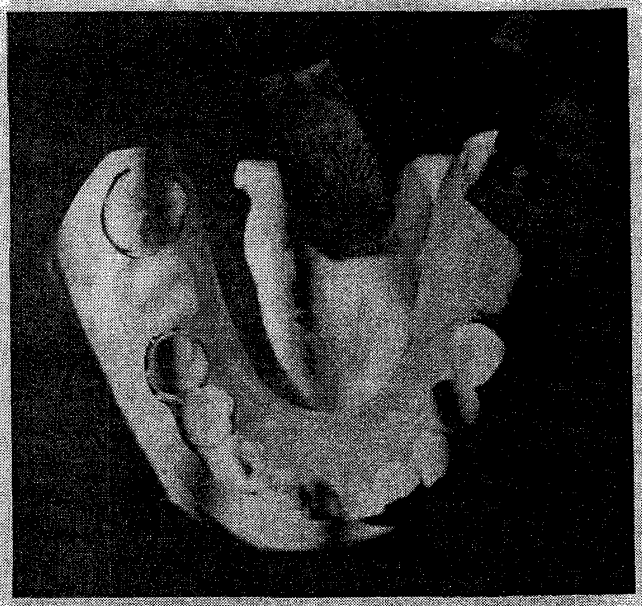


FIGURE 16

Hologram image demonstrates: banding on #19; a single band across #30; #19 is seating completely; and #30 is being pulled occlusally.

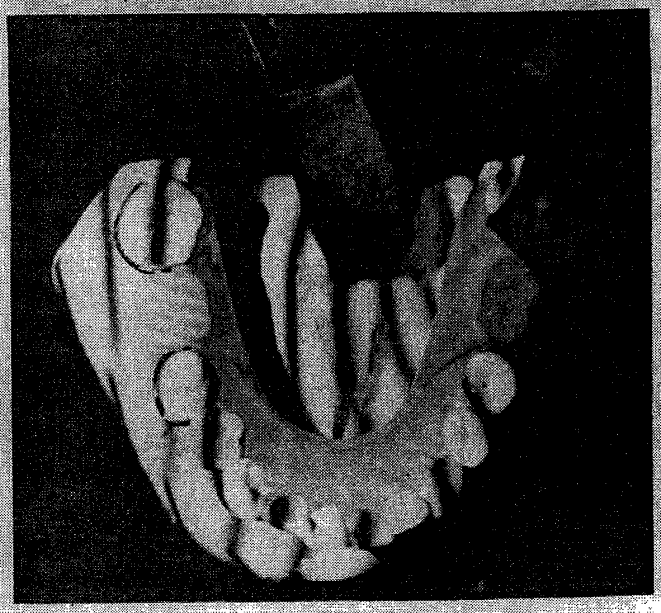


FIGURE 17

Fine fringes are visible on acrylic denture tooth #19, and heavy bands on #30. (Banding on cast shows entire cast moved. Note fringes on partial clasps. Tooth #30 has continued to move occlusally.)

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FIGURE 18

Initial hologram of denture before stress is applied. (Point stressor was not moved between exposures. Denture tooth did not move. Banding on cast was probably due to thermal factors.)



FIGURE 19

Double-exposure hologram image showing banding on tooth and stressor. (Note motion of denture perpendicular to bands.)

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FIGURE 20

Double-exposure hologram image shows that entire cast moved vertically downward as denture tooth was seated on cast.



FIGURE 21

Double-exposure hologram image in which denture tooth is elastically deforming or bending under stress force. (Note curving of bands on tooth. Cast is also bending under stress.)

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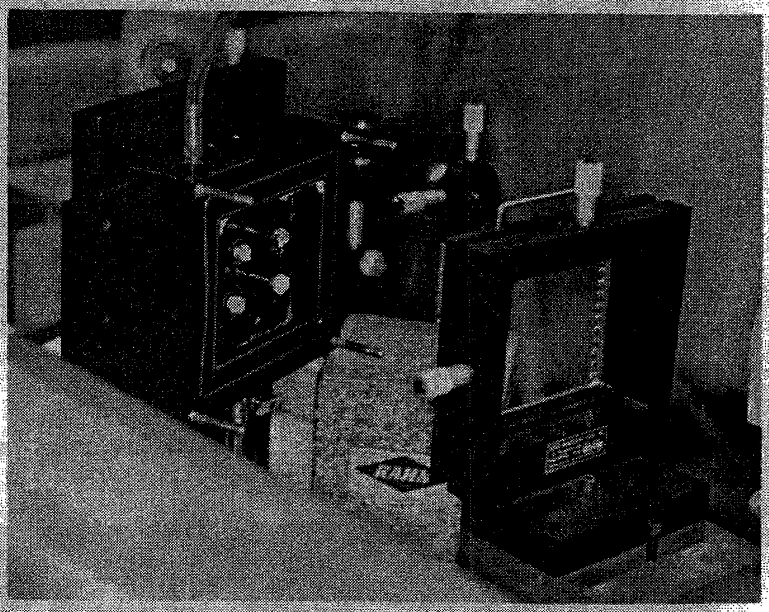


FIGURE 22

Apparatus for holographic interferometry experiments. (Tank, on left, has intake and exit ports for liquid; teeth are mounted sideways in tank. Hologram plate film-holder is box on right.)

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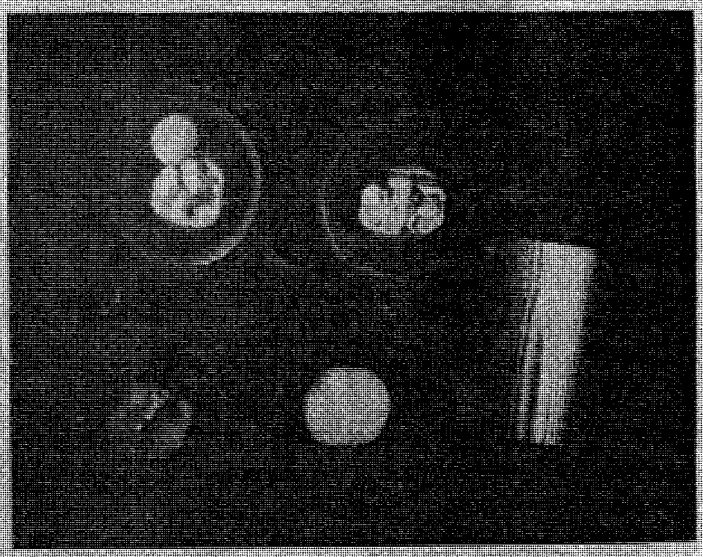


FIGURE 23

Contour interferometry hologram image. (Note contours on cylinder.)

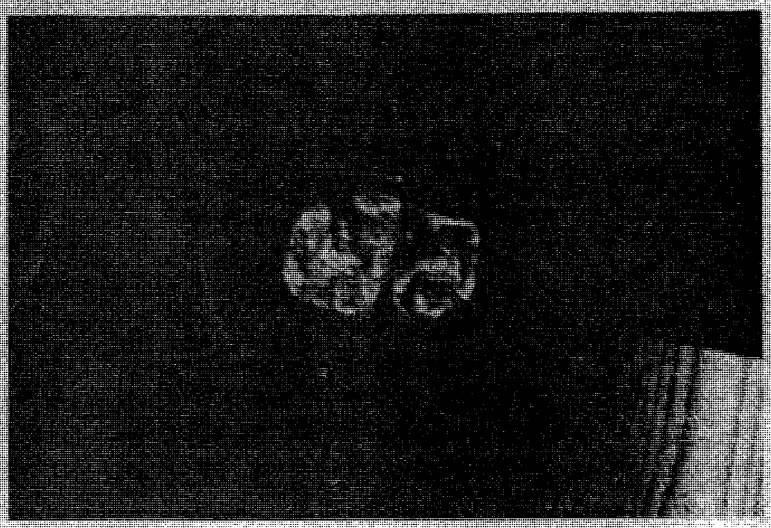


FIGURE 24

Enlargement of a crowned tooth shown in figure 23. In enlargement, fringes become apparent in hologram image.)

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APPENDIX A

PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53 (b)(2).

Docket Number	KELS-001/00US	Type a plus sign (+) inside this box→	+

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Ridgeley	Richard		

TITLE OF INVENTION (280 characters max)

PROCEDURE FOR MOVING TEETH USING A SERIES OF RETAINERS

CORRESPONDENCE ADDRESS

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ENCLOSED APPLICATION PARTS (check all that apply)

X	Specification	*Number of Pages* 16	[]	Small Entity Statement	
X	Drawing(s)	*Number of Sheets* 8	[]	Other (specify)	

METHOD OF PAYMENT (check one)

[X]	A check or money order is enclosed to cover the Provisional filing fees.	PROVISIONAL FILING FEE AMOUNT ($)
[X]	The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 03-3117	150.00

The Invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[X] No.

[ ] Yes, the names of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

21330629

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SIGNATURE _____ Date June 20, 1997

TYPED or PRINTED NAME Craig P. Opperman REGISTRATION NO. 37,078 (*if appropriate*)

[ ] Additional inventors are being named on separately numbered sheets attached hereto.

PROVISIONAL APPLICATION FILING ONLY

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Date: 6-20-97 By: Patricia K. Parry
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21330629

PROCEDURE FOR MOVING TEETH USING A SERIES OF RETAINERS

TECHNICAL FIELD

This invention relates to the field of orthodontics. More specifically, this invention relates to a method of moving teeth using a series of retainers.

BACKGROUND OF THE INVENTION

Repositioning teeth for aesthetic or other reasons is accomplished conventionally by wearing what is commonly referred to as "braces." Braces comprise a variety of appliances such as brackets, archwires, ligatures and O-rings. Attaching the appliances to a patient's teeth is a tedious and time consuming enterprise requiring many meetings with the treating orthodontist. Consequently, conventional orthodontic treatment limits an orthodontist's patient capacity. As orthodontists usually charge patients a fixed fee for an entire treatment, a limitation in patient capacity translates directly into a limitation on income.

Before fastening braces to a patient's teeth, at least one appointment is scheduled with the orthodontist so that x-rays and photographs of the patient's teeth and jaw structure can be taken. Also during this preliminary meeting, or possibly at a later meeting, an algenate mold of the patient's teeth is made. This mold provides a model of the patient's teeth that the orthodontist uses in conjunction with the x-rays and photographs to formulate a treatment strategy. The orthodontist then schedules one or more appointments during which braces will be attached to the patient's teeth.

At the meeting during which braces are first attached, the teeth surfaces are initially smeared with a weak acid. The acid optimizes the adhesion properties of the teeth surfaces for brackets and bands that are to be bonded to them. The brackets and bands serve as anchors

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for other appliances to be added later. After the acid step, the brackets and bands are cemented to the patient's teeth using a special safe glue. No force-inducing appliances are added until the cement is set. For this reason, it is common for the orthodontist to schedule a later appointment to ensure that the brackets and bands are well bonded to the teeth.

The primary force-inducing appliance in a conventional set of braces is the archwire. The archwire is resilient and is attached to the brackets by way of slots in the brackets. The archwire links the brackets together and exerts forces on them to move the teeth over time. Twisted wires or elastomeric O-rings are commonly used to reinforce attachment of the archwire to the brackets. Attachment of the archwire to the brackets is known in the art of orthodontia as "ligation" and wires used in this procedure are called "ligatures."

After the archwire is in place, periodic meetings with the orthodontist are required, during which the patient's braces will be adjusted by installing a different archwire having different force-inducing properties or by replacing or tightening existing ligatures. Typically, these meetings are scheduled every 3-6 weeks.

As the above illustrates, the conventional method of repositioning teeth is a tedious and time-consuming process requiring many visits to the orthodontist's office. From an orthodontist's perspective, this "chair time," reduces the number of patients an orthodontist can treat in a set time period (i.e., reduces patient capacity). Consequently, orthodontists continually seek out new treatment methods that reduce chair time.

One established way of reducing chair time is by using ligatureless brackets. Ligatureless brackets do not require installation of ligatures or O-rings to secure the archwire, thus saving chair time otherwise spent on adjusting the ligatures. A detailed discussion of various ligatureless brackets, for example, can be found in US 5,094,614, issued to Wildman. While the Wildman patent does result in reduced chair time, it still contemplates use of braces as the underlying treatment method. Thus, total chair time remains substantial.

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What is needed is an orthodontic treatment method that reduces chair time by eliminating the time consuming treatment steps peculiar to treatment using braces. Such a method has the promise of increasing patient capacity, and also reducing the cost to patients by eliminating expensive in-office meetings.

In addition to the substantial chair time associated with orthodontic treatment using braces, there a number of other drawbacks. First, the appliances (e.g., the brackets and wires) are visible to others. This is often a concern, particularly for professional and other adult patients who seek orthodontic treatment. Second, braces can result in inter-oral abrasion caused by projecting wires and bracket edges. Such abrasions are very discomforting and are at risk of becoming infected. Finally, brackets and wires make oral hygiene cumbersome and difficult because they easily trap food particles.

Therefore, what is needed, in addition to a reduced chair time method, is an orthodontic treatment method that is less detectable by the casual observer, not prone to causing inter-oral abrasions and makes oral hygiene uncomplicated.

SUMMARY OF THE INVENTION

Briefly, therefore, this invention provides for an orthodontic treatment method using a series of clear retainers custom designed for each orthodontic patient. Accordingly, this invention does not require the use of wires or brackets as do conventional orthodontic treatment methods.

According to the invention, an orthodontist first manufactures a positive replica of a patient's teeth as they are positioned in their initial, untreated state. Next, the orthodontist employs a range acquisition system that scans the replica to produce a electronic, digital model of the replica which is stored in a computer memory. Using component identification software that provides for a graphical user interface, the orthodontist then partitions the digital model into components representing the intraoral components of the patient's mouth (e.g. teeth,

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gingavae, jaw bone substrate, etc.). The identified components are then "manipulated" by the orthodontist preferably via the graphical user interface to produce a digital representation of a goal state. Using treatment planner software, the orthodontist then creates a series of intermediate treatment states. The number of intermediate states generated depends upon the segmentation intensity. Based on the intermediate states, the orthodontist manufactures plastic retainers, each retainer corresponding to an intermediate state. Finally, the orthodontist instructs the patient to wear the retainers in a prescribed sequence. A progressive repositioning of the patient's teeth occurs by the wearing of each retainer until finally the goal state is attained.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 schematically illustrates the steps comprising the present invention;

Figure 2 illustrates the taking of an impression and the making of a positive replica of a patient's teeth;

Figure 3 is a schematic representation of a non-contact-type range acquisition system used to translate the replica topology into a digital model;

Figure 4 illustrates the scanning of the replica using a preferred non-contact-type, reflective, optical range acquisition system;

Figure 5 schematically illustrates the initial, intermediate and goal states as developed by the stage development process;

Figure 6 depicts the preferred method of manufacturing plastic retainers, from positive models manufactured by a stereolithography machine, using a vacuum suction machine; and

Figure 7 depicts an alternative method of manufacturing plastic retainers using only a stereolithographic machine.

DETAILED DESCRIPTION OF THE INVENTION

Overview

The method of practicing this invention is outlined in Figure 1. First, an impression of the patient's teeth is made at 10. Then, as shown at 11, a plaster replica is developed from the impression. Next, a range acquisition system is used to generate a computer-readable

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representation of the shape of the replica, as shown at 12. This computer-readable data is a digitized representation (or "digital model") of the patient's teeth as positioned in their initial state.

As shown at 13, the orthodontist, using component identification software and an appropriately configured graphical user interface (GUI), partitions the digital model into the various components that represent intraoral components of the patient's mouth. As shown at 14, after the component identification step, the orthodontist, again via the GUI, manipulates the components to produce a desired goal state of the patient's teeth. After the goal state of the patient's teeth is determined, a series of intermediate states is created corresponding to progressive stages of teeth movement between the initial and goal states, as shown at 15. These intermediate states are created by the computer as directed by treatment planner software. At 16, using the intermediate state data, a stereolithography or other rapid-prototyping machine is employed to manufacture a set of actual retainers. Finally, at 17, the patient wears the retainers in a prescribed sequence, for a specified length of time, until the goal state is attained. A detailed description of the invention follows.

Making the Digital Model

The first step of this invention involves the making of a digital model of a patient's teeth. Making a digital model of the patient's teeth is a two step process. First, a positive replica of the patient's teeth is created. In the second step, the replica is scanned by a range acquisition system to generate a digital model of the patient's teeth. These two steps are described more fully below.

Creating the Replica

The first step of manufacturing a positive replica of the patient's teeth is a process that is well known in the art. Referring to Figure 2, an orthodontist or an assistant mixes an impression mix 200 with water 201 to make an impression putty 202 from which a patient's teeth impressions can be made. There are a number of impression mixes 200 (or

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"algenates") commercially available. Impression mixes that result in high impression resolution are preferred.

Next, the impression putty 202 is loaded into a putty tray 203 and subsequently placed in the patient's mouth. Once the putty tray 203 is properly positioned in the patient's mouth, the patient is instructed to bite down onto the putty tray 203, as illustrated at 204. After a short period, the impression putty 202 hardens, producing a negative putty impression 205 of the patient's teeth.

After the negative putty impression 205 is made, the orthodontist or assistant proceeds to prepare a wet plaster-of-Paris mixture 207 (or other similar compound) by mixing dry plaster-of-Paris 206 (or corresponding similar compound) with water 201. The wet plaster-of-Paris mixture 207 is then poured into the negative putty impression 205 and allowed to harden. The hardened result comprises a positive plaster mold or replica 208 of the patient's teeth in their initial state.

Scanning the Replica

After the positive replica 208 has been developed, it is positioned for scanning by a range acquisition system that generates a computer-readable, digitized representation (or "digital model") of the surface geometry of a three dimensional sample object. There are a variety of range acquisition systems, generally categorized by whether the process of acquisition requires contact with the three dimensional object.

A contact-type range acquisition system utilizes a probe, having multiple degrees of translational and/or rotational freedom. By recording the physical displacement of the probe as it is drawn across the sample surface, a computer-readable representation of the sample object is made.

A non-contact-type range acquisition device can be either a reflective-type or transmissive-type system. There are a variety of reflective systems in use. Some of these reflective

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systems utilize non-optical incident energy sources such as microwave radar or sonar. Others utilize optical energy. Those non-contact-type systems working by reflected optical energy further contain special instrumentation configured to permit certain measuring techniques to be performed (e.g. imaging radar, triangulation and interferometry).

The preferred range acquisition system is an optical, reflective, non-contact-type scanner. Non-contact-type scanners are preferred because they are inherently nondestructive (i.e. do not damage the sample object), are generally characterized by a higher capture resolution and scan a sample in a relatively short period of time. One such scanner is the Cyberware Model 15 manufactured by Cyberware, Inc.

Either non-contact-type or contact-type scanners may also include a color camera, that when synchronized with the scanning capabilities, provides a means for capturing, in digital format, a color representation of the sample object. The importance of this further ability to capture not just the shape of the sample object but also its color is discussed below.

A schematic illustration of a non-contact-type range acquisition system is shown in Figure 3. The range acquisition system 300 is comprised of a table 301, a turntable 302 upon which the positive replica 208 is placed, a laser 303 and a detector 304. The range acquisition system 300 functions to translate the laser 303 energy reflected from the surface of the replica 208 into a digital model of the patient's teeth. This scanning process is illustrated in FIG. 4.

Referring to FIGS. 3 & 4(a), the first step in the scanning process involves configuring laser 303 so that it reflects from an initial point 320 on the replica 208 surface. (The replica 208 is depicted as a vase in FIG. 4 to highlight the scanning process. The actual replica 208, of course, is a three-dimensional mold of the patient's teeth.) Next, as illustrated in FIG. 4(b), the laser 303 is dispersed through a lens 340 such that it "paints" a slice 330 on the replica 208. The reflection of this painted slice 330 is detected by an off-axis sensor 304 which transduces the optical energy into a computer-readable, digitized representation of the slice

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330. As shown in FIG. 4(c), during scanning, the turntable 302 is rotated such that a dense succession of sample object slices 330 is generated over the surface of the replica 208. Following detection of the reflected optical energy, software, as provided by the range acquisition system manufacturer, performs surface reconstruction of the replica 208. This surface reconstruction software directs the controlling computer to transform the succession of sample object slices 330 into a seamless digital model representing the replica 208 topology.

Designing the Goal State

Once the digital model is available, a goal state is extrapolated from the initial digital model. Extrapolation includes identifying and isolating the digital representations of the various intraoral components of the patient (e.g. teeth, gingavae and other oral tissue) and manipulating the digital components toward a desired final (or "goal") state. The goal state can be either a predetermined or accepted standard prescription (e.g. Roth, Andrews, etc.), or a goal state as prescribed by a treating orthodontist on an individual case basis. Identification and manipulation of the components is accomplished using component identification and manipulation software including a graphical user interface (GUI). The functional aspects of this software are described more fully below.

The goal state can be either the desired outcome of the overall treatment or an in-between treatment target. An in-between treatment target might be used, for example, in cases where one or more teeth need to be extracted before the ultimate goal state can be realized. In such a case, the component identification and manipulation software can be applied prior to tooth extraction to produce an intermediate target state. Following tooth extraction, and after the teeth have been repositioned in accordance with this intermediate target state, a new digital model may be developed (using the replica scanning procedure described above) and a corresponding goal state generated, again using the component identification and component manipulation software.

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Component Identification and Manipulation Software

Preferably, component identification and manipulation is directed by an orthodontist using a graphical user interface (GUI) in a windows-based environment. The component identification and manipulation software of this invention provides an enhanced GUI as developed from an object-oriented toolkit for developing interactive three-dimensional graphics.

The current preferred embodiment employs Inventor, a three-dimensional interface development toolkit. Inventor includes a C/C++ applications programming interface permitting development of tools for identifying and manipulating the components. Software created tools developed to work in the present invention include, for example, a "virtual saw", a "rail", an "eraser" and "wax balls." These interactive tools are used by the operator, via a mouse or other controlling means, to identify and subsequently manipulate the components.

The purpose of component identification is to partition the digital model into representative intraoral components so that they can be individually manipulated toward the goal (or target) state. The virtual saw is used to accomplish this task. The virtual saw comprises a set of points that can be arranged in a variety of shapes for identifying a particular component of the digital model. To identify a particular component of the digital model, the operator first configures the points of the saw into a shape characteristic of the component. (For example, if the component is a portion of the digital model representing either a central or lateral tooth, the saw points are preferably arranged in a "u-shape" to match the peripheral shape of such teeth as they project from the gingavae.) Then the operator "saws" the component away from the rest of the digital image by clicking a mouse or by using some other suitable control means (e.g. function keys on a keyboard). The sawing process thus identifies a component as a distinct subelement of the digital model. Other components are similarly isolated and identified using the saw.

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The orthodontist or other operator may further simplify the identification process by marking the physical replica prior to scanning. Upon scanning, these marks become part of the digital model. The marks may include, among others: (i) the rotational axis of a tooth, marked by straight lines; and (ii) the principal axis of a tooth, also marked by a straight line on the occlusal edge of the tooth. A rotational axis mark restricts how a tooth may be rotated in order to attain the goal (or target) state. An occlusal edge mark assists in aligning the rail tool to the portion of the digital image representing the jaw substrate before commencing component manipulation. (See below for a description of the rail tool).

As alluded to above, and as explained in more detail below, the preferred method of component identification is through the use of a GUI. However, it should be recognized that component identification can be performed in other ways as well. For example, each component of the replica 208 can be painted with a unique and identifying color prior to the scanning step. Subsequent scanning of the colored replica 208, by a range acquisition system incorporating color-capture capabilities, permits the component identification software to automatically partition the digital model into constituent components based on color codes. Another alternative relies on identifying algorithms written into the software itself to identify the boundaries (or gaps) between teeth, supporting structures. A present form of this third alternative supplies a quick first approximation of component identification which can be subsequently refined by application of either of the first two alternatives or a combination thereof.

Once the digital model has been partitioned into distinct components, the operator manipulates the components towards the goal (or target) state. The rail tool, another software created tool of present invention, is a particularly useful tool in this regard. It is used to define a path in the occlusal plane of the digital model along which the teeth are to affiliated and subsequently moved. Using the saw tool, or other appropriate tool, the operator then manipulates the teeth components; the rail assists by requiring the teeth components to maintain its path. Use of the rail is not required, however, and in some

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situations it may be preferable, or, indeed necessary, to override or otherwise disable the rail so that components can be manipulated as desired.

The component manipulation software also has the capability of providing operator tips and instructions concerning certain manipulations. For example, it can suggest paths of teeth movement and caution against excessive forces that may cause patient discomfort or interfere with the mechanical integrity of a retainer. It may also suggest goal (or target) states that best suit the jaw structure of a particular patient and/or ensure good inner digitation and occlusion parameters.

Another software tool is the eraser tool. It permits an operator to correct mistakes and delete selected portions of the digital model during the identification and manipulation processes. Selected deletions are also useful in defining the shape of the retainers. For example, by positioning a virtual "wax ball" (another software-created tool) in a position where a tooth has been extracted permits the later manufacture of a retainer having a cavity or space. Such a cavity or space would be required, for example, to close an interproximal space created following a tooth extraction. The cavity or space allows the teeth adjacent to the cavity or space to be moved toward each other so that the interproximal space can be closed. Without the benefit of the wax ball, a new replica and digital model would have to be made so that a retainer having a space could be manufactured. Wax balls can also be positioned in areas that the orthodontist knows are pressure sensitive to pain. In such a way, the wearing of the corresponding retainer prevents discomfort as it provides a cavity or space in the vicinity of the sensitive area.

Above it was described that the preferred user interface for component identification is a three dimensional interactive GUI. A three-dimensional GUI is also preferred for component manipulation. Such an interface provides the orthodontist with instant and visual interaction with the digital model components. It is preferred over interfaces that permit only simple low-level commands for directing the computer to manipulate a particular segment. In other words, a GUI adapted for manipulation is preferred over an interface that accepts directives,

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for example, only of the sort: "translate this component by 0.1 mm to the right." Such low-level commands are useful for fine-tuning, but, if they were the sole interface, the processes of component manipulation would become a tiresome and time-consuming interaction.

Before or during the manipulation process, one or more tooth components may be augmented with template models of tooth roots. Manipulation of a tooth model augmented with a root template is useful, for example, in situations where impacting of teeth below the gumline is a concern. These template models could, for example, comprise a digitized representation of the patient's teeth x-rays.

The above-described component identification and component manipulation software is designed to operate at a sophistication commensurate with the operator's training level. For example, the component manipulation software can assist a computer operator, lacking orthodontic training, by providing feedback regarding permissible and forbidden manipulations of the teeth. On the other hand, an orthodontist, having greater skill in intraoral physiology and teeth-moving dynamics, can simply use the component identification and manipulation software as a tool and disable or otherwise ignore the advice.

Treatment Segmentation

After the process of identification and manipulation generates a goal st[redacted]e orthodontist proceeds to design a series of intermediate states, between the initia[redacted]' the goal state, using custom treatment planner software. This process is called "tre[redacted]mentation" or simply "segmentation." A simple example of segmentation is as follo[redacted]particular tooth must be repositioned in a certain direction by, say, 1 mm, and the orthodontist contemplates accomplishing this treatment in ten treatment segments (corresponding to ten intermediate states) then, on average, each treatment state must move the tooth 0.1 mm in the prescribed direction. If the orthodontist chooses to increase the number of treatment states to, say, twenty, the segmentation intensity would correspondingly decrease from 0.1 mm to 0.05 mm.

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The purpose of segmentation is to create a series of intermediate states that will produce a treatment sequence that is continuous and steady. Segmentation also involves ensuring that: (i) the force on individual teeth at any time is optimized to make the transformation at each stage the maximum possible without causing the patient excessive pain; and (ii) the goal state is achieved with high certainty.

Orthodontic experience suggests that teeth forced into radical movement are less likely to follow the planned movement path. Moreover, steady and continuous rather than abrupt and then decaying forces are preferable because of the better cellular response of intraoral tissue associated with the former. The treatment planner software is designed to recognize and avoid forces that would cause radical teeth movement by prescribing a treatment sequence plan that is steady, non-decaying and optimal.

Figure 5 illustrates a series of intermediate states 502 and 503, generated between an initial state 501 and a goal state 504. Intermediate state 503, closer to the goal state 504 than intermediate state 502, represents a slight improvement in teeth alignment over the preceding intermediate state 502. There are only two intermediate states shown in Figure 5. They are for illustrative purposes only. Given a set treatment time, the number of steps (or segments) required to complete treatment depends upon the segmentation intensity.

Segmentation intensity is the rate of movement of a tooth during a particular segment of treatment. It may vary for each treatment state. Although the total treatment time can be reduced by increasing the segmentation intensity, there are physical limitations. These physical limitations, in turn, relate to the force inducing properties of the retainers and the case complexity.

Case complexity implicates, for example, the age of the patient, jaw bone density of the patient and the distances and type of movement (e.g., tip, rotate, intrusion, extrusion, etc.) each tooth must experience to move it from the initial state to the goal state.

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Thus, segmentation intensity is limited by the case complexity. It should not exceed a "safe limit" over which a tooth could fracture, or otherwise become disassociated from, the underlying jaw bone (substrate). This safe limit depends on, among other factors, the substrate density and the dimensions of the tooth being repositioned. By way of example, the "safe limit" for closing an interproximal space between two adjacent, fairly vertical and non-tipped lower central and lateral teeth is 1 mm approximately every seven weeks.

The material properties of the retainer delimit its force inducing capabilities, and, therefore, also factor into the permissible segmentation intensity. The geometry of a particular retainer further limits the distance that a particular retainer can move a tooth. A retainer manufactured from conventional retainer plastics can maintain its structural integrity and move a tooth a distance of approximately 0.05 mm without exceeding the "safe limit." Other materials can provide for higher force-inducing capabilities.

In addition to the treatment constraints relating to segmentation intensity, the treatment planner software also determines how long a particular retainer can apply steady, continuous and optimal forces. Such a determination provides a basis for setting a time duration for which a patient should wear that particular retainer to achieve the next intermediate state.

The current version of treatment planning software functions to automatically calculate, for each state, a physically realizable (i.e. collision-free) movement path. However, it also permits the orthodontist or other operator to guide the computer in several ways. The orthodontist may: (i) specify a variable speed of movement, such as forcing a tooth into a slow start followed by accelerated movement; (ii) define specific intermediate positions, called "keyframes," which the tooth should attain during its movement; and (iii) limit the force applied to a tooth at any intermediate state.

Manufacturing

Once the intermediate states have been created, their digital models are downloaded to a rapid prototyping device such as a stereolithography machine. Prior to downloading to the

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rapid prototyping device the individual and intraoral components of a particular digital model must be unified to define a "single" contiguous model. This is because the rapid prototyping device would otherwise create (or attempt to create) a plurality of individual component-based retainers instead of a single retainer for the relevant single treatment stage. According, the digital model can be manipulated so that the individual intraoral components are joined together. This can be done by various means, including digitally filling the spaces between the individual components or joining the individual intraoral components with a line or three-dimensional cylinder or "stick." Once the individual intraoral components are joined together the single unified digital model is downloaded to the rapid prototyping device. The rapid prototyping machine either develops treatment retainers corresponding to each intermediate treatment state directly or, alternatively, develops positive teeth molds of each intermediate state from which the plastic containers can be manufactured using a vacuum driven machine.

Which alternative method is chosen relates principally to the material of which the retainers are made. Because materials used in a stereolithography systems are not strong enough to function as retainers and because they are not necessarily approved by the FDA, the second alternative is currently preferred. However, should FDA-approved materials suitable for use in a stereolithography machine become available in the future, economic and other factors may cause the first alternative to be more preferable.

Figure 6 illustrates the second alternative prototyping process. The stereolithography machine 502 fabricates a series of positive models 601 that correspond to the initial, intermediate and goal states. Then a vacuum suction machine 602 is used to manufacture a series of plastic retainers 603 from FDA-approved plastic, in accordance with these states.

The first alternative prototyping process referred to above is illustrated in Figure 7. From a non-toxic, liquid resin 701, the stereolithography machine 702 fabricates ready-to-wear retainers 703 in accordance with the states of the stage development.

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Various stereolithographic and vacuum suction machines are commercially available. The preferred rapid prototyping system is a stereolithography system employing a small-spot laser, one for example, manufactured by Pure Fluid Magic. Though not necessarily preferred, Raintree Essix manufactures a vacuum suction machine that is adapted for fabricating plastic retainers. Such a retainer maker would provide useful when the second alternative, as described above, is used.

Application and Assessment

Once the retainers are manufactured, the patient wears them in sequence as prescribed by the orthodontist and in accordance with the stage development plan. Each retainer alters the patient's teeth structure progressively towards the goal state until it is attained.

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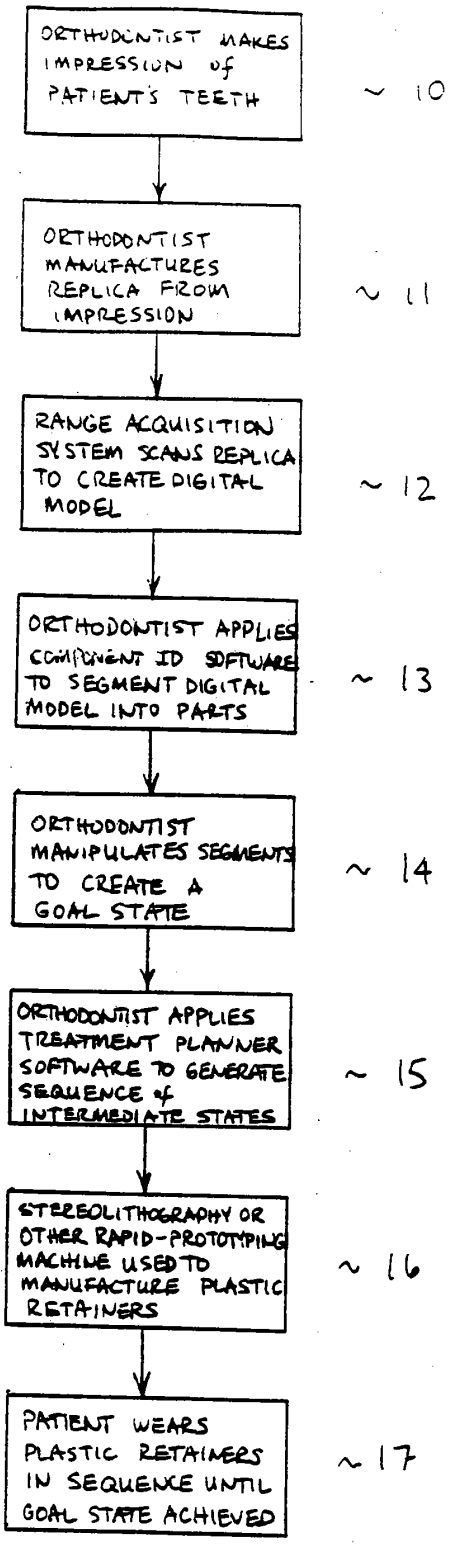

ORTHODONTIST MAKES IMPRESSION of PATIENT'S TEETH
~ 10
ORTHODONTIST MANUFACTURES REPLICA FROM IMPRESSION
~ 11
RANGE ACQUISITION SYSTEM SCANS REPLICA TO CREATE DIGITAL MODEL
~ 12
ORTHODONTIST APPLIES COMPONENT ID SOFTWARE TO SEGMENT DIGITAL MODEL INTO PARTS
~ 13
ORTHODONTIST MANIPULATES SEGMENTS TO CREATE A GOAL STATE
~ 14
ORTHODONTIST APPLIES TREATMENT PLANNER SOFTWARE TO GENERATE SEQUENCE of INTERMEDIATE STATES
~ 15
STEREOLITHOGRAPHY OR OTHER RAPID-PROTOTYPING MACHINE USED TO MANUFACTURE PLASTIC RETAINERS
~ 16
PATIENT WEARS PLASTIC RETAINERS IN SEQUENCE UNTIL GOAL STATE ACHIEVED
~ 17

FIGURE 1

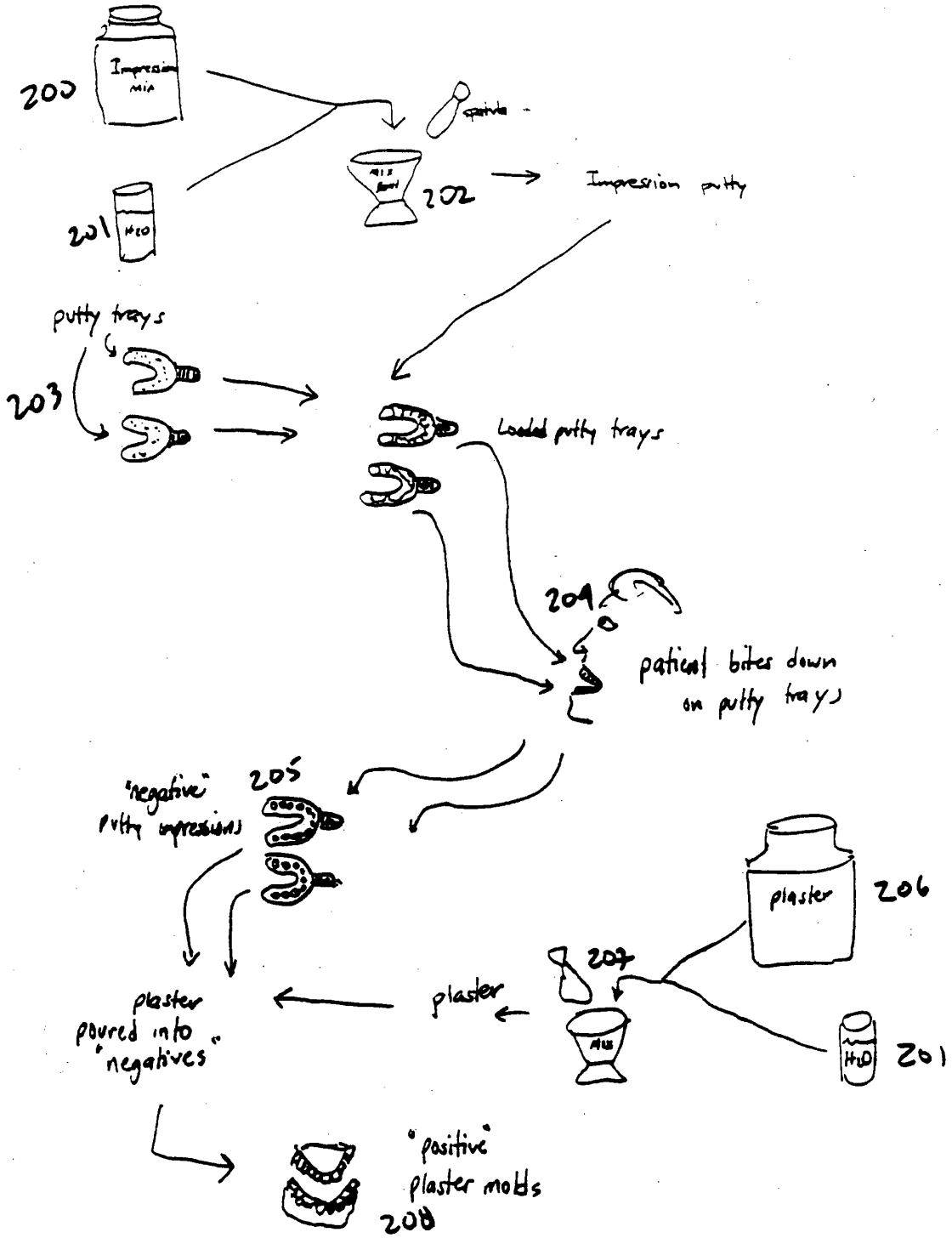

200
Impression MIA
spatula
201
H2O
202
Impression putty
putty trays
203
Loaded putty trays
204
patient bites down on putty trays
"negative" putty impressions
205
plaster
206
207
plaster
plaster poured into "negatives"
H2O
201
"positive" plaster molds
208

FIGURE 2

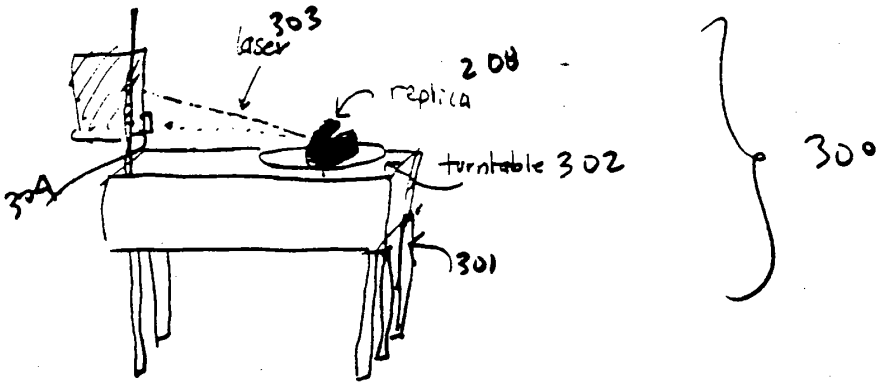
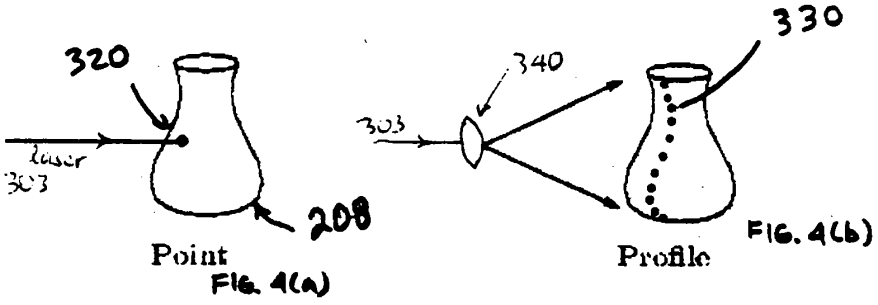


FIGURE 3


320
laser
303
208
Point
FIG. 4(a)
340
303
330
Profile
FIG. 4(b)

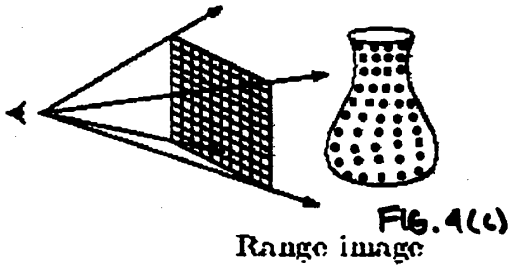

FIG. 4(c)
Range image

FIGURE 4

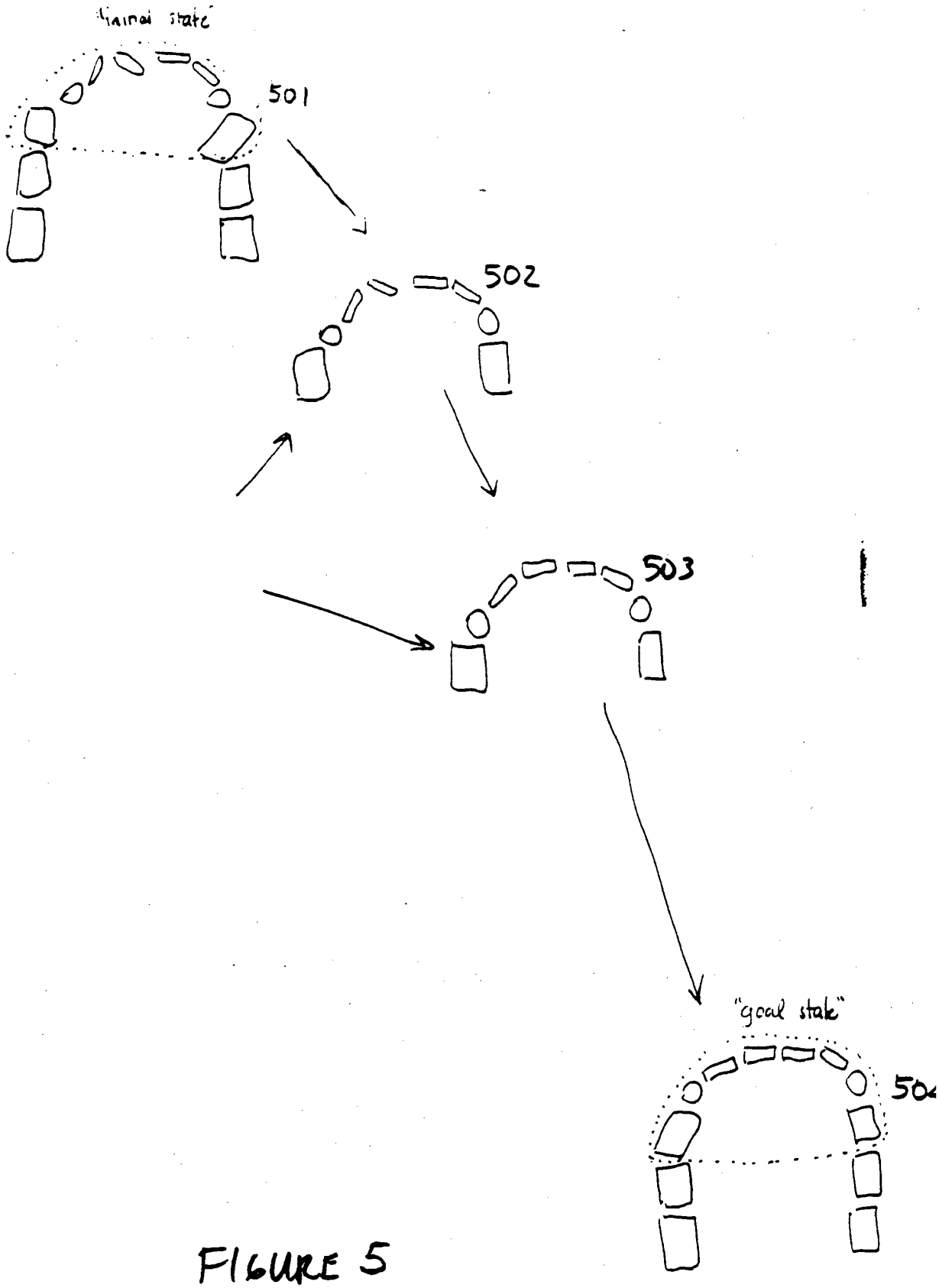


FIGURE 5

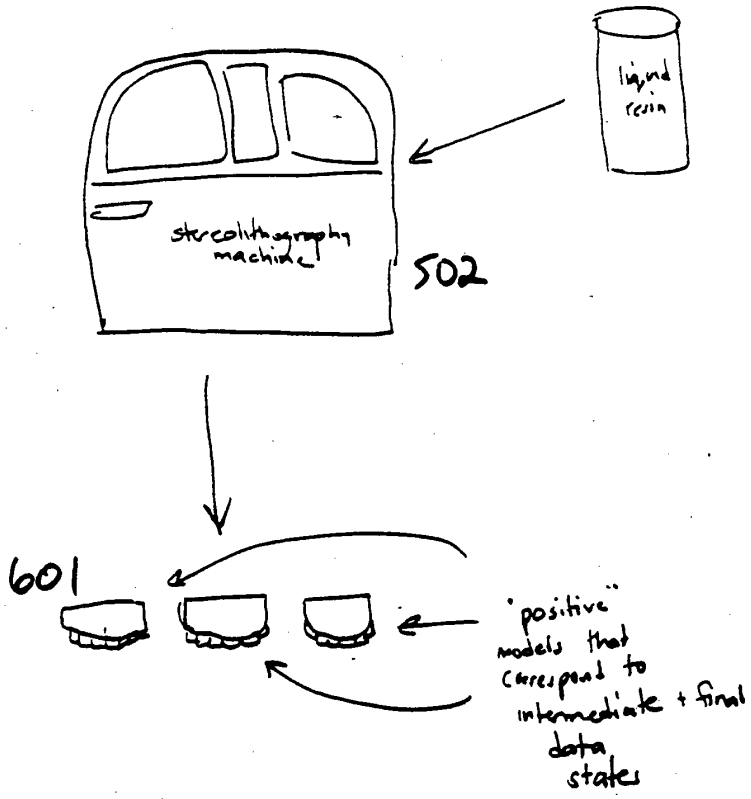


FIGURE 6

1 of 1

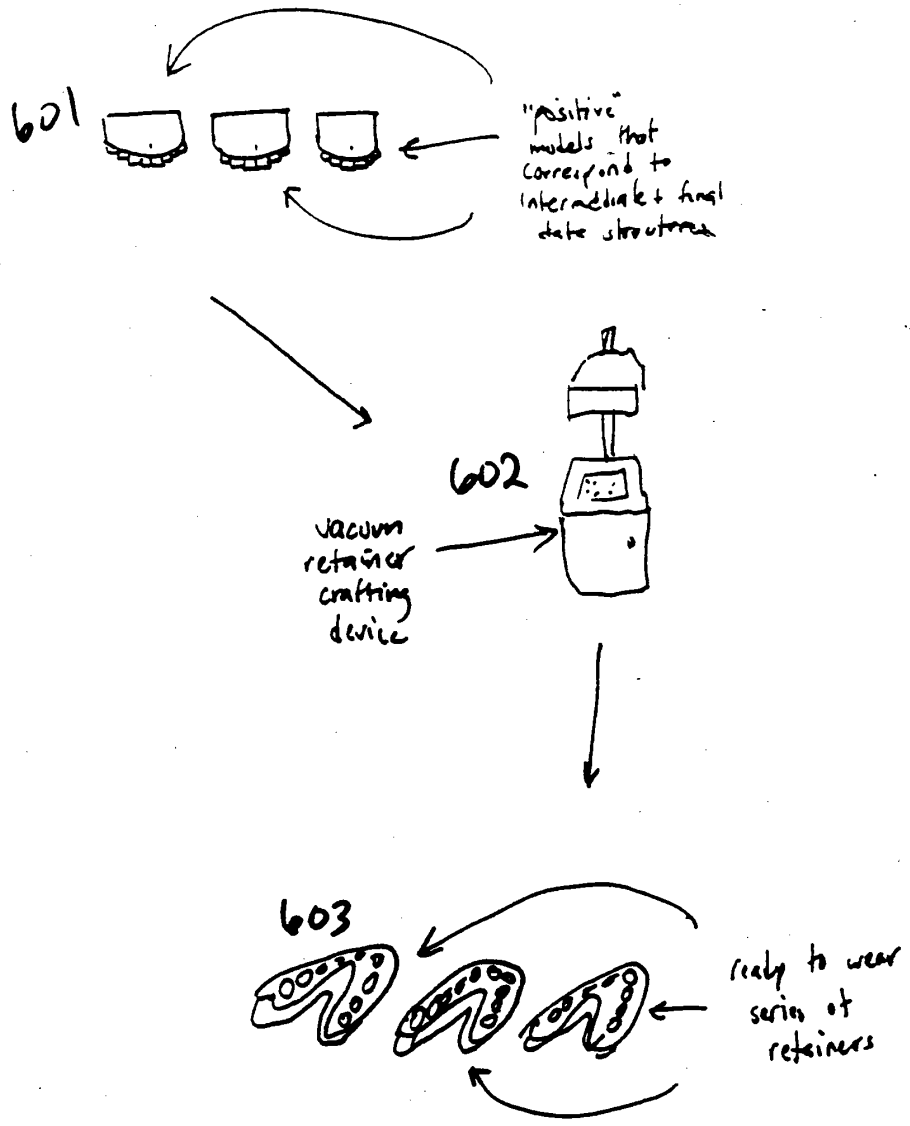


FIGURE 6 (2 of 2

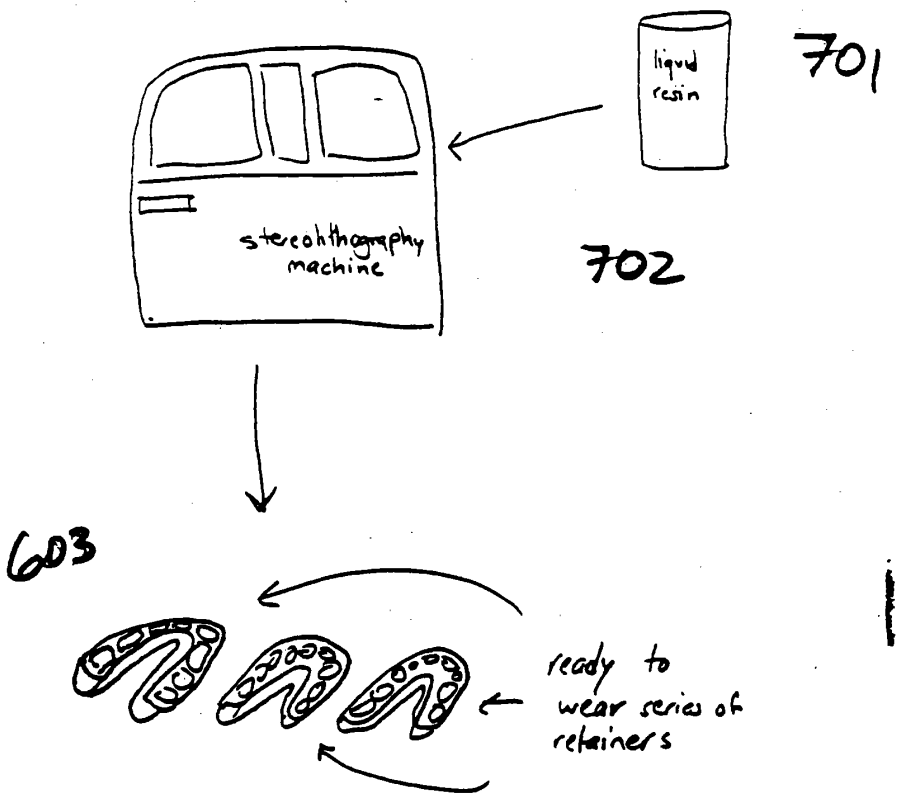

liquid resin
701
stereolithography machine
702
603
ready to wear series of retainers

FIGURE 7

Three-Dimensional Analysis of Dental Casts by Means of the Optocom

F. P. G. M. VAN DER LINDEN, H. BOERSMA, T. ZELDERS, K. A. PETERS and J. H. RAABEN

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Recent technical developments in analyzing dental casts involve computer graphic techniques (BIGGERSTAFF, *Angle Orthodont* 40:28, 1970) and the direct collection of numerical data in a two-dimensional way (SAVARA and SANIN, *Am J Phys Anthropol* 30:315, 1969). The method described here allows the collection of three-dimensional data and treats the upper and lower casts as one unit.

The main instrument, the Optocom, is a microscope mounted over a two-dimensionally movable table (Illustration, *a*). A dental cast attached to a base is placed on the sliding table in a fixed position by means of precision pins and holes. The magnification factor is ten; the field of depth without adjusting is 5 mm. A point to be recorded must be aligned with the center of two cross wires in the microscope. The position of the sliding table is recorded in tenths of a millimeter by using two measuring rules with photoelectric screening heads mounted on the bottom of the sliding table. Two foot and seven hand switches transmit the information from the Optocom through the data converter (*b*) to the Teletype (*c*). All information is typed out on the Teletype and punched on paper tape.

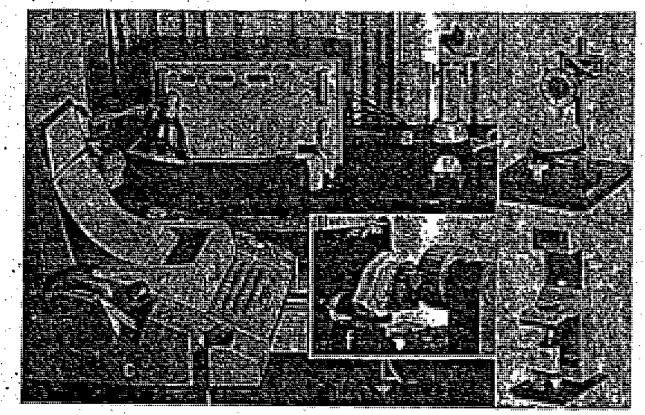
To treat the upper and lower casts as one unit, an orientation tower was built (*d*). This tower has two parallel platforms with corresponding precision pins. First the upper cast is adjusted on its base by making the occlusal plane parallel to the base surface (*e*). Then, both mounted casts are placed in the tower, the mandibular cast is brought down with the vertically movable upper platform into correct relationship and into occlusion with the maxillary cast, and the universal joint of the platform of the mandibular cast is tightened.

To record the third dimension, the base with the cast is placed vertically in a slot at the beam that carries the microscope. A pointer, mounted on a revolving head that is fixed on a standard base, then is placed on the sliding table and used to record the *z* coordinate (*f*).

It takes about 20 minutes for an experienced operator to record one set, which involves 387 points in a complete dentition. The accuracy of the method is high. Special computer programs have been developed to spot operator mistakes and to check validity of data collected.

The information gathered with the method described makes it possible to study many aspects of the dentition and to analyze numerous variables in all types of combinations.

Additional information available on request to authors.
Received for publication November 16, 1970.



a, Optocom, main part is not visible and is situated under the table top; *b*, data converter; *c*, Teletype; *d*, orientation tower; *e*, device to level occlusal plane; *f*, base with revolving head to record height values on vertically placed cast.

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Experientia 20:612, 19

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Note: Values
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A New Method to Determine Tooth Positions and Dental Arch Dimensions

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Dental arch width dimensions have been measured by use of certain cusp tips (MOORREES, *The Dentition of the Growing Child*, 1959) or points at the lingual cervical margin of the teeth (BAUME, *J Dent Res* 29:123, 1950) as reference points. However, cusp tips wear off, vary in number and location, and do not allow adequate transformation from the deciduous canines and molars to their successors (Fig 1). Points at the lingual cervical margin are affected by the buccolingual width of a tooth and its eruption level.

Recent technical developments involve computer graphic techniques in handling dental cast information as recorded by occlusal photographs (BIGGERSTAFF, *Angle Orthodont* 40:28, 1970) and the direct collection of numerical data from dental casts in a two dimensional (SAVARA and SANIN, *Am J Phys Anthropol* 30: 315, 1969) or three dimensional way (VAN DER LINDEN, *IADR Program and Abstracts of Papers*, No. 286, 1970). With both approaches the construction of more appropriate reference points can be realized.

Reference points to determine tooth position and dental arch dimensions should represent the real position, the "center" of the crown, and be independent of number of cusps, location of cusps, abrasion, and eruption level.

Additional information available on request to author.
Received for publication December 6, 1971.

Depending on the anatomy of the tooth crowns these requirements can be met by using two or four points located at the circumference of the crown (Fig 2). For incisors and canines the mesial and distal midpoints are recorded and the point halfway between these two midpoints is used as the registration point for tooth position. For the premolars and deciduous first molars the most buccal and lingual points also are used and the point halfway between the latter is calculated. The midpoint between the two halfway points is used to represent the premolars and the deciduous first molars. For permanent molars the same procedure as described for the front teeth is followed. The most buccal and lingual points on the permanent molars are frequently too far away from the middle to be used in determination of the tooth position as indicated. The same is true for the buccal and lingual fissures. Second deciduous molar crowns resemble strongly the permanent ones, and are treated as such.

The reference points advocated can be used to evaluate arch form as well as arch dimensions. Because they are expressed in x and y coordinates, a large number of variables can be studied.

The points discussed are only some of the reference points that can be used in dental cast analyses. For other purposes, such as the recording of the space relationships within the dental arch, the contact points must be used.

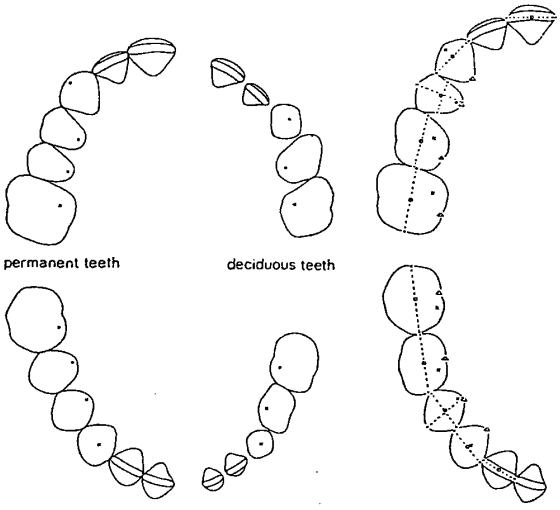


FIG 1 (*left*).—Differences in cusp number and location lead to variation in reference points when cusps are used (x).

FIG 2 (*right*).—Constructed reference points (o) compared with cusp points (x) and points at lingual cervical margin (Δ).

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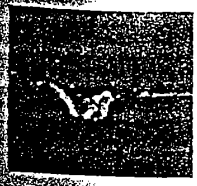


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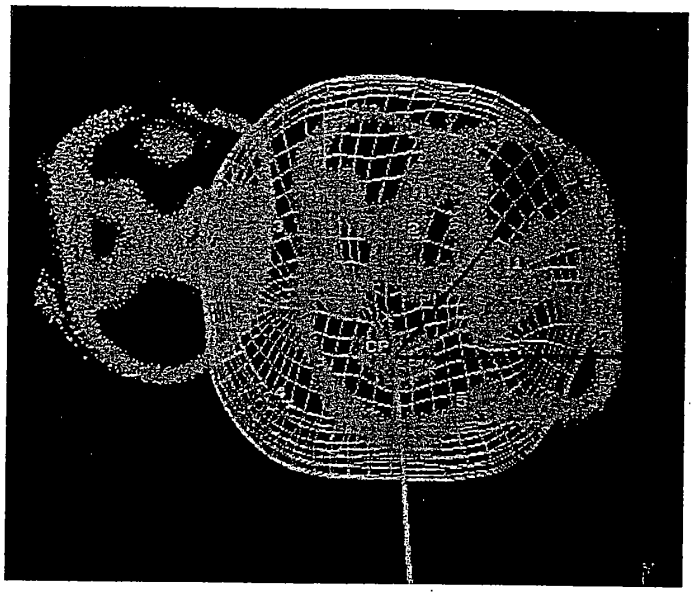
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Ceramic-fused-to-metal restorations with a new CAD/CAM system

Jef M. van der Zel*

Experience has shown that a cast restoration will rarely have proper occlusal contacts. One possible solution could involve the application of a computerized design and fabrication system for restorations with accurately calculated and computer-milled occlusal surfaces. The Cicero system for the production of ceramic-fused-to-metal restorations makes use of optical scanning, nearly net-shaped metal and ceramic sintering, and computer-aided crown fabrication techniques to fabricate restorations with maximal static and dynamic occlusal contact relations. The Cicero system produces crowns, fixed partial dentures, and inlays with different layers, such as metal and dentin and incisal porcelains, for maximal strength and esthetics. Fabrication of a crown for a mandibular first molar is described to demonstrate the computer-based design system.
(Quintessence Int *1993;24:769–778*).

troduction

chievement of dental articulation (occlusion) that is harmonious with an individual's mandibular movement pattern is a goal for all phases of restorative dentistry. Investigations have moved from a wider focus of bodily movements of the human mandible to the more defined focus of dental articulation.[1]

Experience has shown that a cast restoration returned from the laboratory and tried in the mouth will rarely have proper occlusal contacts. The demand for more esthetic dentistry is increasing and the dental profession is being placed under increasing pressure to fulfill this demand. Ceramics more closely approximate the physical and chemical properties of enamel than do composite resins. It is therefore not surprising that the use of porcelain restorations is increasing each year.[2,3] Dental porcelain, however, is the most difficult of all restorative materials with which to develop accurate occlusal surfaces. The dental technician not only has to contend with high firing shrinkages, but also the hardness of dental porcelain that makes the carving of occlusal surfaces more difficult. It seems common to see overcontoured and esthetically displeasing crowns.

Another problem is that careful registration of mandibular movements and its translation to the dental laboratory is too laborious for an economic and practical execution. With the help of the combination of optoelectronics, computer techniques, and sinter-technology, it is possible to morphologically shape crowns in a computer-automated way. Registration of mandibular joint movements or of the functionally generated path in the mouth provides the necessary data for an interference-free escape of cusps from their fossae.

In the laboratory, a crown is cast with the lost wax method in a preheated mold, finished and veneered with porcelain, which is built up and fired in different layers until proper occlusal contacts are obtained. Then the restoration is checked for interferences in an articulator. This method requires at least two visits, during which provisional restorations are placed.

Since 1985 four major computer-aided design/computer-aided machining (CAD/CAM) systems for fabricating prostheses have emerged.[4–7] The Duret (French) system (Sopha Bioconcept), the Minnesota

'ephant Industries, Verlengde Lageweg 10, 1628 PM Hoorn, The .etherlands.

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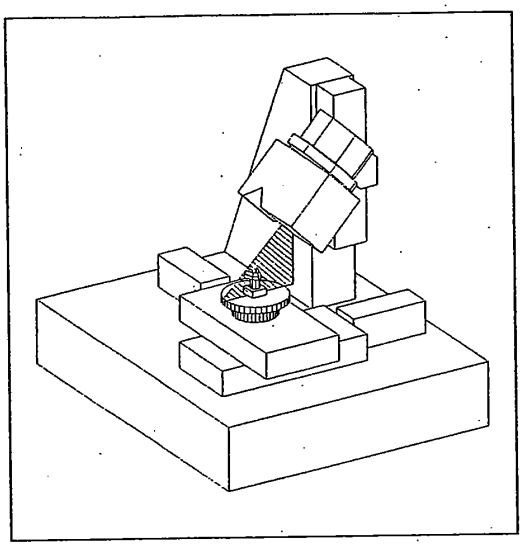


Fig 1 Setup of the laser scanner.

system (Denticad), and the Cicero (Dutch) system (Elephant Industries) are the only three capable of producing complete crowns and fixed partial dentures. The Cerec (Swiss) system (Siemens) is limited to inlays, and the occlusal surface must be manually created after the inlay is seated.

The Cicero (computer-integrated crown reconstruction) CAD/CAM system for the production of state-of-the-art ceramic-fused-to-metal (CFM) restorations makes use of optical scanning, nearly net-shaped metal and ceramic sintering, and computer-aided fabrication techniques. Alloy sintering eliminates casting and therewith many processing steps in the fabrication of metal-ceramic restorations. This makes the fabrication process adaptable for automation. Existing CAD/CAM applications for the production of restorations with accurately calculated and computer-milled occlusal surfaces[8,9] are based on milling of solid materials. The Cicero system produces crowns, fixed partial dentures, and inlays with different layers, such as metal and dentin and incisal porcelains, for maximum strength and esthetics.[10-14] It is to be used for the production of restorations with maximal static and dynamic occlusion. An extensive study indicated that the crowns had properties equivalent or superior to those of conventionally produced crowns at a reduced production cost.[12] The purpose of this paper is to show the design and fabrication of a mandibular first molar (tooth 46) with the Cicero CAD/CAM system.

Technique

Computer surface digitization

The first step in the automated fabrication of a metal-ceramic crown is the optical impression with computer surface digitization.

The Cicero CAD/CAM system makes use of a fast laser-stripe scanning method to measure the three-dimensional geometry of the preparation and its immediate surroundings and the opposing teeth (Fig 1). A straight laser stripe is deformed by the occlusal geometry. A charged-coupled device (CCD) camera scans the projected line and a computer calculates the points by triangulation.[15]

The optical sensor consists of a helium-neon laser, a CCD video camera, acquisition and enhancement software, design software, and an error accommodation provision. The wavelength of the helium-neon laser (640 nm) is within the sensitivity range of the CCD camera. The laser is expanded by a zoom line projector into a long, thin stripe and projected onto the gypsum cast. The light sections are captured by the CCD video camera placed at a known angle to the laser-preparation line. The video information of the consecutive sections is converted to three-dimensional xyz data under microcomputer control and is transmitted to the CAD system.[16]

The 0.3-mm-thick focus laser and the 600 × 625-pixel CCD camera will give a reproducibility of 0.02 mm on each point.

First an impression is made of the arch with the prepared teeth. This step must proceed with the greatest possible accuracy. Then a gypsum cast is obtained. The gypsum cast of the model that contains the preparation is prepared for scanning by indicating the preparation line on the cast with black and white contrast paint.[15] This unique feature of the scanning method makes it possible for the computer to automatically "grab" the preparation line, instead of requiring the operator to trace it afterwards on the screen with an input device, such as a mouse (Fig 2). It also allows great freedom in the preparation method used.

Digitizing the information from a cast rather than directly in the mouth is a compromise, because direct scanning in the mouth still poses many problems. Al-

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...n a silicone impression might be criticized, it ... all the advantages in connection with gingival ...reparation margins.[17]

The cast is placed in the scanner clamping device, ...hich has a ball-and-socket table that can be tilted ...nd locked in a direction so that the path of insertion ...oincides approximately with the vertical z-axis of the ...canner. The clamp of the rotation table is mounted ...n two linear translation tables perpendicular for x- ...nd y-axes.

To prevent a jitter effect during the scanning of both the preparation cast and the checkbite, a special gypsum and checkbite wax are used for optimal reflectivity.[16]

The system is rapid and can supply approximately 100,000 surface points per minute. This is such a high definition that filtering can be used without any loss of information. The accuracy increases with the density of points on the surface.

The checkbite on the cast is scanned first. After removal of the checkbite from the cast, the cast with the preparation is scanned. In this way the preparation and the opposing tooth will be directly in the same coordinate system. A rough overall scan of the ...le of the cast is made and converted to a multi- ...ed iso-Z chart. In this relief map of the scan, the ...al point, the center of the restoration, and the point at the intersect of the connecting line with the saggital plane are marked by clicking on the screen with the mouse. From this information the position of the restoration in the masticatory system is known, and the Cicero scanner software can now generate an intelligent scanning protocol according to a special strategy. The problem of inaccessible, overlapped and shadowed parts is solved by scanning the preparation in multiple rotationable positions. The fully automatic scanning of the checkbite and the cast, including conversion of the data, does not take more than 15 minutes.

Computer-aided crown design

A mandibular first molar (tooth 46) was designed on a die with a chamfer preparation. The preparation and its immediate surroundings, including a checkbite of the opposing teeth, were digitized with the Cicero scanner (Fig 4). First the die in the scan is cropped in occlusal and buccal views on the screen to remove ...s many surrounding points as possible to speed up ...ematical processing. The die, consisting of approximately 60,000 points, is converted to a meshed spline surface of 5,000 control points or more if desired (Fig 5).

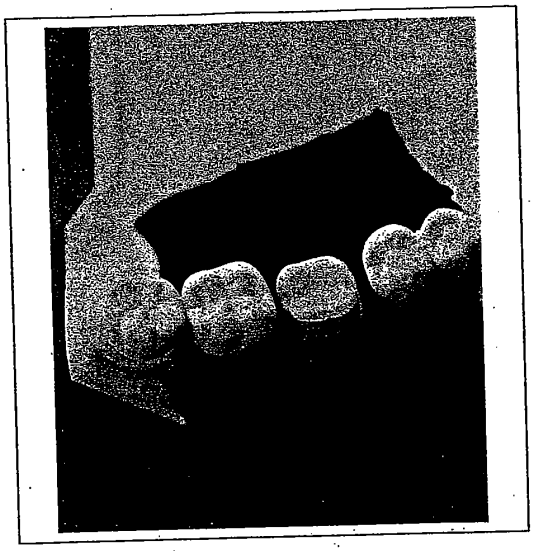


Fig 2 Gypsum cast with the preparation marked in black and white contrast.

The appropriate tooth is then chosen by the operator from an extensive collection of generic forms of theoretical teeth in the program's library (Fig 6). A special program can be used to add more forms to the library by scanning the desired cast of the tooth and indicating some functional occlusal surface references (eg, fossae, cusp line, fissures, and slopes) on the scanned relief surface with an input device, such as a mouse. Between the major landmarks a certain number of splines are then interpolated on the surface of the scanned cast of the crown.[18]

The distal and mesial contacts indicated by the operator in the occlusal and buccolingual views of the scan form the first step in the fitting of the generic tooth. The margin line of the new crown is adjusted to the preparation line that was isolated automatically from the scan of the die. The lingual and buccal boundaries are clicked in with the mouse, to shape the tooth so that it fits in a natural-appearing row with the adjacent teeth. A warping algorithm generates a deformation field and deformation vectors within the field to generate the new form as directed by the drag vector indicated with the mouse. This way the external contours of the new crown can be ad-

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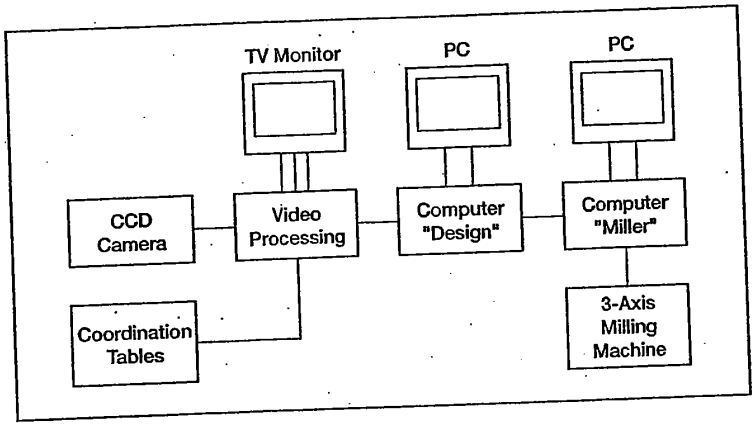


Fig 3 Flow diagram of the Cicero system.

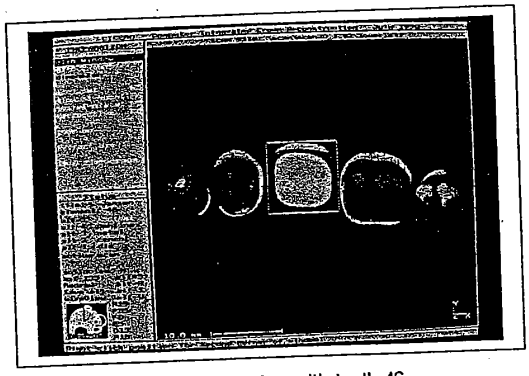


Fig 4 Scan of the preparation with tooth 46.

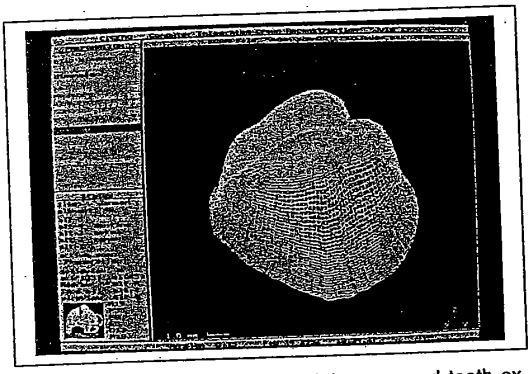


Fig 5 Meshed, splined surface of the prepared tooth extracted from the scanned data.

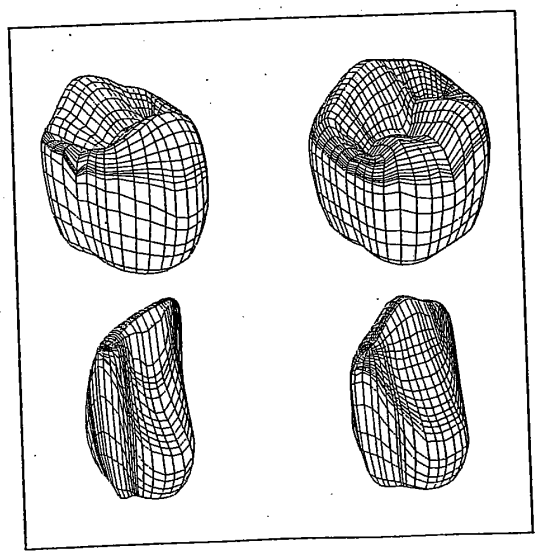


Fig 6 Examples of teeth in the generic tooth shapes.

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ed interactively with the mouse, in much the same y of the building up of porcelain by brush or spatula, to obtain maximum esthetics.

The new crown is then superimposed on the opposing tooth, which is displayed on the screen as a multicolored relief map (Fig 7).

The core of the CAD program is formed by an expert system that deforms the generic tooth parametrically (with conservation of shape) according to gnathologic rules. The crown for tooth 46 was deformed by a seven-step algorithm to give maximal tooth-to-tooth contact with the antagonist. The mesiolingual cusp, distobuccal cusp, distal marginal ridge, distolingual triangular ridge, mesial marginal ridge, and mesiolingual triangular ridge of the maxillary first molar are indicated to close in on possible fields of contact.

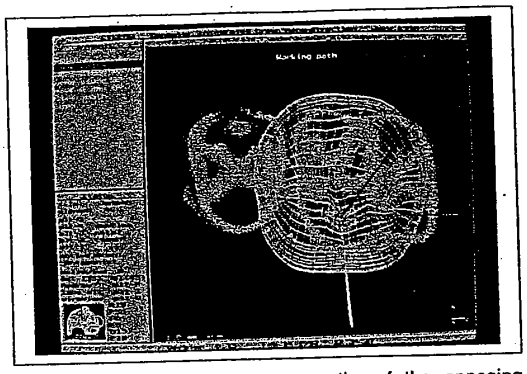


Fig 7 New crown with escape paths of the opposing tooth's main cusp during mandibular movements.

Mathematical articulation model

The aim of tooth design is that cusps should escape and return to their fossae without interferences. Mandibular movements in three dimensions have been simulated by dental articulators whose condylar and incisal guides define the maxillomandibular movement patterns. A three-dimensional locus of points ribed by a cusp tip of one dental arch transversing an opposing occlusal surface may be described as an arc or pathway of movement. These can be obtained by registering the functionally generated path obtained by chewing movements or by registration of the movements of the mandibular joints. In this last case it is possible to calculate the working, balancing, and protrusive pathways and run a simulation of these chewing movement paths of the opposing teeth against the new restoration by the computer, whereby any interferences are removed by withdrawal of the interfering surface as controlled by a parametric warping algorithm.

The optimal type of occlusion that can resist differences in abrasion rate between enamel and porcelain surfaces must conform to one that provides minimal tooth contact outside centric relationship. The three-dimensional pathways that the supporting maxillary or mandibular cusps follow during mandibular movements are computed mathematically.

A model of the craniomandibular system was developed in a way that simulates the action of the human stomatognathic system. All elements of the biomechanic model are incorporated into the mathetical model and can be varied. Initial standard or default settings other than zero are selected for certain parameters. The default setting for the intercondylar distance is 110 mm, or 55 mm on either side of the midline. The standard medial wall configuration, or Bennett angle, is 10 degrees, and the standard anteroposterior condylar inclination is 35 degrees.

Other variables are related to the location of the dental arches within the model system. The standard location of the incisal edges of the mandibular incisors is 85 mm anterior to and 33 mm inferior to the horizontal (transverse) axis. The initial inclination of the occlusal plane is parallel to the horizontal.

The condylar and incisal controls of the mathematical model have limits of the natural model imposed on their ranges. The location of the simulated arches is also limited to keep the arches within the confines of normal anatomy. Registrations such as electronic axiography can be used to change the default settings in the computer.

Incremental locations of the supporting cusp tips, guided by the simulated condylar guides, are computed and recorded in three dimensions. Working, balancing, and protrusive pathways for the new restoration are computed.

It is possible that a choice is made for the functionally generated path technique instead of a full axiographic registration of movements of the mandibular joints. Especially in the case of a single-crown restoration this might be more realistic. The registration of the movement envelope of the opposing teeth in the functionally generated path impression can be scanned, and the surface obtained can be used to de-

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termine the appropriate contacts. Of the occlusal contacts normally required by classic gnathologic concepts, about 50% are eliminated by using the functionally generated path technique. The strong muscular influence on function and dysfunction in relation to a three-dimensional immediate sideshift on a functionally occlusal morphology becomes thus more pronounced.[19]

Vertical contacts are made with the opposing tooth at the mesiolingual cusp, distobuccal cusp, distal marginal ridge, distolingual triangular ridge, mesial marginal ridge, and mesiolingual triangular ridge of the maxillary first molar (Fig 8). Some contacts will also be found on the maxillary second premolar.

It is possible to use the three-dimensional movement as measured with any available axiographic registration computer. The registration data obtained are transferred into the computer and the software uses the data of the registered mandibular movements to calculate escape pathways of the opposing teeth from the new tooth in three dimensions.

After the interior and exterior tooth surfaces have been designed (Fig 9), this is followed by the definition of the different interface surfaces between cement and metal and between dentin and incisal porcelain (Fig 10). The Cicero software calculates the interior surface (corrected with marginal gap, overall cement thickness, and metal-die cement thickness) and the different interfaces between the material layers as specified by the operator. The build-up of the crown ensures that, if the cement thickness between the metal and the die has been defined smaller than the marginal cement gap, the metal protrudes from the porcelain on the inside, forming a step-up in metal that will take most of the load exerted on the crown during placement and during mastication. The stress on the porcelain shoulder will be relieved because the metal substructure is closest to the die. This means that no restrictions are posed on the type of preparation chosen and that metal-free porcelain shoulders can be used for maximal esthetics. A perfect marginal fit can thus be obtained between porcelain and die. The accurate fit of the restoration no longer depends on material properties that are difficult to predict.

Computer-aided crown machining

The tools are positioned in the tool exchange clamps (Fig 11). Standard diamond-coated grinding tools are used, and the exactly measured dimensions of each of the individual tools are entered into a dialog window of the Cicero Miller software on the screen through the keyboard.

Figure 12 shows the movement paths of the following cutting tools: an 9.3-mm-diameter diamond disk grinder, an 0.9-mm round diamond grinder, and a pointed fissure grinder for the accentuation of fissures. The tools are automatically changed as they are used and reset against a zero-switch.

For each tool the CAM software sets the milling spindle to a specific rotation speed, mostly between 30,000 and 45,000 rpm, to prevent resonance and vibration of the tools. The lifetime of the tools is prolonged by the application of a water jet that simultaneously cools and cleans the tools during milling.

The Cicero milling software performs computations to prevent the offset tool paths from erroneously intersecting with the prosthesis surface, designed during the CAD phase. The software checks the minimum radii of principal curvature at the vertices or the original contour lines. The tool is withdrawn until a correct tool contact point is found.

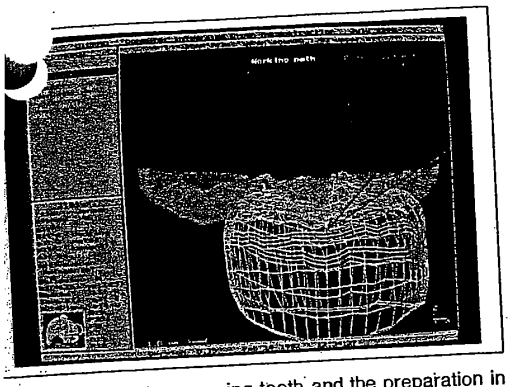
Factory-standardized, preformed Cicero refractory blocks for single elements, which have a precision fit in the milling machine clamping device, are made of material that resembles that of the refractory investments used in the fabrication of ceramic inlays and veneers. The blocks used for single crowns are cylindrical with a diameter equal to the maximal mesiodistal tooth diameter (Fig 13).

The refractory block is fixed in a high-precision vice in the milling machine and the inside surface of the crown is milled, with a diamond-coated disk and a round diamond-coated bur, within 10 minutes (Fig 14).

The next step is the sintering of a thin layer of Synthobond alloy powder (Elephant Industries) on the refractory block, where this is needed for strength purposes (Fig 15). The powder consists of a new type of low-melting, high-expansion gold alloy Carrara PdF (75% gold, 9% palladium, 14% silver, and 2% zinc). The alloy shows excellent biologic and corrosion stability.[20]

The next material applied is Cicero porcelain, in the appropriate shade. This is a special fine-grained, lucite-strengthened ceramic in the form of a colloidal vacuum-kneaded paste. A paste porcelain tablet is simply cold-pressed on the metal-covered refractory shape and fired under standardized conditions under vacuum in a porcelain furnace. After it is fired, the porcelain has a high density and can be easily ground to a feather edge without chipping, because it adheres

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ig 8 Points of the opposing tooth and the preparation in he buccolingual direction.

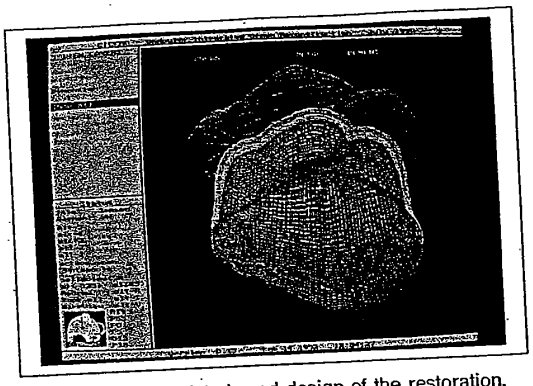


Fig 9 Completed data-based design of the restoration.

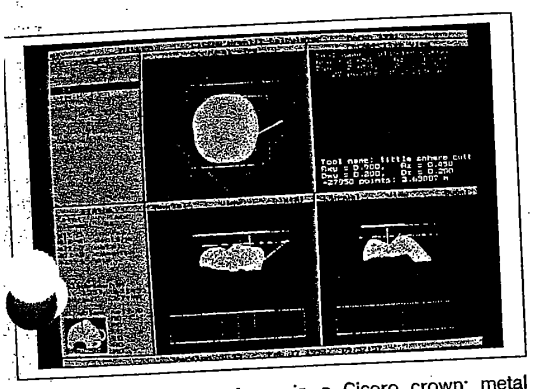


Fig 10 Buildup of interfaces in a Cicero crown: metal (blue), dentin (red), and incisal (green).

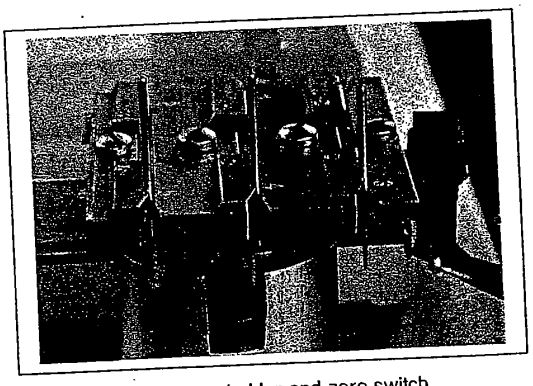


Fig 11 Tool exchange holder and zero-switch.

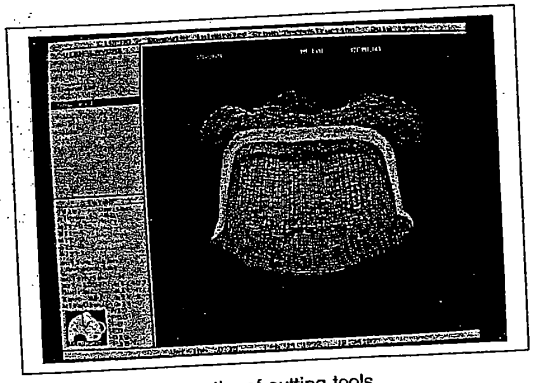


Fig 12 Movement paths of cutting tools.

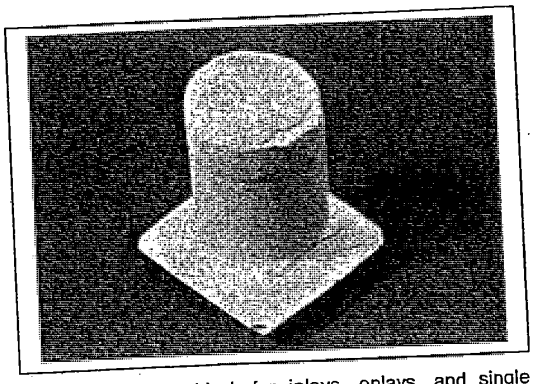


Fig 13 Refractory block for inlays, onlays, and single crowns.

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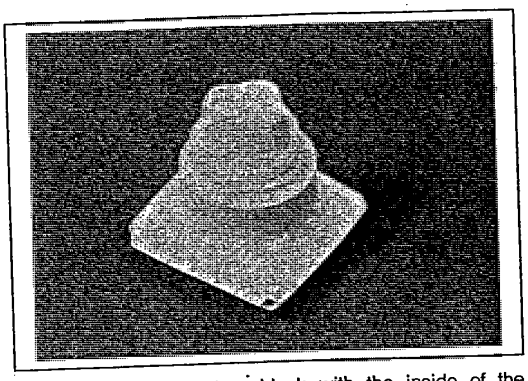


Fig 14 Ground refractory block with the inside of the crown.

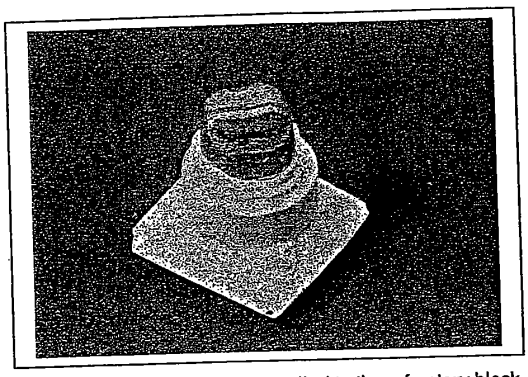


Fig 15 Sintered metal layer applied to the refractory block.

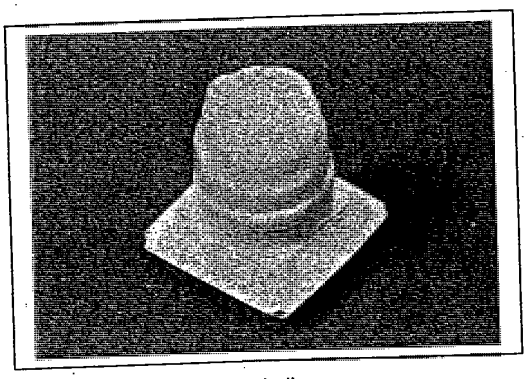


Fig 16 Dentin layer after grinding.

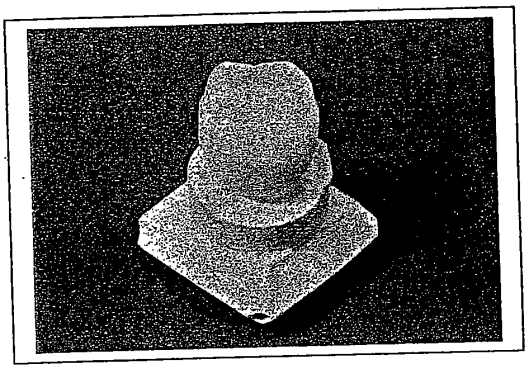


Fig 17 Incisal layer after grinding.

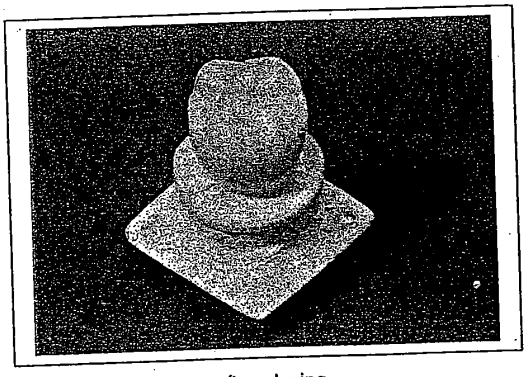


Fig 18 Ground crown after glazing.

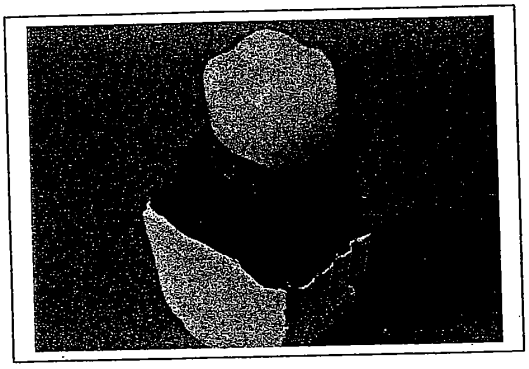


Fig 19 Completed Cicero crown on the cast.

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and is supported by the refractory block and the synthobond layer.

After firing of the porcelain, the refractory block is placed back into the precision vice of the milling machine and the interface of dentinal and incisal porcelains is milled in 15 minutes (Fig 16). Then incisal porcelain is cold-pressed over the dentinal porcelain and fired, and the external surface of the crown is milled in 20 minutes, including the characterization grooves of the fossae (Fig 17). The crown is milled along the primary fossae, the cusp line, the equator line, the margin line, and between these lines. This ensures a sharp but smooth marginal edge (Fig 18) with a marginal gap of up to 50 μm. Preliminary clinical investigations have shown that marginal gaps at least comparable to those of traditionally cast crowns can be obtained[21] (Van de Vijver HL, personal communication, 1992).

The Cicero milling program will interpolate extra tool paths in case the paths are not spread densely enough over the external surface, to obtain a smooth texture on the surface after grinding. Higher porcelain removal rates can be obtained when higher working engagement is applied. However higher power density methods can affect the surface integrity. The Cicero milling software extensively optimizes these grinding parameters.

The last step in the fabrication includes individual staining and glazing of the external surface at a low glazing temperature. Because the surface is finished to a fine texture, an extremely smooth porcelain surface is obtained. If glazing powder is used, the fine irregularities obtained through morphologic grinding of the occlusal surface become filled with the powder and get flat and smooth. As a result the glazed surface becomes less natural. Therefore the use of self-glazing by heating to a predetermined temperature is recommended. A quick elevation to this temperature softens only the superficial layer and, therefore, enables creation of a superiorly glazed surface that reproduces the fine details without causing slumping (Fig 19). At the same time, the surface integrity that might have suffered from the grinding operation will be restored during this final glazing step.

Polishing of the final restoration is not necessary because the glazing step is performed as a final treatment before the refractory die is removed by grinding and air abrasion in the usual manner. The smooth final surface of the new crown minimizes abrasion of the opposing teeth.

Results

When placed on the cast in the articulator, a piece of blue contact paper shows the location of the occlusal contact points between the newly fabricated crown and the opposing teeth. The marginal gap is checked by placing the crown on the cast. The scanning electron microscope indicates the accuracy of the margin to be within 50 μm. The accuracy is an accumulation of deviations in the different steps of the CAD/CAM system and can differ from the value for the marginal gap (normally 25 μm) that was entered in the dialog window of the CAD software.

The striation texture that can be found on the crown on careful examination after glazing is comparable with that found on the teeth of young persons. These natural crown surfaces show fine irregularities running horizontally. In principle, they run from the center of the incisal tip mesiodistally at a right angle to the longitudinal axis of the tooth. These stripes encircle the coronal portion without intersecting each other in much the same way as the tools striate the artificial crown during fine grinding.

Discussion

This article has emphasized the application of the Cicero CAD/CAM system for the production of a metal-ceramic crown for tooth 46. The Cicero system deviates from the other CAD/CAM techniques developed recently in that it makes use of a layered crown for better strength and esthetics. Metal structure–sintering techniques will give a durable support to crowns, fixed partial dentures, and inlays made with this CAD/CAM system. The esthetic and functional requirements generally accepted for state-of-the-art ceramic-fused-to-metal restorations can be fulfilled by this new fabrication method.

Although functional and esthetic demands can be met with the automated production system, attention should also be directed to the important cosmetic requirements, including color-related aspects. Internal staining, varying the thickness of the translucent incisal porcelain layer and appropriate external staining applied to the occlusal fossae and the cervical region are some of the methods that can be used. The metal-free stress-relieved porcelain shoulder plays an important part in the esthetic quality of the restorations.

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Reverse Engineering of Geometric Models - An Introduction

Tamás Várady, Ralph R Martin & Jordan Cox
Computer-Aided Design, Vol. 29 (4) pp. 255-268, April 1997.

Abstract

In many areas of industry, it is desirable to create geometric models of existing objects for which no such model is available. This paper reviews the process of reverse engineering of shapes. After identifying the purpose of reverse engineering and the main application areas, the most important algorithmic steps are outlined and various reconstruction strategies are presented. Pros and cons of various data acquisition techniques are described with related problems of boundary representation model construction. Specific issues addressed include characterization of geometric models and related surface representations, segmentation and surface fitting for ***simple*** and ***free-form*** shapes, multiple view combination and creating consistent and accurate B-rep models. The limitations of currently known solutions are also described, and we point out areas in which further work is required before reverse engineering of shape becomes a practical, widely-available engineering tool.

Keywords : CAD; geometric modelling; reverse engineering; scanning; segmentation; surface fitting; boundary models.

Notes

The shape model representation is fundamental as it determines the computational algorithms applied to the data sets.

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Reverse Engineering of Geometric Models - An Introduction

Tamás Várady * Ralph R. Martin † Jordan Cox ‡

13 May 1996

Abstract

In many areas of industry, it is desirable to create geometric models of existing objects for which no such model is available. This paper reviews the process of reverse engineering of shapes. After identifying the purpose of reverse engineering and the main application areas, the most important algorithmic steps are outlined and various reconstruction strategies are presented. Pros and cons of various data acquisition techniques are described with related problems of boundary representation model construction. Specific issues addressed include characterization of geometric models and related surface representations, segmentation and surface fitting for simple and free-form shapes, multiple view combination and creating consistent and accurate B-rep models. The limitations of currently known solutions are also described, and we point out areas in which further work is required before reverse engineering of shape becomes a practical, widely-available engineering tool.

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1 Introduction

Reverse engineering is a rapidly evolving discipline, which covers a multitude of activities. In this paper we will only be concerned with reverse engineering of shape, but a broader interpretation of the term to involve understanding of design intents and mechanisms is also possible. While conventional engineering transforms engineering concepts and models into real parts, in reverse engineering real parts are transformed into engineering models and concepts. The advantages of the extensive use of CAD/CAM systems need not be reiterated here. The existence of a computer model provides enormous gains in improving the quality and efficiency of design, manufacture and analysis. Reverse engineering typically starts with measuring an existing object so that a surface or solid model can be deduced in order to exploit the advantages of CAD/CAM technologies.

There are several application areas of reverse engineering. It is often necessary to produce a copy of a part, when no original drawings or documentation are available. In other cases we may want to re-engineer an existing part, when analysis and modifications are required to construct a new improved product. In areas where

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aesthetic design is particularly important such as in the automobile industry, real-scale wood or clay models are needed because stylists often rely more on evaluating real 3D objects than on viewing projections of objects on high resolution 2D screens at reduced scale. Another important area of application is to generate custom fits to human surfaces, for mating parts such as helmets, space suits or prostheses.

It seems important to clearly distinguish between the concepts of a *3D copier* and a *3D scanner*. A photocopier takes a piece of paper and produces another piece of paper just like the original. A 3D copier is a device which takes a solid object and makes another one of just the same shape (let us ignore material). In fact, copy machining has been a well established technology for a long time. A scanner however, in 2D, not only inputs a page of text into the computer, but can also recognize the characters and figures, thus providing a text file and graphical structures. Similarly, a 3D scanner will not only capture raw data from the object, but the data will be interpreted and some computer model will be created. Now, not only may a single copy be generated, but knowledge of the shape is obtained, and thus we can derive new shapes, make variations, analyze properties and determine characteristic quantities such as volume or surface area.

The ultimate goal of reverse engineering systems is to realize an intelligent 3D scanner. However, there is a long way to go. Even capturing shape and translating it into a CAD model is a difficult and complex problem. In spite of several encouraging partial results in particular areas, a fully automatic solution to build a complete and consistent CAD model is still a goal. The purpose of this paper is to describe the most important elements of a reverse engineering system and to identify problems, which still require further research. At the same time, we attempt to summarize the basic achievements of current reverse engineering research, as well.

The reverse engineering procedure can be characterized by the flowchart in Figure 1:

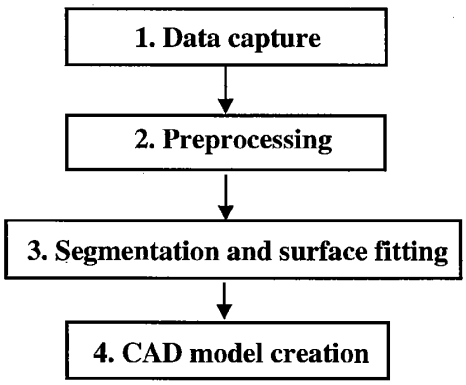


Figure 1: Basic phases of reverse engineering

Of course this sequence is fairly notional. In fact, these phases are often overlapping and instead of the sequential process shown, several iterations are required. Nevertheless, this outline may help the reader to understand the information flow and serves as a basis for organizing the content of our paper.

A crucial part of reverse engineering is *data acquisition*. After reviewing the most important measuring techniques, the relative merits and difficulties associated with these methods are discussed. Often, methods for reverse engineering are developed

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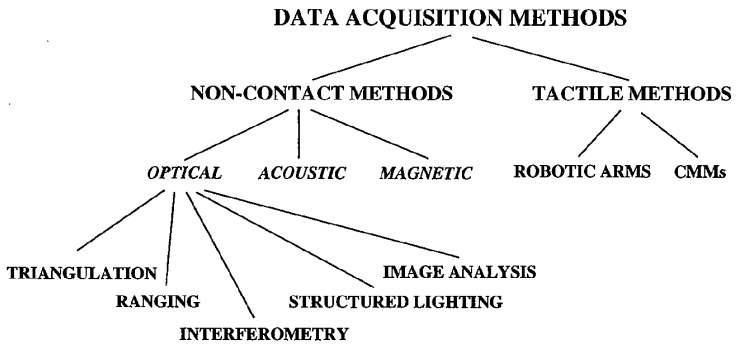


Figure 2: Classification of data acquisition methods

based on simulated data acquisition only. Our experience is that a certain amount of reservation is needed in such cases, as actual physical measurements may display many problems and undesirable side effects not present in artificial data.

As was indicated earlier, the main topic of this paper is the geometric part of reverse engineering. Data structures for representing shape can vary from point clouds to complete boundary representation models. We give later a *hierarchy of shape models*. This is particularly important since the representation chosen fundamentally determines the computational algorithms applied to the data sets.

The most critical part of reverse engineering is *segmentation and surface fitting*. By means of these processes, data points are grouped into sets to which an appropriate single surface can be fitted. We believe that segmentation and surface fitting methods must be carefully matched to each other. A range of techniques and problems will be described in the following sections, including methods for various surface representations used in CAD ranging from planes and quadrics to composite free-form surfaces.

Data acquisition systems are constrained by physical considerations to acquire data from a limited region of an object's surface. Hence, multiple scans must be taken to completely measure a part. See the section on *combining multiple views*.

The problems of *creating geometric models* will be discussed in the last section. There are various representations providing approximate or incomplete models which may be sufficient for certain applications, such as computer vision, animation, collision checking etc. For CAD purposes this is not so. Here we restrict our scope of interest and concentrate on accurate and consistent boundary representation models, using standard surfaces acceptable by commercial CAD/CAM systems. Identifying sharp edges, adding blends, providing proper continuity where smooth connections are needed, tidying up the model and enforcing constraints are all part of the problem.

Finally, in the conclusion we present our view of the current status of this technology and what are the most important research issues. This paper is an overview, so we do not attempt to describe individual topics in detail. We try to concentrate on important conceptual issues, while hopefully the reference list at the end will help readers to find the most relevant research contributions.

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2 Data acquisition

There are many different methods for acquiring shape data, as shown in Figure 2. Essentially, each method uses some mechanism or phenomenon for interacting with the surface or volume of the object of interest. There are *non-contact methods*, where light, sound or magnetic fields are used, while in others the surface is touched by using mechanical probes at the end of an arm (*tactile methods*). In each case an appropriate analysis must be performed to determine positions of points on the object's surface from physical readings obtained. For example, in laser range finders, the time-of-flight is used to determine the distance traveled, and in image analysis the relative locations of landmarks in multiple images are related to position. Each method has strengths and weaknesses which require that the data acquisition system be carefully selected for the shape capture functionality desired. This section will discuss the principles of various methods and the next section will address the practical problems of acquiring data. Jarvis' paper [1] is a very good survey on the different methods of data acquisition.

Optical methods of shape capture are probably the broadest and most popular with relatively fast acquisition rates. There are five important categories of optical methods we discuss here: triangulation, ranging, interferometry, structured lighting and image analysis.

Triangulation is a method which uses location and angles between light sources and photo sensing devices to deduce position. A high energy light source is focused and projected at a prespecified angle at the surface of interest. A photosensitive device, usually a video camera, senses the reflection off the surface and then by using geometric triangulation from the known angle and distances, the position of a surface point relative to a reference plane can be calculated. The light source and the camera can be mounted on a traveling platform which then produces multiple scans of the surface. These scans are therefore relative measurements of the surface of interest. Various different high energy light sources are used, but lasers are the most common. Triangulation can acquire data at very fast rates. The accuracy is determined by the resolution of the photo sensitive device and the distance between the surface and the scanner. Motavalli and Bidanda [2] present a reverse engineering strategy using laser triangulation. Moss et al [3] present a detailed discussion of a classic laser triangulation system used to capture shape data from facial surfaces. A discussion of accuracy and applications is also included. The use of laser triangulation on a coordinate measuring machine is presented by Modjarrad [4]. These references give a broad survey of methods, approaches to and limitations of triangulation.

Ranging methods measure distances by sensing time-of-flight of light beams; practical methods are usually based on lasers and pulsed beams. *Interferometry* methods measure distances in terms of wavelengths using interference patterns. This can be a very accurate method of measurement since visible light has a wavelength of the order of hundreds of nanometers, while most reverse engineering applications distances are in the centimeter to meter range. In principle, other parts of the electromagnetic spectrum could also be used. In practice, a high energy light source is used to provide both a beam of monochromatic light to probe the object and a reference beam for comparison with the reflected light. Moring et al [5] describe a range finder based on time-of- flight calculations. The article presents some information on accuracy and performance. Jarvis [6] presents an in-depth article on time-of- flight range finders giving detailed results and analysis.

Structured lighting involves projecting patterns of light upon a surface of interest and capturing an image of the resulting pattern as reflected by the surface. The image must then be analyzed to determine coordinates of data points on the surface. A popular method of structured lighting is shadow Moiré, where an interference

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pattern is projected onto a surface producing lighted contour lines. These contour lines are captured in an image and are analyzed to determine distances between the lines. This distance is proportional to the height of the surface at the point of interest and so the coordinates of surface points can be deduced. Structured lighting can acquire large amounts of data with a single image frame, but the analysis to determine positions of data can be rather complex. Will and Pennington [7] use grids projected onto the surface of objects to determine point locations. Wang and Aggarwal [8] use a similar approach but use stripes of light and multiple images.

The final optical shape capture method of interest is *image analysis*. This is similar to structured lighting methods in that frames are analyzed to determine coordinate data. However, the analysis does not rely on projected patterns. Instead, typically, stereo pairs are used to provide enough information to determine height and coordinate position. This method is often referred to as a *passive method* since no structured lighting is used. *Active methods* are distinguished from passive methods in that artificial light is used in the acquisition of data. Correlation of image pairs and landmarks within the images are big difficulties with this method and this is why active methods are preferred. Another image analysis approach deals with lighting models, where an image is compared to a 3-dimensional model. The model is modified until the shaded images match the real images of the object of interest. Finally, intensity patterns within images can be used to determine coordinate information. There is a vast amount of literature on stereo imaging, and we just cite four papers that address this technique. Nishihara [9] uses a real-time binocular stereo matching algorithm for making rapid range measurements. Posdamer and Altschuler [10] describe a method for real time measurement of surface data using stereo methods. Also, see Woodham's work [11] on shape from shading. Finally, a contribution by Rockwood and Winget [12] in this special issue describes an energy minimization approach of a mesh to match a collection of 2D images.

Tactile methods represent another popular approach to shape capture. Tactile methods touch a surface using mechanical arms. Sensing devices in the joints of the arm determine the relative coordinate locations. These methods are mostly limited by the measuring device limitations. For example, a 3-axis milling machine can be fitted with a touch probe and used as a tactile measuring system. However, it is not very effective for concave surfaces. There are many different robotic devices which are used for tactile measurement. These methods are among the most robust (i.e. less noise, more accurate, more repeatable, etc.), but they are also the slowest method for data acquisition.

Probably the most popular method is the use of coordinate measuring machines (CMM). These machines can be programmed to follow paths along a surface and collect very accurate, nearly noise-free data. Xiong [13] gives an in depth discussion of measurement and profile error in tactile measurement. Sahoo and Menq [14] use tactile systems for sensing complex sculptured surfaces. Butler [15] provides a comparison of tactile methods and their performance.

The final type of data acquisition methods we will examine are *acoustic*, where sound is reflected from a surface, and *magnetic*, where a magnetic field touches the surface. Acoustic methods have been used for decades for distance measuring. Sonar is used extensively for this purpose. Automatic focus cameras often use acoustic methods to determine range. The method is essentially the same as time-of-flight, where a sound source is reflected off a surface and then distance between the source and surface is determined knowing the speed of sound. Acoustic interference or noise is often a problem as well as determining focused point locations. Dynamic imaging is used extensively in ultra-sound devices where a transducer can sweep a cross-section through an object to capture material data internal to an object.

Magnetic field measurement involves sensing the strength of a magnetic field source. Magnetic touch probes are used which usually sense the location and orien-

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tation of a stylus within the field. A trigger allows the user to only record specific point data once the stylus is positioned at a point of interest. Magnetic resonance is used in similar applications to ultra-sound when internal material properties are to be measured. MRI (magnetic resonance) activates atoms in the material to be measured and then measures the response. Watanabe [16] uses an ultrasonic sensor for object recognition and Tsujimura et al [17] place the ultrasonic device on a manipulator.

To sum up, all measuring methods must interact with the surface or internal material using some phenomenon, either light, sound, magnetism or physical contact. The speed with which the phenomenon operates as well as the speed of the sensor device determines the speed of the data acquisition. The amount of analysis needed to compute the measured data and the accuracy are also basically determined by the sensor type selected. On the technical parameters of various commercial 3D digitizers see the table in [18].

3 Practical problems of data acquisition

There are many practical problems with acquiring useable data, the major ones being:

- Calibration
- Accuracy
- Accessibility
- Occlusion
- Fixturing
- Multiple views
- Noise and incomplete data
- Statistical distributions of parts
- Surface finish

Calibration is an essential part of setting up and operating a position measuring device. Systematic sensing errors can occur through lens distortions, non-linear electronics in cameras, and similar sources. Any sensing must be calibrated so as to (i) accurately determine parameters such as camera points and orientations, and (ii) to model and allow for as accurately as possible systematic sources of error. Most of the papers cited present some discussion of accuracy ranges for the various types of scanners, but all methods of data acquisition require accurate calibration. Optical scanners' accuracies typically depend largely on the resolution of the video system used. Distance from the measured surface and accuracy of the moving parts of the scanning system all contribute to the overall measurement error.

Accessibility is the issue of scanning data that is not easily acquired due to the configuration or topology of the part. This usually requires multiple scans but can also make some data impossible to acquire with certain methods. Through holes are typical examples of inaccessible surfaces.

Occlusion is the blocking of the scanning medium due to shadowing or obstruction. This is primarily a problem with optical scanners. However, acoustic and magnetic scanners may also have this problem. Multiple scanning devices are one approach to obviate this problem. See Rioux [19] and Koivunen [20] for methods

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of eliminating occlusion in optical systems. As well as self-occlusion, occlusion may also arise due to fixturing—typically parts must be clamped before scanning. The geometry of the fixtures becomes a part of the scan data. Elimination of fixture data is difficult and often requires multiple views. Multiple views introduce errors in acquired data because of registration problems (see more details later).

Noise elimination in data samples is a difficult issue. Noise can be introduced in a multitude of ways, from extraneous vibrations, specular reflections, etc. There are many different filtering approaches that can be used. An important question is whether to eliminate the noise before, after, or during the model building stage. There are times when the noise should not be eliminated at all. Noise filtering, though, is often an unavoidable step in reverse engineering, but note, that this also destroys the "sharpness" of the data i.e. typically sharp edges disappear and are replaced by smooth blends, which in some cases may be desirable, but in other cases may lead to serious problems in identifying features. For an example of noise elimination see Koivunen [21].

A similar problem is restoration of missing data. This is partly necessary due to the above mentioned inaccessibility and occlusion problems. Moreover, because of the nature of optical and even tactile scanning, the data close to sharp edges is also fairly unreliable. Finally there are situations where only parts of a certain surface can be measured, there are missing parts or parts obscured by other elements, but we need to reconstruct the whole surface from just the visible parts. Further ideas on surface extensions, intersections and patching holes are given in the last part of the paper.

Statistical distribution of parts deals with the fact that any given part which is scanned only represents one sample in a distributed population. When reverse engineering methods attempt to reproduce a given shape, the tolerance distribution of the scanned part must be considered. This gives rise to multiple part scans and the averaging of the resulting data. However, it may be somewhat impractical to attempt to sample many parts from a population, and indeed, often only one is available.

The final issue we bring up is surface finish of the part being measured. Smoothness and material coatings can dramatically affect the data acquisition process. Tactile or optical methods will produce more noise with a rough surface than a smooth one. Reflective coatings also can affect optical methods. When scanning human faces noise is often introduced when the light reflects off the eye or spectacles. Hair is an example of a rough surface which presents very difficult problems in scanning.

Imagine an ideal scanner: the object is 'floating' in 3D space, so it is accessible from all directions. The data is captured in one coordinate system with high accuracy, with no need for noise filtering and registration. Possibly, the measurement is adaptive, i.e. more points are collected at highly curved surface portions, etc. Unfortunately, such a device does not exist at present. But, despite the practical problems discussed, it is possible to obtain large amounts of surface data in reasonably short periods of time even today using the methods described. Once the measured data is acquired, the process of recognition and model building can begin. The imperfect nature of the data, particularly inaccuracy and incompleteness, however, makes these steps fairly difficult as will be seen in the following sections.

4 Global characterization of shape

As indicated earlier the main purpose of reverse engineering is to convert a *discrete* data set into a *piecewise smooth, continuous* model. In this section various aspects of this conversion are described. The discrete data set typically consists of (x, y, z) coordinate values of measured data points. Concerning the *organization of data*,

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we may classify the pointset as either scattered or regular. In the former case the points come from random or manual pointwise sampling. In the latter case the measurements may have taken place along contours or slicing planes, which results in a sequence of scanlines; within each scanline there is a sequence of points. Alternatively the measurement may provide regularly organized points in two dimensions, as for example does the grid structure of range finders.

Another important issue is the *neighbourhood information.* For example, a regular grid implicitly provides neighbourhood information, which implicitly gives connectivity except at step discontinuities. In a scattered data set the neighbourhood information will be usually absent unless a specific triangulation is also associated with the data points.

Triangulated models are particularly important in computer graphics and animation, which explains why research work in this area has obtained a large momentum recently. Related work on mesh optimization and multiresolution analysis of triangular meshes can be found among others in Schroeder [22], Hoppe [23], Rossignac [24] and Eck [25]. Veron and Leon [26] describe an algorithm for polyhedron modification using error zones. Guo [27] prepares approximating polyhedra by using 3D α-shapes [28] to capture the topological structure before surface fitting. (See papers [26, 27] in this special issue).

The exact type of model created depends on the intended use envisaged for the model. One alternative is just to generate a collection of faces, i.e. planar facets or possibly higher order surface patches, without enforcing connectivity or continuity between neigbouring elements and without explicitly storing topological relationships. In this situation small gaps between the elements will not matter, assuming the bulk of the data points is compactly covered, and provided that the neighbourhood information is not needed for further computations. Typical examples include representations using superquadrics [29] or $z = f(x, y)$ surfaces [30, 31] which are adequate for many computer vision tasks or for surfaces to be used in medical applications. See, for example [3]. A variety of surface representations is considered in the review work by Bolle and Vemuri [32].

In the majority of CAD/CAM applications, particularly in mechanical engineering, connectivities and continuity in the data structure are also very important. For example, many manufacturing methods depend strongly on surface type, which requires a perfect representation of the related data set. Thus it would not be sufficient to represent a plane or a cylindrical hole by approximating facets, since these may be functional faces presumably to be manufactured by grinding or drilling. Gaps larger then a given tolerance may also cause problems since small areas of superfluous material may remain on the surfaces of the machined object. Moreover, aesthetic parts such as car body panels require at least second order continuity between the constituent surface elements, which again must be assured by the constructed mathematical model.

Our interest in this paper is mainly directed towards these higher-level geometric models. We assume an abstract boundary representation (B-rep) model [33, 34], where the skin of the object is represented as a set of faces, each bounded by one or more loops of edges. Each edge separates two faces and the edges meet in vertices. (We ignore non-manifold data-structures, since we want to deal with objects which have been and can be physically realized.) Within B-reps we may distinguish between partial models and complete models (see [35]). In the former case the result of the reverse engineering procedure will be a model of just some part of the object, for example the visible portion of a panel or a well-defined functional detail. In the latter case, which will generally need multiple views to be merged (see section later), a complete solid model is created which contains all boundary elements of the object.

Although ideally we would like to have a fully automatic reverse engineering

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system which can make decisions and classifications without any user interaction, we believe that at the present state of the art it is very important to have as much *a priori information* about the object as possible. For a human carrying out reverse engineering, it is easy to recognize whether an object has planar faces or not, or whether the whole object is smooth everywhere. For the computer this sort of information is crucial, since it will determine the final model to be constructed and have a significant effect on the efficiency of the computations. The a priori information required here may specify what sort of surface elements occur in the object—global characterization—and may provide certain threshold values. For example, suppose we are given a set of measured points from a cylindrical surface (this data is noisy, and so inaccurate). If we are told that cylindrical surfaces may be present, and set our measurement tolerances correctly, we will successfully try to fit a cylinder to the data before considering more general surface types. However, if we do not look for cylinders, or if we set our tolerances incorrectly, this feature is unlikely to be recognized, and the area will be represented as some free-form surface element.

The above reasoning explains that it is important to specify a hierarchy of surface types in order of geometric complexity (see Figure 3) . Note that we can extract simple types more reliably than more complex types, so if we think we have found a plane, it is quite likely we are right. This is less certain for more complex types, which also gives us a sensible order in which to look for them.

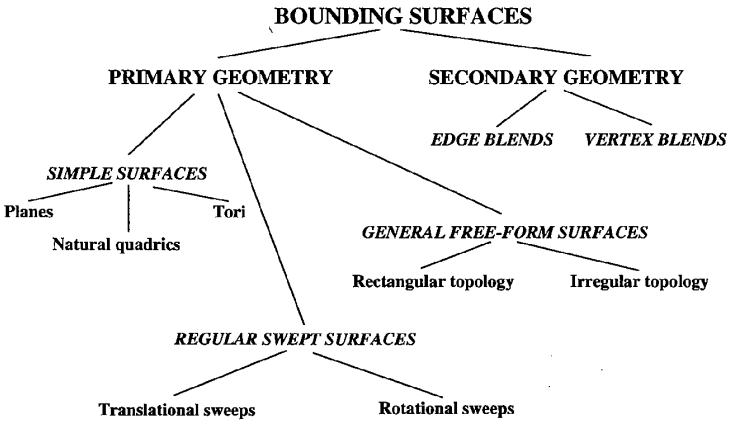


Figure 3: A hierarchy of surfaces

This hierarchy may be coupled with the following useful abstraction when describing complex objects. (The following concept reflects the authors' own view, which is similar to that held by many other researchers working in this area.) We may say that objects are bounded by relatively large *primary* or functional surfaces. The primary surfaces may meet each other along *sharp* edges or there may be *secondary or blending surfaces* which may provide smooth transitions between them [36]. (See a simple example in Figure 4.) Of course, the notion of a sharp edge is also an abstraction: in physical terms a sharp edge does not exist, but one may say that for all edges where the radius of curvature is less than a very small value, our model should contain sharp edges. (This threshold value will be presumably smaller than the resolution of our measurements.) Alternatively, the user may require that we always fit small blends between neighbouring faces due to the fact that measured

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data is particularly unreliable along discontinuities.

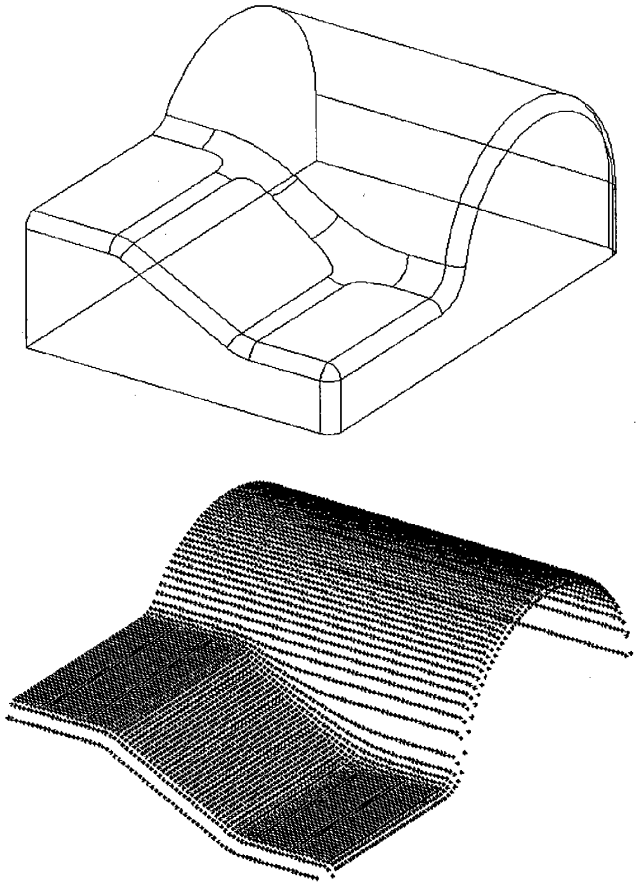


Figure 4: A simple solid object and measured data

Returning to the hierarchy of primary surface elements, we restrict our interest to surface types which are used as standard representations in the majority of CAD/CAM systems. We start with simple surfaces which have both simple implicit and parametric representations and conclude with more general piecewise parametric surface representations. The advantage of the simple surfaces, which are *planes, natural quadrics* and *tori*, is that they have a simple representation in terms of a few geometrically meaningful parameters. This makes segmentation and surface fitting relatively easy (see later). We prefer to consider the subclass of natural quadrics (spheres, cylinders and cones) since these are the most important in mechanical engineering. General quadrics other than the natural ones rarely occur. Further-

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more they are specified by algebraic coefficients without direct geometric meaning, making them more difficult to segment.

Considering more general free-form surface elements, it is worth also specifically considering simple *translational* and *rotational sweeps*, characterized by some profile curve and a sweeping direction or an axis of rotation, respectively. This classification can be extended by recognizing more general sweeps. Finally our most general surface class is that of *composite surface elements* where no geometric or topological regularity can be recognized. This composite surface element may be a collection of patches or possibly trimmed patches, across which internal smoothness is assured.

We mentioned earlier the surface class of blends, which play a special role in connecting primary geometry. As will be explained later, blends are important not only from a functional point of view, but they are also important in stitching or 'healing' gaps between neighbouring surface elements, and thus providing overall consistency of the geometric model. From a representational point of view we remark that it is worth distinguishing between *edge blends*, which run along edges between surfaces, and *vertex blends*, which serve to provide smooth transition surfaces at junctions where several edge blends meet.

The above classification is also somewhat related to conventional machining operations, which are such that natural motions generate planar cuts (face cutting on a mill) or rotational cuts (lathe) with high accuracy, and the remaining mostly free-form elements are typically machined on 3 and 5 axis milling machines with less accuracy.

To conclude this section, with the current state-of-the-art, it is important to have an a priori global characterization of the shape to be reverse engineered, and to have a prior understanding of the measurement process. These are to specify the class of possible surface elements and to set parameters for making decisions about whether a point belongs to a surface. It should be noted, however, that a sophisticated system might be able to adaptively adjust tolerance values for surface fitting.

5 Segmentation and simple surface fitting

In this section we consider the related problems of segmentation and surface fitting. A good general overview of segmentation is provided by Besl and Jain's survey paper [37]; another useful source is Shirai [38]. We assume here that the initial data is in the form of a dense set of points sampled from the surface of the object; rather different methods will be required if for example points have only been digitized along certain key curves on the surface of the object. (A fully automatic method is likely to produce dense data, as human interaction would be required to choose key curves.) The aim is to produce a higher level representation of the shape of the object, in the form of a set of surfaces. Possibly their boundary curves will also be produced at this stage, but it is also possible that further processing will need to be done at later stages to ensure each surface is properly joined to its neighbours by a boundary curve lying in each surface.

We also assume that the surface of the object can be 'naturally' broken down into various component surfaces, which meet along sharp or smooth edges. As was explained earlier, some of these will be simple surfaces, such as planar or cylindrical surfaces; others will need to be represented by more general free-form surfaces. The tasks to be solved at this stage of shape reconstruction are

segmentation to logically divide the original point set into subsets, one for each natural surface, so that each subset contains just those points sampled from a particular natural surface,

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classification to decide to what type of surface each subset of points belongs (e.g. planar, cylindrical), and

fitting to find that surface of the given type which is the best fit to those points in the given subset.

It should be clearly noted that these tasks cannot in practice be carried out in the sequential order given above, as, for example, deciding whether a point belongs to a given subset requires some measure of how well it matches the underlying surface the points in the subset represent. Thus, in practice, some approach is needed where each of these problems is solved simultaneously, and either backtracking, iterative, or probabilistic methods are used to finally converge on a consistent answer. A good discussion of these control problems is given by Leonardis [30]; their approach is to consider several possibilities in parallel, and to find the final answer by solving an optimization problem.

Two basically different approaches to segmentation may be considered, namely *edge-based* and *face-based* methods. The first works by trying to find boundaries in the point data representing edges between surfaces. If sharp edges are being sought, we must try to find places where surface normals estimated from the point data change direction suddenly, while if smooth (tangent-continuous) edges are also possible, we will need to look for places where surface curvatures or other higher derivatives have discontinuity. This technique thus basically attempts to find edge curves in the data, and infers the surfaces from the implicit segmentation provided by the edge curves. A representative example of this approach is described by Smith and Kanade [39]. Another edge-based segmentation technique is presented in this special issue by Milroy et al [40], where wrap-around objects are segmented. In this approach, several, user specified "seed loops" are inflated to obtain edge-loops of faces.

The second technique goes in the opposite order, and tries to infer connected regions of points with similar properties as belonging to the same surface (e.g. groups of points all having the same normal belong to the same plane), with edges then being derived by intersection or other computations from the surfaces. Besl and Jain's [41] work is a classical example of the latter approach.

Comparing these two approaches, we may make the following observations (see also Marshall [42] for further details of some of the points below). Edge-based techniques suffer from the following problems. Sensor data, particularly from laser-based scanners, is often unreliable near sharp edges, because of specular reflections there. The number of points used for segmenting the data is small, i.e. only points in the vicinity of the edges are used, which means that information from much of the data is not used to assist in reliable segmentation. In turn, this means a relatively high sensitivity to occasional spurious data points. Finding smooth edges, which are tangent continuous, or have even higher continuity, is very unreliable, as computation of derivatives from noisy point data is error prone. On the other hand, if smoothing is applied to the data first to reduce errors, this distorts the estimates of the required derivatives. Thus sharp edges are replaced by blends of small radius which may complicate the edge-finding process; also the positions of features may be moved by noise filtering.

On the other hand face-based techniques have the following advantages. They work on a larger number of points, in principle using all available data. Deciding which points belong to which surface is a natural by-product of such methods, whereas with edge-based methods, it may not be entirely clear to which surface a given point belongs even after we have found a set of edges (3D edges do not surround a region of space). Typically, this type of approach also provides the best-fit surface to the points as a by-product. Overall, the authors believe that face-based rather than edge-based segmentation is preferable.

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In fact, segmentation and surface fitting are like the "chicken and egg" problem. If we knew the surface to be fitted, we could immediately determine those sample points which belonged to it, by just picking those points which were within a small distance of the surface. If we knew for certain the exact set of points which belonged to the surface, it would be easy to find the best surface class and the best fitting surface within this class. Unfortunately, neither of these holds. The difficulties of automatic segmenting can be seen even when processing the data points from the simple object shown in Figure 4. (Note that this is for illustration only, and the density of sample points shown may not be sufficient to actually determine the existence or radii of blends.) To overcome this problem we must either ask for interactive help or apply iterative methods. Within the latter one we may distinguish between *bottom-up* and *top-down* methods.

Let us assume that we adopt a face-based approach to segmentation. The class of *bottom-up* methods initially starts from *seed points*. Small initial neighbourhoods of points around them, which are deemed to consistently belong to a single surface, are constructed. Local differential geometric or other techniques are then used to add further points which are classified as belonging to the same surface. Growing stops when there are no more 'consistent' points in the vicinity of the current region. Typically, several such regions may be grown in parallel, and a later step may then be required to merge regions which have grown until they touch, and are found to be compatible in that they represent the same surface.

In practice, during the growing phase, we may also have to be prepared to update our idea of what surface the region represents. For example, a set of points comprising a region may initially be well represented by a plane, but as more points are added, it may be necessary to assume instead that the points in the region belong to a cylinder of large radius. The region is kept, but our idea of to what underlying surface the region belongs can change in type as well as in parameters. Good examples of the state-of-the-art in region growing can be found in Leonardis [30] and Sapidis [31]. In Fitzgibbon et al [43] (see this special issue) after the segmentation of planar and quadric surfaces the adjacency information is also recovered and converted into a special B-rep data structure.

On the other hand, the class of *top-down* methods starts with the premise that *all* the points belong to a single surface, and then tests this hypothesis for validity. If the points are in agreement, the method is done, otherwise the points are subdivided into two (or more) new sets, and the single-surface hypothesis is applied recursively to these subsets, the process continuing until all generated subsets satisfy the hypothesis. Most approaches to surface segmentation seem to have taken the bottom-up approach, e.g. Besl [41], and while the top-down approach has been used successfully for image segmentation, e.g. Pietikäinen [44], its use for surface segmentation is less common.

Various problems exist for both of these approaches. In the bottom up case, they include the following: choosing good seed points to start growing the surface from can be difficult—obviously, a seed point lying on an edge will not be suitable. We need to decide whether to distribute the seed points uniformly, or in some more sophisticated way. If more than one type of surface is being considered, choosing which surface type to use for a region, and possibly changing this surface type as the region grows, requires careful thought. Also, updating the hypothesis based on the points which currently belong to the region must be done carefully—if bad points are wrongly added to the region, this will distort current estimates of the nature of that surface. We do not wish region growing to prematurely stop if an occasional bad point is encountered. Deciding whether to add points to the region can be difficult, as again, the decision is generally based only on local geometry, which is susceptible to noise.

A major problem associated with the top-down approach is choosing where and

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how to subdivide. Often, the subdivision will be done along a straight line rather than a "natural" boundary, and so in practice, merging steps are also required to re-combine pieces. This leads to edges which are rather jagged in nature. When surfaces slowly and smoothly blend into one another, the subdivisions chosen may be quite some way from the real boundary, and so a lot of extra work may be done subdividing in the wrong place. Another major problem with the top-down approach is that after splitting, surface parameter estimates must be recomputed ab initio, whereas with the bottom-up approach, as new points are added to a region, the parameter estimates can be incrementally updated, resulting in a much lower computational effort. At best this problem will waste time, and at the worst, will result in poor segmentation results. Finally, both approaches, unless carefully controlled, are likely to end up representing a complex free-form surface of a type which is not included in the model as many small pieces of say planar or quadric surfaces, which is not the desired result.

Surface fitting for simple surface types generally is done during the segmentation process, as noted earlier, as we can only determine whether a subset of points all belongs to the same surface if we have an underlying model for that surface which includes both its type, and some estimate of its parameters. Fitting planes to point data, using least-squares methods, is a stable and fairly reliable process. The vision community have next looked to quadrics as an obvious generalization to planes [41, 45], and even superquadrics [29]. However, a general quadric has many free parameters, and the fitting problem can often be numerically ill-conditioned. In practice, attempting to fit a general quadric to noisy, real world data can lead to poor results, especially in the context of a segmentation scheme. Better results can be obtained by restricting attention to only the natural quadrics, since - as mentioned earlier - each of these can be represented by a smaller number of parameters, which furthermore have some direct geometric (rather than algebraic) significance.

6 Segmentation and surface fitting for free-form geometry

While it is not easy to do segmentation even for simple surfaces, such as planes and cylinders, further difficulties arise when trying to segment free-form shapes. For the following discussion let us assume that we have a *composite free-form face*, which is smooth internally and bounded by edge loops. These edges may be partly or entirely the boundaries of some underlying patches or they may also be trimming curves cutting across the patch structure. Such trimming curves may have been determined by higher level operations such as intersections, Boolean operations, or blending. For example we may want to reconstruct just a large, single surface with high geometric complexity or we may wish to deal with a composite free-form surface, which has already been separated from the rest of a solid object.

The most widely used parametric surfaces such as Bézier patches and NURBS surfaces map a rectangular parametric domain into 3D, resulting in surface patches with four boundary curves, but complex free-form shapes cannot be represented by a single surface. A composition of several surface pieces is required while maintaining appropriate continuity between the constituent elements. The key issue here is how to do this additional free-form segmentation, i.e. how to find appropriate internal boundaries, which delineate such local regions, and which are representable by single surface patches.

There are four important approaches for free-form segmentation which we will refer to as *global approximating surfaces*, *curve network based surfaces*, *arbitrary topology surfaces* and *functionally decomposed surfaces* as described in the following

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paragraphs.

In the first approach a *large* roughly approximating four-sided surface is chosen. Its movable boundaries and corner points are chosen in such a way that all the data points of interest lie within the boundary of the surface. (We assume here that the point data represent just some part of the boundary of the complete object, and not an entire closed surface.) After choosing corresponding points on the approximating surface, the distances between the surface points and the measured data points can be minimized by well-known least-squares methods [46]. By means of these procedures the free parameters of the surface are computed. Having found a best fit surface in some sense, the actual distances of the measured points from the surface can be evaluated. If these are too large, we try to iteratively improve the parametrization and refit. If the result is still too bad, a new approximating surface needs to be created, which has more free parameters to provide a better fit. This surface can be constructed by subdividing the previously obtained surface or by making local refinements, which may lead to some quadtree-like surface representation. The outside parts of the approximating surface will behave in an uncontrolled way, since outside there are no positional constraints. However, this does not matter, because internally a good fit is reached and the trimming curves constructed around the measured data points will help to separate the useful surface area from the rest. This sort of surface representation is illustrated in Figure 5.

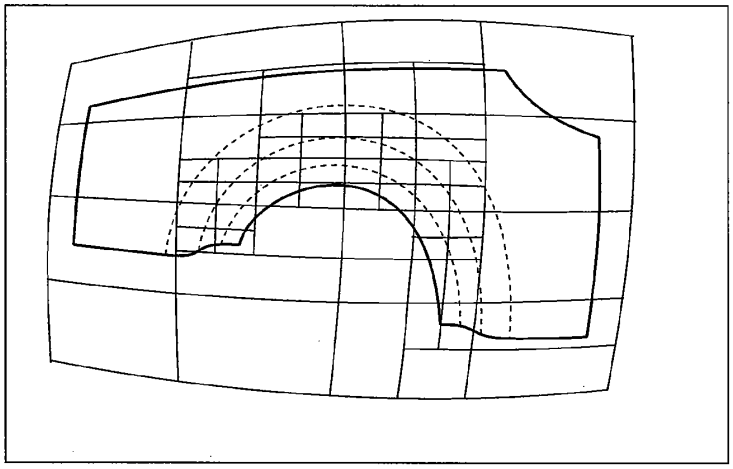


Figure 5: Global approximating surface

The basic advantage of this technique is its relative simplicity, but it is not necessarily straightforward to construct a sufficiently good initial surface which can then be refined as described. By repeated least-squares fitting and subdivision a surface model will be obtained at the end and practically no user interaction will be required. The basic disadvantage from an engineering point of view, however, is that no attempt is made to interpret the underlying structure of the shape. For example ribs or free-form pockets, which could be represented otherwise in a *natural manner* as a single surface, now may belong to several, separate small surface elements, depending on how the initial surface was oriented and the subdivision was performed.

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The second approach is based on a curve network, which divides up the surface by means of a series of 'characteristic curves', which might be sharp edges of the boundary, lines of extremal curvature, lines of symmetry, etc. Constructing the curve network is tricky, and also potentially unreliable. Firstly, only local parts of the data are used to determine the curve network and secondly, estimating differential properties is highly susceptible to noise. *Automatic patching* of such networks is thus not usually done, but instead interactive solutions are used where the user helps to specify the curve network. Furthermore, choosing which 'characteristic' curves are of engineering significance and hence are useful, is not obvious. The user has to pick characteristic vertices and define connecting edge curves, and in this way the internal face structure is explicitly defined (see Figure 6). Typically further patching is applied and finally the whole surface is covered by exclusively four-sided patches. This representation does not require internal trimming since the boundaries of the composite free-form surface are explicitly incorporated into the curve network.

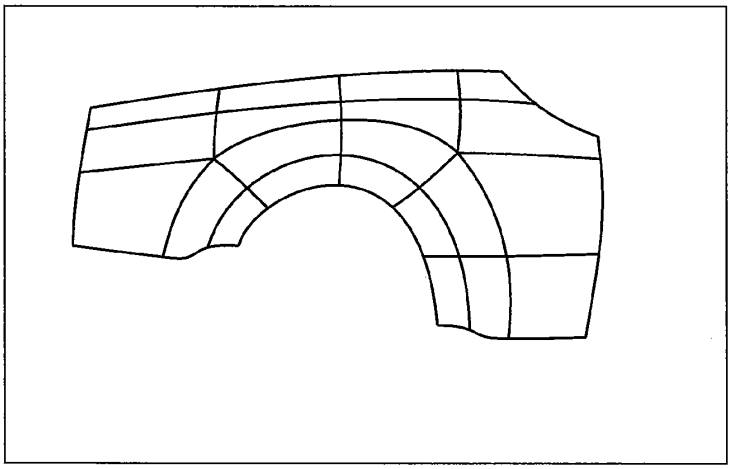


Figure 6: Curve network based surface

Fitting faces across the boundaries of the regions obtained is relatively easy. There are several publications on how to subdivide n-sided regions into four-sided ones, how to restructure the curve net structure if T-nodes occur, and how to smoothly join adjacent parametric patches along their boundaries: see e.g. [46, 47]. Typically compatible cross-derivative functions are assigned to each curve segment and in the final phase patches are generated locally which satisfy the previously determined positional and tangential constraints along the boundaries. The advantage of this approach is obviously that the patch structure reflects the user's concept of the structure of the surface, and this technique will guarantee overall G1 or G2 continuity for the whole surface. At the same time the enforcement of a curve network with four-sided patches creates artificial boundaries as well, i.e. parts which naturally would belong together may get separated. This is a particularly crucial issue for example when a global surface fairing is required, but the artificial internal segmentation separates functionally connected pieces. Note that a small change to the underlying geometry may lead to relatively large changes in the structure of the curve network. Furthermore, at times it may be difficult to incorporate the

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trimming curves into the network in a natural way.

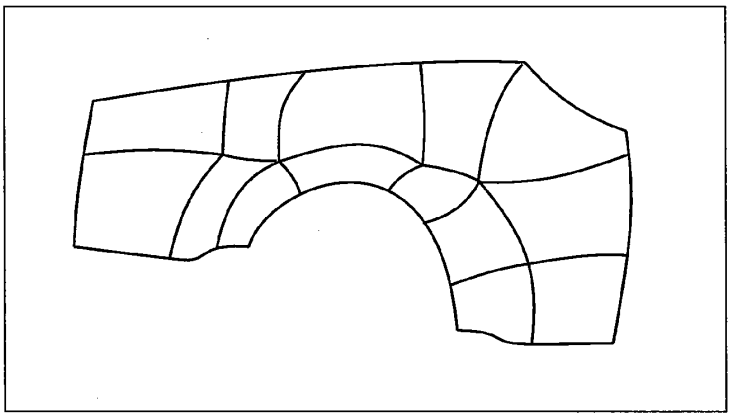


Figure 7: Arbitrary topology surface

The third approach - arbitrary topology surfaces - represents a combination of the previous two approaches (Figure 7. Here a global approximating surface with arbitrary topology is created in an automatic manner. The patch structure is generated by simplifying the underlying triangulation, and this provides a particular parametrization for the final surface. Based on this, first a general topology free-from curve network is created, which will be interpolated by piecewise polynomial surfaces. Special constructions are applied to satisfy overall cross-boundary continuity. Typical representatives for this approach are the publications by Eck and Hoppe [48] and Guo (this special issue) [27]. The advantages and disadvantages of arbitrary topology surfaces also combine those of the previous two approaches. In this case we get a collection of smoothly connected, untrimmed patches automatically, which globally reflects the topological structure of the shape. At the same time, this collection cannot reflect the functional structure of the shape, since the basis of these methods is the triangulated data structure, which does not hold information on how one should subdivide the shape in a sensible manner.

Of course, the fourth method of functional decomposition also holds its difficulties. The main idea here is to try to somehow discover the design intent behind a given shape. If there is information on how the shape was possibly created, i.e. what the original functional surface elements were and what modelling operations were performed to get the final shape, it may be possible to find the original surfaces and redo the operations using the individually reengineered surfaces. An example is shown in Figure 8, where the overall shape is the result of an intersection operation between a translational-like surface and another surface with rotational symmetry, which have been smoothed by a third blending surface. This sort of representation seems ideal from an engineering point of view, but several problems may arise. First of all, with our present knowledge it is very difficult to discover general functional elements without user interaction, unless there is an underlying information base which somehow a priori describes the CAD history of the given model. Moreover the surface fitting problem is also difficult, since we have to fit a complete surface, but only a well-defined part of it may be represented by measured data. In our example, there are missing portions which disappeared during the intersection and blending operations. The basic advantage of this method is that it provides an ap-

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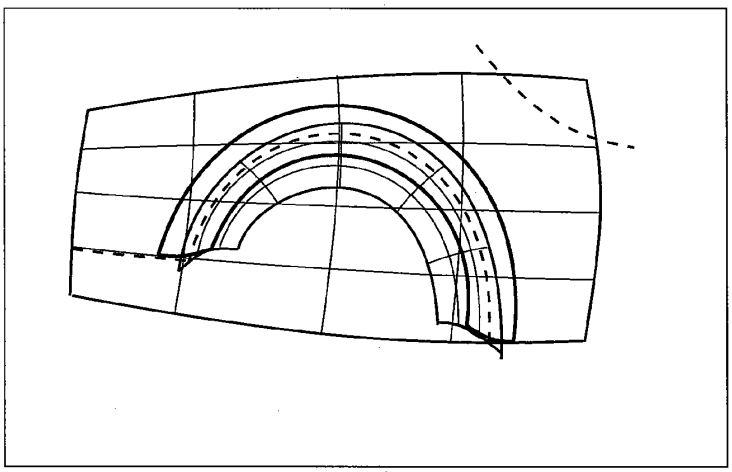


Figure 8: Functionally decomposed surface

propriate engineering decomposition of the shape. The basic disadvantage is that it requires a potentially large amount of interaction or a fairly detailed a priori knowledge about the part. In comparison with the previous methods, here the surface elements join each other along internal trimming curves, so it is difficult to assure exact mathematical continuity. The surface elements will join with numerical continuity, and special care is required to guarantee that the connections are within prescribed system tolerances relating to matching positions and tangent planes.

We note that in principle a really good system might combine the above four approaches in different regions of the surface.

The majority of related reverse engineering publications deal with fitting four-sided surfaces to measured data. Further practical problems include the following. Given a surface, how do we find good parameter values for the measured data points to put them into correspondence with points on the surface, see related works by Hoschek [46] and Ma and Kruth [49]. Another issue is whether it is sufficient to minimize only a function of distances, or whether more advanced surface fairing techniques are needed to minimize some sort of *surface energy*, taking into consideration higher order derivatives as well. Such methods generally lead to non-linear system of equations which are computationally very expensive. The literature on surface fairing is very extensive, methods differ in whether an ideal shape with certain constraints needs to be created or an existing or approximating surface representation needs to be improved (see some of the related work in [50, 46, 51, 52, 53]. A third issue is what to do when there are missing regions in the measured data set or the data is very unevenly distributed (see, for example, Dietz [54] and Hermann et al [55]).

The techniques described above can help in creating local topology for a composite free-form surface, but further steps are required to construct a complete and consistent B-rep model. Before we look at that, the problem of merging multiple views is discussed in the next section.

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7 Multiple view combination

While some applications may only be interested in reverse engineering part of an object, many will require a geometric model of the whole surface of the object. This leads immediately to the following problem: ideally we would have the object "floating" in 3D space (in a fixed position with a fixed orientation), so that the scanner could move around the object from all sides to capture data in a single coordinate system. In practice, the object will have to rest on some surface, so part of it will be inaccessible to the scanner. Furthermore, if the scanner is fixed in position, at any one time, it will be able to capture data from an even more limited region of the object's surface. Thus, generally, it will be necessary to combine multiple views taken with the object placed in different orientations in front of the scanner. We outline some of the important issues involved in view combination in this section; many are discussed in further detail in Marshall [42].

There may also be other good reasons for combining views—for example, some parts of the object may have more details than others, and so a low-resolution scan may be taken of the whole object, while higher-resolution scans may also be taken of the detailed areas. Other considerations may also be important in deciding how many scans are taken. For example, the more scans that are taken, the longer the whole scanning process will take, and the scanner may be an expensive resource. On the other hand, the more nearly face-on the scanner views a given surface, the more accurate the data collected from that surface is likely to be. Clearly, some compromise must be made between these conflicting requirements.

Naturally, sufficient views must be taken so that every part of the object's surface is visible in at least one view. This may not be trivial to arrange if the object has many concavities. Indeed, it may be necessary for some sort of geometric model to be made from the initial scan of the object to determine those places where further scanning is required. This again demonstrates the interplay between the different phases of an overall reverse engineering system.

The major problem in combining multiple views is *accurate registration*, i.e. finding the transformation (rotation and translation) which relates information in one view with information in another view, so all sets of information can be combined. Various approaches exist for capturing multiple views in such a way that registration is possible.

The simplest approach is to place the object on a turntable; this must have a high accuracy to infer registration reliably. Even so, the bottom of the object will not be visible, and if a model of the complete object is required, the object will have to be turned over. It may be possible to use a robot to do this, but compliance in the robot gripper is likely to lead to positioning errors which are too large for the registration to be computed directly from the robot's commanded movements. Instead, it will be necessary in such a case to determine the registration directly from the multiple views themselves, by correlating the information in the views. Once this is deemed necessary, the object may as well be turned over and placed in roughly the right position for the next view by hand.

When determining the registration directly from multiple views, it is necessary to ensure that there is sufficient overlap of information between successive views. Various sophisticated approaches have been suggested for comparing object models, most of them for use in the field of object recognition where accuracy is not an issue, although they have also been used for inspection [42]. Such methods can match either higher level information [56], (partial geometric models constructed for each view) provided enough 'simple' surfaces can be seen in each view to uniquely determine the registration, or the point data can be matched directly [57, 58, 59].

A rather more pragmatic approach to provide overlapping data for registration of multiple views, which has been adopted in commercial environments (for exam-

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ple: [60]), is to clamp some reference objects (e.g. three spheres) to the object being scanned. This ensures that enough simple surfaces *are* present in each view, and a direct algorithm can then be applied to compute the registration once these surfaces have been found in each view. It is much easier and more reliable to use specific surfaces known to be present than to use a general algorithm. Unfortunately, clamping the reference objects to the object to be scanned will obscure part of the latter, so this trick does not directly solve the problem of producing a complete object model.

A relatively untried technique is to use multiple sensors to view the object from several sides at once [38]. This has the obvious disadvantage of the requirement for extra equipment. Also, calibration of several sensors at the same time will lead to a large set of simultaneous (probably nonlinear) equations, whose solution is likely to be time consuming, and numerically unstable. However once the system is calibrated, many objects can then be scanned—in effect, it is the sensors which are registered rather than parts of the objects being scanned. Another disadvantage of this approach, however, is that it is never possible to guarantee that there are sufficient sensors to see the whole of the object at once—consider a cog wheel with many deep teeth.

Having captured several views of the object, with the appropriate registration data, another choice still remains to be made—whether to merge the data at the point set level, before segmenting and further processing it, or whether to process each view to produce a corresponding partial geometric model, and then to merge the latter. There are two relevant issues here. Merging extracted features rather than the point sets may seem computationally attractive, as smaller data sets need to be processed at any one stage. However, features extracted from different views may be inconsistent. At best, estimates of parameters for the same feature will differ and must be combined. Worse still, features may be unexpectedly absent from a view, or a single feature in one view may be segmented as multiple features in another view. A single point set leads to a large, but consistent data structure, while the merging of partial models is likely to need complex methods to resolve these inconsistencies. Furthermore, the approach of processing a single point set has the advantage that any face which appears in multiple views can be estimated from the complete subset of original points belonging to it. If higher level, partial face descriptions are constructed before merging, and the lower level data is discarded, this is likely to lead to less reliable parameter estimation for the whole face, as demonstrated by Fisher's recent work [61].

8 B-rep model creation

In previous sections we described various alternatives for extracting geometric information from a dense set of measured data points. Due to the diversity of surface representations and applicable algorithms, the input for the model creation can also be in various formats at different levels of geometrical and topological completeness. For this reason to present a detailed uniform approach for the final model creation would be very difficult, but various relevant ideas will be discussed here.

The purpose of this final phase is to create a consistent and contiguous model of vertices, edges and faces, where both the adjacency relationships between the constituent elements and the mathematical equations of underlying edge curves and surfaces are explicitly stored (see [33, 34]). In certain approaches some boundary curve structure is created simultaneously with the segmentation (particularly for edge-based methods and free-from curve network driven algorithms), but generally we have to start model building just from a set of *untidy* elements. These are created by local region growing or fitting algorithms and usually no effort has been made to

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provide consistency between them. For example, region growing algorithms provide subsets of points to which well-defined surfaces are fitted, but there may be gaps (i.e. unassigned data points) between them or they may partly overlap each other. The surfaces may not be consistent - e.g. two almost adjacent parallel planes may be segmented with a step between them; or we may not have the desired/expected degree of continuity. Similarly edge detection algorithms may produce a sequence of curve segments which may cross each other and which do not necessarily form a network of smooth connected edges. On boundary tracking see the paper of Fitzgibbon et al [43] (this issue); on the problems of building polyhedral boundary models see also the work of Hoover et al [56].

If there are no explicit edges defined in the previous steps we have to compute these by means of extending the regions. Assuming the underlying surfaces can be extended beyond the boundaries of their segmented regions, surface-surface intersections will provide proper edge curves, which need to be limited by two end vertices. Intersection is not always possible or not even the right thing to do. In these cases we may need to insert blends or adjust the parameters of the surfaces to make them meet smoothly: for example consider a plane meeting a semicylinder along a smooth edge.

To locate a vertex where three surfaces meet seems relatively simple if they meet in sharp intersection, since then a unique intersection point can be determined. The situation is more difficult when we have to compute vertices where smooth edges meet or more than three edges meet, due to numerical instability problems (see related work by Higashi et al. [62]). An example of the latter case is shown in Figure 9. Figure 9/a shows a pyramid object to be reverse engineered, while Figure 9/b depicts possible regions identified looking at it from a top view. It can be seen that data along the edges will be fairly disordered and unreliable. If we extend the four planes of the side faces, due to inaccuracies the edges will not meet in a single vertex, but a little artificial edge segment will be created. In other cases not only small edge artifacts but small facets will be generated. Obviously these are undesirable and when possible should be removed. One may choose a single vertex as in our example and adjust the fitted planes to a small extent to go through it (see Figure 9/c). This can be done in many cases, but in other situations other constraints will prevent this.

The generation of blending surfaces should also be based on primary surfaces. The blends may be explicitly present on the surface of the measured object, or we may create these artificially to bridge the gaps due to the imperfection of data close to edges. Either the intersection curve of two surfaces will provide a spine curve for some range-based blend, or the intersection of the related offset surfaces will provide a spine curve for the center point of a rolling ball which sweeps out a blending surface. More general blends with variable parameters can also be derived based on the primary surfaces together with the data points in the *blending region* which can give us some clue as to the extent of a varying blend radius etc. Details of blending methods are given in [46] and [36]. Narrow blending strips can be used to solve certain inaccuracy problems, such as those shown in the previous pyramid model (see Figure 9/d), whereupon there is no longer need to adjust the side faces.

Beside edge blends, smooth vertex blends need to be created at the junctions of edge blends. One technique is to create n-sided patches when n blend surfaces run together. The corners are computed as the intersection points of the neighbouring trimlines lying on the same face. Another possibility is to apply *setback type* vertex blends (see for example [63]). These are $2n$-sided patches which are bounded by small curve pieces running across the primary faces to be blended; these pieces smoothly connect the adjacent trimlines. Both vertex blend types can be depicted in Figure 4.

We have mentioned earlier the problem of generating smooth segmenting curves

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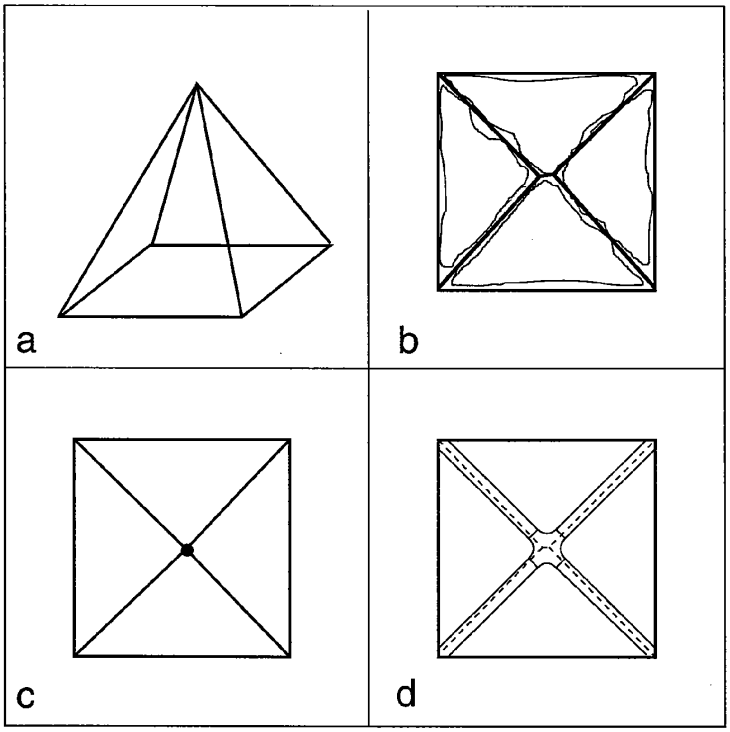


Figure 9: Fixing a solid pyramid model

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within large free-form regions. This may take place with some interactive help or automatically, but to generate projected curves or geodesic curves or curvature lines etc. is not trivial without having an explicit representation rather than just the underlying point clouds. In order to create *fair* curves the known curve fairing techniques [47, 46] need to be extended.

Assuming we have managed to create a consistent B-rep model, there are further tasks to make the representation acceptable from an engineering point of view as well. Particularly for man-made objects, there are many important geometric properties, such as symmetry, parallelism, orthogonality, concentricity etc., which represent essential information (see [64] and [65]). We may want to enforce such constraints on the model, when it is likely that they hold, but this should not be done without careful consideration, as the following example shows. If due to the inaccuracies of measurement and surface fitting the angle between two planar faces is almost 90 degrees, we might decide to set the faces to be orthogonal. But in mould making, small draft angles are a necessary feature for the *quasi-vertical* faces in order to be able to easily remove the part from the mould. Thus, the issue of where and how to 'improve' the model is very difficult, and requires higher level information to determine. User interaction or artificial intelligence techniques may help.

9 Conclusion

Reverse engineering of geometric models for CAD/CAM is a rapidly evolving discipline in which interest is currently high. This is due in no small part to the relatively recent commercial availability of active stereo based laser scanners which are of sufficient accuracy for many applications. Nevertheless, we are still at a similar stage to the early days of computer graphics displays—although various people sell the raw hardware, the range of software to make full use of the hardware is still lacking in many cases, and underdeveloped. Current commercial software systems often only allow simple point cloud processing and single surface fitting with interactive help; the production of complete B-rep models is only possible for very simple objects or polyhedral approximations. (See also the paper by Skifstad [66].) On the other hand, users wish to automatically process a wide range of objects, possibly from a variety of data capture devices with differing characteristics, to produce models in a variety of representations and accuracies.

In summary, while systems exist which can perform the simple operation of 3D copying, the goals of extracting higher level information which can be edited and analyzed are still some way off. Key research areas which still need further work before general-purpose reverse engineering becomes widely available include: improving data capture and calibration, coping with noise, merging views, coping with gaps in the data, reliable segmentation, fair surface fitting, recognizing natural or human-intended structure of the geometry of the object, and finally ensuring that consistent models are built.

10 Acknowledgments

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Dr. Tamás Várady received a DiplIng in Electrical Engineering from the Technical University of Budapest, in 1976. He obtained a doctorate degree in 1977 and an advanced degree of technical sciences (PhD) from the Hungarian Academy of Sciences in 1986 with a dissertation titled the 'Integration of free-form surfaces into a volumetric modeller'. He led the CAD Department at the Computer and Automation Research Institute between 1984 and 1990, where he directed several research projects on geometric modelling and software developments for various industrial applications. In 1990, he was the cofounder of CADMUS Consulting and Development, of which he is president. Since January 1991, he has been heading the Geometric Modelling Laboratory at the Institute. His recent research interest include general-topology surface modelling, vertex blending in B-rep solid modellers and reverse engineering.

Dr. Ralph Martin has been working in the field of CADCAM since 1979. He obtained his PhD in 1983 from Cambridge University for a dissertation on "Principal Patches", and since then has been a Lecturer and Senior Lecturer at the University of Wales College of Cardiff. He has coauthored more than 65 papers and coauthored or edited 4 books covering such topics as solid modelling, surface modelling, intelligent sketch input, vision based geometric inspection and geometric reasoning. He is a Fellow of the Institute of Mathematics and its Applications, and a Member of the British Computer Society. He is currently working on an EU Copernicus grant on reverse engineering.

Dr. Jordan J. Cox received his Bachelor and Master's degrees from Brigham Young University in 1983 and 1984 respectively. After working in industry he returned to Brigham Young University to teach in the Design Engineering Technology department until September of 1988 when he entered Purdue University to pursue his doctoral work. He received his Ph.D. from Purdue University in December of 1991. He joined the faculty of the Mechanical Engineering department of Brigham Young University in January of 1992 and has taught in that department since then.Dr. Cox has worked in the aerospace industry at Garrett Turbine Engine Co. and the Navy Labs. He has consulted with various companies ranging from the orthotics industry, software companies and is currently a special consultant to the Vice President of Aeromechanical systems for the Aerospace Sector of AlliedSignal developing and directing the implementation of 3rd generation engineering graphics, product data management and knowledge based engineering. His academic emphasis is in engineering analysis and geometric modeling.

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An image-guided planning system for endosseous oral implants

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Abstract
A preoperative planning system for oral implant surgery was developed which takes as input computed tomographies (CT's) of the jaws. Two-dimensio (2-D) resiices of these axial CT slices orthogonal to a curve following the jaw arch are computed and shown together with three-dimensional (3-D) surfa rendered models of the bone and computer-aided design (CAD)-like implant models. A technique is developed for scanning and visualizing an eventual existing removable prosthesis together with the bone structures. Evaluation of the planning done with the system shows a difference between 2-D and : planning methods. Validation studies measure the benefits of the 3-D approach by comparing plans made in 2-D mode only with those further adjusted using the full 3-D visualization capabilities of the system. The benefits of a 3-D approach are then evident where a prosthesis is involved in the planning For the majority of the patients, clinically important adjustments and optimizations to the 2-D plans are made once the 3-D visualization is enabled, effectively resulting in a better plan. The alterations are related to bone quality and quantity ($p<0.05$), biomechanics ($p<0.005$), and esthetics ($p<0.005$), and are so obvious that the 3-D plan stands out clearly ($p<0.005$). The improvements often avoid complications such as mandibular nerve damage, sini perforations, fenestrations, or dehiscences

Index Terms
Inspec

Controlled Indexing
computerised tomography dentistry medical image processing orthopaedics prosthetics surgery

Non-controlled Indexing
axial CT slices bone structures clinically important adjustments dehiscences dental implants endosseous oral implants existing removable prosthesis fenestrations image-guided planning system mandibular nerve damage oral implant surgery sinus perforations surgical planning

Author Keywords
Not Available

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An Image-Guided Planning System for Endosseous Oral Implants

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Abstract— **A preoperative planning system for oral implant surgery was developed which takes as input computed tomographies (CT's) of the jaws. Two-dimensional (2-D) reslices of these axial CT slices orthogonal to a curve following the jaw arch are computed and shown together with three-dimensional (3-D) surface rendered models of the bone and computer-aided design (CAD)-like implant models. A technique is developed for scanning and visualizing an eventual existing removable prosthesis together with the bone structures. Evaluation of the planning done with the system shows a difference between 2-D and 3-D planning methods. Validation studies measure the benefits of the 3-D approach by comparing plans made in 2-D mode only with those further adjusted using the full 3-D visualization capabilities of the system. The benefits of a 3-D approach are then evident where a prosthesis is involved in the planning. For the majority of the patients, clinically important adjustments and optimizations to the 2-D plans are made once the 3-D visualization is enabled, effectively resulting in a better plan. The alterations are related to bone quality and quantity ($p < 0.05$), biomechanics ($p < 0.005$), and esthetics ($p < 0.005$), and are so obvious that the 3-D plan stands out clearly ($p < 0.005$). The improvements often avoid complications such as mandibular nerve damage, sinus perforations, fenestrations, or dehiscences.**

Index Terms—**Dental implants, image-guided therapy, OpenGL, OpenInventor (OI), surgical planning.**

I. Introduction

ORAL endosseous implants are used to rehabilitate (partially) edentulous patients. The Brånemark system is one of the clinically best documented implant systems [1], [2]. In this system, a fixed prosthesis is mounted on titanium cylinders that are inserted into predrilled holes in the jaw. Through the use of pure titanium in combination with an atraumatic surgical technique an intimate bone apposition to the implants is obtained and a very high long-term cumulative success rate (>95%) can be reached.

A patient who is considered for receiving endosseous oral implants undergoes a thorough clinical and radiological examination before being elected for surgery [3]. The examination can consist of a radiographic status (a number of small intraoral radiographs), an orthopantomogram (both X-ray source and film rotate around the patient's head) or ortho-radial tomograms. For clinically more difficult cases where the highest accuracy is needed a computed tomography (CT) scan is still the method of choice [4] and does not necessarily result in a higher dose [5]. We will further focus on this method since it is also for these more difficult cases that a planning is most useful.

The acquired CT images are used during surgery, where necessary in combination with available radiographs. Combining all these data with his clinical experience, the surgeon reflects the mucoperiosteum (the gums), inspects the bone structures, drills the planned number of holes, and then inserts the implants. Angulation and depth are taken from measurements on the images, but eventually adjusted on the basis of intraoperative information, such as the tactile sensation of the bone density experienced during drilling. After insertion of 4–6 implants for one jaw, the mucoperiosteum is closed. A healing period of several months is respected before the gums are reopened, this time above the implants, and the top connectors (abutments) are placed whereupon the fixed prosthesis will be mounted. This superstructure is designed to fit the existing implant situation. In full edentulism 4–7 implants can carry a prosthesis with a full dental arch.

However, a good surgical technique alone is not sufficient, several important design criteria have to be met for the procedure to be a success. First, it is beneficial for a good osseointegration that the implant is inserted in well-mineralized bone of sufficient height, and that a (bi)cortical contact is obtained. Second, the axes of the implants should be inclined toward the occlusal force vectors to better withstand the relatively high chewing forces. And third, the implants should be placed in such a manner that the prosthetic superstructure can mask them so as not to interfere with oro-facial aesthetics.

Aside from the design criteria, there exist constraints inherent to the anatomy of the region. Vulnerable structures such as the mandibular nerve and, to a lesser extent, the sinus cavities, must be avoided. These constraints often severely limit the number of available locations and so result in an absolute contraindication for endosseous oral implants for a significant number of patients. They are the reason that a preoperative plan is routinely made for the more demanding cases. A preoperative planning aims at optimizing all the design specifications, which can related to bone quality/quantity, biomechanics and esthetics, while remaining within the constraints.

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The manual planning procedure previously in use at our center is described first: There exist commercially available software packages (e.g., Dental CT, Siemens, Erlangen, Germany) that perform on the scanner console a reformatting specifically tailored to oral applications. The resulting set of images consists of axial slices, an overview axial slice with the curve, panoramic images along the curve, and reslices orthogonal to it. The reformatting process is guided by a technician on the CT console: On one of the axial slices, a flexible curve is aligned with the centerline of the jaw arch, and multiplanar reformatted images are constructed orthogonally upon this curve. These images are printed to film and are then used to determine whether implant surgery is possible or not and to define a case-specific success percentage related to the individual bone parameters of the patient. Implant lengths are derived from jaw bone height and width, measured with a simple transparent ruler overlaid on the film. Positions are given numerical values related to standard tooth locations. The information of this planning is recorded in the patient file and used as such during surgery.

There also exists planning software that is based on the axially reconstructed images from the CT scanner, such as the software mentioned in [6] and the commercial package Sim/Plant (Columbia Scientific, Inc., Columbia, MD). These packages are inherently two-dimensional (2-D) and can be compared to a computerized version of the manual planning method. However, several specifications and constraints can only be evaluated using a three-dimensional (3-D) approach due to their spatial nature. Specifications arising from biomechanics or esthetics are often difficult to incorporate into a 2-D planning method. Biomechanics involves the orientation of the implant axis toward the occlusal plane of the teeth and this requires alterations in all directions of the axes. Esthetics requires a frontal view of the implant-superstructure relationship together with the teeth of the prosthesis. Planning packages that allow an interactive 3-D visualization do exist, but either are not (yet) commercially available [7], [8], or are more aimed at intraoperative navigation [9], [10]. Therefore, a 3-D computerized planning system had to be developed in-house [11], [12].

The aim of this paper is to demonstrate the usefulness of an entirely interactive 3-D planning approach based on a "one object-multiple views" paradigm. A combination of 2-D images, CAD-like implant models and 3-D surface rendered models of bone and prosthesis is highly beneficial to the result of the planning provided the planner is able to interact with them in an intuitive and immediate way. A quantitative and a qualitative validation on a number of patients confirms the added value of this approach. This was especially so when a removable prosthesis was scanned together with the patient to incorporate biomechanical and esthetic considerations into the planning.

II. Materials and Methods

A. Hardware

A Somatom Plus CT (Siemens, Erlangen, Germany) is used in spiral mode with a table feed of 1 mm/rotation together with an aperture of 1 mm. Reconstruction is at an interslice distance of 0.5 mm. A maximum height of 40 mm can be scanned with this CT and these settings, but this is sufficient for these structures. The reconstructed images are transferred to the workstation over the intranet of the hospital. The workstation is a Silicon Graphics Octane Maximum Impact with 256-Mb RAM, 4 Mb of texture memory and 4-Gb hard disk.

B. Software

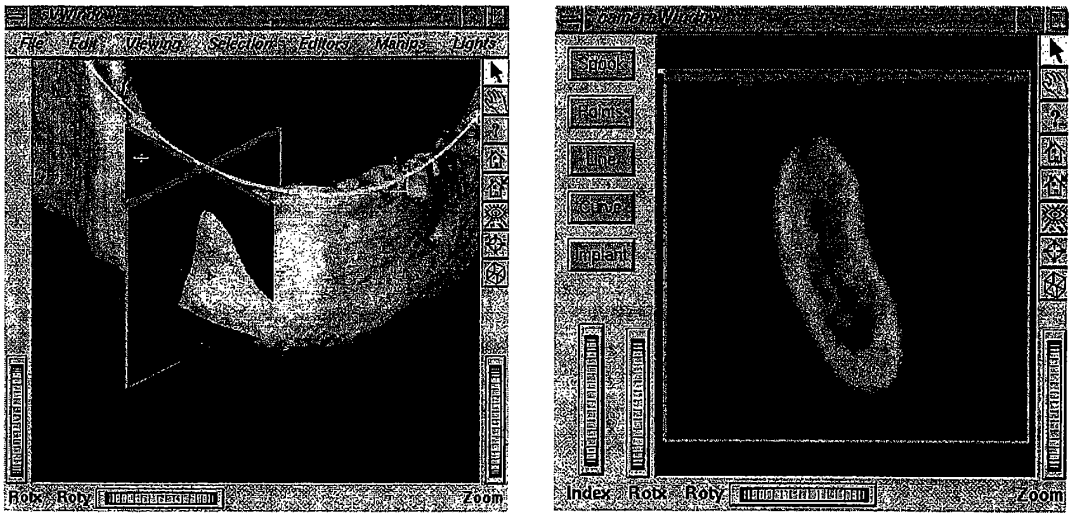
The main concept that underlies the whole planning system can be summarized as "one object, multiple views," meaning that each object will consistently have the same aspect in all windows. This corresponds to what is common for the surgeon, who will not see an intact skin from one angle and a transparent skin from the other. If an object has to change its aspect, e.g., become transparent or invisible, it may do so, but it will change in all windows, so that no extensive bookkeeping is needed to keep track of what is happening in every window. A source of many errors is, thus, avoided. This additional safety is welcome in a system that is used for clinical purposes.

The user is working in a virtual environment (the scenery), wherein all objects are located. Toward this scenery, cameras are pointed from random viewing points and with various viewing angles and zoom factors. The windows that are seen on the computer screen are the monitors of these cameras, much as is the case on a film set. Following the philosophy of object-oriented design, the objects themselves know how to "behave themselves:" They monitor their own position and will adapt their properties and aspect accordingly. For example, images from the CT are represented as texture mappings on planes whose locations correspond to the table position during scanning and whose texture corresponds to a slice through the data set that is located as an invisible voxel block underneath the plane. This implies that scrolling through a stack of images is done by altering the spatial position of a plane relative to a block of voxels, whereupon the slice will update its own texture to reflect the appropriate voxels from the CT dataset. Moving the slice out of the voxel block leaves it totally blank, since it then has no underlying voxels. A tilted slice is then analogous to a multiplanar reslice. Additionally, altering the position of a slice will also alter all its intersections with other objects, such as implants and 3-D models.

To allow the construction of and interaction with such a virtual environment, the whole planning program is written as a generic library [13] in the C++ programming language on top of the object-oriented OpenInventor (OI) graphical library, thus, exploiting to the maximum the rendering power of the workstation. This OI library basically uses OpenGL [14], which is a state machine language used to drive the graphic pipeline. The OI file format is used for storage of objects that are derived from OI classes. Every object the surgeon uses during his planning, including the resulting plan, is an equivalent child object derived from an OI parent and can be stored in an OI file.

OI objects known as draggers and manipulators act as an interface between the user and the virtual scenery. These

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(a) (b)

Fig. 1. (a) Curve with attached reslices and bone model. The implants are in most cases defined on the slice at the arrow. (b) The view of the camera that is attached to the curve.

can constrain interactions to a plane, or only allow rotation around certain points, or modify object properties such as color and transparency. Manipulators such as trackballs alter the orientation of a plane in space, and so provide an interactive multiplanar reslice.

Surface models are created separately by the Marching Cubes algorithm [15], [16] as implemented in the visualization toolkit (VTK) [17]. Other functionalities used from VTK are decimation of triangle meshes and connected component selection.

Not only surface rendered models are used, volume rendering for an implant neighborhood can be obtained using a sequential set of transparent slices that are aligned to the viewport, so that a correct calculation of the lighting is obtained.

C. Planning Steps

A stepwise account of the planning procedure with the computerized system is now given.

The input consists of the axial images from the CT scanner, and does the reformatting directly on the workstation. To this end a nonuniform rational B-spline (NURBS) curve is added to the scenery, with draggers attached to its control points. The draggers constrain the curve to a plane parallel to the axial plane of the scanner. The user adjusts the curve just as is done on the scanner console for the manual procedure. A set of planes is attached to the curve [Fig. 1(a)]. Each of these planes shows a slice through the data set, thus, immediately providing an interactive multiplanar reslice. If the curve is adapted, the planes will immediately adjust their surface texture. The curve is also used as a guidance path for a camera, whose view is shown in a separate window [Fig. 1(b)]. This camera is aimed at the slice that intersects the curve along the normal direction and it is moved along it by means of a thumbwheel widget.

In contrast to what is done for the manual planning, the planner does the curve reformatting himself and is able to adapt it afterwards depending on additional information, with immediate updates of the attached reslices. Not only does this save valuable time on the scanner console, the planner, thus, also has full control over the angle of the reslices through adjustment of the curve.

If the structure in question is a mandible, the user will then move the camera along the jaw and indicate the mandibular nerve, which is sometimes barely visible, by a line. This line interpolates between slices where the nerve or its canal is easily identified (Fig. 2). Once the curve is adequately positioned, and the nerve is delineated, the planner scrolls along it until a suitable location for implant insertion is found. An implant, represented as a cylinder with a central axis, is then defined using two points, commonly named target and entry point. The cylinder has a transparent safety zone around it that indicates a distance of 2 mm, which is the minimal bone thickness that must be kept around it. No other implant may intersect this zone, which is also used to check the distance to the nerve (Fig. 3). Once the first implant is inserted, the angulation is adjusted, and the dimensions adapted to obtain a good (bi)cortical contact. The user then proceeds to insert the next implants. A ruler with a millimeter division is attached to the curve, which aids in finding the nearest possible location for insertion of the next implant.

After definition of all implants, the parallelism is checked, which is done by rotating the camera so that it shows frontal and lateral views of all implants (Fig. 6). The alignment of the axes is corrected and the result is checked simultaneously on the 2-D reslices. A 3-D model of the bone surface is then

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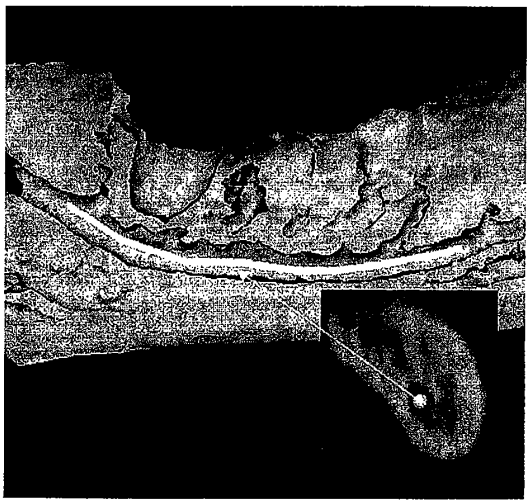


Fig. 2. Delineation of the nerve on the reslices (inset) creates a line within the 3-D model.

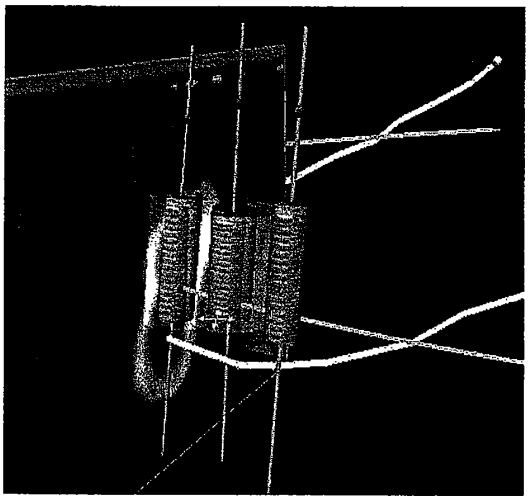


Fig. 3. The relation between 2-D reslice, nerve, and implants is clearly seen.

shown together with the implants (Fig. 7). When a patient has a removable prosthesis, the double-scanning technique (see further) is used to incorporate it into the planning, and a model is visualized together with the bone and the implants (Fig. 5).

The design process, thus, consists of a loop where 2-D and 3-D are alternatively or simultaneously checked and adjusted. The final result is saved in the OI file format.

D. User Interface Aspects

A virtual environment has several advantages but also suffers from a user interface that is never as perfect as that of the real world. Several inputs of the human body, such as tactile feedback, are left unused. The disorientation that is often the result can be solved through the use of additional windows and planned paths. The curve that is aligned to the jaw is in fact such a path. The first view, thus, acts as a map whereupon the movement of the camera from the second window is plotted as an adjustable curve.

Information overload is another problem inherent to such virtual environments: Normally only the outer surfaces are visible to the surgeon. The inner structures are disclosed stepwise and always with the access path as a guidance. If the internal anatomy is visible the external surface is removed. The two are never present at the same time. Not so during virtual surgery. There is so much information presented simultaneously that a selection of the relevant data for each step is in order. Irrelevant objects can be removed from the visible scenery, which comes down to making them invisible. A problem occurs if these same objects are needed during a later step, since selection of the invisible items is not possible anymore. A special mode is introduced to cope with this problem. The planner has the choice between two desktops, where each desktop contains the objects that are invisible on the other desktop. Selection is then again possible whereupon the object is automatically moved from one desktop to the other.

The hardware that is needed for the planning system is expensive and not widely available. Some means, thus, have to be provided to at least view the result of a planning on a standard PC. The views that approximate the intraoperative viewpoints of the surgeon are exported to hyper text markup language (HTML) format, effectively trading interactivity for portability. These views are shown in the operating room using a web-browser (e.g., Netscape) on a standard PC. The 3-D bone surface extracted from the CT corresponds to what is seen upon exposition of the bone, and this is a great aid in positioning and aiming the drill. The browser can also be used as a teleconsultation and training tool and as a demonstrator toward the patient.

III. Double-Scanning Procedure

Many patients selected for oral rehabilitation by means of implants already have a removable prosthesis which in many cases reflects optimal tooth position. As we will see, it is highly beneficial to the planning procedure if this prosthesis can be visualized together with the bone structures. One could try to scan the patient while he is wearing his prosthesis. However, most prostheses are made of a resin-like material and, thus, have a very low density, similar to those of the surrounding soft tissue, which makes it impossible to segment out from the CT images by simple thresholding. But even when a prosthesis of sufficient density is present, it is often totally obscured by the streak artifacts caused by fillings in the remaining teeth. In standard jaw acquisitions where bone quality is to be judged these artifacts cause no problems because the scatter lies mainly in the occlusal plane, but for prosthesis design the position of the teeth in the occlusal plane is essential information that should not be lost. Even when only one side of the teeth remains, these are not sufficient to use as an

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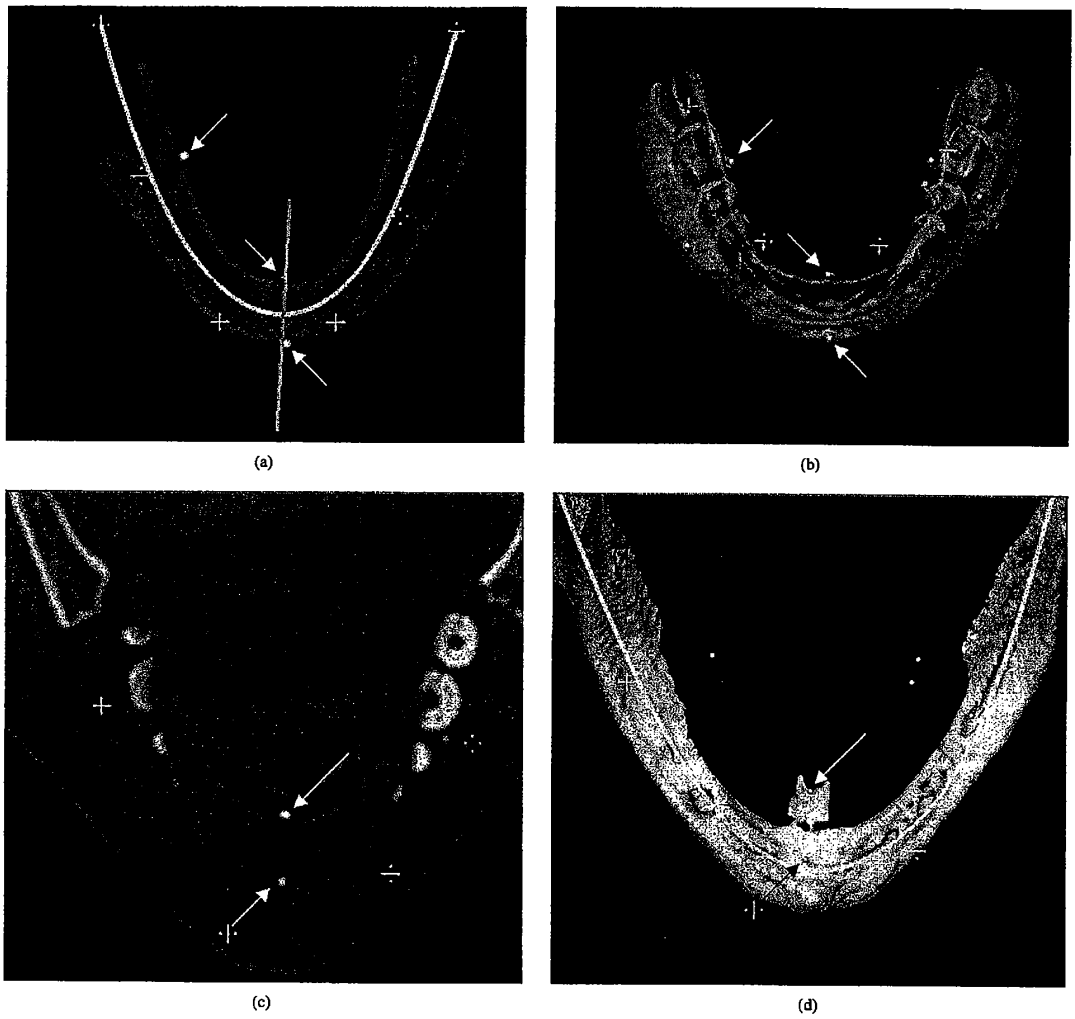


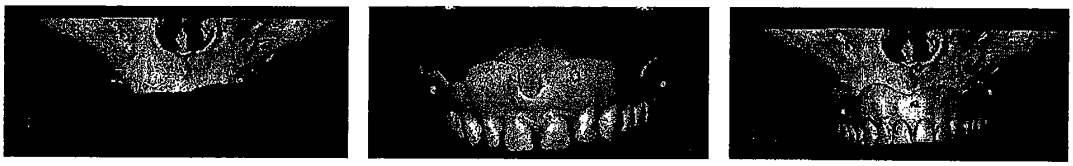
Fig. 4. (a) Prosthesis scanned separately. The arrows point at the attached markers. (b) The model made from the previous images, showing the same markers as small balls on the structure. (c) The same markers as in the prosthesis scans are visible on the patient.

orientation aid, but they often do create enough artifacts to obscure an eventual radio-opaque template.

However, there is a solution to clearly see the prosthesis: A second scan of the prosthesis alone is used to obtain its structure: A clearly visible structure can be extracted for radiolucent objects when they are scanned in air. The contrast with the surrounding medium is now sufficient, but a new problem is created: The position of the prosthesis relative to the patient's anatomy is lost.

To solve this problem, a double-scan technique is used: Small radio-opaque markers are attached to the prosthesis. A first scan of the marked prosthesis shows the prosthesis surface clearly enough together with these markers [Fig. 4(a)], and allows a good surface rendering of the removable prosthesis [Fig. 4(b)]. Then a second scan of the patient and the intraoral marked prosthesis is made [Fig. 4(c)], showing the location of the markers with respect to the bone, but not the prosthesis itself. A surface model of the bone can, however, be constructed [Fig. 4(d)]. The markers are visible in both sets and so allow the transformation between the two sets to be computed. Once this transformation is known, the scan of the prosthesis can be realigned with the scan of the patient, and both can be inspected together (Fig. 5). Care has to be taken that the computed transformation is orthogonal, however, to avoid deformations of the prosthesis. This is called an orthogonal Procrustes problem, and a solution method is given in [18].

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(a) (b) (c)

Fig. 5. (a) A surface rendered model of the maxillar bone. (b) A model of the prosthesis with fiducials (arrows). (c) The combination of the two registered models.

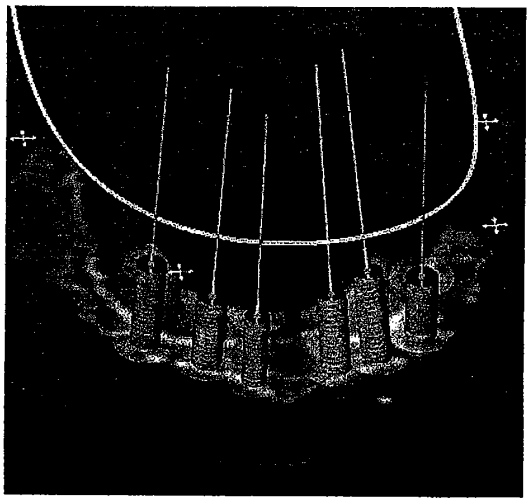


Fig. 6. The parallelism of the inserted implants is checked from a frontal viewpoint. Note the transparent safety zones around the implants.

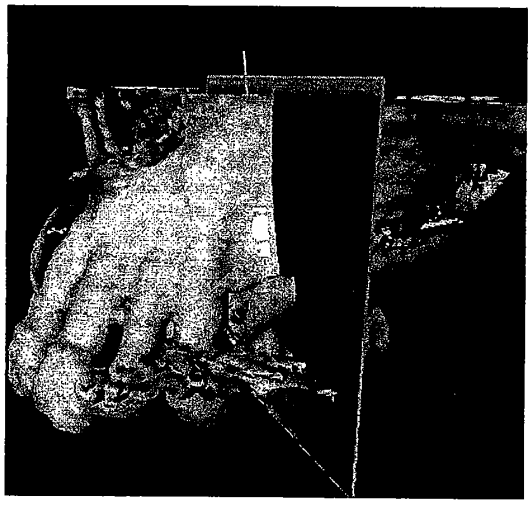


Fig. 7. Superimposed bone surface model of maxilla. The configuration of the teeth would be difficult to reconstruct from the 2-D images alone.

IV. Validation

The computerized system has significant benefits that make it superior to both the manual and the 2-D-only planning methods. To identify these benefits unambiguously, a quantitative validation was done.

A set of 20 patients was planned by a periodontologist, in two stages: The first stage only used the 2-D reformatted images along the curve. No 3-D models or spatial views were used, thus, effectively mimicking the manual planning procedure. However, the scrolling ability along the curve provided more functionality than would be obtained by the manual procedure only, since the intersection of the implants with all reformatted slices could be used. So the "2-D mode" was in fact better than the manual procedure alone and comparable to 2-D computerized systems. The resulting 2-D plan was saved. During the second stage the full 3-D functionality of the system was used to make adjustments to the 2-D plan where deemed necessary. Examples of these corrections are given in the discussion (qualitative validation). The planner did not know at that moment that an intermediate plan was saved and that a study was made, nor that adjustments were expected, thus, avoiding bias. The (eventually adjusted) plan was then saved again as the 3-D plan. It was silently assumed that planner-specific habits would show both in the 2-D and in the 3-D part of the plans, thus, effectively canceling out.

The saved plans were compared both by a surgeon and by a prosthodontist. They did not know which plan was the 2-D and which was the 3-D even though the full 3-D functionality was used to inspect the plans in both cases. The following questions were then answered.

1) Which plan is the best for osseointegration?
2) Which plan is the best for biomechanics?
3) Which plan is the best for esthetics?
4) Which plan do you think is the 3-D plan?

Moreover, the evaluators motivated certain answers so that a good idea was obtained which features of the system were most useful, thus, resulting in a subjective, but still useful, validation.

V. Results and Discussion

An overview of the data is given in Table I. The answers to the questions are given in Table II.

A. Quantitative Validation

When we look at the results for all the patients together (Table III), corrections are done for ten patients (50%). In

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TABLE I
PATIENTS AND IMPLANTS IN THE STUDY

	No prosthesis		Prosthesis	
# of patients planned	11		9	
# of corrected plans	2	18%	8	89%
# of implants	50		38	
# of corrected implants	2	4%	19	50%

TABLE II
THE ANSWERS GIVEN BY THE EVALUATORS

		Evaluator 1			Evaluator 2		
Osseointegration?		2-D>3-D	2-D=3-D	2-D<3-D	2-D>3-D	2-D=3-D	2-D<3-D
Patients	Prosthesis	1	5	3	0	4	5
	No prosthesis	1	9	1	1	10	0
implants	Prosthesis	3	25	10	0	11	27
	No prosthesis	2	42	6	6	44	0
Biomechanics?		2-D>3-D	2-D=3-D	2-D<3-D	2-D>3-D	2-D=3-D	2-D<3-D
Patients	Prosthesis	1	3	5	0	4	5
	No prosthesis	1	10	0	1	10	0
implants	Prosthesis	3	12	23	0	11	27
	No prosthesis	2	48	0	6	44	0
Esthetics		2-D>3-D	2-D=3-D	2-D<3-D	2-D>3-D	2-D=3-D	2-D<3-D
Patients	Prosthesis	1	2	6	0	4	5
	No prosthesis	0	11	0	1	10	0
implants	Prosthesis	2	4	32	0	11	27
	No prosthesis	0	50	0	6	44	0
3-D?		2-D>3-D	2-D=3-D	2-D<3-D	2-D>3-D	2-D=3-D	2-D<3-D
Patients	Prosthesis	0	3	6	0	4	5
	No prosthesis	1	10	0	1	10	0
implants	Prosthesis	0	9	29	0	11	27
	No prosthesis	2	48	0	6	44	0

terms of implants placed, corrections were done for 21 of the 88 implants placed (24%). That is not impressive. However, if we take only those patients that had a removable prosthesis that was scanned using the double-scanning technique, the picture is different.

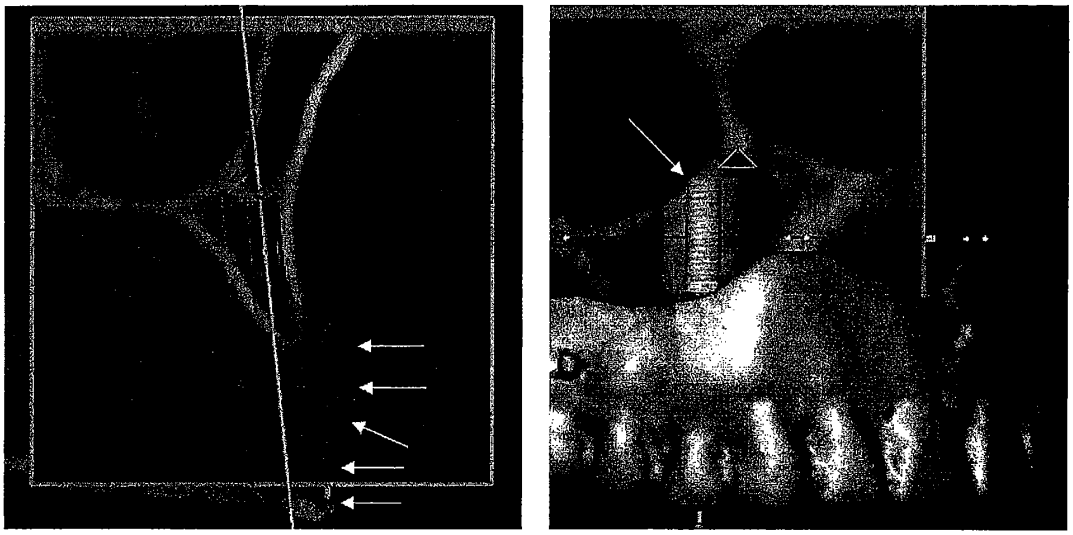
From the nine patients that have a prosthesis, eight plans were corrected (89%), representing 19 corrected implants on 38 placements (50%). This is very relevant and can be considered a confirmation of the importance of the prosthesis. The hypothesis is then that there is a strong connection between the presence of a prosthesis model and adjustments of the plan. To further prove this hypothesis, we pose the null hypothesis that there is no connection between the presence of a prosthesis and the answers given by the evaluators. Table II then contains four contingency tables, one for each question. A chi-square test yields the results from Table III. Data for patients and for the implants are shown.

The central column contains the scores for both observers combined, when their data are considered as separate experiments (chi-square values and degrees of freedom each added). These results are significant, and the null hypothesis can, thus, be rejected, implying that there is indeed a connection between the presence of a prosthesis and the scoring by the observers. Inspection of Table II learns that there is a shift toward the 3-D, meaning that the 3-D plans are significantly improved.

These results, thus, suggest that, if a prosthesis is present and scanned with the patient, the plans can almost surely be enhanced by using the 3-D features of the planning system. Not surprisingly, the significance of the osseointegration question was somewhat less, due to the fact that osseointegration is indeed mainly judged on the 2-D images rather than on the 3-D models. However, it is important to know that the 3-D adjustments did not decrease the quality of the "underlying" 2-D plan. The answers to the three first questions were even the same for the second observer, thus, reflecting the point of view of a prosthodontist.

From the fourth question we learn that the corrections often leave little doubt as to which plan was 3-D. Though this might interfere with the blind manner in which the study was conducted, the fact that the corrections are that obvious and that they improve the plan is also an argument in favor of the system.

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(a) (b)

Fig. 8. (a) When only one slice is seen this seems a good location to insert an implant. The axis of the implant is oriented toward the tooth from the prosthesis (arrows). (b) A lateral view, a risk for sinus perforation is apparent (arrow). Wedging before the sinus (triangle) would be a better option.

TABLE III
THE CHI-SQUARE ANALYSIS OF THE ANSWERS GIVEN BY THE EVALUATORS. THE EXACT PROBABILITY THAT THE GIVEN DATA COULD BE EXPLAINED BY COINCIDENCE IS GIVEN BY *p*. THE CENTRAL COLUMN CONTAINS THE DATA FOR THE TWO OBSERVERS COMBINED

	Evaluator 1	Evaluator 1 & 2	Evaluator 2
Osseointegration?	*p*	*p*	*p*
Patients	0.3748	0.0339	0.0146
Implants	0.1387	0.0000	0.0000
Biomechanics?			
Patients	0.0132	0.0018	0.0146
Implants	0.0000	0.0000	0.0000
Esthetics?			
Patients	0.0014	0.0002	0.0146
Implants	0.0000	0.0000	0.0000
3-D?			
Patients	0.3748	0.0339	0.0146
Implants	0.1387	0.0000	0.0000

Several sources of possible bias can be identified: A planner could grow used to the 3-D features of the system and so postpone eventual corrections until the 3-D mode is enabled. This is even more so since the separation of the 2-D and 3-D parts of the planning resulted in a rather inefficient way of working. Indeed, the planners had developed the reflex of adjusting the viewpoints immediately after the first implant was inserted. The OI viewers had to be locked in plane mode, which does not allow any rotations out of the initial plane, to force a 2-D behavior on the planner. This might result in an overestimation of the 3-D score. Such a bias would, however, not discriminate between the presence or absence of a prosthesis, since the prosthesis is only used once the 3-D is enabled. This bias is, thus, not relevant here.

On the other hand the 3-D system was not really used in an optimal way. It is much more difficult and tedious to correct an already finished 2-D plan than to adjust each implant immediately after the insertion. The normal method would be to check and adjust in 3-D after each implant definition. This artificial way of using the system might produce a bias in favor of the 2-D since the 3-D is not used in the most efficient manner. We can only hope that this was indeed the case, since then the 3-D system would be even better than was demonstrated in the study.

B. Qualitative Validation

Representative examples of the adjustments to the 2-D plan that were made in 3-D mode are now given. They provide further evidence in favor of the 3-D approach.

Corrections involving the parallelism of the implant axes are quite frequent (Fig. 6). Aberrations are indeed readily visible once the slice is tilted. Parallelism is not only important for the biomechanics: Prosthesis design is also facilitated by parallel axes since it is then easier to slide the prosthesis over the abutments. If the abutments are not parallel, the prosthesis often has to be made in several parts, which is more expensive.

Some alterations to the plan were related to the better visualization of the remaining teeth from 3-D images (Fig. 7). But also the ability to show reslices along every direction makes a difference. The CAD models of the implants are visible on every reslice they intersect, and corrections on these slices are

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Fig. 9. The sinus perforation of Fig. 8 is confirmed by the 3-D inspection: The implant itself (arrow) is visible in this view from above, penetrating into the maxillary sinus.

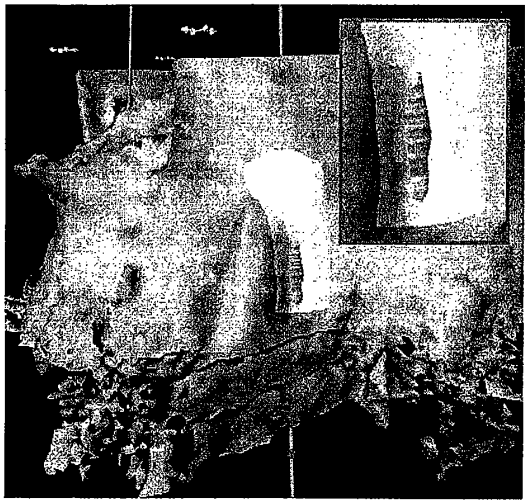


Fig. 11. A fenestration risk is clearly seen on the 3-D model, here from the maxilla.

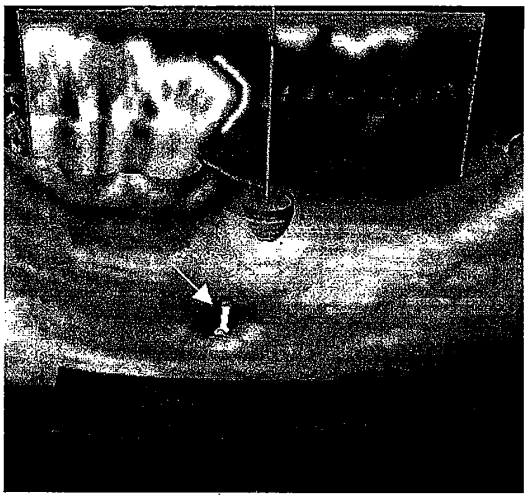


Fig. 10. This implant in the mandible is too close to the neighboring crown (line), which was impossible to see on the orthogonal (defining) reslice, but only shows up in the 3-D view. Note the nerve in the foramen (arrow).

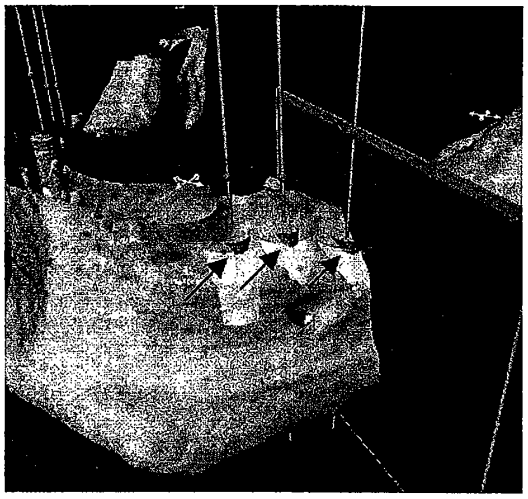


Fig. 12. Bone model combined with implants. The arrows indicate possible dehiscences. Further inspection on the 2-D is then needed.

quite often done. An example of this is a sinus bottom that dips in between the roots of two teeth. A sinus perforation on adjacent slices of the slice whereupon the implant was defined would not be visible in the manual planning procedure (Figs. 8 and 9). Wedging of the tip of the implant in a place where the cortex configuration allows it, is commonly used to enhance the primal stability. Previously, the wedging was planned for the labio-oral (normal to the jaw arc) directions since it is mostly seen on the orthogonal reslices, but the computerized system also allows assessment of mesio-distal (tangential to the jaw arc) wedging of the implant tip through the use of tangential reslices. An example is found in Fig. 8, where the implant tip could better be wedged before the sinus.

An implant that is planned too close to an overhanging crown is not spotted on the tangential reslice nor on the orthogonal view since these fall entirely outside the implant volume (Fig. 10). Only the 3-D view gives a clear warning about the proximity of the crown. The same result could be obtained by a set of reslices or by projections in 2-D only, but the superimposed structures are not as clear as this view and scrolling through the set would be time consuming.

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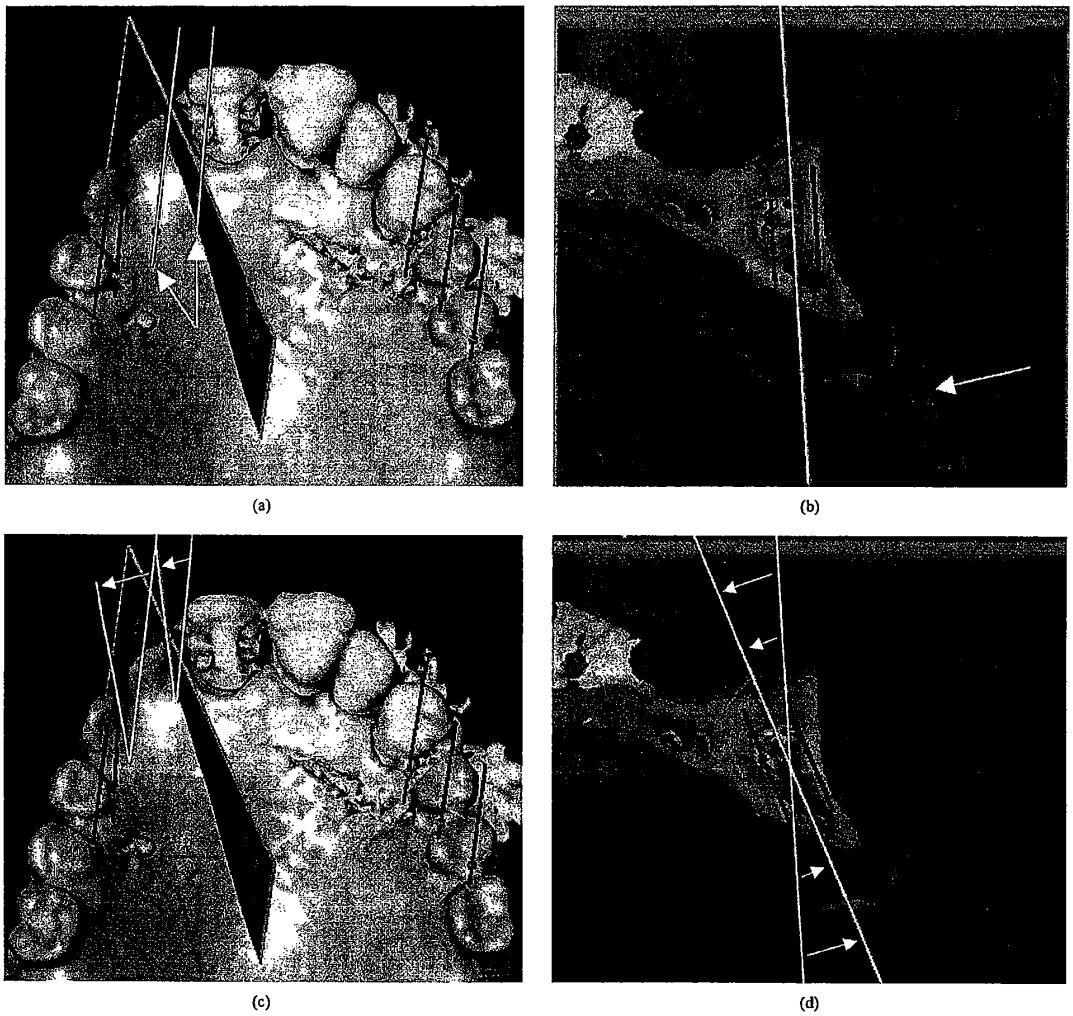


Fig. 13. (a) The implant axes (arrows) are too palatal. The prosthesis is too thin in this area to insert a screw for the attachment of the abutment. (b) The 2-D slice shows how the prosthesis (arrow) extends in front of the bone. (c) The axes from (a) are shown by the lines. Adjustments to the orientation were made. (d) Further corrections were needed to keep the implants within the bone.

Many corrections try to avoid complications that were simply not visible in the 2-D mode. The surface model of the bone allows an instantaneous visualization of risk for anatomical structures, sinus perforation, fenestrations (penetration of the bone surface at the sides of the jaw) (Fig. 11), and dehiscences (a small bone chip coming of at the entrance of the drilling hole) (Fig. 12), since the mantle of the implant will penetrate the surface. However, this does not always represent the real situation, due to the influence of thresholding on the position of the surface. Moreover, phantom holes may be present in such models. The partial volume effect that occurs for less-dense structures often brings the voxel values below the threshold in such places. Since we can always return to the 2-D slices and overlay these on the 3-D structures, the inaccuracies in the surface model are an asset instead of a problem, because they act as a warning. Weak places in the bone cortex show through holes in the surface. If we really need an accurate representation, it is better to use volume rendering [19].

The prosthesis model gives a good idea of the final result for a given implant configuration. Just as the inspection of the parallelism brings in both elements of biomechanics and prosthesis design, so does the prosthesis. Visualization of the tooth surface on the reslices allows an orientation of the axes toward the occlusal surfaces, with a better load of the implants and, thus, a configuration that is biomechanically

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more stable. The planner is pointed at several suboptimal situations, especially concerning the esthetics, that are to be avoided. Interdental axes are sometimes difficult to hide in the frontal area. An implant (and, thus, an abutment) that comes out at the labial side (outer side) of the prosthesis will create a severe problem due to its visibility. An implant that is too palatal (inner side) does not show but the prosthesis is often too thin to provide enough support for the abutment screw. Results can range from a prosthesis that is more expensive to make, to esthetically displeasing visible abutments. Visualization of the prosthesis during planning avoids these problems where the underlying bone allows it (Fig. 13).

VI. Conclusion and Future Developments

In oral implant surgery, a careful preoperative planning is a *conditio sine qua non* for success with clinically more difficult cases. An optimal use of the remaining bone has to be made to obtain osseointegration, the axes have to be oriented to optimize the biomechanics and the prosthetic superstructure must be taken into account for a good esthetic result. Therefore, a preoperative planning system was developed. A patient study to confirm the clinical usefulness of this system was done—proving the importance of the double-scanning technique for the biomechanical and esthetical result—provided a removable prosthesis is available and used during the planning and a good visualization is available. This can be considered a strong argument for taking this technique into routine clinical use and indeed in the University Hospital Gasthuisberg this is the case. For those patients that have no removable prosthesis or whose prosthesis contains metal parts, a specially designed cheap template such as is used in [20] and [21] will be made. In terms of a cost-benefit analysis the double-scanning technique yields a very important benefit for the negligeable investment in scanner time.

Extension of the planning system for intraoperative use is currently implemented and does, already, yield good preliminary results in phantom studies. Ideally a tracking device or even a template can be used to transfer the plan to the patient. New developments will also aim at providing information intraoperatively in an efficient and clear manner. Ideally, enough information from various sources should be presented so that the plan can immediately be made during surgery. If the transfer to the patient becomes more accurate, the planning will increase in importance accordingly. At first, a plan is only as good as its transfer, but once the transfer is accurate enough the surgery is also only as good as the plan.

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Physical and mechanical properties of elastomers in orthodontic positioners

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Elastomers for conventional Kesling-type tooth positioners are relatively inelastic and are primarily indicated as finishing devices. However, new materials, first described in the Japanese literature, with claims of a greater range of tooth movement warrant a comparison with conventional materials. Physical and mechanical property testing of positioner elastomers has not been reported in the orthodontic literature. This investigation compared properties of a high temperature vulcanizing (HTV) Japanese silicone (Orthocon) to three traditional polyurethane and vinyl-based polymers and five experimental silicone elastomers. Fourier transform infrared spectroscopy established the definitive chemical composition of the urethane and vinyl materials obtained from a commercial positioner laboratory. Tear strength, tensile strength, tensile stress at selected elongations, and ultimate elongation of all materials were evaluated at 37° C in an aqueous environment. Hardness and water sorption values also were determined and an in vitro force measurement apparatus was fabricated to determine force levels exerted by positioner materials at low displacements. Orthocon was statistically different (Duncan's multiple range test, $p < 0.05$) from the traditional commercial urethane and vinyl materials. Orthocon had lower tear strength than the traditional materials. It also demonstrated lower stress values below 100% elongation. The parameters of tensile stress at 50% elongation and ultimate elongation were statistically identical for Orthocon and one experimental silicone material. (Am J Orthod Dentofac Orthop 1989;95:388-400.)

Traditionally elastomers in tooth positioning appliances are relatively inelastic and have been used to effect minor tooth movement near the end of treatment. Kesling[1,2] introduced the tooth positioner appliance for use as a finishing device. However, he also envisioned a wider range of use of his appliance, limited at that time by insufficient elasticity of the rubber compositions available. As he stated in 1945:

> The positioner has many uses other than final positioning and retention. Major tooth movements could be accomplished with a series of positioners by changing the teeth on the setup slightly as treatment progresses. At present, this type of treatment does not seem practical. It still remains a possibility, however, and the technique for its practical application might be developed in the future.[1]

since the introduction of this device, most of the subsequent articles on the subject have evaluated its construction and effectiveness. It was generally concluded[3-6] that the positioner appliance was used to best advantage when basic treatment has been completed. Although

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most types of tooth movement could be effected in a limited degree, it was best suited for guidance of erupting teeth and for tipping movements.

since the advent of Kesling's rubber composition positioner, Nishiyama, Kamada, and Horiuchi[7] noted that various materials with rubber-like elasticity have been introduced, but few have all the necessary properties. Defects noted included a limitation of elasticity, a degradation of these properties when used in the mouth over time, limited effect of tooth movement, and lack of patient comfort. Polyurethane rubber, which is tasteless, odorless, and superior in elasticity, has been introduced to improve these defects. However, processing requires a rather complicated compression molding procedure.

The construction of tooth positioners with a low temperature vulcanizing (LTV) silicone composition was first described in Nishiyama's article. This type of elastomer could be easily processed in a dental flask and the set product was odorless, tasteless, and possessed excellent elasticity. Yoshii[8-11] addressed concept of a "dynamic positioner." Clinical case ports attempted to show that a series of two or three positioners might be used from case initiation until retention. A high-temperature vulcanizing (HTV) silicone elastomer (Orthocon) was used. In 1984, Kamada and associates[12] presented three cases with pre- and posttreatment cephalometric analyses; their observations included the following:

Unlike the material used for conventional tooth positioners, the one used in the present tooth positioners (LTV vinyl silicone rubber [Tomy Inc., Tokyo, Japan]) is easy to handle in the laboratory and the time to make it is short. since it can be adjusted to highly variable changes, the range of the appliance is larger than for the conventional one.

By using this kind of tooth positioner, injuries to periodontal tissue, which may occasionally be caused when mechanical orthodontic appliances are used, can be avoided.

By using tooth positioners, dentists can give patients with poor oral hygiene the necessary guidance during treatment, and can avoid periodontal diseases, caries, etc.

A review of the orthodontic literature showed no references characterizing properties of positioner materials. The purpose of this investigation is to:

1. Provide baseline data for physical/mechanical properties of elastomers that are or may be used in the fabrication of positioners
2. Determine the uniqueness of the Japanese positioner material Orthocon
3. Indicate forces that a positioner might deliver within its clinical working range with an in vitro force measurement model

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MATERIALS AND METHODS

There are several general compositions of positioner materials that have been available to orthodontists, including rubber, urethane, and thermoplastic vinyl. Orthocon, a polyvinyl siloxane (silicone) material commercially available in Japan, has recently been introduced for positioner fabrication as previously noted. This material is available in three grades of elasticity.

It was our original expectation to obtain and compare samples of all materials commercially available. However, one manufacturer rejected our request on the basis of the proprietary nature of their materials. Likewise it was not possible to obtain sufficient quantities of all grades of Orthocon. Another manufacturer provided polymerized samples of urethane and thermoplastic vinyl compositions (P1, P2, and P3).

Nine materials were evaluated in this study (Table I), three of which are representative of polymer types traditionally used. The commercial materials, P1, P2, and P3, were identified by infrared spectroscopy (FT-IR) as indicated in the table. The remaining materials were medical grade silicone elastomers as shown in Table I.

Tensile, tear, hardness, and water sorption tests

A two-piece anodized aluminum mold was used to form 6.0 × 6.0 × 0.098-inch sheets of silicone material. Following the appropriate molding and curing procedures, fabricated sheets were stored at 23° C, 50% relative humidity. Tensile tests required ring specimens (American Society for Testing Materials [ASTM] D412-83, type 1), which were cut from an assembly with No. 15 Bard-Parker blades. A disk cutter for preparation of water sorption specimens was used in a similar fashion on a lathe with the application of a 5% soap solution. Tear strength specimens were cut (die C) accordingly and durometer hardness was determined on 2.0 × 3.0-inch strips.

Tensile, tear, and durometer hardness specimens were stored in 37° ± 1° C water for 30 days before testing. Water sorption studies required disks dried to constant weight before immersion in the water bath. Tensile specimens were measured 24 hours before testing and outside diameter, radial width, and thickness recorded. All specimens for tensile and tear strengths were tested in a Plexiglas container mounted on an Instron tester (Figs. 1 and 2). A constant flow of distilled water at 37° ± 1° C was maintained during all tests. Crosshead and recorder chart speeds were set at 50 cm/min. Buoyancy effect corrections were made with reference to a calibration curve. Water sorption values were recorded at 24 hours postimmersion relative to constant dry weight and at 7, 14, 21, and 28 days thereafter.

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In vitro force measurement model

since it was observed that stress-strain measurement at low deformations could not be precisely resolved with a standard tensile test, the following model was designed and constructed. The maxillary left central incisor of an acrylic study model was sectioned and a stainless steel post inserted into the area that approximates the coronal one third of the root. A matched stainless steel tube was inserted into the palatal area of the maxillary cast in such a manner that the acrylic incisor was freely movable on one axis in a labiopalatal direction (Fig. 3, A and B). The post-tube assembly in the maxillary cast was aligned with a modified extension post attached to a dial indicator and the cast mounted to the upper section of an articulator. The mandibular acrylic cast was then mounted with the casts in centric occlusion. The position of the central incisor could be adjusted and read on a dial gauge accurate to 0.001 mm (Fig. 4, A and B).

A transducer (Model ALD-MICRO) was to be positioned in the labial portion of the positioner so that the transducer's axis of measurement was normal to the axis of the freely movable tooth. The acrylic models were duplicated in dental stone, which served as construction models. A cast gold alloy duplicate of the transducer was affixed to the midlabial surface of the maxillary central stone model. A positioner was patterned in wax over the models and the assembly invested, boiled out, dehydrated, and molded with EXP1. Each additional positioner of several other selected materials (Orthocon, GL1, and P3) was fabricated from investment of the first positioner as a direct pattern. These materials were selected as being representative of different grades of elasticity.

The transducer was inserted into the processed positioner (Fig. 5, A) and the assembly placed on the articulator (Fig. 5, B). Measurements were made at 23° ± 1° C. The movable acrylic tooth was advanced 0.5 mm and the force read within 2 seconds on the readout display. The position was advanced farther and force values read in grams at displacements of 1.0 mm, 1.5 mm, 2.0 mm, and 2.5 mm. The acrylic tooth was returned to its initial position and the positioner removed from the model. On replacement the measurements of force versus displacement were repeated five times. This sequence of steps was followed for each of the four materials selected.

RESULTS

All data were evaluated with a one-way analysis of variance. Duncan's multiple range test was then applied to test each property for statistical significance among the materials tested. The level of statistical significance was set at 95%.

Tensile tests

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Tensile stress versus percentage elongation is illustrated for five representative polymer types in Fig. 6. P2 produced the highest stress and EXP3 the highest elongation at failure. The modulus of elasticity (stiffness) of the Orthocon silicone was approximately one fourth that of the P2 urethane at low elongations and was most similar to that of EXPl over the entire stretch of the samples. At elongations of 25%,50%, and 100%, the tensile modulus of all silicones was lower than that of the urethane and thermoplastic vinyl materials. The tensile strength of the material exhibiting the highest tensile strength, P2, was approximately six times that of the lowest strength material, MDX-4-4210 (Fig. 7). The ultimate elongation of EXP3 was approximately three times that of MDX-4-4210 (Fig. 8).

Duncan's multiple range test showed that the tensile stress of Orthocon at failure was statistically different at the 5% level of significance, but the ultimate elongations of Orthocon and EXPl were similar. At selected elongations from 25% through failure, the tensile stress of Orthocon was statistically similar only to one material, EXP1, at 50% elongation.

Tear strength

The materials ranged in strength from a low value of 5.8 kN/m for MDX-4-4210 to the highest for EXP1 of 37.5 kN/m (Fig. 9). Tear strength values at failure showed no statistical difference for P2-EXP3 and EXP1-EXP3 at the 5% level of significance. Some of the test pieces developed an initial crack or tear before failure. The presence of this initial tear has not been reported in the dental literature for die C specimens.

Durometer hardness

The materials ranged in hardness from a low value of 33 for MDX-4-4210 to a maximum of 85 for P2 (Fig. 10). Orthocon'S hardness of 51 was intermediate between GL1 and P1. The three highest hardness measurements were obtained on the commercial positioner materials P1, P2, and P3. Analysis of durometer-measured hardness showed no significant difference between EXPl and EXP3 at the 5% level of significance.

Water sorption

Water sorption values were most constant and lowest overall for P3, whereas values for EXP2 increased throughout measurement (Fig. 11). Materials may be qualitatively grouped into three levels of water sorption with P3, MDX-4-4210, EXP3, EXP1, GL1, and Orthocon representing the lowest levels, P1 and P2, at an intermediate range, and EXP2 in the highest category. At 7, 14, and 21 days immersion, there were no statistical differences among Orthocon, GL1, EXP1, and EXP3. At 28 days, Orthocon was similar only to GLl, the other peroxide catalyzed silicone.

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In vitro stress measurements

The low displacement force measurement apparatus indicated that P3 produced the highest forces at all displacements; Orthocon M and GL1 were the most similar at intermediate levels; and EXP1 produced the lowest overall readings (Fig. 12). Duncan's multiple range test showed all values to be statistically different.

DISCUSSION

The Japanese product Orthocon was not readily obtainable and a secondary objective of this investigation was to identify generically similar materials. Five elastomers were selected as representative silicone compositions that might have application in orthodontic positioners. MDX-4-4210 has been used in maxillofacial prosthetics[13,14] and the remaining silicones have seen either limited or no previously known dental application.

Tensile, tear, and hardness relationships

In this study tensile strength, elongation at failure, and tear strength served as useful indicators of a material's durability or resistance to rupture under standard conditions in an aqueous environment at 37° C. The commercial urethane material P2 showed the greatest tensile strength at failure. Several silicone compositions— EXP1, Orthocon, and EXP3— exhibited higher tensile strengths than the urethane P1 and thermoplastic vinyl P3 materials. The tensile strength, ultimate elongation, and tear strength values of the facial prosthetic material MDX-4-4210 were the lowest values for all materials tested.

High-tear strength is an essential characteristic for positioners and tear data should be interpreted carefully. Failure of elastomeric materials usually occurs through the initiation and growth of a tear. In principle, molecular structure and formulation variables such as filler type and loading fraction, plasticizer content, and cross-link density can all be optimized to create a composition with superior tear strength. In practice, however, optimization is difficult to accomplish since the tear process in rubber is a complex phenomenon not readily broken down into fundamental relations. Tear strength also depends on the shape of the test piece and rate of the tear, so comparisons with other values in the literature must consider the methods used. The importance of the initial crack in some materials, as noted previously, and its relationship to the ultimate tear values remain to be investigated.

EXP1 represented the highest tear strength of all materials, but its tear and tensile strength data also showed the highest standard deviation. Product uniformity is an important consideration and should be monitored closely with this material.

Tensile modulus provides an indication of a material's flexibility and the silicones were

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the most elastic at all displacements less than 100%. EXP3 is a high-tear strength silicone that produces less force per unit of displacement than EXP1. In vitro data suggest that EXP3 may be too flexible for use in this application. Durometer hardness is another measure of flexibility and indicates that the most inelastic materials are the urethanes (P1 and P2) and thermoplastic vinyl (P3) polymers.

Water sorption

The methodology for water sorption measurements on elastomers has not been reported in the orthodontic literature. Tests were based on references examining mouthguard materials,[15-17] ASTM D47-74, and specifications by the American Dental Association.[18]

Water sorption is an indication of a material's long-term stability in an aqueous environment and represents the amount of water adsorbed on the surface and absorbed into the body of the material. Alteration of mechanical properties, dimensional change, and possibly unhygienic conditions may be associated with increased levels of water sorption.

Values were the lowest for the vinyl (P3), which reached equilibrium after 24 hours and maintained the lowest weight gain throughout the 28-day period. In contrast, EXP2 had a 24-hour weight gain less than the urethanes (P1 and P2), but continued to absorb water throughout the test period at a greater rate than any other material. The urethane materials demonstrated water sorption levels approximately 10 times greater than those of all silicones except EXP2.

In vitro stress measurements

Optimum orthodontic force has been defined by Nikolail[19] as that which produces a maximum desirable biologic response with minimum tissue damage, resulting in rapid tooth movemet with little or no clinical discomfort. Smith and Storey[20] suggest a force of 150 to 200 gm as being optimum for translation of lower canines in human beings; Reitan[21] advocates 250 gm; Lee[22] recommends 150 to 260 gm; whereas Ricketts and associates[23] prescribe 100 to 150 gm. If forces between 100 and 260 gm are considered to be physiologic, this model indicates that EXP1, Orthocon M, and GLl deliver forces inside this range if displacements are on the order of 1.0 mm or less for Orthocon and GL1, and 1.0 through 2.5 mm for EXP1. Forces that may be considerd above the ideal range are present in P3 even at low displacement. It was noted that force levels decreased with time at each displacement after the 2-second recording period. Further investigation into the effect of stress relaxation and recovery of elastomers used in this model is required.

A limitation of this in vitro model is that a single malposed tooth is a very restricted type

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of malocclusion. However, the subject of force delivery in positioners has not been addressed in the orthodontic literature and this study provides baseline data until more sophisticated instrumentation is developed.

CONCLUSION

This investigation presents the results of tests that were performed on nine materials, three of which are representative of types used in commercial positioners today. The tests that were chosen (tensile strength, tensile stress at selected elongations, ultimate elongation, tear strength, durometer hardness, and water sorption) and the conditions of the tests permit evaluation of durability, flexibility, and stability in an aqueous environment. Orthocon, the Japanese silicone material with claims of unique properties, was statistically different from the commercial urethane (P1 and P2) and vinyl (P3) materials. Overall Orthocon had somewhat less durability than P1, P2, and P3, but also demonstrated lower force levels at all displacements less than 100% elongation as compared with the same materials. In comparison with other silicone materials, Orthocon was most similar to EXP1 and GL1. The mechanical parameters of ultimate elongation and tensile stress at 50% elongation were statistically the same for Orthocon and EXP1. MDX-4-4210 and EXP2 have been shown to possess inadequate durability and a relatively high degree of water sorption, respectively.

The results of this study suggest that certain elastomers (Orthocon, GL1, and EXP1) have the potential to effectively move teeth over a greater range as compared with conventional positioner materials. The tear strength of GL1 may be a limitation, but Orthocon and EXP1 appear to possess adequate durability. These materials also absorb (adsorb) less water than urethane polymers and may be processed in gypsum molds at 100° C or less.

This investigation generally supports many observations in the Japanese literature, although clinical data at this time are incomplete. Current research is examining clinical effects of these materials and correlation with in vitro data.

The suitability of any one material is determined by a complex set of interacting variables. A complete characterization of all the molecular and structural properties that determine a material's response under a given set of conditions is impractical. Therefore the objectives of this study were to select and perform a set of tests that could compare a range of orthodontic positioner elastomers and predict the suitability of new and experimental materials.

We would like to acknowledge the help of Mr. Robert Johnson for technical assistance and manuscript preparation, and Dr. Paul Mashimo for translation of the Japanese publications.

Stephen P. Warunek

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Professor and Chairman, Orthodontics Department.

Larry J. Green

Professor, Orthodontics Department.

Orthocon

Sankin Industry Co. Ltd., Tokyo, Japan.

one manufacturer

TP Laboratories, La Porte, Ind.

Another manufacturer

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Professional Positioners, Racine, Wis.

D412-83, type 1

ASTM designation D412-83, standard method of tension testing of vulcanized rubber.

Bard-Parker

Becton Dickinson & Co., Rutherford. N.J.

die C

ASTM designation D624-81, standard test method for rubber property— tear resistance.

durometer hardness

ASTM designation D2240-81, standard test method for rubber property— durometer hardness.

Instron tester

Instron Corp., Canton, Mass.

ALD-MICRO

A.L. Design, Inc., Amherst, N.Y.

GL1

Great Lakes Orthodontics Ltd., Tonawanda, N.Y.

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MDX-4-4210

Dow Corning Corp., Midland, Mich

ASTM D47-74

ASTM designation D47-74, standard method of test for rubber property-effect of liquids.

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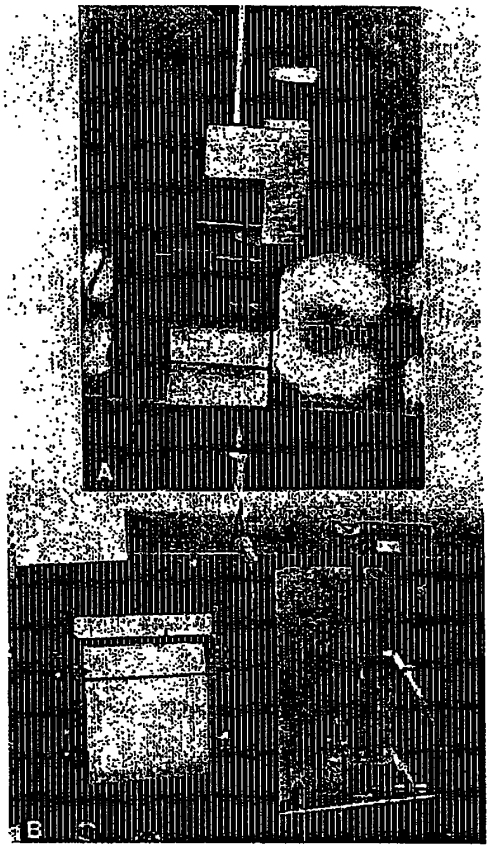


Fig. 1. A, Tensile ring specimen supported on roller bearing fixture. **B**, Controlled temperature water chamber mounted in Instron machine for tensile test.

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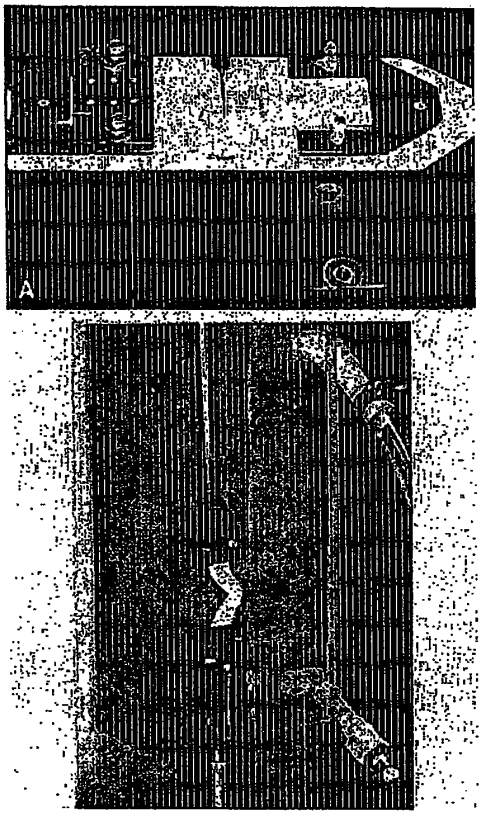


Fig. 2. A, Alignment of tear specimen on positioning jig. **B**, Tear specimen mounted in controlled temperature water chamber.

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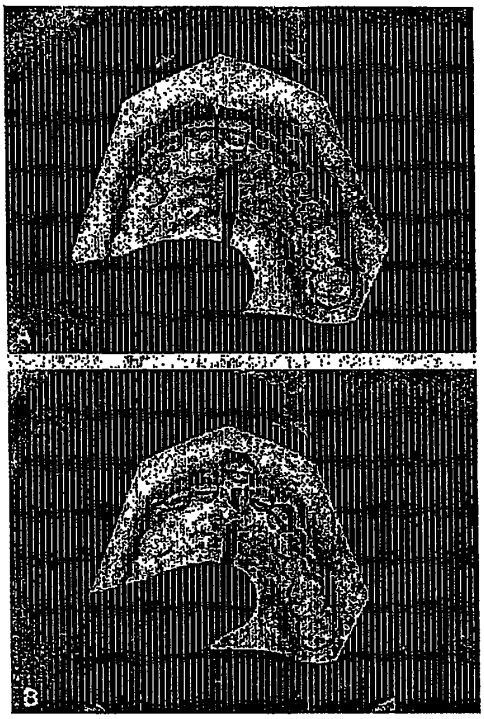


Fig. 3. A and B, Movable acrylic incisor for transducer measurements.

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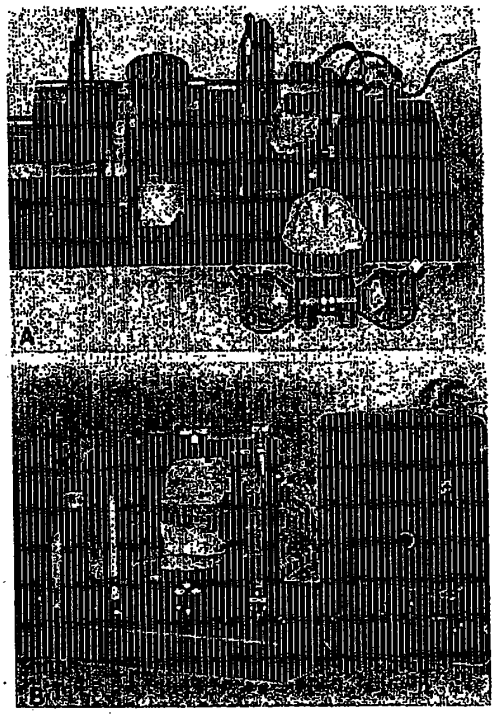


Fig. 4. A and B, Force-displacement measuring apparatus.

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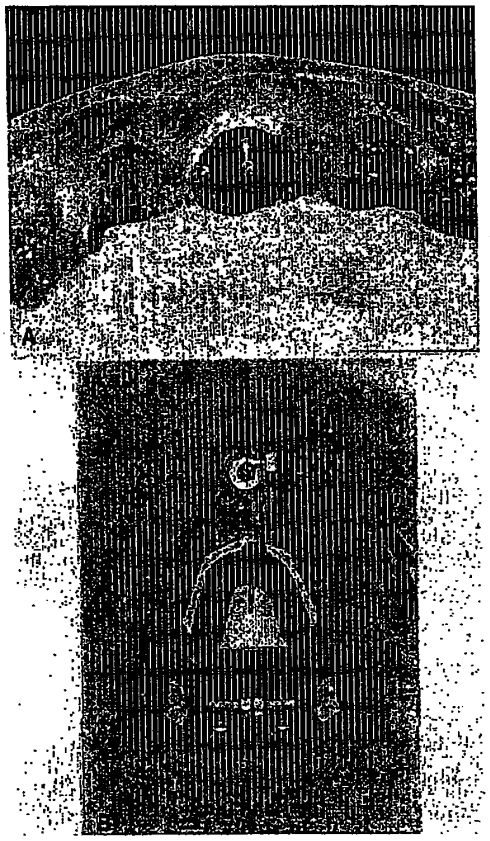


Fig. 5. A, Transducer inserted into labial flange of positioner. **B,** Transducer, positioner, and model assembly mounted on upper part of articulator.

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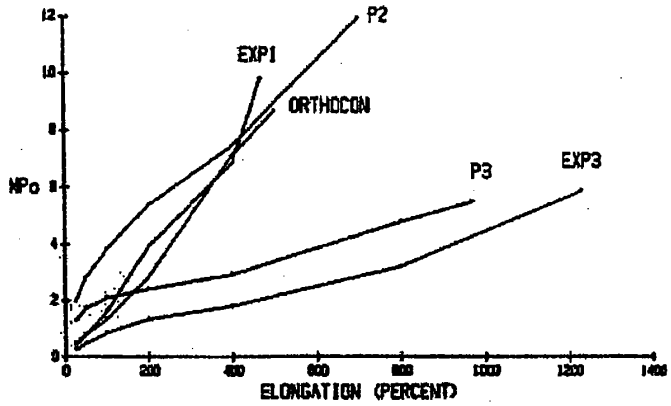


Fig. 6. stress elongation curves for five elastomer types.

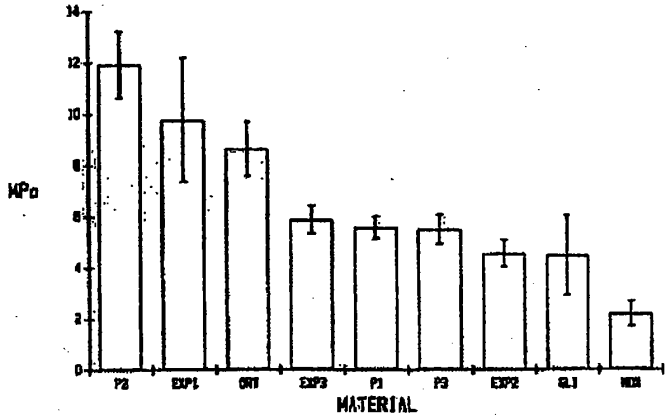


Fig. 7. Tensile strength.

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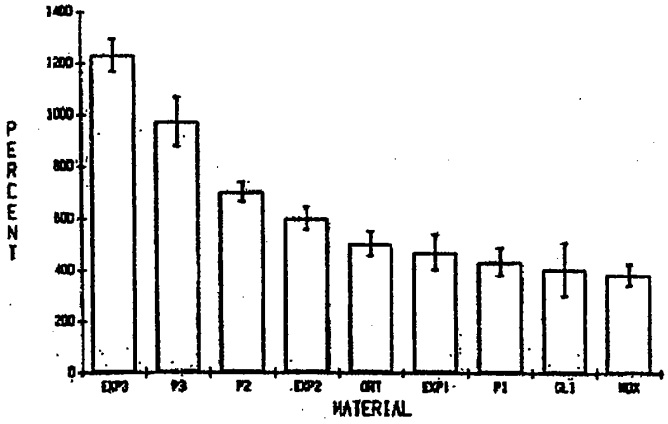


Fig. 8. Ultimate elogation.

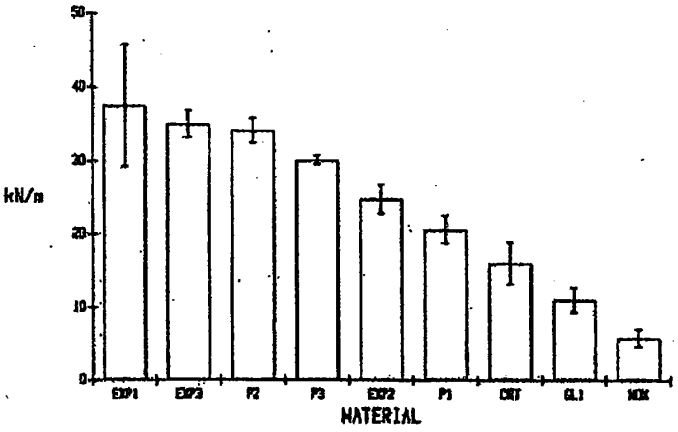


Fig. 9. Tear strength.

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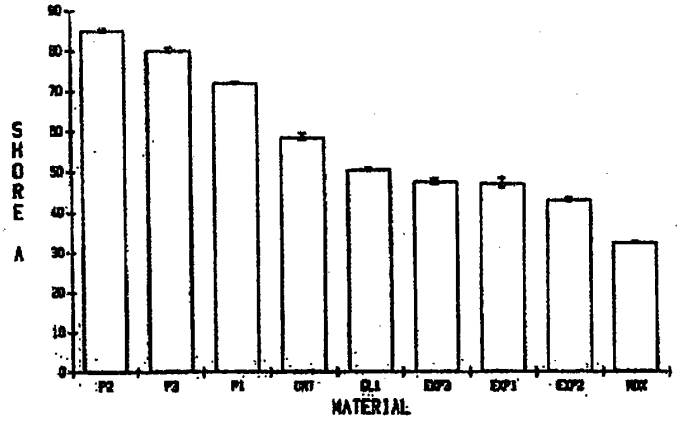


Fig. 10. Hardness.

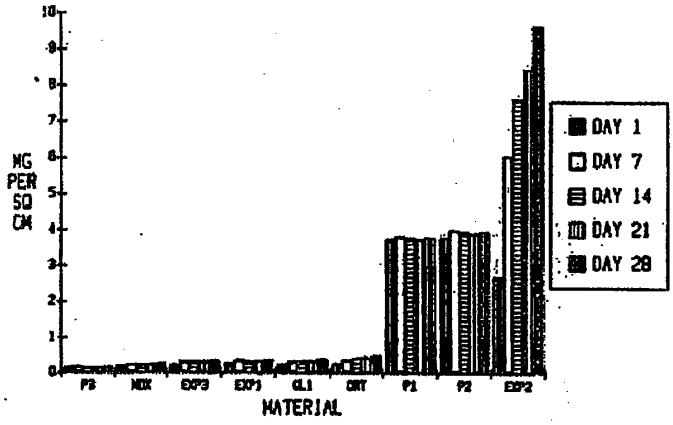


Fig. 11. Water sorption.

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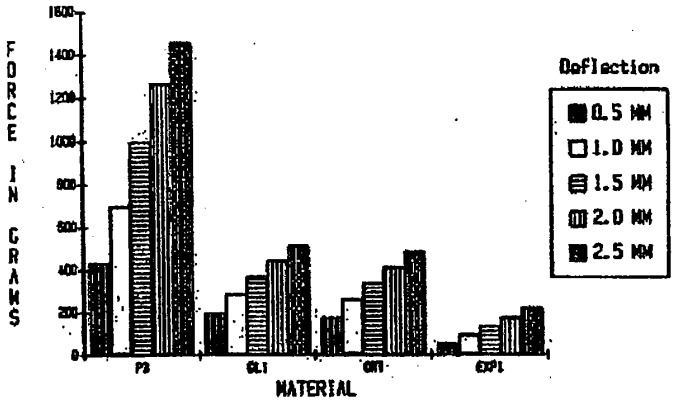


Fig. 12. Results of low-displacement force measurement model.

Table I. Materials tested

Material	*Type of polymer chemistry*
P1	Polyether urethane
P2	Polyether urethane
P3	Ethylene vinyl acetate
MDX-4-4210	Addition reaction silicone
GL1	Peroxide reaction silicone
Orthocon (medium hardness)	Peroxide reaction silicone
EXP1	Addition reaction silicone
EXP2	Condensation reaction silicone
EXP3	Addition reaction silicone

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Clinical Use of Silicone Elastomer Appliances

STEPHEN P. WARUNEK, DDS, MS
IRENE D. STRYCHALSKI, DDS, MS
JOHN J. CUNAT, DDS, MS

Kesling introduced the tooth positioner for artistic finishing in 1945,[1] and proposed a series of positioners for graduated movement toward a corrected occlusion in 1946.[2] Because these positioners were made of hard natural rubber, however, they were restricted to the finishing and retention stages of orthodontic therapy.

If too much tooth movement is expected from a single positioner, it will not seat adequately without discomfort and will adversely affect patient cooperation.[3] Furthermore, in cases where the basic treatment is not completed properly, use of positioners can result in closure of the vertical dimension. A series of positioners could effect extensive tipping movements, but time and cost would have to be considered when constructing several appliances.

Various substitutes for rubber have been tried in making positioners. Polyurethane rubber worked well, but processing involved a complicated pressure-molding procedure. In 1977, an improved elastomer made of low temperature vulcanizing (LTV) polydimethyl silicate (silicone) rubber was introduced.[4]

Yoshii developed the concept of complete orthodontic therapy using a series of two or three "dynamic positioners" (marketed under the name of Orthocon*).[5-7] This heat-cured silicone appliance was considerably more elastic than previous types and was available in three gradations of hardness that could be mixed for further flexibility. It had excellent elasticity, stretching range, and pulling intensity, with less form change and less decrement of elasticity than with previous materials. Because the appliance was translucent, the teeth and gingivae could be observed with it in place.

A 1989 study compared properties of silicone elastomers and conventional positioner materials and demonstrated the high strength, low water sorption, and relatively low force per unit displacement of the silicone types.[8] This article will describe how such an enhanced-elasticity appliance can be used both for finishing and for comprehensive orthodontic treatment.

Case 1

A 10-year-old female patient presented with a Class I skeletal and dental relationship, with undersized, peg-shaped maxillary lateral incisors and impacted maxillary cuspids (Fig. 1A).

The maxillary laterals were extracted and the cuspids surgically exposed. Fixed appliances were placed and, following eruption of the cuspids, the maxillary posterior teeth were protracted with intra-arch and Class III elastics. Vertical elastics were used for several months to correct the intercuspation of the buccal segments, but without measurable improvement.

After 18 months of treatment, the patient's molars were in a Class II relationship. All intra-arch spaces had been closed, and the overbite and overjet were both 2mm. There was an open bite of as much as 3mm between the first molars and central incisors (Fig. 1B).

We chose a silicone elastomer finishing appliance (Elastofinisher**) instead of a con-

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*Sankin Industry Co., Ltd., Tokyo.

**Great Lakes Orthodontics, 199 Fire Tower Drive, Tonawanda, NY 14150.

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Dr. Warunek Dr. Strychalski Dr. Cunat

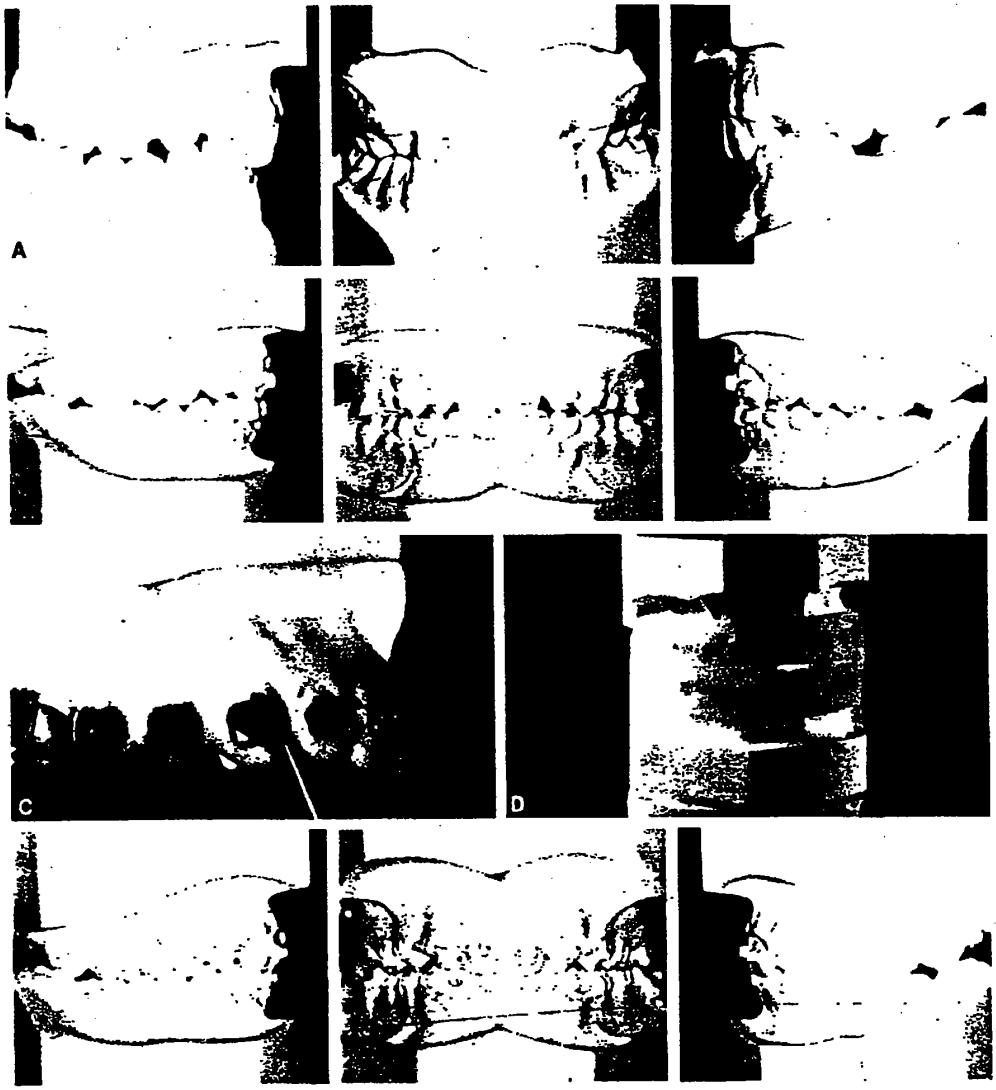


Fig. 1 Case 1. A. Before treatment. B. After 18 months of fixed appliance treatment. C. Elastic modules improve impression accuracy. D. Completed silicone elastomer appliance. E. After six weeks of wearing finishing appliance.

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ventional positioner because of its greater elasticity and its ability to stretch and couple to fixed appliances. Accurate impressions, facebow transfer, and centric registration are essential in fabricating this appliance. In this case, the wax registration was taken in a centric position slightly open from first posterior contact.

Archwires were removed, and elastic modules† were placed to improve the accuracy of the alginate impressions in the bracket areas (Fig. 1C). Impressions taken without modules or with elastic O-rings can tear or lack detail.

After the impressions were taken, the modules were removed and the archwires replaced. In the laboratory, the model was carved around each bracket area and undercut to improve retention. Therefore, elastic modules are not worn during treatment.

Archwires were removed, and the patient first wore an appliance made of a relatively elastic and low-durometer elastomer for 10 hours per day. This was followed by a medium-elasticity appliance.

After six weeks, the patient showed improved interdigitation with full occlusal con-

†Hug Caps, Kreative Koncepts, Inc., 5 W. Second St., Hinsdale, IL 60521.

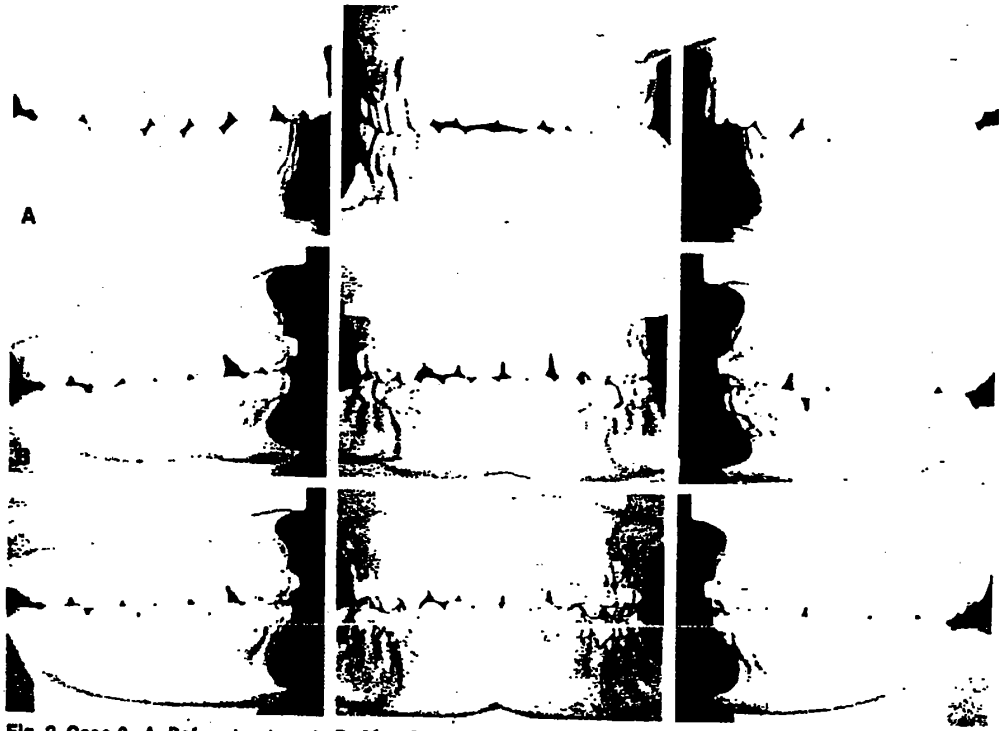


Fig. 2 Case 2. A. Before treatment. B. After 21 months of fixed appliance treatment. C. After eight weeks of wearing finishing appliance.

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tact (Fig. 1E). She is currently wearing the medium-elasticity appliance at night as an interim retainer. Treatment will be completed with cosmetic bonding of the cuspids and conventional Hawley retainers.

Case 2

A 15-year-old female patient presented with a Class II subdivision malocclusion, with an anterior open bite due to a thumbsucking habit. The overjet was 7mm and the overbite −2mm (Fig. 2A).

After 21 months of conventional fixed appliance therapy, the patient showed a Class I malocclusion with no overbite, a 1mm overjet, and spacing in the lower left quadrant and the maxillary anterior area. The mandibular midline was 1mm to the right of the maxillary midline (Fig. 2B).

We decided to use an Elastofinisher to improve the result. Impressions, facebow transfer, and centric registration were taken as described above. The patient wore a low-durometer appliance for eight to 10 hours at night for two months.

At this point, the lower spacing had been eliminated and the upper spaces greatly reduced. The overbite was increased to 1mm, the overjet corrected to 2mm, and the midlines aligned (Fig. 2C).

The patient is being retained with a maxillary wraparound and mandibular Hawley appliance. She will consult with her general dentist about cosmetic bonding of the undersized maxillary lateral incisors.

Case 3

A 12-year-old male patient presented with a Class I skeletal and dental relationship, mild to moderate spacing in both arches, 1mm of overbite, and 5mm of overjet. The mandibular midline was displaced 1mm to the left (Fig. 3A).

Alginate impressions, facebow transfer, and centric registration were taken for a comprehensive silicone elastomer appliance without fixed attachments. Teeth were reset on the models using the initial lower incisor position

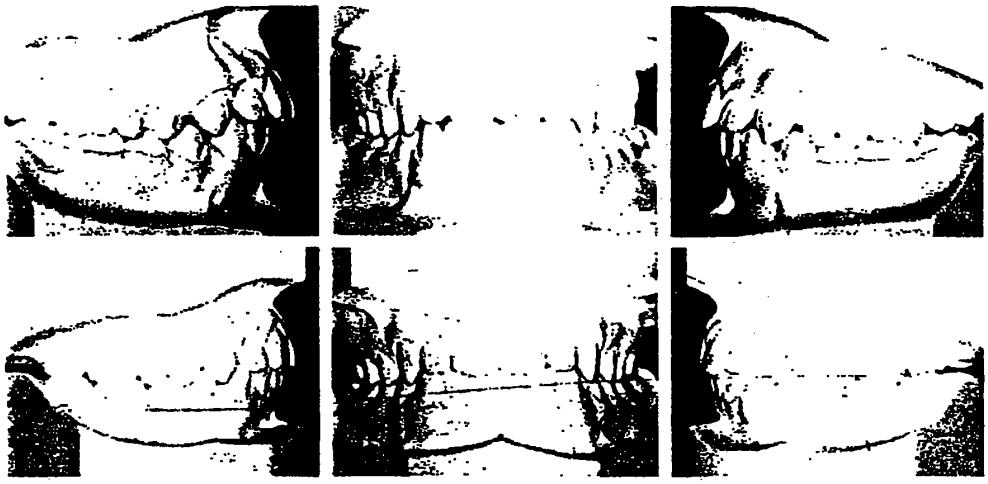


Fig. 3 Case 3. A. Before treatment. B. After two months of wearing silicone elastomer appliance without fixed attachments.

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as a reference.

After a two-day break-in period of wearing the appliance for several hours a day, the patient wore a light-elasticity appliance for an average of nine hours per day. After two months, the overjet was reduced to 2mm, the overbite increased to 2mm, the midlines aligned, and the interproximal spaces almost completely closed (Fig. 3B).

The patient is currently wearing a medium-elasticity appliance for eight hours on alternate days as a retainer.

Case 4

A 25-year-old male patient presented with a Class I dental and skeletal relationship and mild crowding, particularly in the maxillary arch. The right first and second molars were in crossbite (Fig. 4A).

A silicone elastomer appliance was chosen for comprehensive treatment in conjunction with fixed attachments. Alginate impressions, facebow transfer, and centric registration were taken.

Acrylic buttons were bonded indirectly[‡] to the labial surfaces of the teeth (Fig. 4B). A medium-elasticity full-coverage appliance was fabricated to engage the buttons (Fig. 4C). A divided, elastic-strip version of the appliance

[‡]Rely-A-Bond for Plastic, Reliance Orthodontic Products, Inc., P.O. Box 1107, Itasca, IL 60143.

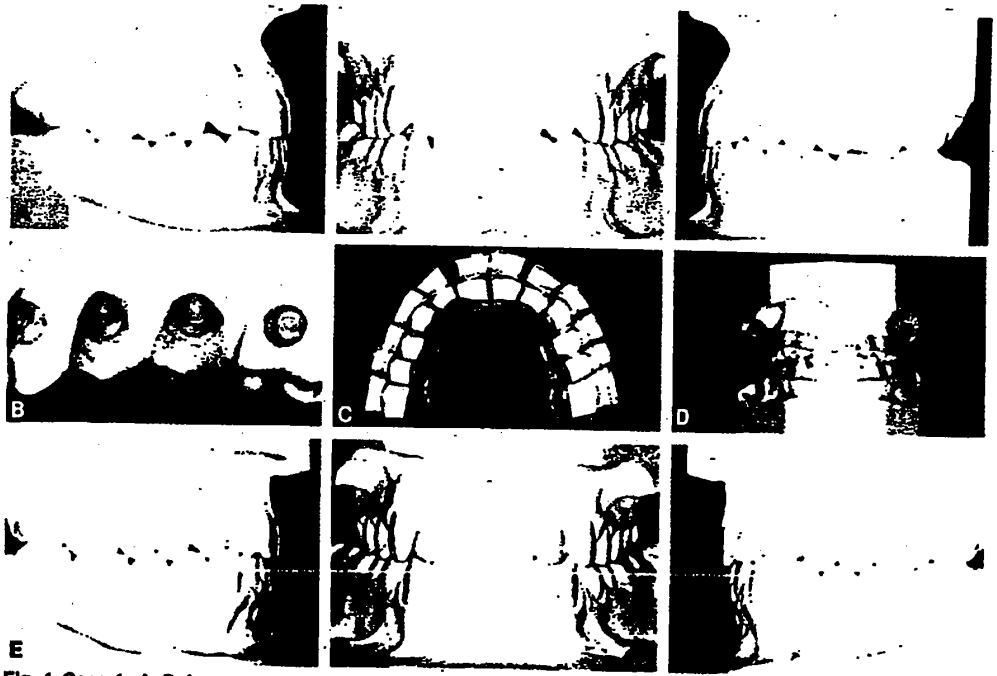


Fig. 4 Case 4. A. Before treatment. B. Acrylic buttons on model. C. Construction of silicone elastomer appliance. D. Divided strips for daytime wear. E. After six months of wearing silicone elastomer appliance.

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was also constructed for patient comfort during the day (Fig. 4D).

The patient wore the full appliance for an average of nine hours per night for six months. The molar crossbite was corrected, the buccally displaced maxillary right cuspid was aligned, and the overall occlusion improved (Fig. 4E).

The acrylic buttons were then removed, and the patient is currently wearing the medium-elasticity appliance at night as a retainer.

Clinical Management

When the appliance is coupled to fixed attachments, the laboratory technique is critical. Upon insertion, a properly constructed appliance usually does not engage all the attachments. Patients typically adjust to the appliance within two or three days, and the coupling effect improves with patient use and tooth movement.

Patients should be instructed to keep the appliance in the mouth with gentle closing pressure. Exercising by biting and releasing the material, as prescribed for conventional positioners, is not recommended. However, in vitro studies have demonstrated adequate tensile and tear strength of the silicone material.[8] Mutilation from chewing has been observed only rarely, and several of the appliances have been worn nine hours a day for 18 months with no significant signs of deterioration.

Discussion

Positioner-type appliances made of flexible silicone elastomers can perform a greater range of functions and produce more tooth movement than those made of rubber, urethane, or vinyl. Our experience shows that they are most effective for correcting mild crossbite and crowding when used with fixed attachments. Mild midline discrepancies, open bites, and interproximal spacing can be corrected without fixed attachments. We have observed tooth movement of as much as 2-2.5mm per appliance (Fig. 5).

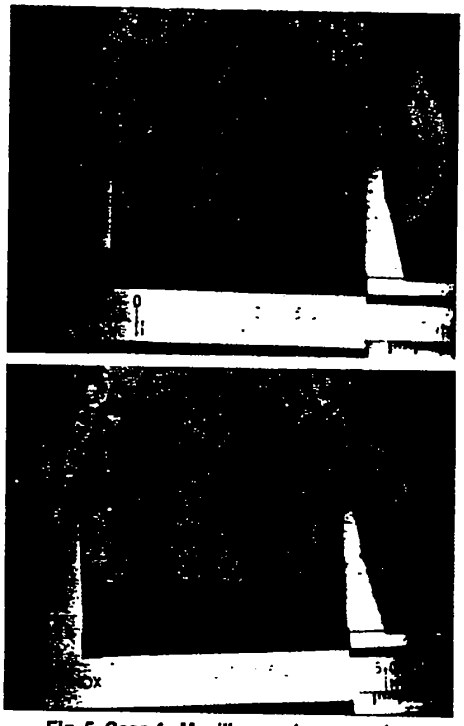


Fig. 5 Case 4. Maxillary molar expansion.

Silicone elastomer appliances may be superior to interarch vertical elastics because they prevent pressure on the dentition from tongue or fingersucking habits. An additional advantage is that the clinician can return to fixed mechanics if noncooperation necessitates further detailing.

As with any removable appliance worn less than full-time, attention is required to situations prone to relapse after archwire removal, such as correction of tooth rotations and arch expansion. These appliances are contraindicated for patients with significant airway restriction, and their effectiveness in correcting rotated posterior teeth appears limited.

Silicone positioner-type appliances rep-

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resent a new and viable treatment alternative. In the cases reported here, chairtime was minimal and satisfactory results were obtained with adequate patient cooperation.

ACKNOWLEDGMENTS: The authors would like to thank Mr. Gary Abbatte and Mr. Brian Willison for technical assistance and Mrs. Catherine Winney for help in the preparation of this article.

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Application of the positioner appliance in orthodontic treatment

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The objectives of tooth positioner treatment are substantially those of all orthodontic treatment procedures. It is desired that the teeth be brought into proper alignment in harmony with the supporting tissues and in equilibrium with the forces acting on the dentition and on the individual teeth. This goal is admittedly difficult to attain for many patients, and perhaps it is impossible to attain for some patients. This concept is well stated by Thurow[1]: "No dentition is ever stable in the sense that the teeth are fixed in position or that bone has hardened around them. The only possible stability is a dynamic one in which all of the forces acting on the teeth are in balance."

The purpose of the present article is to discuss the role of the tooth positioner in attaining these objectives. A description of treatment, its timing, and an analysis of tooth movements initiated by the appliances will be supported by representative cases.

Review of the literature

The tooth-positioning appliance was described by H. D. Kesling[2] in an article published in June, 1945. As an appliance, it would allow the teeth to move into their best possible positions in relation to one another without any interference from bands or wires. This appliance was to be "effective under functional forces and would produce arch form in accordance with type that would attain the desired harmony between facial features and tooth arrangement and that would serve as a retainer to conserve all the advantages gained above."[2] Later, in 1946, Kesling presented the technique of rearranging the teeth in plaster models, a step in the construction of the tooth positioner, as a method of coordinating a predetermined pattern with conventional treatment.[3] Thus, the setup for the tooth positioner became, first, a diagnostic aid and then the method of constructing the finishing and possibly retaining appliance.

In 1950 Elsasser[4] discussed what he believed to be the chief advantages and

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disadvantages of this appliance. He, like others, warned of the positioner's tendency to close the bite. In 1960 Vorhies[5] presented an appraisal of the results of short intensive use of the positioner wherein the patient had worn the appliance for an average of more than 17 hours a day for approximately 1 to 2 months. He demonstrated quantitative changes in tooth position that could be accomplished with the tooth positioner in a short period of time and showed that axial inclination changes were due primarily to tipping. He thought that the positioner did not establish a definite pattern in the selective depression or eruption of teeth.[5] Bunch,[6] in 1961, presented a thesis on positioner therapy during orthopedic treatment of scoliosis. He stated that several types of tooth movement were demonstrated in response to positioner wear: closing of space, rotation of teeth, depression of teeth, increase or decrease in overbite, increase in overjet, uprighting of teeth, and improvement of interdigitation by both tipping and bodily movements. He also stated that midlines could be corrected, as could some cross-bites.

Materials and methods

Records of twenty-nine patients were analyzed for response with the tooth positioner. Twenty-seven of the cases were selected from my practice; these were cases in which there were adequate records to demonstrate a favorable response during positioner treatment. Models of two patients were loaned to me by a former classmate who uses the Begg appliance and technique for routine treatment of his patients.

All patients included in this study were given positioners constructed in the usual manner. A typical positioner setup is illustrated in Fig. 4*B*, and views of the positioner appliance are given in the left lateral and occlusal views. Black rubber material was found to be the most satisfactory. In some cases other materials were used for the initial positioner. However, if positioner wear of more than 2 to 4 months was prescribed, these positioners were usually remade of black rubber. The patients were instructed to exercise actively into the positioner 4 hours a day in addition to nighttime wear. This procedure has been advocated in most publications on the subject of positioner treatment and use. The period of tooth positioner wear varied from 21 days to 3 years. Cooperation by the patient in wearing the appliance as prescribed varied from complete cooperation, to night wear only on a part-time basis with occasional week-long or several-week intervals of active exercise.

The twenty-nine patients were divided into five groups according to the manner in which the positioners was used:

Group I. Positioner used as total therapy (three cases, one illustrated).

Group II. Positioner used following other removable appliance therapy (eight cases, two illustrated).

Group III. Positioner used following minimum edgewise banded therapy (eleven cases, two illustrated).

Group IV. Positioner used following full edgewise banded therapy (five cases, two illustrated).

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Group V. Positioner following Begg banded therapy (two cases, not illustrated).

Discussion

Before the advantages of the positioner in these five groups of patients are analyzed, some of the limitations and disadvantages of the positioner for each type of treatment should be mentioned. In addition, some criteria of case selection should be noted.

Very few malocclusions warranting treatment can be corrected by positioner therapy alone, as was done with the cases in Group I. In the more than 1,000 patients for whom I have instituted some type of orthodontic treatment, I have only three exceptional cases in which I feel that satisfactory tooth movement and occlusal relation were achieved by using the positioner alone. The needed tipping and rotation movements of teeth were moderate in degree and distance in these three cases. In one of the cases, an anterior cross-bite was corrected; in another case, an open-bite with incisors rotated 45 degrees was satisfactorily treated and retained with the positioner; and in the third case (Fig. 1, Case 684), a buccal cross-bite in the upper left posterior quadrant was treated. The use of the positioner in the prescribed manner in Case 684 resulted in the

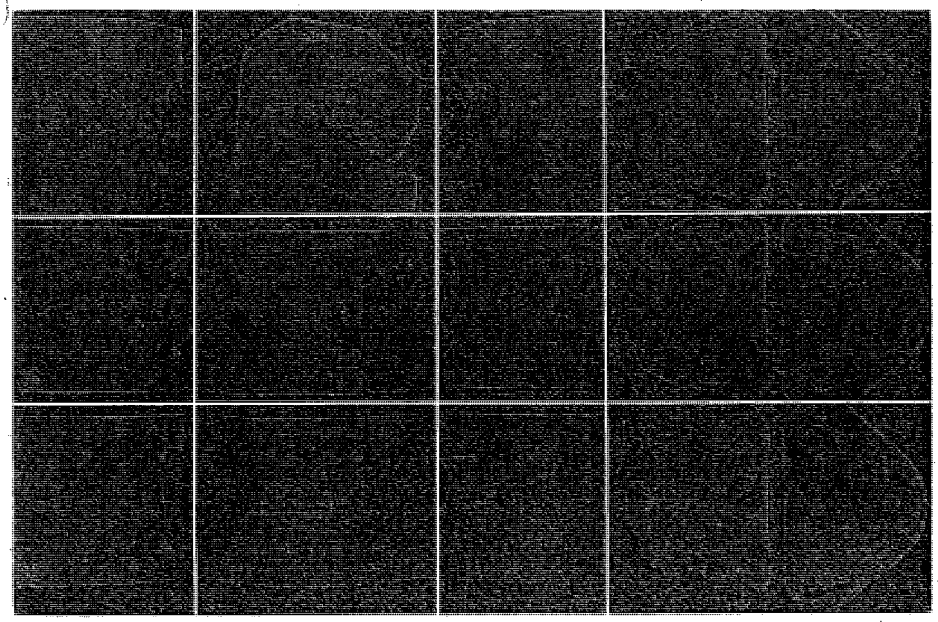


Fig. 1. Cast record, Case 684, male. **a,** Pretreatment (Sept. 3, 1963). Positioner started. Worn actively for 13 months. Age: 14 years 7 months. **b,** Postretention (Dec. 15, 1966). Positioner discontinued, used as mouth guard. Age: 17 years 10 months. **c,** Postretention (Aug. 11, 1967). Two years after positioner therapy. Age: 18 years 6 months.

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correction achieved by a significant amount of tipping of the left upper canine and premolars lingually and the lower canine and premolars buccally. There was also noticeable improvement in the alignment of the lower incisors as well as correction of the rotational position of the lower canines and upper right lateral incisor (Fig. 1, models *b* and *c*).

Treatment with the positioner as the initial appliance (Group I) requires exceptional cooperation from the patient. The tooth movement needed for the correction of the malocclusion should be relatively small. In accomplishing these movements, the positioner should bring the teeth into functional harmony in the oral environment. The plaster teeth should be positioned to allow the inclined planes of the cusps to ultimately act in perfect harmony for mutual support. This also means balance with respect to size and relationship of the dental arches. There is a likelihood of successful positioner therapy if balance and harmony are obtained. It must be pointed out to the patient and the parents that the positioner may not be able to accomplish all the corrections needed and that a fixed appliance may be required later.

The positioner can be very rewarding in Group II cases, where correction of bite and alignment has been initiated with a Hawley type of retainer. I believe that the primary difficulty in this type of case is lack of cooperation from the patient since the most objectionable esthetic and functional evidences

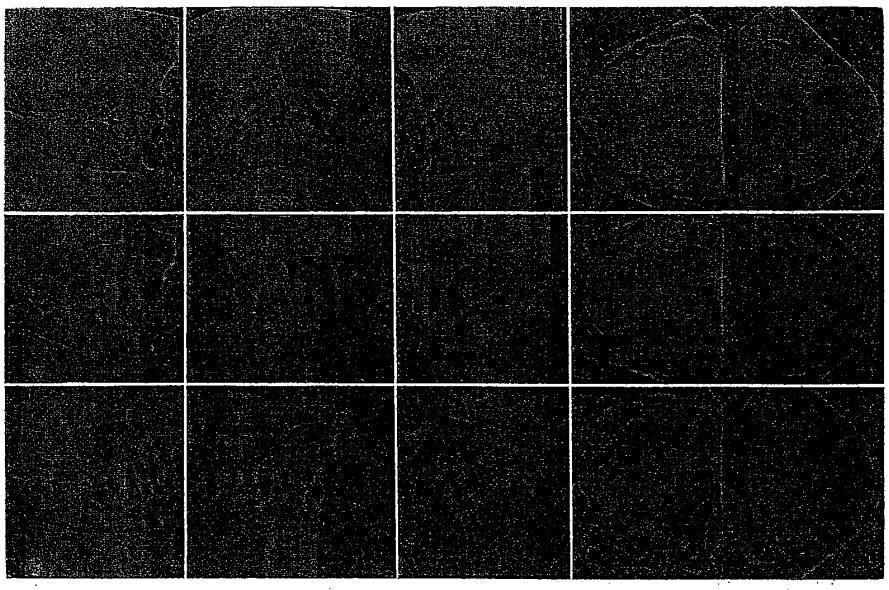


Fig. 2. Cast record and résumé, Case 227, female. **a,** Pretreatment (March 21, 1961). Upper removable plate started. Age: 11 years 7 months. **b,** Progress (Oct. 9, 1963). Positioner started. Age: 14 years. **c,** Posttreatment (March 11, 1966). Retention with positioner worn at night. Age: 16 years 7 months.

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of the malocclusion have been corrected. Even with a high degree of patient cooperation, the positioner may not be sufficient to effect an ideal result. Unless the procedure is properly explained beforehand, both the orthodontist and the parents may find themselves in a dilemma with respect to the time and expense of subsequent banding therapy. This problem is demonstrated by Case 227 (Fig. 2), in which sufficient improvement was achieved for the parents to decline subsequent banding treatment. In this case, the four first premolars were extracted. During eruption of succedaneous teeth, an upper removable plate was used for 27 months to align incisors, to tip the upper right first molar distally, and to guide eruption of succedaneous teeth (model *b*). The positioner was worn 4 hours a day for 3 months and at night for 2 years. It effected improvement but not full correction of tooth positions (model *c*).

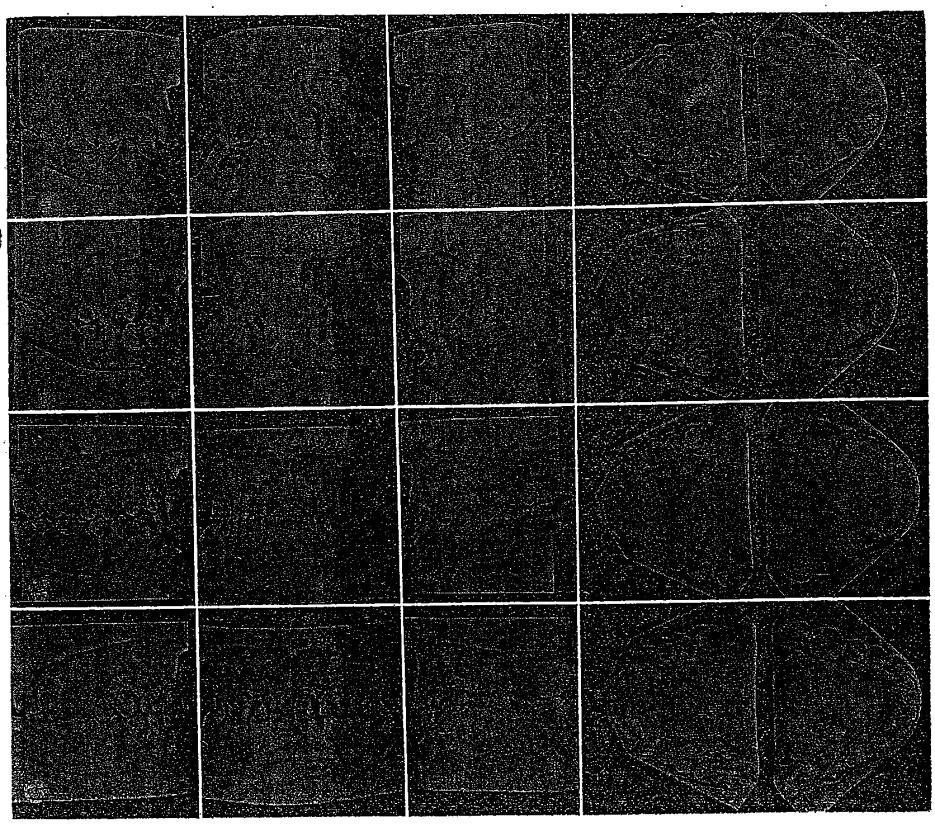


Fig. 3. Cast record, Case 606, male. **a,** Pretreatment (March 5, 1963). Bite plane after extraction of upper deciduous first molars. Age: 13 years 3 months. **b,** Progress (Nov. 17, 1964). Positioner started. Age: 14 years 11 months. **c,** Progress (Feb. 14, 1967). Positioner stopped; upper removable plate. Age: 17 years, 2 months. **d,** Posttreatment (Aug. 14, 1967). Upper plate for retainer. Age: 17 years 8 months.

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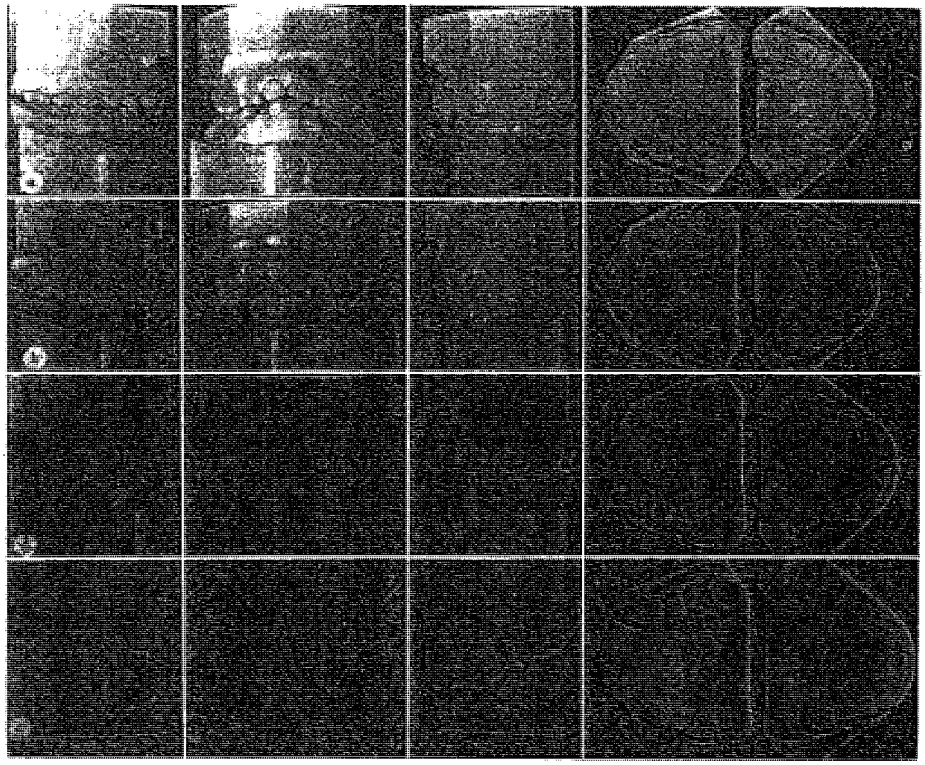


Fig. 4A. Cast record, Case 284, female. **a,** Pretreatment (July 31, 1961). Cervical traction started. Age: 7 years 5 months. **b,** Progress (April 15, 1966). Positioner started. Retainer stopped. Age: 12 years 2 months. **c,** Progress (Aug. 22, 1966). After 4 months' positioner wear. Age: 12 years 6 months. **d,** Posttreatment (Sept. 1, 1967). Retention with positioner worn at night. Age: 13 years 7 months.

Fig. 3 (Case 606) shows the records of a patient who wore a retainer as the initial guiding appliance to tip the upper right first molar distally, open the bite, and retract the upper incisors. At the time use of the positioner was started, the right posterior relationship was essentially with cusps tip to tip and the left posterior teeth were displaced to the buccal (Fig. 3, model *b*). Positioner wear was intermittent, primarily at night. There was occasional wear up to 3 hours a day for several-week intervals. There was an improvement in the posterior relationship and interdigitation during positioner therapy (model *c*). The upper right second molar erupted in buccal cross-bite. A maxillary retainer was placed and was successful in guiding this tooth lingually and in allowing further improvement in the interdigitation in the right buccal segments (model *d*). This case shows favorable improvement, including midline correction with long-term nonintensive use of the positioner appliance.

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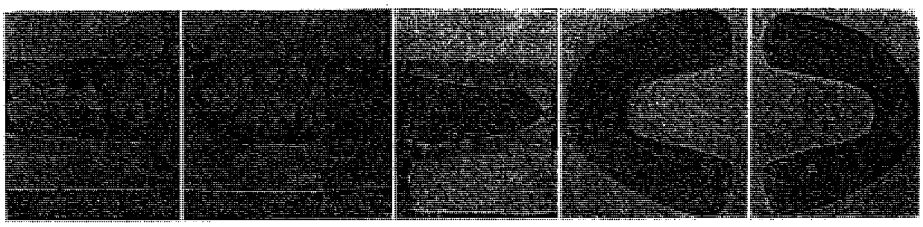


Fig. 4B. Positioner setup from Case 284, model **b**, with positioner in place in left lateral view of cast. Maxillary and mandibular occlusal views of positioner appliance on right.

The positioner is used in Group III cases after treatment with a minimal banded appliance, such as the face-bow traction directed against the permanent maxillary molars. This is illustrated by Case 284 (Fig. 4*A*), in which the positioner was offered as an alternative to additional banding treatment. The patient understands that complete cooperation is necessary and a favorable response of the dentition must be elicited. If either cooperation or response is not forthcoming, the use of a rigidly controlled fixed appliance can be instituted.

Treatment was started for this patient (Case 284) prior to eruption of the permanent molars. The lower right and left deciduous canines were extracted because the lower permanent lateral incisors were erupting lingually (Fig. 4, model *a*). When the first molars erupted, a face-bow headgear was placed and worn for 29 months. A normal molar relation was established. A bite plane retainer aided in correction of the overbite and in establishment of a more favorable positioning of the lower incisors. After loss of the deciduous molars and eruption of the succedaneous teeth (model *b*), a positioner was placed and achieved an improvement in the interdigitation of the canines and premolars. A favorable improvement in the axial inclination of the incisors occurred with a decrease in overjet. The improvement in interincisal angle and incisor position appears to be due to an uprighting of the lower incisors. In addition to more favorable alignment, there were slight diastemas between the incisors which previously were crowded (models *c* and *d*).

Because of the severity of the malocclusion in Case 452 (Fig. 5), treatment was started with molar bands and a face-bow, even though the patient was leaving this country in 12 months. This resulted in an improvement in jaw relation and correction of the cross-bite (model *b*). Through the use of the positioner, the alignment and interdigitation of the teeth had dramatically improved by the time the patient returned from abroad (model *c*). Use of the positioner was then discontinued. The primary function of the positioner while the patient was abroad was to retain the correction achieved by the face-bow and cross-bite elastics. However, details in bite and alignment were corrected with the positioner.

In Case 902 (Fig. 6) the positioner appliance was presented as an alternative to lower banding treatment after a good response to upper banded treatment (model *b*). Significant responses to the positioner include improvements

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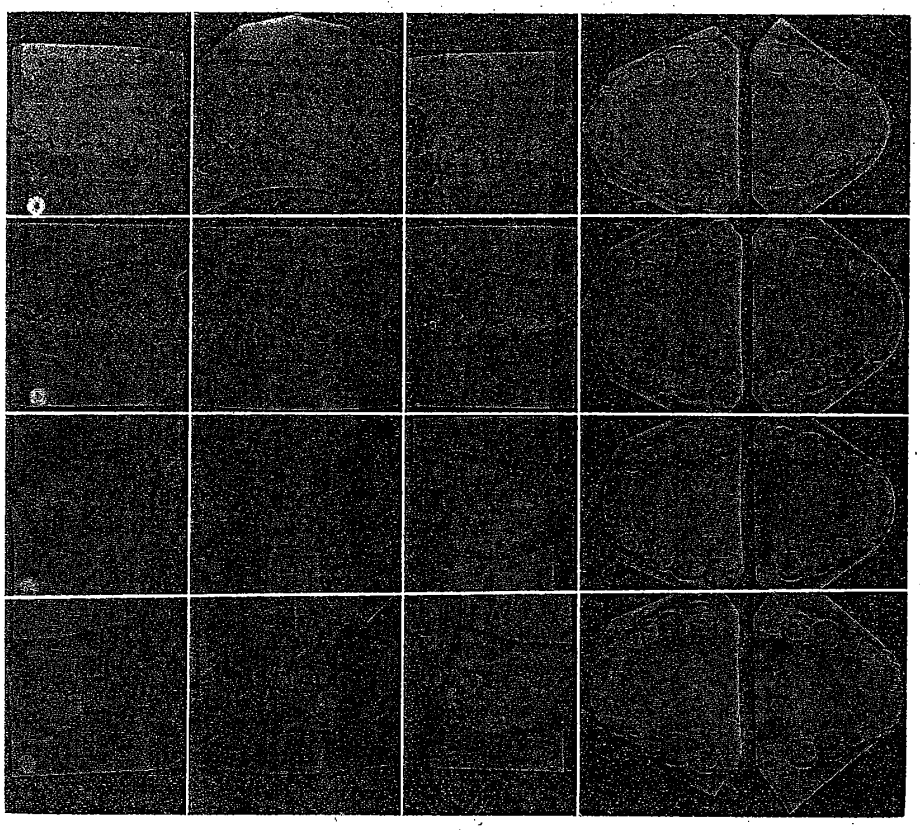


Fig. 5. Cast record and résumé, Case 452, female. **a,** Pretreatment (July 27, 1962). Cervical traction started. Age: 11 years 1 month. **b,** Progress (July 25, 1963). Bands removed; positioner started. Age: 12 years 1 month. **c,** Posttreatment (Oct. 19, 1964). Positioner stopped 1 month before. Age: 13 years 4 months. **d,** Postretention (Sept. 21, 1967). Three years after positioner stopped. Age: 16 years 3 months.

in the excessive curve of Spee, the left posterior open-bite, and the alignment of the lower anterior teeth (models *c* and *d*).

The faults attributed to the tooth positioner are often seen in Group IV cases following full banded treatment. The bite may close or open, diastemas may appear, anterior protrusions may recur, rotations may relapse, and so on. These difficulties may not necessarily be attributed to the positioner on a cause-and-effect basis. Some of these disadvantages can be minimized if the impression for the positioner is taken with the banded appliance in place. The positioner then becomes a useful adjunct in sequential band removal to effect space closure. The teeth are cut off and recontoured mesiodistal to the diameter of the tooth without bands and reset with the contacts closed. The positioner then acts as a space-closing device as the bands are removed. The undercuts of the

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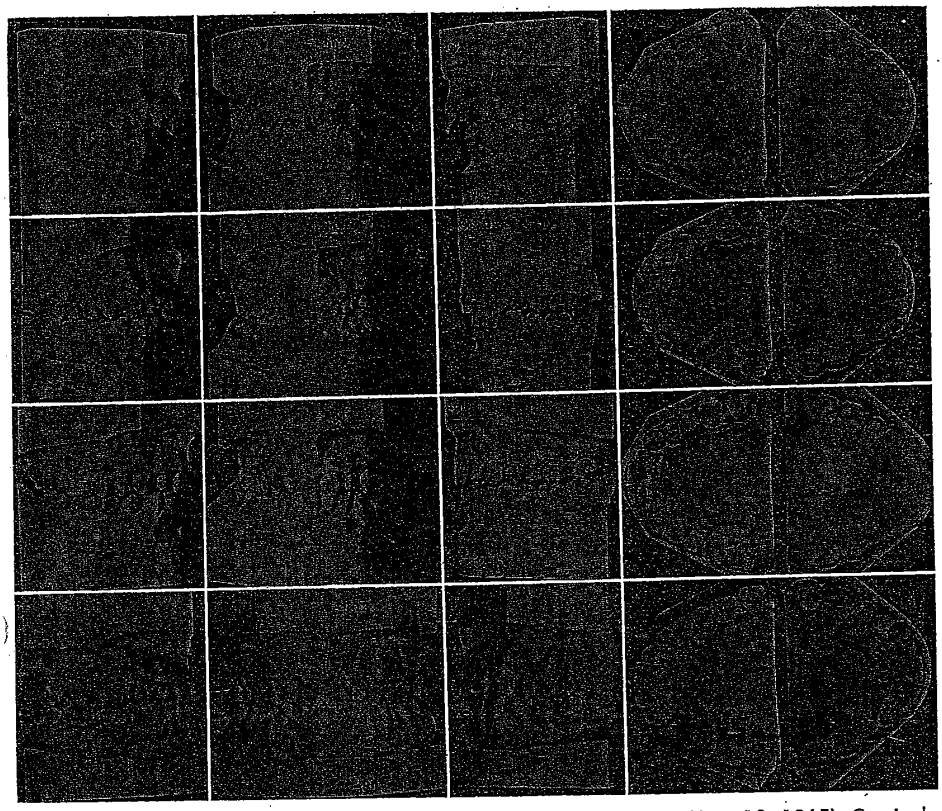


Fig. 6. Cast record and résumé, Case 902, male. **a,** Pretreatment (Jan. 12, 1965). Cervical traction started with upper bands. Age: 14 years 4 months. **b,** Progress (Sept. 9, 1966). Positioner started. Age: 16 years. **c,** Progress (Oct. 18, 1967). Positioner continued. Age: 17 years 1 month. **d,** Postretention (Dec. 30, 1969). Positioner discontinued 21 months before casts. Age: 19 years 3 months.

bracket are waxed over, and the bracket contour in the positioner tends to lock it into place in the patient's mouth while the bands are in place. The promise of band removal can be made as an inducement for the patient to wear the positioner as prescribed. The arch wires or other mechanics can be re-employed if there are factors, including lack of co-operation from the patient, that may result in an unsatisfactory response from the positioner.

Fig. 7 (Case 43) shows a case of severe open-bite and tongue-thrust in which a banded appliance was used for 3½ years to reduce the malocclusion. The positioner was the only retention appliance used for 18 months following active treatment. Initially, it was worn 4 hours a day and at night with the bands in place. Bands were removed after 3 months and the patient was instructed to wear the positioner at night only. Casts taken 18 months after use of the positioner was discontinued show only slight relapse in overbite and overjet.

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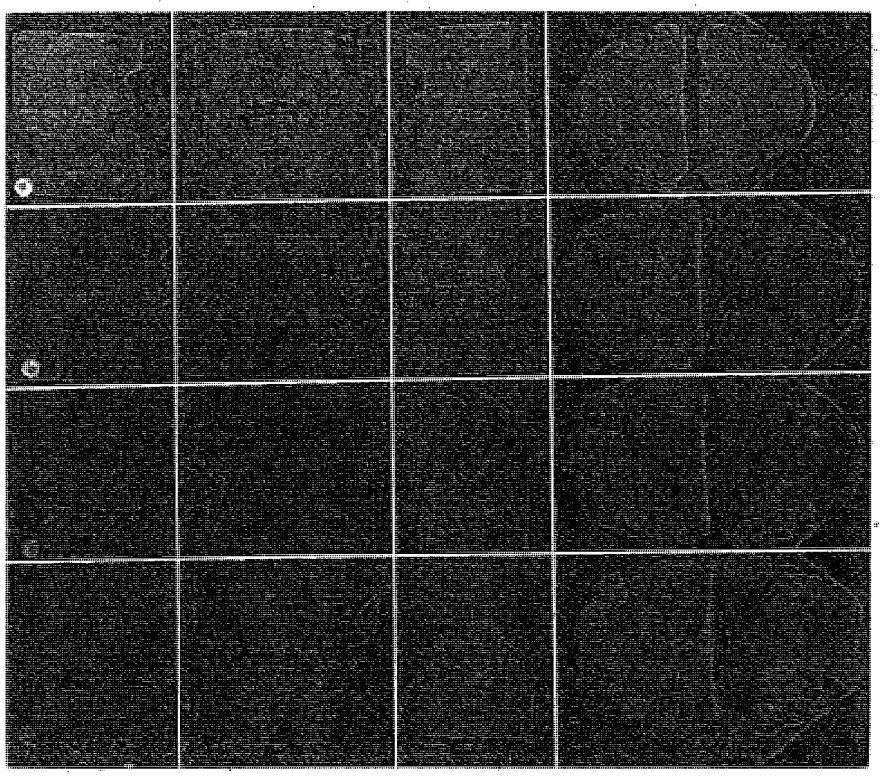


Fig. 7. Cast record, Case 43, female. **a,** Pretreatment (Nov. 20, 1959). Started banded appliance and upper tongue cup retainer. Age: 9 years 1 month. **b,** Posttreatment (May 12, 1964). Positioner being worn for retention. Age: 13 years 6 months. **c,** Postretention (April 12, 1965). Positioner discontinued 3 months before. Age: 14 years 5 months. **d,** Postretention (May 19, 1966). Positioner discontinued 17 months before. Age: 15 years 6 months.

Fig. 8, *b* illustrates another case (Case 337) in which, with bands in place and arch wires removed, the positioner was successful in perfecting the correction of a complicated malocclusion. A significant midline correction is noted between models *b* and *c*. With the positioner used for retention, the correction remains stable, including the corrected alignment of the lower anterior teeth.

Results

The role played by the growth of the face and jaw in the following observations was not evaluated separately from the influence of the positioner. The positioner may allow normal occlusal changes to occur. Therefore, the response noted during positioner therapy is not necessarily attributable to the positioner.

The changes in overbite were measured in millimeters from models of the original malocclusion, models taken after the initial appliance therapy, and models taken during or after positioner therapy (Table I). The degree of over-

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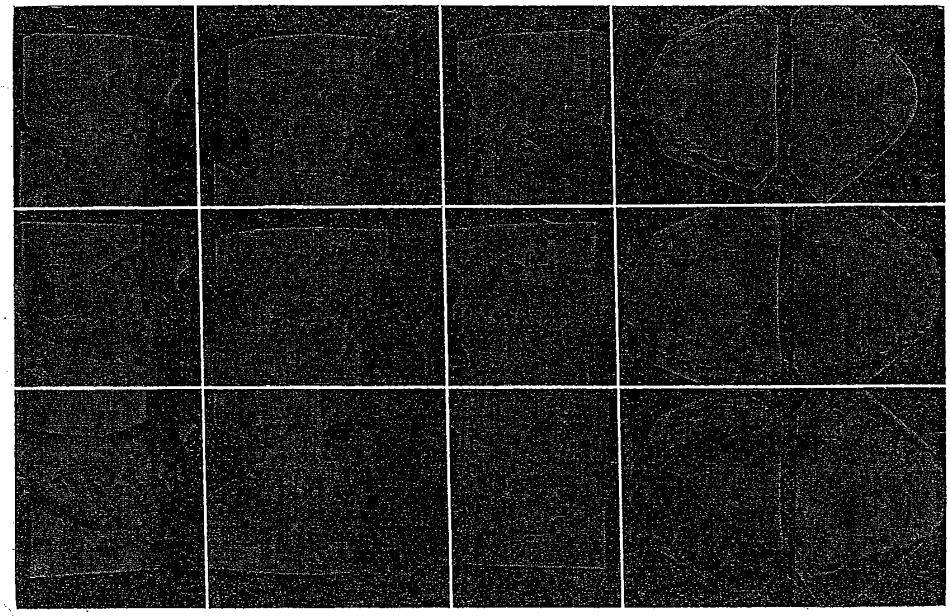


Fig. 8. Cast record, Case 337, female. **a,** Pretreatment (Nov. 2, 1961). Started lower retainer to open space for removal of impacted deciduous left second molar. Age: 7 years 3 months. **b,** Progress (Dec. 20, 1966). Positioner started with bands in place. Age: 12 years 5 months. **c,** Posttreatment (Nov. 4, 1967). Retention with positioner worn nights. Age: 13 years 3 months.

bite in the original malocclusions varied from a normal of 2 mm. to open-bite or close-bite. The extremes ranged from 5 mm. of open-bite to 7 mm. of overbite. Nine of the twenty-nine cases demonstrated improvements of 1 to 2 mm. in overbite correction during positioner treatment. The positioner was effective in correcting or improving the overbite in the three cases in Group I in which the positioner was the only treatment. Three cases from the remaining groups demonstrated from 1 to 2 mm. of overbite relapse. In certain instances this unfavorable change occurred during the time the positioner was being worn, and in others it occurred after use of the positioner had been discontinued.

The change in overjet was measured in all twenty-nine cases (Table II). The overjet was measured in millimeters from models of the original malocclusion, models taken after the initial appliance treatment, and models taken during or after positioner treatment. The overjet in the original malocclusions varied from 15 mm. to no overjet where the incisors were in open-bite relation. The positioner was successful in maintaining improvement or correcting all cases except two. In Case 43 (Fig. 7) an open-bite in the original malocclusion demonstrated a slight relapse of about 1 mm. decrease in both overbite and overjet.

Extensive correction of either overbite or overjet was not obtained by using

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Table I. Influence of positioner on overbite

Group	*Case No.*	*Mm. of overbite in original malocclusion*	*Mm. of overbite after correction*	*Mm. of overbite after positioner*	*Evaluation of effect of positioner*	
					Response	*Amount (mm.)*
I	318	0.5	2	2	Corrected	1.5
	598	1	2	2	Corrected	1
	684	3	2	2	Corrected	1
II	110	5	3	3	Maintained	
	153	2	4	3	Improved	
	164	4	3	1	Corrected	2
	227	4	4	4	Maintained	
	351	−2	2	2	Maintained	
	403	5	3	4	Relapse	1
	599	2	2	2	Maintained	
	606	3	2	1	Corrected	1
III	284	3	4	3	Corrected	1
	298	1	3	1	Corrected	2
	355	4	3	3	Maintained	
	395	7	4	4	Maintained	
	429	5	3	3	Maintained	
	445	4	3	2	Corrected	1
	452	4	3	3	Maintained	
	858	4	3	3	Maintained	
	879	4	2	2	Maintained	
	902	5	3	2	Corrected	1
	1,094	4	2	2	Maintained	
IV	43	−5	1	0.5	Relapse	0.5
	254	6	2	3	Relapse	1
	337	4	2	2	Maintained	
	611	4	3	3	Maintained	
	895	3	0.5	1	Maintained	
V	1,089	6	2	2	Maintained	
	1,773	3	2	2	Maintained	

Corrected: Complete correction by positioner of original or remaining discrepancy.

Improved: Improvement by positioner in original or remaining discrepancy but not complete correction.

Maintained: Retention by positioner of discrepancy corrected by previous appliance.

Relapse: Return toward original position during or after positioner wear.

positioners. There are several reasons for this. First, it would be difficult for a patient to wear a positioner with a marked correction built in, since the limitation of the elastic would preclude its fit or cause excessive pain. Even though a series of positioners could effect extensive tipping movements, the time consumed and the cost make this impractical. Treatment with more precise control would be indicated.

Eight of the twenty-nine cases demonstrated anterior midline discrepancies

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Table II. Influence of positioner on overjet

Group	Case No.	*Mm. of overjet in original malocclusion*	*Mm. of overjet after correction*	*Mm. of overjet after positioner*	*Evaluation of effect of positioner*	
					Response	*Amount (mm.)*
	318	0.5	2	2	Corrected	1.5
I	598	4	3	3	Corrected	1
	684	4	3	3	Corrected	1
	110	2	1	1	Maintained*	
	153	10	4	3	Improved	1
	164	8	4	3	Corrected	1
	227	5	3	3	Maintained	
II	351	4	3	2	Corrected	1
	403	3	2	2	Maintained	
	599	9	3	3	Maintained*	
	606	5	3	2	Corrected	1
	284	10	3	2	Corrected*	1
	298	7	3	2	Corrected*	1
	355	4	2	2	Maintained	
	395	14	5	4	Improved	1
	429	10	3	4	Relapse*	1
III	445	4	3	2	Corrected	1
	452	5	2	2	Maintained	
	858	8	3	3	Maintained	
	879	6	6	4	Improved	2
	902	8	4	2	Corrected	2
	1,094	3	3	2	Corrected	1
	43	0	2	1	Relapse	1
	254	7	2	2	Maintained	
IV	337	4	3	2	Corrected	1
	611	6	3	3	Maintained	
	895	4	1	2	Relapse	1
V	1,089	7	3	3	Maintained*	
	1,773	8	2	2	Maintained*	

Corrected: Complete correction by positioner of original or remaining discrepancy.

Improved: Improvement by positioner in original or remaining discrepancy but not complete correction.

Maintained: Retention by positioner of discrepancy corrected by previous appliance.

Relapse: Return toward original position during or after positioner wear.

*Significant improvement observed in the axial inclination of upper and lower incisors.

of 1 to 3 mm. (Table III). The effect of the positioner was to maintain the existing relation or improve the deviated midline between the teeth by 1 to 2 mm. In one of the cases there was a 2 mm. relapse of the midline after use of the positioner was discontinued. In another case there was a relapse of 1 mm. during retention with the positioner.

The positioner was found to be helpful in effecting correction of alignment

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Table III. Influence of positioner on midline discrepancy

Group	*Case No.*	*Mm. deviation in original malocclusion*	*Corrected to mm. deviation*	*Mm. deviation after positioner*	*Evaluation of effect of positioner*	
					Response	*Amount (mm.)*
I	598	3	2	2	Improved	1
II	227	3	3	2	Improved	1
	403	2	2	0	Corrected	2*
	606	3	3	1	Improved	2
III	879	2	0	0	Maintained	
	1,094	2	1	1	Maintained	
IV	337	1	1.5	0	Corrected	1.5
	895	1	0	1	Relapse	1

*Subsequent total relapse.

and rotational position of the anterior teeth. Fig. 1 (Case 684) illustrates a good response in the alignment of anterior teeth with significant rotational improvement in the position of the upper right lateral incisor and lower canines. In all cases analyzed, good correction or maintenance of correction of lower incisor alignment can be attributed to the positioner.

Evaluation of the influence of the positioner on the posterior occlusion was not made on a quantitative basis; instead, the role of the positioner was described by noting the direction and type of change. The mesiodistal molar relation was brought to complete correction in six of the twenty-nine cases. Five cases showed full correction of a Class II tendency. (Fig. 3, Case 606 is an example.) Five cases showed improvement but not full correction of a Class II tendency, as exemplified in Fig. 2 (Case 227). These last five cases are ones in which some further improvement would be desirable. The remaining cases showed that the positioner maintained the molar relation or satisfactorily retained molar correction that had been achieved by the use of another appliance.

Improvement in the buccolingual molar relation or retention of proper buccolingual interdigitation is seen in cases in all groups. The most significant corrections are seen in Fig. 5 (Case 452) and Fig. 1 (Case 684), where the original buccal cross-bite of the maxillary molars was corrected and maintained. (One case, No. 355, exhibited relapse tendencies in buccal width.)

Improvements or corrections in the mesiodistal relationship of canines and premolars were significant in all cases in Groups I, II, and III. Likewise, improvements or corrections of the buccolingual relationship of canines and premolars were evident in all cases in Groups I, II, III, and V, with the exception of Case 355. In this instance, both the upper premolars and molars relapsed lingually one year after discontinuation of positioner therapy. Both mesiodistal and buccolingual corrections were maintained or improved in the cases in Group IV, which had been treated with a full banded appliance.

The positioner was effective in guiding erupting canines and premolars

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in Group II cases treated initially by means of a Hawley type of retainer. These teeth either had been held out of occlusion by the bite-opening device or had not fully erupted. Open-bites that were maintained into the permanent-dentition stage showed little response to the positioner. However, good improvement was noted in the unilateral posterior open-bite evident in Case 598 (not illustrated) and Case 902 (Fig. 6). Similarly, the effect of the positioner in leveling an excessive curve of Spee was mild. Some improvement of the curve of Spee was evident in five cases (Fig. 1, Case 684; Fig. 2, Case 227; Fig. 3, Case 606; Fig. 6, Case 902; and Case 599, not illustrated). Rotational correction of posterior teeth is usually not expected in response to the positioner. Poor response would be expected on the basis that most posterior teeth tend to be circular in shape and rotational pressure from the positioner would be minimal. However, in some instances in which premolars were erupting, complete correction occurred during positioner wear when these teeth had been rotated as much as 45 degrees prior to positioner therapy.

Some space closure can be effected in mandibular diastemas, as shown in Fig. 2 (Case 227). No other lower appliance had been placed on these teeth. However, the positioner was ineffective in uprighting severely tipped posterior teeth. The lower right second premolar in Case 227 erupted mesially and occlusally during positioner wear but remained unfavorably tipped with its mesially marginal ridge under the height of contour of the lower right canine.

It must be pointed out that care in diagnosis and appliance construction is very important in positioner therapy. Thus, a positioner setup in which arch form is not compatible with the patient's arch form may result in total failure of positioner treatment. An error in setting the individual teeth or occlusal relationships between teeth usually results in this error being reproduced fully or in part in the patient's mouth.

Summary

An outline and categorization of some of the types of treatment and tooth movement possible with the positioner have been made. Twenty-nine cases in which successful response to tooth positioner therapy was evident in some phase of orthodontic correction were studied. The degree of movement or improvement of tooth position was limited to 3 mm. or less of tipping movement. Rotational correction of incisors, canines, and premolars was possible in certain instances. Virtually all types of correction of occlusion and tooth movement, with the exception of translation or bodily movement, were evidenced. These were correction in interdigitation of cusp, correction of cross-bites, decrease in overbite and overjet, rotation of anterior and posterior teeth, closing of spaces, improvement of midline deviations, and maintenance and retention of the above.

Conclusions

1. The positioner can be effective in correcting and retaining overbite or overjet in certain selected cases.
2. The positioner can effect most types of tooth movement in limited degree.

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3. The positioner is effective in certain cases with less than ideal cooperation from the patient.

4. The positioner can effect significant tooth movements rapidly in a short time or slowly over a long period of time.

5. It appears that the positioner is best suited for guidance of erupting teeth and for tipping movements of teeth.

6. The positioner is useful for retaining teeth placed in harmony with the oral environment.

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Dentistry and CAD/CAM: Another French Revolution

Dr. Francois Duret, with the development of the laser probe, has now brought to dentistry computer-assisted design/computer-assisted manufacturing.

Arthur G. Williams, D.D.S., F.A.C.D., Editor

At the 40th International Educational Congress of Dental Technology, I believe that I experienced a preview of the future technology of our profession. Dr. Francois Duret, a dentist from France, made his first American presentation of his "Computer-Assisted Design of Dental Restorations" and the "Computer-Assisted Manufacture of Dental Restorations;" the CAD/CAM of Dentistry.

As trite as it may sound, as I sat waiting for the start of the program, I had the opportunity to observe Dr. Duret, a highly animated man. I could not help but compare Dr. Duret, a slight man with metal Ben Franklin glasses, a small mustache, rumpled dark hair, and a cane to aid in walking, with another Frenchman who changed the course of the world's health, Dr. Louis Pasteur. It may be that Duret's impact on the field of dentistry may be as profound as Pasteur's was on medicine.

Duret has developed, over the past 15 years, a technology that combines the computer and milling machine. In brief, the CAD/CAM system allows for the use of a computer to design and a milling to form a crown, inlay, onlay, or denture.

A laser or scanner probe about 10 inches in length and 3/4 of an inch in diameter, developed by Dr. Duret, is directly attached to a computer. There are two techniques that can be used with the laser probe and computer.

When using the first technique, the probe is placed in the patient's mouth and various "pictures" are taken of the area to be treated. In this instance, Duret is about to prepare a lower right second bicuspid for a crown, so the probe is placed over each area, buccal, lingual, lateral, and various angles of the marginal area. "Pictures" are taken and sent to the computer for storage in the memory bank. The tooth is then prepared in the normal manner using diamonds and burs. After the preparation is complete, the probe is reintroduced into the patient's mouth, and a series of "pictures" of the preparation are taken. These pictures are fed into the computer for storage in the memory bank. Duret then operates the computer to design the crown that is to be fabricated by the milling instrument that also is attached to the computer. He makes various entries as he designs the crown, connecting various points so that the crown will be compatible with

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the environment, leaving a predetermined amount of space for the cementing media.

When using the second technique, the tooth is prepared in the usual manner, and "pictures" are taken of the preparation. The computer is instructed by the dentist as to which tooth is being prepared. In the case of the example which was shown in New York, it is a lower left second bicuspid. The computer has stored in its memory the configurations of 32 adult teeth. It then takes out the one for the lower left second bicuspid and alters this ideal configuration to meet the size of the space in the patient's mouth. If the dentist wishes, he or she can alter the design on the screen. In the example, it is shown that moving the interproximal contact points, as well as the altering of the occlusal surface, could be accomplished.

In the example, the tooth is designed as if on an Hanau articulator. If the dentist prefers, the computer can modify the way it designs the restoration so that the results are exactly the same as if it were made on any other type of articulator.

In fact, if the dentist wishes, it is possible to go beyond the static bite relationship which was demonstrated and take a dynamic occlusal record. It is possible for the computer to track the actual movements of the mandible. As such, it can go beyond any present day articulator using the equivalent of an infinitely adjustable articulator.

This ability alone is enough to insure that the restorations being created by the CAD/CAM will transcend the present limits of day-to-day dentistry for the majority of dentists.

After the design was finalized, the computer activated the attached milling machine and, from a solid block of Dicor material, a crown was fashioned. The milling machine changed cutting tools automatically, and fabricated not only the external surface, but the internal surface as well. The fit of the CAD/CAM crowns have a tolerance of 2–20 microns, whereas the average fit of the lost wax technique has a fit tolerance of up to 200 microns. Various materials, including metal, can be used in the milling machine.

The crown preparation, milling machine operation, and insertion that were seen on video tape was completed in 50 minutes from beginning to end. No impression is taken, no temporization, no bite registration, no second visit. It is a fact that I did not see the actual procedure, but, rather, a video tape. I did not test the fit, the margins, or the occlusion, but the impact made by this CAD/CAM procedure was tremendous. Its affect on the field of dentistry and the allied dental laboratory will, I believe, cause a revolution of a monumental nature. It is with this thought in mind that I conducted an interview with Dr. Gerald McLaughlin, American dentist, who has more knowledge and background in CAD/CAM than any other person on the American dental scene.



In September, 1981, Dr. McLaughlin was the first to publish the technique of etched metal bridges in the scientific press. He was also the first to publish the etching recipe against which all others are currently measured (that of Rexillium III and sulfuric acid). He also developed the One Step etch technique, slotted technique, and a number of other innovative procedures.

He has lectured in eight universities and presented over a hundred seminars all over the world.

He is the author of two books, "Questions Patients Most Often Ask Their Doctors," published by Bantam Books, Inc., N.Y., in 1983, and "Direct Bonded Retainers—The Advanced Alternative," published by the J.B. Lippincott Company, Philadelphia, in 1986.

He is a Clinical Instructor, Department of Pediatrics, New York University College of Medicine, since 1982, and a Clinical Assistant Attending, Department of Oral Surgery, Bellevue Hospital, New York University College of Dentistry, since 1985.

He attended New York University College of Dentistry from 1968 to 1972. Dr. McLaughlin has been in private practice since 1975. He is a member of the International Academy of Dental Research, American Academy of Dental Research, and American Dental Association, among numerous other affiliations.

Interview with Dr. Gerald McLaughlin

1) *How long have you been involved with this work?*

I first became involved with computer-assisted dentistry in 1977, when a friend of mine in a computer club described a process which he was developing, known as "solid photography." Using his "solid photography," it was possible to eliminate the casting process of making crowns. To do this, the dentist would prepare a tooth for a restoration and take an impression in the usual manner. Next, a model was poured. A wax-up was then made, and a computer "photograph" was taken of the wax-up. The computer then operated a milling machine to cut a duplicate of the wax pattern from a block of metal. This finished crown would be a "solid photograph" of the original wax-up.

Then in January of 1986, while teaching in France, I met Dr. Duret. After talking for several hours, Dr. Duret asked me to collaborate with him on his CAD/CAM project.

2) *Why does Duret seem to look down on the use of the x-ray to check fit, since it is a basic tool used by dentists at this point to do it?*

You must remember that the x-ray is simply a sophisticated shadow picture and subject to all the distortions of shadows. Just as your shadow changes length depending

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on the time of day, so too are there changes in the apparent size of objects being x-rayed. The distance between the film and the tooth, the tube and tooth, and the angle of the central beam all conspire to make for variations in the apparent size and shape of objects being x-rayed. In situations where direct observation is not possible (such as in the mouth), dentists must settle for this type of indirect and relatively inaccurate information for diagnosis. When direct measurement is possible, however, it is far more accurate.

3) A) *What are cost factors of the equipment both for the lab and the dental office? B) How can this system be used when part of it is in the dental office and part of it is in a commercial laboratory?*

A) The final cost factors have not yet been determined. Fortunately, however, there has been a clear pattern over the last 20 years regarding the cost of high technology. Every year the technology gets better, and less expensive. I would expect the costs of this type of equipment to follow the same pattern. What is an equally good question is "what is the value of this equipment"?, and for that question I think only the individual dentist or laboratory can answer.

For the dentist, what would it mean to your practice to be able to have a completed denture that need fewer adjustments completed in, possibly, a single visit? What would be the effect on your practice if your bridges could be completed in a single day? What would be the effect on your practice when patients find out that impressions are no longer necessary at your office?

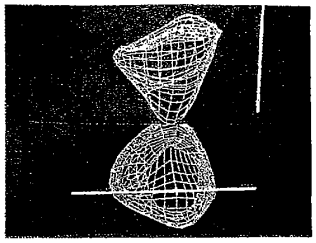
And for the technician, what would be the effect on your costs if you didn't have to have any pick-ups, but instead had the "impression" and bite that the dentist's optical scanner took sent over the telephone? What would be the effect on your business if you could have crowns, bridges, and dentures delivered less than an hour after the order came in over the telephone?

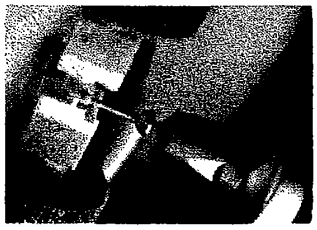
These are all very exciting questions, and their answers will only come with time.

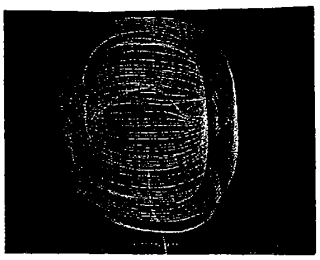
B) If a laboratory is working with a dentist that has none of the equipment, it will be possible for the laboratory to simply scan the impressions with the laser probe, and have the computer do the rest. If the dentist invests in a laser probe, computer, and modem, it is possible to eliminate the impressions. In this case, the dentist would scan the teeth with the laser probe, and the data would be sent to the laboratory over the telephone lines. The laboratory would then be able to return the finished restoration that same day.

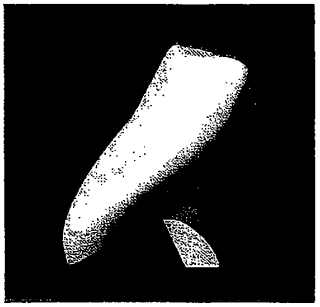
4) *What is the time needed for dentists and technicians to learn the use of the probe, components, and milling machine?*

It takes about 2 days.









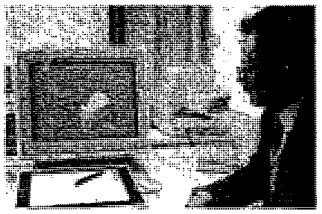


FIG. 1. (*top left*) Two computer views of the suggested tooth design. This can be used as suggested, or modified by the dentist via the keyboard.

FIG. 2. (*top right*) On occlusal view of the suggested design of the crown. Both the internal and external views are superimposed. The operator can determine the exact amount of space which will be left for cement.

FIG. 3. (*left*) The milling machine has begun to carve the crown from a solid block of material. It will first carve out the external aspect of the crown, and then will turn the material over and carve out the internal aspect. The machine is self-calibrating, and automatically selects and changes its own burs as needed.

FIG. 4. (*right*) An example of a finished crown manufactured by Dr. Duret's CAD/CAM unit.

FIG. 5. (*bottom right*) Dr. Francois Duret is shown seated in front of his CAD/CAM device.

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5) *What is the future of the laboratory technician in dentistry? Are their days numbered?*

You have asked a very important question. I think the future of the laboratory technician will continue to be exactly what it has been in the past. In other words, the future will be whatever the laboratory technicians make it to be.

The situation which the technicians face with this marvelous new technology is the same one which dentists have been facing for the last decade.

So, I predict, will be the future of dental technicians. Those who choose to utilize the amazing new power of "laser- and computer-guided dentistry" will surely profit from it, and those dental technicians who choose not to utilize this technology can also have a significant place in dentistry. Not all dentists will own a laser probe. Many practices will simply not be big enough to warrant owning such equipment. Other dentists will prefer to work with the old familiar materials and methods. Many dentists will simply feel more comfortable writing laboratory prescriptions than having a dialogue with a computer.

Those labs who choose to use the new technology will also be able to provide a unique and valuable service. Accuracy can be improved, speed can be enhanced. Further, the decrease in adjustments, remakes, and pick-ups, as well as the use of newer, cheaper materials, should allow for a lowering of fees at the same time. The development of such a "high-tech" laboratory will allow a formidable advantage in the marketplace over the laboratory of today.

I would also confidently predict that the most successful laboratories of all will be the ones who learn to use the new technology to provide faster, more accurate service, but utilize the time that the machinery frees for them to create a close relationship with the dentists they serve. This "high-touch/high-tech" combination will not be for every laboratory. But those laboratories that manage to create such a combination will be the biggest winners of tomorrow.

In short, the introduction of this marvelous technology has simply accelerated the changes that are already taking place in the dental laboratory industry. Everyone knew that this sort of thing was coming. What most technicians have not realized is just how soon and how great the changes will be in tomorrow's laboratory. The introduction of this new technology has made it clear that, just as in the broadway show "Annie," tomorrow is always only a day away.

6) *How will CAD/CAM effect the dentist and his future?*

It is clear to me that CAD/CAM will be an important part of the future of dentistry. It will allow the dentist to provide a faster, more comfortable, and more accurate service for his or her patients. It can also lead to a higher level of satisfaction on the part of those dentists who seek greater control over the fabrication process of dental prosthesis.

The amount of time necessary for certain procedures will diminish dramatically, and this will either allow the dentist to be more productive or have more leisure time. In addition, it may prove cost-effective for dentists to lower the fee for some services, while, at the same time, receiving more profit. This, in turn, may have the effect of increasing the patient demand for certain services.

As CAD/CAM in dentistry continues to develop, machines will be made which are capable of assisting the dentist in preparing teeth for prosthesis, or even taking over the tooth preparation itself. When these units become practicable, the impact of CAD/CAM will be even greater. The role of the dentist will increasingly become one of diagnostician and treatment planner, and less of tooth mechanic.

We must also remember that there surely will be many other developments beside CAD/CAM which will impact on the future of the dentist. And none of these changes will occur overnight. Still, it is clear that change is occurring at an ever-increasing rate, and the future is now closer than ever before. It is a very exciting time.

Future Notes from Dr. Williams

In the April/June, 1987, issue of the JDPA, I will have further information on this exciting new idea. I attended a 2-day meeting sponsored by Dr. Omer Reed that featured Dr. Francois Duret, as well as other men and women representing some of our dental schools that are involved in this type of research. I will bring reports from these universities, and possibly from the Armed Forces that are also working in these areas.

In addition, I have had the opportunity of listening to Dr. Werner Mormann and Dr. Marco Brandestini of Zurich, Switzerland, present a paper, "Chairside Computerized Dentistry." This paper, though similar in approach to Duret's, has significant differences.

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Work Simplification

The Switzerland and Minnesota Developments in CAD/CAM

Although the ***Journal*** *is not a technical publication, we are interested in keeping our readership aware of new techniques that will have a philosophical and psychological, as well as financial, effect on dentistry, its patients, and its family of auxiliaries.*

In a continuation of efforts to be on the cutting edge of changes in the dental profession, the JDPA brings you this continuing report (J.D.P.A., Vol. 4, No. 1, January/March 1987) on Computer Assisted Design/Computer Assisted Manufacture (CAD/CAM) and its future regarding the practice of the profession in this country, covering the accomplishments of Drs. Mormann and Brandestini of Switzerland and Dr. Dianne Rekow of the University of Minnesota. The Minnesota portion of this article was contributed by Dr. Rekow.

Arthur G. Williams, D.D.S., F.A.C.D.

Dr. Werner Mörmann, a Swiss dentist, and Dr. Marco Brandestini, a Swiss electronics engineer, have developed CEREC®-Systems (Computer Assisted Ceramic Reconstruction) comprising a three-dimensional mouth camera, an interactive computer-aided design unit, and a computer-aided machining facility that they presented to the profession as a fully integrated mobile unit (Fig. 1).

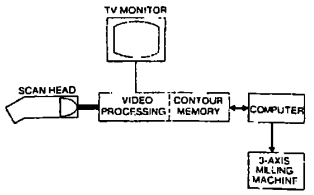
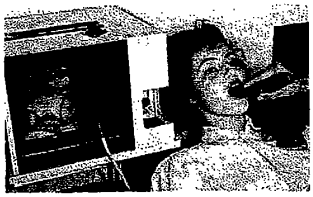


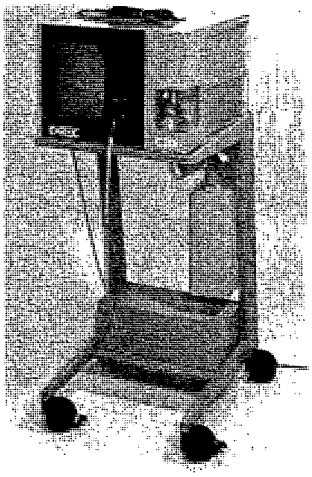
FIG. 1. The CEREC® System is shown.

The CEREC®-System includes a scan-head which is positioned on the prepared tooth. The scanning of a class II cavity lasts 0.2 seconds. A conventional graphics unit, comprising a contour memory and a monitor, displays the cavity/inlay data being processed by the system. A micro-computer can access the data in the contour memory, as well as control a three-axis milling machine. The inlay fabrication system has been designed to fit the dental office setting; it allows fabrication and insertion of the restoration during the same appointment (Figs. 2-4).

The machining of a class II inlay

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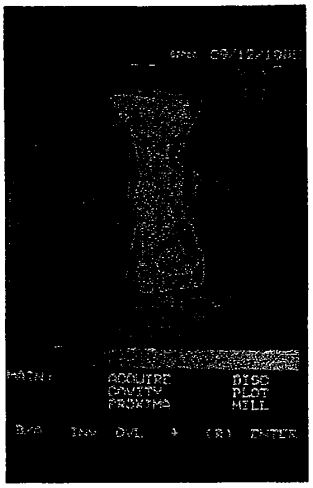


FIG. 2. The scan head is positioned over the tooth and monitor display.
FIG. 3. The CEREC® Unit is shown.
FIG. 4. A computer "blueprint" of the inlay is shown.

starts from prefabricated rod-shaped blanks of dental porcelain measuring approximately 9 × 9 ×13 mm. The porcelain blanks are bonded to a stub, which allows the blank to be fixed inside the three-axis milling machine. The milling of a class II porcelain inlay is completed within 5–7 minutes (Figs. 5,6). The inner surfaces of the porcelain inlays opposing the cavity walls are etched with a hydrofluoric acid substitute for 60 seconds. After etching, the porcelain inlays are thoroughly rinsed with tap water and dried with compressed air. The enamel is etched with a 37% phosphoric acid etchant gel applied for 1 minute to the cavo surface margins of the preparation. The walls of the cavity and floor must first be coated with a glass ionomer lining to prevent the etching material from reaching these areas and causing injury to the dentine if the acid etch material were to accidentally reach these areas during the etching of the enamel.

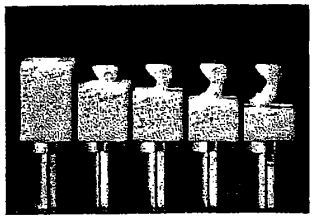


FIG. 5. Step-by-step fabrication from blank to finished inlay.

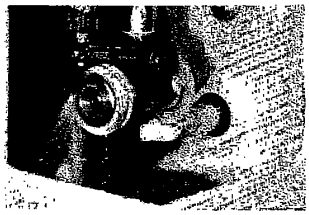


FIG. 6. The three-axis milling machine is shown during fabrication.

Light-curing luting composite is mixed and placed into the cavity with the aid of a spatula. The porcelain inlay is then seated, and excess luting composite material is removed using a fine spatula. The margins of the occlusal and proximal inlay surfaces are light-cured for 60 seconds each. After the light-curing process, the occlusal surface of the procelain inlay is carved and contoured using diamond finishing burrs, and the proximal surfaces are finished under water spray using flexible discs (Fig 7).

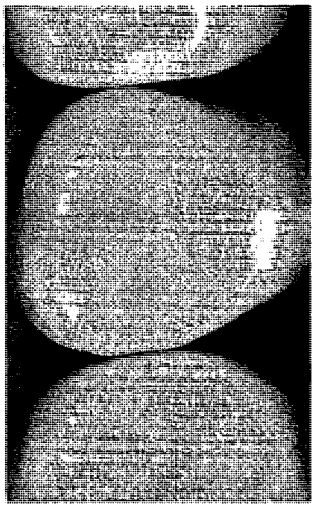


FIG. 7. The completed inlay is shown.

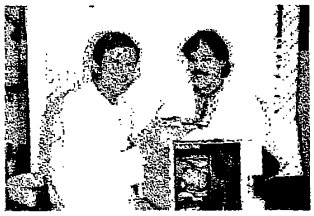


FIG. 8. Drs. Mörmann and Brandestini are shown (left to right).

At this point in time, the CEREC® unit is limited to the fabrication of porcelain onlays, inlays, and lami-

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nates. Dr. Mörmann has elected not to be involved with the use of metals (gold), but rather with materials that are highly esthetic, have high strength, and have physical, chemical, and biological qualities that are equivalent to the properties of tooth structure. He has incorporated in the development of his system the 10–15 years of adhesive technology, "bonding," that has had wide acceptance by the profession. In his search for materials for his technique, he has settled on one porcelain, which he feels meets the criteria he has established. Mörmann further feels that the control and quality of the mixing and fusion of porcelain blanks can be assigned to the control of the factory, eliminating the hit and miss approach of the dentist and his assistant mixing materials. He further feels that porcelain is the best choice of materials, since it can be etched, developing a highly retentive surface that can then be bonded to the etched surface of the tooth enamel.

Today, Mörmann's and Brandestini's instrument will fabricate only inlays, onlays, and veneer laminates. They feel that, with the addition of a burr to the milling machine process, which at present uses only a disc to fabricate the inlay, they will then have the ability to fabricate a full crown, bridge, etc.

Being dedicated scientists, when asked about the financial ramifications, Drs. Mörmann and Brandestini were understandably vague. They feel that there are certainly economic implications; that patients will be well aware of spending only one visit at the dental office for a service that regularly consists of two visits, and will be happy to pay a fee equal to the amount charged for a gold inlay/onlay that normally requires two visits.

The Minnesota System

The system being developed at the University of Minnesota under the leadership of Dianne Rekow, B.M.E., M.S.M.E., D.D.S., was not seen personally by me, but I did have the pleasure of meeting and speaking with Dr. Rekow. The following is a report of her work, written by her, and, though of a technical nature, is published in its entirety so that our readers would have a complete picture of what is being accomplished at the University of Minnesota. Dr. Rekow was kind enough to develop a comparison and summary of the three approaches. The **J.D.P.A.** is most grateful to this unique, gifted lady for her contribution.

The system at the University of Minnesota is still under development. With this system, data is acquired in the dental office and then sent to another location for processing and machining. This permits system costs to the practitioner to be kept at a minimum, well below $5000. The system is being developed to be capable of milling a metal full-coverage crown. When that is possible, other, more conservative restorations are simple modifications. Potentially, the system will also be able to mill frameworks for partial dentures and full denture bases, as well as multiunit bridges. The major focus on the development of this system is to make it completely automatic, without requiring any interaction by the user[1,2] To date, no demonstrations have been given with this system. The design criterion for this system, however, is that final crown margins will fit to within 20 microns at the margin.[1]

Data is acquired using a photographic-based system. In the opinion of this group, tolerances for good fit at the crown margins can only be met with very high-resolution data acquisition and digitizing equipment.[3] At that resolution, it is not yet possible to obtain data real-time, since no more than 512 × 512 pixels can be written to a computer real-time unless extra frame buffers are available, but increase the cost substantially. Data acquired includes the surface of the tooth prepared for a crown, the proximal segments of both adjacent teeth, and the surface morphology of the opposing tooth or teeth. The position of the cusp tips of the opposing dentition are obtained relative to the surface of the prepared tooth with the teeth in centric occlusion, working and balancing positions, and anterior slide.

Data is acquired with a standard 35-mm camera through a 10-mm diameter single rod lens (a Wolf magnifying laryngo-pharyngoscope) which attaches to a standard 55-mm lens (Fig. 9). A prism system

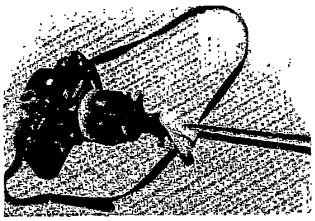


FIG. 9. Data acquisition system—standard 35-mm camera with rod lens attached. Data is acquired using a standard medical laryngo-pharynogoscope mounted on a standard 35-mm camera. Stereo photographs are taken of the prepared tooth (and adjacent teeth), the occlusal surface of the opposing teeth, and the positions of the opposing teeth in various occlusal relationships.

at the distal end of the rod lens permits the field of view to be 90° from the long axis of the lens. Depth of field is essentially infinite. An entire crown preparation can be viewed from a single position approximately 25 mm above the surface of the tooth (Fig. 10). A number of

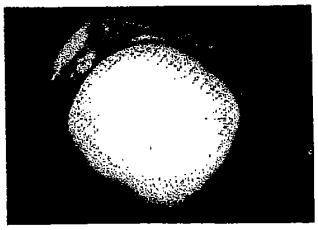


FIG. 10. View of prepared tooth as recorded through data acquisition system.

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views are used, however, to ensure that complete information is obtained and to minimize the likelihood of blur caused by the patient moving. The tooth is illuminated with fiber optics which surround the lens. A three-dimensional calibration device is in the field of view of every image, permitting continuous calibration of the image without imposing any constraints on the position for the lens relative to the teeth or in any way constraining the patient's head (Fig. 11).[4]

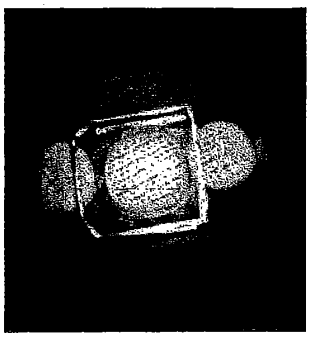


FIG. 11. View of prepared tooth with calibration cube in place, through data acquisition system. The calibration cube, together with a set of stereo photographs, provides sufficient information to reconstruct the three-dimensional coordinates of the surfaces of the tooth.

In order to permit three-dimensional surface reconstruction and reconstruction of the movements of the jaw (at least in the positions where the teeth are in contact), stereo pairs of images are made. The images are recorded on standard film (Ectachrome, ASA 400). The exposed film is developed by commercial processors.

The color slides are digitized using an Eikonix EC 850 digitizing system interfaced with a Digital Equipment Corporation (DEC) PDP 11/44 with RSX 11-M-PLUS operating system. The digitizer has a resolution of 4096 × 4096 pixels. The image of the tooth fills the entire field of view of the digitizer, providing a limiting resolution of 2.44 microns (for a 10-mm diameter image broken into 4096 pixels by 4096 pixels). Repeatability of the digitizer is 1 pixel. Each pixel has an x,y image address. The digitizer senses the intensity of light passing through each pixel and writes that value, along with the address, to the computer. Images can be analyzed in grey scale, as well as in red, blue, and green. Digitizing time is between 10 and 90 seconds per slide, depending on the color scale being used.

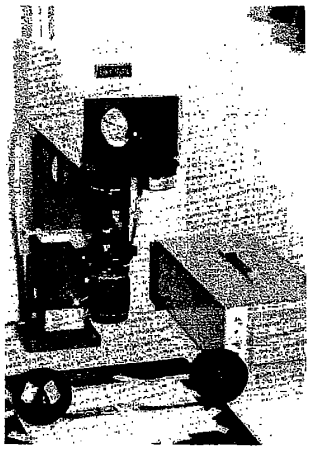


FIG. 12. Very high resolution (4096 × 4096 pixel) Eikonix digitizer. The digitizer is capable of digitizing in three color planes and has a color depth of 32 bits. For a molar prepared for a restoration, this resolution permits data to be acquired for each 2.4 microns.

Two techniques are being investigated for three-dimensional reconstruction. The first is the method of direct linear transformation.[5] Before three-dimensional analysis can begin, each of the points in one stereo image must be matched with its corresponding point in the other half of the stereo pair. To provide original alignment, strong edges (like the margin of the prepared tooth) in each image are found using algorithms developed by Canny for robot three-dimensional obstacle avoidance and robot vision.[6] Then, less strong edges (like burr scratches on the prepared surface) are found using algorithms devised by Haralich and Marr and Hildreth.[6] Correlation techniques are then used to obtain the most likely relative orientation of the two images. When the correspondence between points has been established, the direct-linear transform is applied to reconstruct the three-dimensional image. Accuracy with this method is currently undergoing investigation.

Grimson[7] has proposed an alternative technique to the direct linear transformation. He argues that, for any given set of edges (for any image) and intensities, there exists one unique surface. The accuracy of reconstructions with this technique are currently being evaluated.

The three-dimensional coordinates provide the computer-based equivalent of perfectly mounted casts on an infinitely adjustable articulator. The internal surface of the crown is defined by the reconstructed three-dimensional coordinates of the prepared tooth surface.

When the three-dimensional coordinates from all the images have been reconstructed, the paths of motion of the opposing dentition as they pass over the prepared tooth are established. This is done using kinematic analysis of the positions of the occluding teeth relative to the prepared tooth (Fig. 13).[8] The external surface of the crown is automat-

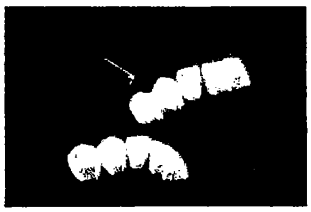


FIG. 13. Arch form for mandible, with teeth shown in two positions. Relative position of the teeth are determined and the helical axis about which rotation of the jaw occurs is calculated. This permits the final configuration of the occlusal surface of the restoration to be established, integrating the elements of each patient's occlusion and jaw motion.

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ically designed. A data base has been created which contains the configuration of each of the tooth forms, in their ideal configuration (Fig. 14).[8] For any crown designed

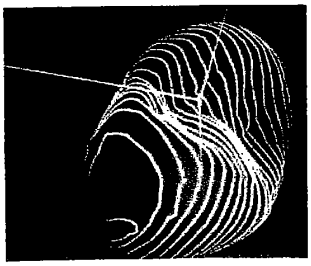


FIG. 14. Computer graphics image of ideal premolar morphology. Each of the 14 unique tooth forms has been digitized and forms a data base of ideal tooth shapes. The forms are represented as B-splines so that each tooth can be scaled and skewed to fit the unique requirements of a single patient.

with this computer system, that ideal form is used, but it is automatically modified to fit the unique requirements of the medial-distal and buccal-lingual size, margins, and occlusal function of the patient being treated.

The internal and external surfaces of the computer-designed crown are described by B-spline and/or Bezier surfaces, permitting subsequent machining.[9] The CAD/CAM system used is Control Data Corporation's ICEM-DDN package (Integrated Computer-Aided Engineering and Machining—Design, Drafting, and Numerical Control) (Fig. 15). The computer-designed surfaces are used to generate machine tool paths for subsequent machining with a five-axis N/C machine (Figs. 16,17).

Comparisons and Summary

Three groups are actively engaged in integrating CAD/CAM techniques into the development of automated systems for production of dental restorations. Demonstrations



FIG. 15. Dr. Dianne Rekow at computer terminal with mandibular arch form ready for CAD/CAM manipulations.



FIG. 16. Numerically controlled system. When the final configuration of the restoration is established, tool paths are written using a CAD/CAM package (ICEM-DDN of Control Data Corporation, Minneapolis, MN). The tool paths are then transferred to a milling machine, permitting the restoration to be milled. (Photo provided by CAMAX Corporation, Minneapolis, MN)

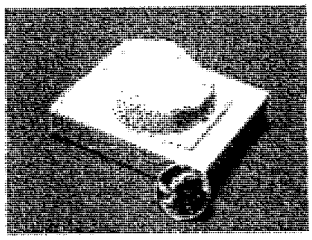


FIG. 17. An example of a machined occlusal surface. (Both internal and external surface of the restoration will have to be machined. Photo provided by CAMAX Corporation, Minneapolis, MN)

of both the French and Swiss systems have been held. Both of these systems use optical-based real-time data acquisition devices. Data acquisition with the Minnesota system used photographs and a very high-resolution digitizer.

The Minnesota and French systems are both designed to fabricate crowns and to integrate the unique requirements of each patient's occlusal function. The Swiss system is designed to fabricate inlays only, and the occlusal surface is created by the dentist after the inlay is seated.

All of these systems use state-of-the-art techniques for designing the restoration. All three systems mill restorations with commands generated by a state-of-the-art CAM package. However, the Swiss and French rely on a three-axis milling machine; the Minnesota system uses a five-axis machine, providing greater freedom in producing required external contours.

Costs of the systems cannot yet be compared, since only the cost of the French system has been published. By limiting the amount of work done in the dental office, the cost of equipment in the office will be the least with the Minnesota system.

All three systems offer an alternative to the currently practiced impression-die-lost wax-casting technique. Potentially, each can save the practitioner time by providing restorations which accurately fit the patient, without requiring any chair-side adjustments. Additionally, they can provide more consistency in restoration design and open the possibility of a whole array of different restorative materials, including machinable tooth-colored ceramics.

Dentistry is approaching a major departure in the delivery of dental care. As with the advent of high speed handpieces, washed field technique, and even dental insurance, many have looked upon these advances with reluctance and fear.

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Let us hope that the profession has matured to the point where change for the good of dentistry will be welcomed, and that we can continue the learning process which will lead to the finest of dental care for our patients.

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Educational Summaries and Outlines

AAOMS 72nd ANNUAL MEETING
AND SCIENTIFIC SESSIONS
September 12–16, 1990
New Orleans

Journal of Oral and Maxillofacial Surgery
Volume 48, Number 8
Supplement 1, August 1990

American Association of Oral and Maxillofacial Surgeons

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SYMPOSIUM: COMPUTERIZED FACIAL IMAGING IN ORAL AND MAXILLOFACIAL SURGERY

Presented on Thursday, September 13, 9:00 a.m.-12:00 noon
Moderator: Bejan Iranpour, DDS, MS, Rochester, NY

New Advances in Personal Computer Applications for Cephalometric Analysis, Growth Prediction, Surgical Treatment Planning and Imaging Processing

Melvyn S. Wishan, DDS, MDS, Beverly Hills, CA

A decade has seen a revolution in the way in which we diagnose, treatment plan, and counsel our patients. Advancing technology in Computer Graphics has led the way in Facial Imaging. The Video Treatment Objective (VTO) has now become commonplace in many offices and institutions throughout the nation. Through continuing efforts in software enhancements, our tasks as practitioners are made easier and less time consuming, while at the same time we are able to look into the future with more assurance than ever before. These computer modalities increase our own awareness and at the same time enrich our patient doctor rapport. We are once again "personalizing" our approach to patient treatment. As databases evolve and programming efforts continue, editing of the images becomes more automated. Growth Forecasting is more reliable and Video "Aging" becomes more of a reality.

The orthodontist and oral and maxillofacial surgeon may not only be able to predict that a 10 year old will need orthognathic surgery at age 17, but will also be able to graphically show the patient and family why, i.e. the expected dentofacial deformity is readily apparent in the "aged" Computer Image.

Current advances in realtime treatment planning, analysis, and forecasting will be shown in this presentation. Challenges for the immediate future will be demonstrated.

Imaging—Basic Soft Tissue

Bruce S. Kuhn, DDS, MD, Omaha, NE

The time is past due where hard and soft tissues are separated in the treatment of many facial deformities. Oral and maxillofacial surgeons have been a leader in osseous surgery of the face for the past thirty years. Oral and maxillofacial surgeons are in a unique position having a unique opportunity to treat the total face. Changes of the aging face as well as developmental deformities require both hard and soft tissue evaluation as well as treatment. Computer imaging will not only help us to better diagnose and treatment plan patients but also allow these patients to visualize possible changes proposed and allow them to objectively judge their own facial aesthetics.

Computer facial imaging has become a major tool in many progressive orthognathic and facial plastic surgery practices academically and privately over the past three years. Until recent advances in computer facial imaging, soft tissue surgical predictions were difficult, cumbersome and time consuming. Acetate, cut and paste photographs and hand drawings were crude visual representations at best. Computer technology now allows visual diagnosis, treatment planning and treatment objectives for surgeons and patients with life like images. The ability to educate patients, referring doctors and surgeons by the use of these computers is unparalleled.

Evaluation of the facial components in two dimensions are excellent at this time. We are now seeing technology for skeletal and soft tissue evaluation in three dimensions.

An overview will be presented to include the goals of computer imaging, components of an imaging system generating quality images, skeletal and soft tissue evaluation as well as clinical presentation of predictions and surgical results.

References

Sarver, D.M., Johnston, M.W., Matukas, V.J.: Video imaging for planning and counseling in orthognathic surgery. JOMS 45:939-945, 1988

Cutting, C., Bookstein, F.L., Grayson, B., et al: Three dimensional computer assisted design of cranial facial surgical procedures: Optimization and interaction with cephalometric and CT based models. Plast Reconstr Surg 77:877-885, 1986

Laney, T.L., Kuhn, B.S.: Computer imaging in orthognathic and facial cosmetic surgery. Clin Oral Maxillofac Surg, September 1990

New Methods for Three Dimensional Analysis of Craniofacial Deformity

Barry H. Grayson, DDS, New York, NY

The purpose of this presentation is to demonstrate the application of three-dimensional cephalometric analysis in the evaluation and treatment plan of patients with craniofacial asymmetry. While this technique provides a true three-dimensional computer generated image of cephalometric landmarks, it allows the clinician to rotate the image for viewing from various angles and to perform mock surgery. The mock surgical data regarding change in location of dental landmarks (molars and incisors) are used for the construction of the intermedi-

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W S C G ' 9 8

The Sixth International Conference in Central Europe on Computer Graphics and Visualization'98

in co-operation with EUROGRAPHICS and IFIP
working group 5.10 on Computer Graphics and Virtual Worlds

was held

February 9 - 13, 1998

University of West Bohemia, Campus Bory, Plzen - Bory, Czech Republic

Chairs

Nadia Magnenat Thalmann, MIRALab-CUI, University of Geneva, Switzerland, Co-Chair
Vaclav Skala, University of West Bohemia, Czech Republic, Co-Chair

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A part of the WSCG conference was available all over the world via Mbone videoconferencing system.

Please, see conference photos and WSCG'98 Exhibition - program & photos

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Received:	over 157 submissions of very high quality; the acceptance ratio was approx. 64%

Supporting Organisations

Hewlett Packard s.r.o. , IBM CR s.r.o. , Digital Equipments s.r.o. ,
Intergraph CR s.r.o. , Silicon Graphics s.r.o. , Bentley Systems CR s.r.o. ,
Microsoft s.r.o. , DTP Studio Praha s.r.o.
Kodak Foto-World, Pilsner Urquell

WSCG'98 - Conference Program

REGISTRATION: Monday 9.2. in the SLOVAN hotel 17.00-21.00

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Conference proceedings
(ZIP file)

Tuesday February 10, 1998

9.00 - 9.10 Opening session UP 108

9.10 - 10.30 UP 108 Fundamental Algorithms **Chairman: Tokuta, A. (USA)**

- Aguilera,A., Ayala, D.: Solving Point and Plane Vs. Orthogonal Polyhedra Using the Extreme Vertices Model (EVM) (ES, Mexico)
- Fang,S.,Srinivasan,R.,Venkataraman,S.: Volumetric CSG - A Model-Based Volume Visualization Approach (USA)
- Halír,R., Flusser J.: Numerically Stable Direct Least Squares Fitting of Ellipses (CR)
- Reginald,J.R.,Painkras,E.,Prakash,E.C.: Fundamental Algorithms for Projective Voxelization (USA, India)

11.00 - 12.20UP 108 Global Illumination **Chairman: Sbert,M (Spain)**

- Szirmay-Kalos,L.,Csebfalvi,B.,Purgathofer,W.: Importance Driven Quasi-Random Walk Solution of the Rendering Equation (H, A)
- Tobler,R., Hynst,S.,Purgathofer,W.: Linearly Combining Shading Models for Texturing in Global Illumination Algorithms (A)
- Zhukov,S.,Iones,A.,Kronin,G.: Using Light Maps to Create Realistic Lighting in Real-time Applications (Russia)
- Szirmay-Kalos,L.,Foris,T.,Purgathofer,W.: Quasi-Monte Carlo Global Light Tracing with Infinite Number of Rays (H, A)

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11.00 - 12.20 UP 104 Computer Vision, Pattern Recogn. & Image Processing **Chairman: Pelikan,J. (CZ)**

- Gallo,G.,Spinello S.: Pixel Classification in Noisy Digital using Fuzzy Arithmetics (I, Sicily)
- Hisayoshi,Z.,Tsuyoshi,Y.: Reconstruction of Outer Surfaces by Bi-directional Rays (Japan)
- Moltedo,L.,Vitulano,D.:An Automatic Classification of Materials Degradation (I)
- Zlatanova,S.,Paintsil,J.,Tempfli,K.: 3D Object Reconstruction from Aerial Stereoimages (NL)

12.20 - 13.20 LUNCH

13.20 - 15.40 UP 108 Constraint Motion & Surface Meshing **Chairman: Hinkenjann,A. (D)**

- Murta,A., Miller,J., Emley,S.: Managing Complexity and Feature Placement in Planetary Terrain Synthesis (UK)
- Raffin,R.,Neveu,M.,Derdouri,B.: Constrainted Deformation for Geometric Modeling and Object Reconstruction (F)
- Yu,Y.-J.,Jung,H-Y.,Cho,H.-G.: A New Rendering Technique for Water Droplet using Metaball in the Gravitation Force (Korea)

14.20 - 14.40 Break

- Ogan,G.,Metzger,F.J.,Seybold,B.J.,Engeli,M.: Kinematic Chain Substitution for Geometric Constraints Solving (CH)
- Yuen,M.M.F.,Wang,B.,Wu,Z.,Sun,Q.: A Deformation Model of Thin Flexible Surfaces (China, HonkKong)
- Jaar,F., Derdouri,B.,Neveu,M.: Constrained Surface Modeling and Deformation (F)

13.20 - 14.20 UP 104 VR & Interaction, Animation **Chairman: Benes,B. (CZ)**

- Buck,M.,Schömer,E.: Interactive Rigid Body Manipulation with Obstacle Contacts (D)
- Chen,J.X.,Wegman,E.J.,Wang,J.: Animation of Dust Behaviors in a Networked Virtual Environment (USA)
- Zhukov,S.,Iones,A.,Kronin,G.: Navigation of Intelligent Characters in Complex 3D Synthetic Environments in Real-time Applications (Russia)

16.00 - 17.30 UP 108 Computer Animation Festival - video show

Wednesday February 11, 1998

8.00 - 9.40 UP 108 Visualization **Chairman: Csebfalvi,B. (H)**

- Andrienko,G.L.,Andrienko,N.V.: IRIS: Intelligent Visualization for Data Exploration Support in GIS (D)
- Birra,F.P.,Santos,M.P.: A Framework for Data Visualization Based on Particle Systems (P)
- Carr,J.C.,Gee,A.H.,Prager,R.W.,Dalton,K.J.: Quantitative Visualisation of Surfaces from Volumetric Data (UK)
- Crescenzi,P.,Bongiovanni,G.,Rago,G.: JAZ: Java Algorithm visualiZer. A Multi-Platform

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Collaborative Tool for Teaching Graph Algorithms (I)
- Fung,P.-F.,Heng,P.-A.: Efficient Volume Rendering by IsoRegion Leaping Acceleration (China,HonkKong)

8.00 - 9.40 UP 104 Man Machine Interaction & Applications **Chairman: Sochor,J. (CZ)**

- Chen,J.-M.,Wu, B.-H.: Interactive Design Tools for Minimal Energy Spline Curves (ROC-Taiwan)
- Lemström,K.,Korte,J.,Kuusi,P.,Kyheröinen,P.,Päivärumpu,P.: PICSearch - A Platform for Image Content-based Searching Algorithms (Finland)
- Romera,M.,Pastor,G.,Álvarez,F.,Montoya,F.: Growth in Complex Exponential Dynamics (ES)
- Starling,M.,Ashdown,N.: Impresionistic Techniques for Rendering Woodlands Scenes (UK)
- Usami,Y., Unuma,M.: Scaffold Design by a Visualized Genetic Algorithm (Japan)

10.10 - 11.50 UP 108 Fundamental Algorithms **Chairman: Kolingerova,I. (CZ)**

- Jünger,B.,Snoeyink,J.: Selecting Independent Sets for Terrain Simplification (CA)
- Khouas,L.,Odet,Ch.,Friboulet,D.: 3D Furlike Texture Generation by a 2D Autoregressive Synthesis (F)
- Lebiedz', J.: Structural Description of Digitized Straight Line Segments (PL)
- Shirman,L.,Kamen,Y.: A New Look at Mipmap Level Estimation Techniques (USA)
- Schlechtweg,S., Schönwälder,B., Schumann,L.,Strothotte,T.: Surfaces To Lines: Rendering Rich Line Drawings (D)

12.00 - 14.00 UP 104 Commercial presentations & LUNCH

14.00 - 15.20 UP 108 Computational Geometry **Chairman: Egbert,P. (USA)**

- Duckstein,F.:Extension of Validity Calculation to Moving Objects within a Virtual Reality System using Frame to Frame Coherence (D)
- Ghali,S.: Computation and Maintenance of Visibility and Shadows in the Plane (CA)
- Kolingerová,I.: Genetic Approach to the Minimum Weight Triangularization (CR)
- Tokuta,A.: Extending the VGRAPH Algorithm for Robot Path Planning (USA)

16.00 - 17.40 UP 108 Posters

Commercial Presentations - part of the WSCG98 Exhibition

10.00 - 12.00 UP 104 Computer Animation Festival - video show

12.00 - 14.00 UP 104 Commercial presentations

- Hewlett Packard
- IBM

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- DEC
- Intergraph

14.00 - 16.00 UP 104 Computer Animation Festival - video show

Thursday February 12, 1998

9.00 - 10.20 UP 108 WWW Technology & Multimedia **Chairman: Slavik,P. (CZ)**

- Klimenko,S.V.,Litvin,V.A.,Smirnova,V.V.: Visualization of the Non-linear Dynamical Systems using WWW (Russia)
- Lorenz,M.,Schmalfuss,R.:Multimedia Authoring Systems : A Proposal for a Reference Model (D)
- Martins,J., Correia,N., Guimaraes,N.: Software Tools for Content Based Hypervideo (P)
- Ulmer,H.,Lindenbeck,Ch.: Geology Meets Virtual Reality: VRML Visualization Server Applications (D)

9.00 - 10.20 UP 104 CAD/CAM & GIS Systems **Chairman: Szirmay-Kalos,L. (H)**

- Filho,W.P.P.,Ribeiro-Neto,B.,Menezes,V.M.,Oliviera,A.A., Padua,G.P.S., Macedo,E.M.: A GIS-based Environment for Telecommunications Engineering (Brazil)
- Podgorelec,D.,Žalik,B.,Kolmanic,S.: Interactive Modifying the Method Set of a Geometric Constraint (Slovenia)
- Röttger,S.,Heidrich,W.,Slusallek,P.,Seidel,H.-P.: Real Time Generation of Continuous Levels of Details for Height Fields (D)
- Yuen,M.M.F.: 2D/3D Isometric Transformation Using Spring/Mass System (China)

11.00 - 12.40 UP 108 Visualization & Animation **Chairman: Wuetrich,Ch. (D)**

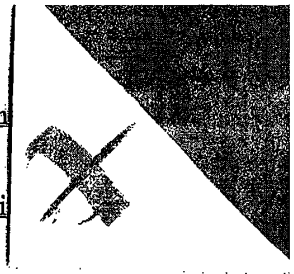
- Scheuermann,G.,Hagen,H.,Krueger,H.: Vector Field Topology with Clifford Algebra (D)
- Sommer,O.,Dietz,A.,Westermann,R.,Ertl,T.: An Interactive Visualization and Navigation Tool for Medical Volume Data (D)
- Zhu,Y.,Chen,J.X.: Establishing a 3D Human Gait and Knee Model (USA)
- Steele,K.L.,Egbert,P.K.: A Unified Framework for Collision Detection, Avoidance, and Response (USA)
- Wcislo,R.,Kitowski,J.,Moscinski,J.: Cellular Automaton as a Fast Tool for Animation of Liquid in Multi-object Scenes (Poland)

12.40 - 13.00 LUNCH

13.00 - 14.40 UP 108 Parallel and Distributed Processing & CAGD **Chairman: Wolter,E.F. (D)**

- Bartz,D.,Grosso,R.,Ertl,T.,Strasser,W.: Parallel Construction and Isosurface Extraction of Recursive Tree Structures (D)
- Contassot-Vivier,S.,Miguet,S.: Optimization and Parallelization of a Geographical Stereo Vision Code (F)

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- Meyer,K.: A Nearly Output Sensitive Parallel Hidden Surface Removal Algorithm Space (D)
- Karciauskas,K.,Krasauskas R.: Rational Biangle Surface Patches (Lithuania)
- Puntambekar,N.Y.,Jablokow,A.G.: Selection of Number of Control Points for Spli Approximation (USA)

15.10 - 16.40 UP 108 Keynote speech

- Thalmann,N.M.,Kalra,P., Esher,M.: Communicating with Virtual Characters (CH)

20.00 Conference dinner

Friday February 13, 1998

9.00 - 10.40 UP 108 Ray Tracing **Chairman: Koenig,A. (A)**

- Krajecki,M.,Habbas,Z.,Herrmann,F.,Gardan,Y.: A Performance Tool Prediction for Parallel Ray Tracing (F)
- Lukaszewski,A., Formella,A.: Fast Penumbra Calculation in Ray Tracing (PL)
- Sanna,A., Montuschi,P.: An Efficient Algorithm for Ray Casting of CSG Animation Frames (I)
- Wonka,P., Gervautz,M.: Ray Tracing of Non-linear Fractals (A)
- Zaninetti,J.,Peroche,B.: A Vector Model for Global Illumination in Ray Tracing (F)

11.20 - 13.00 UP 108 Visualization **Chairman: Iones,A. (RU)**

- Fuhrmann,S.,Kunath,K.,Strasser,W.,Wagner,H.: Animated Finite Element of a Human Mandible with Dental Implants (D)
- Kopp,M., Purgathofer,W.: Interleaved Dimension Decomposition: A New decomposition Method for Wavelets and its Application to Computer Graphics (A)
- Kuo,M.H.,Chen,M.C.: Biomedical Data Interpolation for 3D Visual Models (ROC-Taiwan)
- Lux,M.,Fruehauf,T.: A Visualization System for Operational Meteorological Use (D)
- Mioc,D., Anton,F.,Gold,Ch.: Visualizing Changes in a Dynamic Voronoi Data Structure via Time Travel (Canada)

13.00 - 13.40 LUNCH

13.40 - 15.00 Radiosity **Chairman: Zara,J. (CZ)**

- Arques,D.,Michelin,S.,Piranda,B.:Extending the Zonal Method to Specular Surfaces (F)
- Besuievsky,G.,Pueyo,X.: A Motion Blur Method for Animated Radiosity Environments (ES)
- Hinkenjann,A.,Pietrek,G.: Reconstructing Radiosity by Scattered Data Interpolation (D)
- Sbert,M.,Martinez,R.,Pueyo,X.: Gathering Multi-path: A New Monte Carlo Algorithm for Radiosity (ES)

15.00 - 15.20 Closing session

Last update: 24-VII-2001

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AbstractPlus - Print Format

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Three-dimensional virtual-reality surgical planning and soft-tissueprediction for orthognathic surgery

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Abstract
Complex maxillofacial malformations continue to present challenges in analysis and correction beyond modern technology. The purpose of this paper is present a virtual reality workbench for surgeons to perform virtual orthognathic surgical planning and soft-tissue prediction in three dimensions. A result surgical planning system, i.e., three-dimensional virtual reality surgical planning and soft-tissue prediction for orthognathic surgery, consists of four majc stages: computed tomography (CT) data post-processing and reconstruction, three-dimensional (3-D) color facial soft-tissue model generation, virtual surgical planning and simulation, soft-tissue-change preoperative prediction. The surgical planning and simulation are based on a 3D CT reconstructed bone model, whereas the soft-tissue prediction is based on color texture-mapped and individualized facial soft-tissue model. Our approach is able to provide a quantitative osteotomy-simulated bone model and prediction of postoperative appearance with photorealistic quality. The prediction appearan can be visualized from any arbitrary viewing point using a low-cost personal computer-based system. This cost-effective solution can be easily adopted any hospital for daily use

Index Terms
Inspec
Controlled Indexing
bone computerised tomography image reconstruction medical computing planning realistic images surgery virtual reality

Non-controlled Indexing
3D CT reconstructed bone model color texture-mapped model computed tomography cost-effective data post-processing image reconstruction maxillofacial malformations orthognathic surgery osteotomy personal computer photorealistic quality simulation soft-tissue model generation soft-tissue prediction surgical planning virtual reality
Author Keywords
Not Available

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Three-Dimensional Virtual-Reality Surgical Planning and Soft-Tissue Prediction for Orthognathic Surgery

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***Abstract*—Complex maxillofacial malformations continue to present challenges in analysis and correction beyond modern technology. The purpose of this paper is to present a virtual-reality workbench for surgeons to perform virtual orthognathic surgical planning and soft-tissue prediction in three dimensions. A resulting surgical planning system, i.e., three-dimensional virtual-reality surgical-planning and soft-tissue prediction for orthognathic surgery, consists of four major stages: computed tomography (CT) data post-processing and reconstruction, three-dimensional (3-D) color facial soft-tissue model generation, virtual surgical planning and simulation, soft-tissue-change preoperative prediction. The surgical planning and simulation are based on a 3-D CT reconstructed bone model, whereas the soft-tissue prediction is based on color texture-mapped and individualized facial soft-tissue model. Our approach is able to provide a quantitative osteotomy-simulated bone model and prediction of postoperative appearance with photorealistic quality. The prediction appearance can be visualized from any arbitrary viewing point using a low-cost personal-computer-based system. This cost-effective solution can be easily adopted in any hospital for daily use.**

***Index Terms*—Maxillofacial deformity, orthognathic surgery, soft-tissue-change prediction, three-dimensional surgical planning and simulation, virtual reality.**

I. Introduction

IT IS frequently difficult to make a precise surgical plan to correct for complex maxillofacial deformity using conventional methods. Traditional surgical planning for orthognathic surgery is determined by cephalometric analysis, and clinical and aesthetic judgment.

Three-dimensional (3-D) studies in medicine started at the beginning of the 1970's [1]. The cross-sectional imaging capability of computed tomography (CT) [2] and 3-D reconstruction have led to a tremendous leap in diagnostic radiology. Although cross-sectional slices avoid superimposition of adjacent structures and permit high-resolution details of bone, 3-D rendered visualization provides the radiologists and surgeons with readily recognizable images of complex anatomic structures. It can exactly record and represent the life size and shape of bone for precise bone surgery planning and simulation.

Orthognathic surgery attempts to reestablish functional and aesthetic anatomy by repositioning displaced bones or by grafting and recontouring the deformed bone contour. Soft-tissue changes usually accompany these skeletal alterations, but, despite the advance in imaging modalities, the prediction soft-tissue deformation upon the bone structure change still poses major challenges to both surgeons and computer scientists. Although there are several methods to capture the soft-tissue contours, such as laser scanning [3], Cyberwere [4], the Moiré imaging technique [5], 3-D digitizer [6], and 3-D photographic method [7], to quantify bone-soft-tissue relations and to predict soft-tissue changes remain as open research problems.

Surgical planning, postoperative prediction, and visualization requires a combination of the knowledge between medicine and computer graphics. With respect to the point presented earlier, the purpose of this paper is to present a virtual-reality environment for orthognathic surgical planning. The environment provides facilities for a surgeon to make surgical plans, to simulate various orthognathic surgical procedures as they are routinely performed in an operating room, and to predict soft-tissue changes before operation. Furthermore, we present a surgical-planning system, which is termed the three-dimensional virtual-reality surgical-planning and soft-tissue prediction for orthognathic surgery (3DVRSP). The development of the 3DVRSP system is based on our previous studies on 3-D color facial-model generation [8], 3-D virtual osteotomy [9], and 3-D soft-tissue planning and prediction [10].

II. VRSP Overview

The virtual-reality workbench 3DVRSP consists of four major functions:

1) CT data post-processing and reconstruction;
2) 3-D color facial soft-tissue model generation;
3) virtual surgical planning and simulation;
4) soft-tissue-change prediction before operation (Fig. 1).

Mensurations such as linear and spatial measurements are also included as supplemental functions. Anatomy modeling and visualization were based on 3-D reconstructed axial CT data. Surgical planning and osteotomy simulation were made on the reconstructed 3-D bone structures, whereas soft-tissue changes

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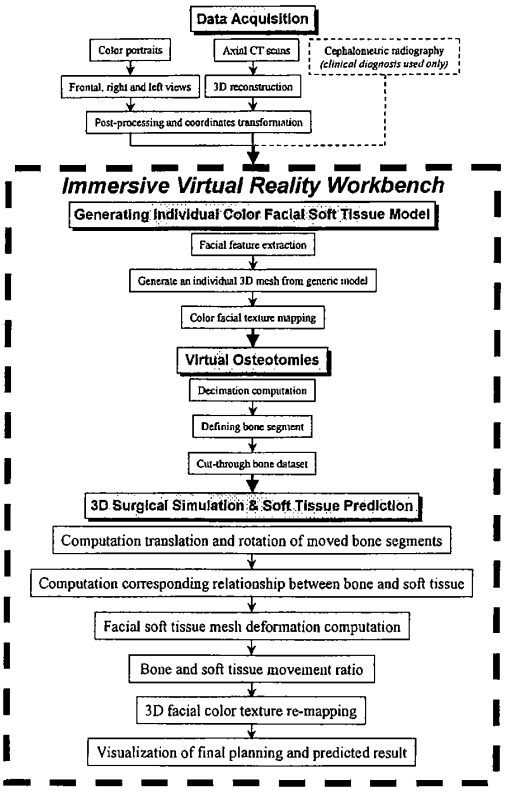


Fig. 1. System overview of 3DVRSP system.

were then predicted on the individualized and color texture-mapped facial soft-tissue model.

More interestingly, the approach here allows an immersible virtual-reality surgical planning environment to be implemented on a relatively low-cost personal computer (PC)-based system when high-end graphics workstations were normally required. Within the virtual environment (or "Cyberspace") of VRSP, an surgeon can get hold of a virtual "scalpel" to operate on a "virtual" patient, to execute various surgical plans, and to visualize and predict the postoperative results through VRSP's 3-D virtual osteotomies and 3-D soft-tissue prediction facilities (Fig. 2). VRSP outputs orthognathic surgical plans and a 3-D color photorealistic patient's facial soft-tissue model. The osteotomy-simulated bone model and predicted color model can be rotated and visualized from any point-of-view.

An IBM-compatible PC was configured as an Intel Pentium-II 400 processor (Intel Inc., Santa Clara, CA) with 256-MB RAM and a Matrox Millennium G400 AGP display card (Matrox Graphics Inc., Québec, QC, Canada). An iomega ZIP (Iomega Corp., Roy, UT) drive is used to digitally transfer CT data from a CT scanner to our PC.

To create a virtual-reality workbench, the virtual-reality devices, such as stereo glasses and a 3-D flying mouse, are also applied for this study. The Logitech 3-D flying mouse system (Logitech Inc., Fremont, CA) is used as a virtual "scalpel."

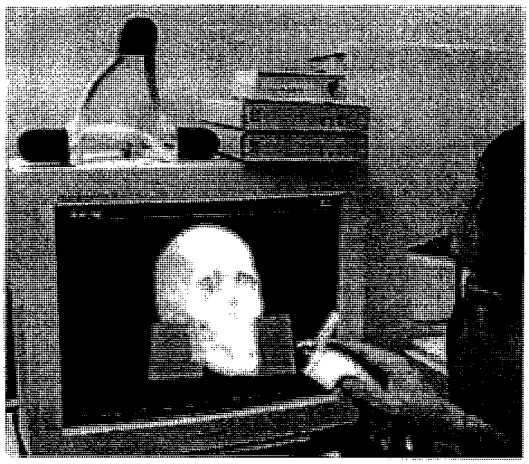


Fig. 2. Surgeon immersed into virtual-reality environment to operate on a virtual "patient."

CrystalEyes 2 eyewear (StereoGraphics Corporation, San Rafael, CA) is a device used to visualize stereoscopic images in Cyberspace.

The operating system was a Microsoft Windows NT Workstation 4.0 with Service Package 4, and all the programs were developed by Microsoft Visual C^{++} 6.0 (Microsoft Corporation, Redmond, WA).

OpenGL (Silicon Graphics Inc., Mountain View, CA), the environment for developing portable and interactive 3-D graphics applications, was used for developing interactive two-dimensional (2-D) and 3-D visualization.

VTK (Kitware Inc., Clifton Park, NY), a visualization toolkit for developing computer graphics and visualization algorithms, was used for programming surface rendering and decimation computation.

III. Clinical Data Acquisition and Application

A. Clinical Data Source

Fourteen patients with maxillofacial deformities were randomly selected from a large pool of patients awaiting surgical correction of their deformity from December 1995 to December 1998. All patients were evaluated at the Surgical-Orthodontic Joint Assessment Clinic, Oral and Maxillofacial Surgery, University of Hong Kong.

Standard cephalometric radiographs were taken with a 165-cm tube-to-film distance, 15-cm patient midsagittal plane-to-film distance, and with a magnification ratio of 110%. Diagnosis and preliminary operative plan were made by the cephalometric radiographs and clinical examination.

The patient's portraits were photographed as conventional medical documentation. CT scanning was carried out especially for this study. The rules of data acquisition are as follows [10].

1) The patient's facial expression is natural.
2) The teeth should be in occlusion.
3) View angles should be at 0°, 90°, and 270° during photography.

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4) The corresponding facial organ's position, i.e., the mouth, should be as similar as possible between CT scanning and photography.
5) The Frankfort Plane should be parallel to the horizontal plane as close as possible during photography, whereas the Frankfort Plane of the supine patient need to be vertical in relation to the horizontal plane during CT scanning.
6) Head and jaw's movements and facial expressions are prohibited during CT scanning.
7) Both portraits and CT scanning should be taken in the same period (normally within one week of each other).

B. Color-Portrait Photography

The frontal, right-, and left-side views of the patient's face in the natural head position were photographed separately by a Medical-Nikkor 120 mm/f4 lens (Nikon Corporation, Tokyo, Japan). The magnification was fixed at 1 : 8 or 1 : 11, depending on the height of the patient's head. The central focal axis of the lens was adjusted to remain horizontal during the photography process. The patient's Frankfort Plane was parallel to the horizontal plane. Portraits were then scanned as 24-bit images into the computer via a Nikon LS-20 film scanner (Nikon Corporation, Tokyo, Japan) and the digitized images were resampled to 360 × 550 pixels each.

C. CT Data Acquisition

All patients were examined by a GE Pace CT Scanner (GE Medical Systems, Waukesha, WI) at the Hong Kong Adventist Hospital, Hong Kong, with a thickness of 2.0 mm and original 512 × 512 matrix with 16 bits. The display fields of view (FOV) ranged from 21 to 30 cm. CT scanning was performed at 120 KV, 80 mA, and 2.0 s each by 99∼125 slices, depending on the height of the patient's head. The Frankfort Plane of the supine patient was vertical in relation to the horizontal plane. A rubber band was used to restrict the patient head's movement during CT scanning. The 2-D axial slices started from the submandibular region and covered the whole head. All the raw data of CT scans were digitally transferred from the CT scanner to our PC by an iomega ZIP drive without losing any signal.

IV. METHODS

A. Processing of CT Data and 3-D Unique Coordinate System

1) Processing of CT Data: For the true perspective of data visualization, image-processing techniques were used to manipulate image contents to improve the results of subsequent processing and interpretation. The post-processing functions included: 1) removing undesired objects; 2) masking individual bone structure; and 3) the bone-structure enhancement.

Segmentation was the process of classifying pixels in the image or volume [11]. Depending on the scene complexity, it can be one of the most difficult tasks in the visualization process. Interactive segmentation was used if the threshold filter was not able to mask the bone in the CT dataset during the marching cubes process.

2) 3-D Reconstruction: A volumetric dataset was then prepared by using the marching cubes algorithm [12], [13] from the processed CT raw data. For fast rendering and shading, all the succeeding operations were based on this volumetric dataset. The original CT slices were discarded in the subsequent processing.

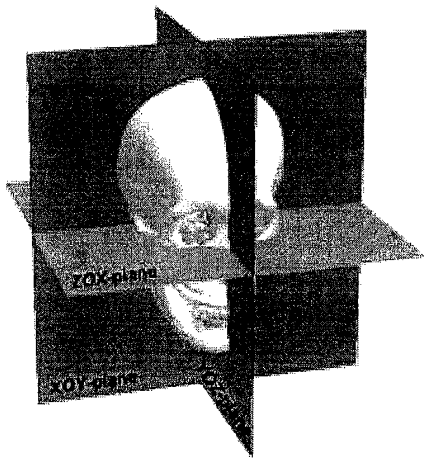


Fig. 3. 3-D coordinate system transformation.

3) Unique 3-D Coordinate System: The view coordinate system represented what was visible to the observer. The x and y coordinates specified location of object in a plane, whereas the z coordinate represented the depth. The original coordinates in the CT dataset were transformed to the patient's coordinate system, accounting for slight malpositioning of the patient during the CT scanning [8]–[10].

A 3-D spatial coordinate system should be defined for visualization and further process. Five landmarks were needed to be interactively digitized on the reconstructed skull: *nasion*, right- and left-hand-side *porion* and right- and left-hand-side *orbitale*. These landmarks could usually be easily located on the frontal, right- and left-hand-side views of reconstructed bone visualization.

The horizontal plane was defined by right- and left-hand-side porion, and the average coordinates of the right and left orbitale. The frontal plane was perpendicular to the horizontal plane and through the right- and left-hand-side porion. The midsagittal plane was set perpendicular to the horizontal plane and the frontal plane, and through the nasion (Fig. 3).

After generating the 3-D coordinates, the polygons and triangles of the reconstructed models were transformed from the world coordinate system into the view coordinate system via vector product computing. Like cephalometric analysis, 3-D visualization and manipulation could be performed in this unified 3-D spatial coordinates repeatedly.

B. 3-D Facial Soft-Tissue Model Generation

Two separate techniques were applied during this stage of the process: individualized facial soft-tissue model generation from a generic mesh and color texture mapping.

1) Generic Facial Soft-Tissue Model: Our generic facial model is a triangular mesh consisted by 2665 vertices and 5302

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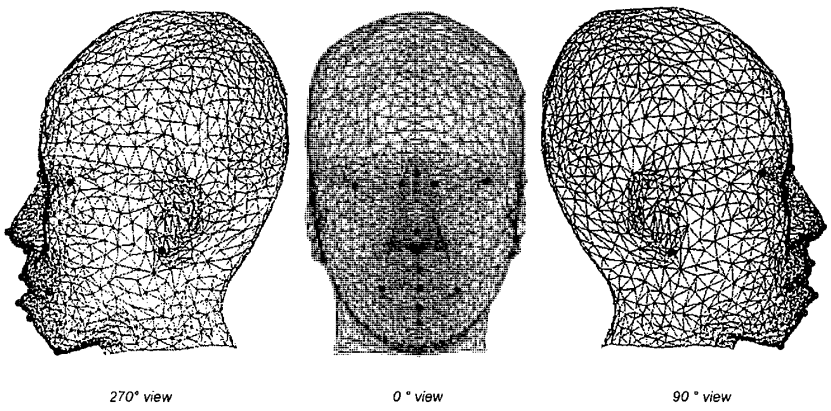


Fig. 4. Registration on the generic mesh.

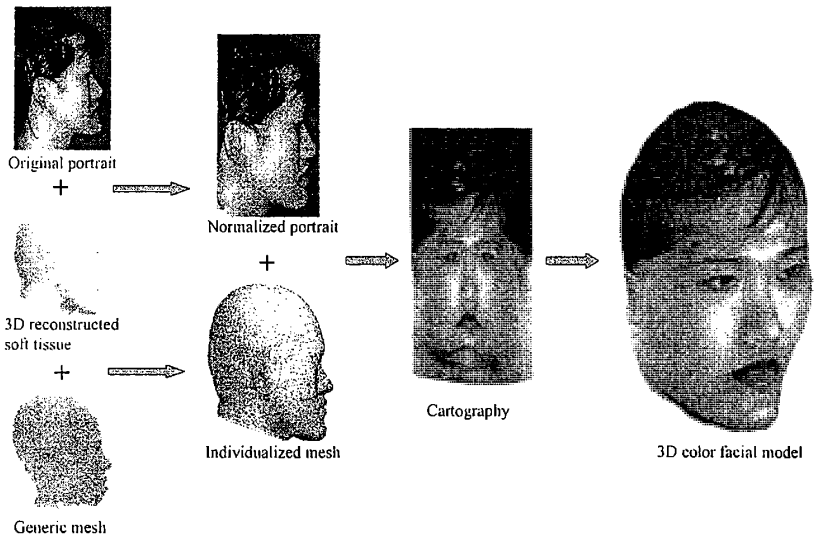


Fig. 5. Generating 3-D individual color facial model.

triangles. This generic mesh was created from 3-D bone and soft tissue, which have been reconstructed from CT scans of a real human head. It contained the corresponding relationship of the coordinates between bone structure and soft tissue. Each coordinate on the bone surface had its own unique projection to the soft-tissue mesh. When each point on the bone surface was changed, the corresponding coordinate of soft tissue would be changed accordingly. This allows us to simulate soft-tissue movement as a result of bone movement. Additionally, there were a series of built-in vertices representing facial outlines and features.

2) 3-D Color Facial-Model Generation: Facial feature and outline key vertices were extracted from the 3-D reconstructed soft tissues from CT scans (Fig. 4), the generic mesh was then individualized as a texture coordinates by correspondence matching, interpolation, and transformation computation based on these fiducial points.

The texture mapping was a procedure similar to pasting a picture to the surface of an object. Three digitized color portraits with the "third" dimension from reconstructed soft tissue were blended into a cartograph as a texture map.

After the cartograph was texture mapped on to the 3-D head model, a photorealistic model of a human head was generated from frontal, right-, and left-hand-side real color portraits.

Individualized Facial-Model Generation from Generic Model: A soft-tissue color facial model, containing a bone–soft-tissue relationship and facial color information, was generated from a generic model and color portraits (Fig. 5).

The feature points characterized each facial organ and outline of the patient's face, with the same definition as the built-in

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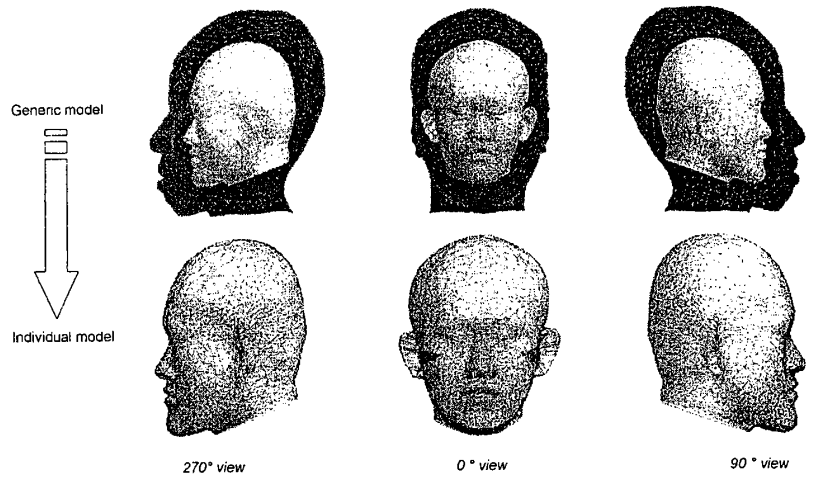


Fig. 6. Individualizing generic model.

landmarks in the generic mesh, and were registered interactively on both of the color portraits and 3-D reconstructed soft tissues.

To approximate an individualized facial mode, the facial outline and features of the organs should be mapped to the generic mesh first. The translation vectors were automatically computed by matching the feature vertices on the generic model to the corresponding feature points. A transformation vector field, which defined the translation vectors for both feature and nonfeature vertices in the generic model and transformed the generic model to individual for right-hand side, frontal and left-hand-side views, was also automatically estimated using the sets of translation vectors and bilinear interpolation. The outline and facial organs were correctly created although the nonfeature areas, such cheek area, might still be slightly deformed on the mesh.

To generating the fully individualized facial model, the vertices without feature landmarks should be accurately remapped onto the 3-D reconstructed images by an automatic and time-consuming computation. Superimposing this approximated individualized mesh and reconstructed soft-tissue surface together by the facial outline and feature vertices, the nonfeature and mispositioned vertices on the mesh were displaced to the intersection points of the reconstructed surface along the ray projections from the y-axis. The individual mesh could then be precisely generated (Fig. 6). It contained all the 3-D information transformed from the 3-D reconstructed soft-tissue and bone–soft-tissue corresponding relationship from the generic mesh.

Color Texture Mapping: Although the facial soft-tissue model was precisely individualized, it was still lacking color information. Texture mapping was used to paste color onto this model.

Color texture mapping requires two elements: a texture map, where the texel could be obtained from, and a texture-coordinate where the texel could be pasted to. To define a texture map, a cartograph was generated from three digitized color portraits and reconstructed soft tissue. We assume each point on the cartograph, as corresponding to a sphere coordinate. Projecting a ray from the y-axis to a point, along this direction, an intersection point $P_s(x, y, z)$ could be found on the reconstructed CT soft-tissue surface. This point was projected on to the frontal view at $P_0(x, y)$ and lateral view at $P_{90}(z, y)$ of the portraits, respectively. Blending these three points together, the color information and coordinate of this pixel were generated as a cartographic pixel (Fig. 7). By repeating the above procedures, a complete cartograph with 3-D coordinates and full color information was generated as a texture map.

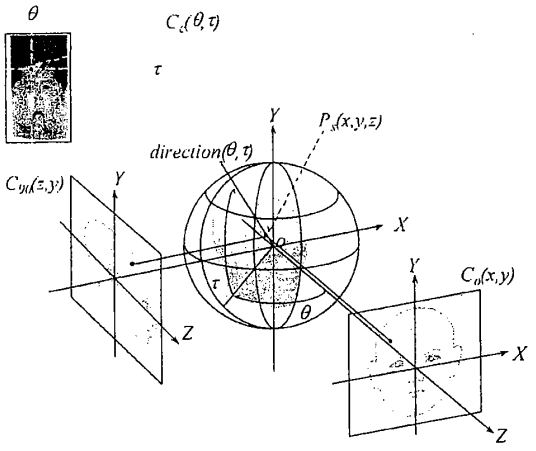


Fig. 7. 3-D facial texture mapping from cartography.

To generate a texture-mapped mesh projection in an arbitrary view direction, the texture coordinate on the cartograph for each triangle vertex on the mesh was calculated as the ideal relationship first. The color textures were then mapped onto the individualized facial model and the texture-mapped model could be visualized in real time.

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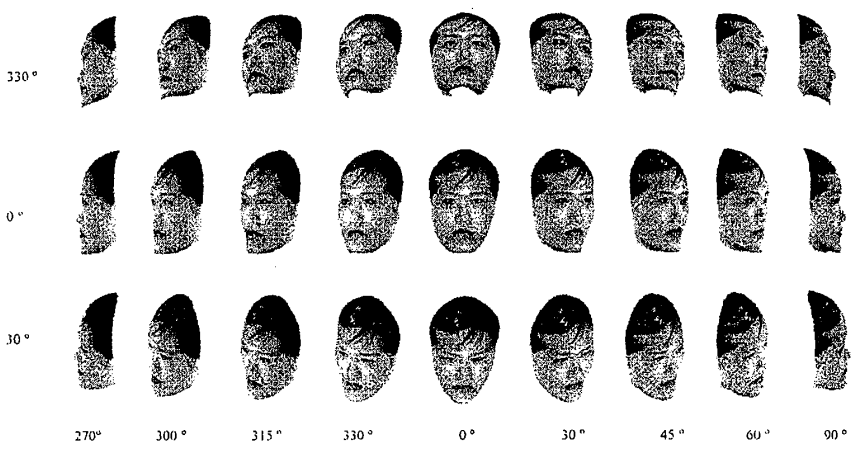


Fig. 8. Sequence of 3-D color facial model.

The patient might close his/her eyes during CT scanning, the eye features on the individualized model would also be represented as closed eyes. Instead of point-to-point mapping, the color information of eye details was extracted *en bloc* from 3-D color portraits (cartograph) and mapped onto the individualized model directly.

An individualized color texture-mapped facial model with photorealistic quality could be rotated freely and visualized from any viewpoint at real-time speed (Fig. 8). All the procedures described in the texture-mapping stage were fully automatic, no interactive operation was required, although it involved very complex computations.

C. 3-D Virtual Osteotomy Planning and Simulation

This stage cut through the 3-D reconstructed bone dataset with a surface and then displayed interpolated data values on the surface in order to achieve the virtual osteotomy simulation.

The bone surface was represented by millions of polygons and triangles. A fully automatic decimation computation [14] was first applied on the reconstructed bone surface to reduce the triangles up to 70% in order to keep a balance of maintaining more bone structure details and obtaining an acceptable speed of rendering and a reasonable interval of feedback during cut-through of the bone dataset.

The data cutting operation required two pieces of information: a definition for the surface (cutting surface) and a dataset to cut (which bone to be cut). It was assumed that the cutting surface was defined by an implicit function (virtual knife). Fig. 2 showed the cutting planes of bilateral subsigmoid osteotomies were defined by moving a 3-D mouse. A property of implicit functions was to convert a position into a scalar value. This property in combination with a contouring algorithm, i.e., marching cubes, to generate the cut surfaces.

Scalars were generated for each point of each cell of the CT dataset, and then contour the surface value $F(x, y, z) = 0$. For each cell, function values were generated by evaluation $F(x, y, z)$ for each cell point. If all the points evaluated either positive or negative, then the surface did not cut the cell. However, if the points evaluated both positive and negative, then the surface passed through the cell. A contouring algorithm was then applied to generate the isosurface on the cutting surface.

The virtual osteotomy was performed interactively. The surgeon needed to decide which osteotomy would be used. The osteotomy was performed intraoperatively based on the surgeon's clinical experience. The immersible virtual-reality workbench simulated the environment of the operating room.

The decimated skull was subdivided into osteotomized segments with a corresponding overlying skin region. This was accomplished by visually editing the 3-D bone surface models with a virtual knife. The object (bone) was selected and separated into two parts immediately after defining the cutting plane (cutting through the bone dataset).

In the virtual osteotomy simulation, the binary tree structure was used to identify the bone segments during maxillary and mandibular osteotomies. Each bone segment was assigned a unique element identity (ID) automatically. A nonlinear structure, called a tree, consisted of nodes, branches, and leaves. In the simulation of the operative procedures of a segmentalized Le Fort I osteotomy and bilateral vertical subsigmoid osteotomies with genioplasty, the root of the tree was the skull (ID1). Separating the neck from the skull, there were two nodes in the tree, the neck (ID2) and remaining part of the skull (ID3). Separating ID3 into ID6 and ID7, the maxilla (ID13) could be osteotomized from the skull without the mandible and the neck (ID6)—Le Fort I osteotomy. Four leaves with ID 26, 54, 110, and 111 were then assigned after the maxilla was segmentalized into four pieces. In the same principle, the mandible (ID7), also separated from ID3, was osteotomized as the right distal segment (ID14), the left distal segment (ID28), and the proximal segment (ID29) by bilateral subsigmoid osteotomies. Lastly, the chin segment (ID58) was osteotomized from proximal segment (ID29) by genioplasty. Fig. 9 shows a diagram of osteotomized bone segments with their unique ID.

After osteotomies, each bone segment with its own ID could be manipulated separately, including translation, rotation, eleva-

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Fig. 9. Diagram of osteotomized bone segments.

tion, changing rotation center, displaying movement parameter, color masking, scaling, range boundaries, and switching each object to visible or invisible.

D. 3-D Soft-Tissue Planning and Prediction

This was a soft-tissue deformation scheme for predicting the soft-tissue change before operation.

The movement of the osteotomized bone segment was assumed as a series of coordinate transformations in the 3-D space. After the bone segment was moved to a new position, the coordinates of feature points (vertices) on the bone segment were accordingly translated and rotated. The transformation matrices of bone segment were combined by matrix multiplication to achieve combinations of translation and rotation.

Two soft-tissue deformation algorithms were used in this scheme: the surface normal-based model deformation algorithm and the ray projection-based model deformation algorithm [10]. The corresponding relationship of the vertices of the triangles between the bone and soft-tissue surface was computed and saved as an intersection data file. The computation of the transformation of the soft-tissue model (individualized mesh) was then made by using a 4×4 transformation matrix. For the ray projection-based model deformation, the cylinder sampling model was applied to compute the intersection data along the ray projection from origin of coordinate, between eyebrow level and labiomental-fold level. The sphere sampling model was applied to calculate the remaining parts along the ray projection. If the surface normal of the vertex inferior to the plane of landmark labiomental fold was equal to or smaller than minus 10° ($\leq -10^\circ$), the intersection data was computed along the direction of the surface normal instead of the ray projection for the surface normal-based model deformation.

To orchestrate the soft-tissue prediction with different operation types, the parameters of bone and soft-tissue movement ratios were transferred from intervened ratio files correspondingly [10].

3-D color facial texture-mapping technique was applied again to regenerate a color photorealistic facial model after soft-tissue deformation.

The soft-tissue changes were simply predicted by interactively and intraoperatively dragging the bone segments to the desired position. When the surgeon translated, rotated, and elevated each bone segment (Fig. 10), the soft-tissue model was correspondingly deformed and the texture was remapped from the cartograph in a real-time speed. A predicted 3-D facial visualization with color photorealistic quality was precisely created. Both the bone and soft-tissue models could be rotated freely and visualized immediately from arbitrary observing angle with zoom out or zoom in. Each object of the bone and soft tissue also could then be masked as visible or invisible in order to get the best visualization during the virtual operation. To check the soft-tissue and bone movement, the soft tissue could be displayed as a wire frame overlying on the bone. The predicted facial model could generate a sequence of images and be printed on glossy paper via a photo-quality color printer (Fig. 11).

V. Clinical Trial

To date, 14 cases have been planned using integrated 2-D and 3-D data and analysis. Surgical planning and simulation has been performed by this VRSP system. The postoperative visualization is predicted before operation.

The surgeon can use different combinations of shortcut keys, 2-D mouse, 3-D flying mouse, and CrystalEye eyewear, to perform the virtual osteotomies, to move bone segments, and simulate soft-tissue changes.

Based on the procedures and time requirements for analysis, six stages of treatment planning are available. The operator's clinical experience is important for achieving successful planning.

The first stage involves data acquisition and clinical evaluation, such as CT scanning, color-portrait capturing, cephalometric analysis, and primary clinical assessment. This requires a 2–7-h effort.

The second stage involves CT raw data post-processing, including removing undesired objects, enhancement processing, masking bone structure, etc. This requires a 2–3-h effort.

The third stage involves interactive visualization of the 3-D images, including the volumetric dataset generation, 3-D coordinates geometry transformation, etc. This requires about a 1-h effort.

The fourth stage of planning is to generate individual facial soft-tissue model with a color texture mapping. This is an important and semiautomatic step, which can directly affect the accuracy of predicted effects. This procedure requires about 1–2 h.

The fifth stage of planning is to make decimation computation, to add digitizing landmark coordinates to the bone model in

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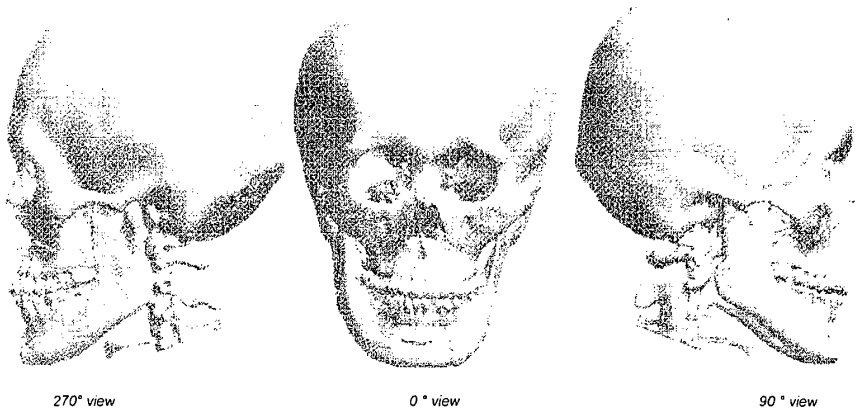


Fig. 10. Bone segments after movement.

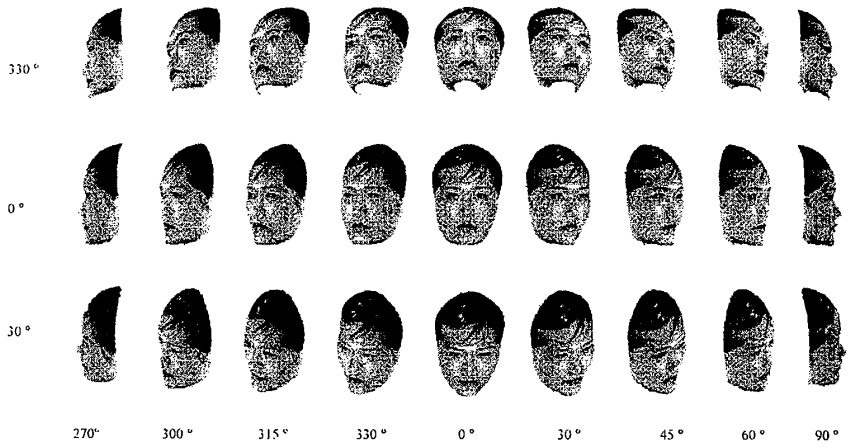


Fig. 11. Predicted image sequence.

order to perform varieties of procedures of virtual "osteotomies" in virtual-reality environment. This step is only operated on the bone. It requires about 1 h or less.

The sixth stage of planning is much quicker and requires about 10–15 min. This step is totally operated in the virtual-reality environment with virtual-reality devices. The surgeon can move and rotate the osteotomized bone segments freely and observe the predicted result with full-color visualization. The operator may also compare results between the predicted and original facial models in 3-D visualization. If the predicted effectiveness is not satisfactory, the prediction can be discarded and repeated again. The movement data of a different bone segment is displayed on the computer monitor by selecting the required bone segment.

A planning and simulation session was held at the computer system with the maxillofacial team for review and final modifications. The quantitative translation and rotation data of each object could be displayed, respectively. The final result of planning and simulation can be visualized from arbitrary viewpoints in the virtual-reality workbench. It can also be produced as a sequence of color-texture remapped images and printed on glossy paper via any high-resolution photo-quality color printer (Fig. 11).

Follow-up was performed six months after operation. A comparison between original color portraits, predicted facial model, postoperative portraits, simulated osteotomies, and bone structures after surgery is shown in Figs. 12–14.

VI. Discussion

Surgical planning and simulation has wide applications, such as for orthognathic surgery, craniofacial surgery, cleft palate, trauma, distraction osteogenesis, etc. In general, surgical simulation is to perform the "surgery" in the computer and to con-

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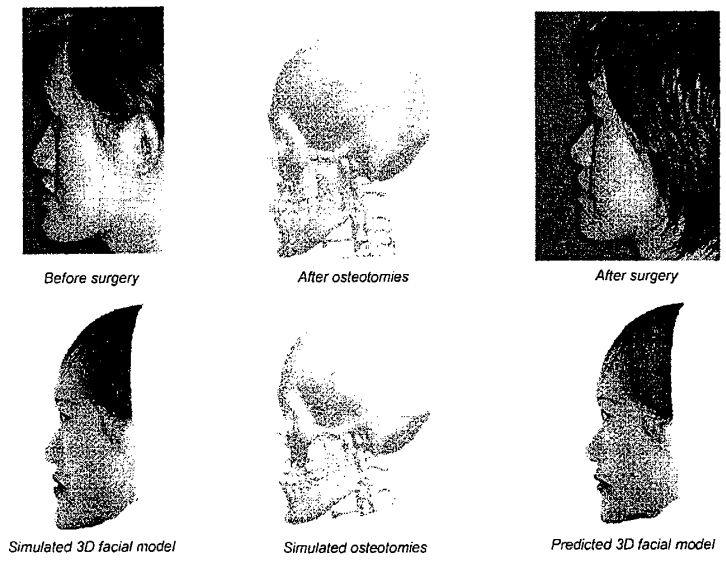


Fig. 12. Comparison between predicted facial models and color portraits (270° view).

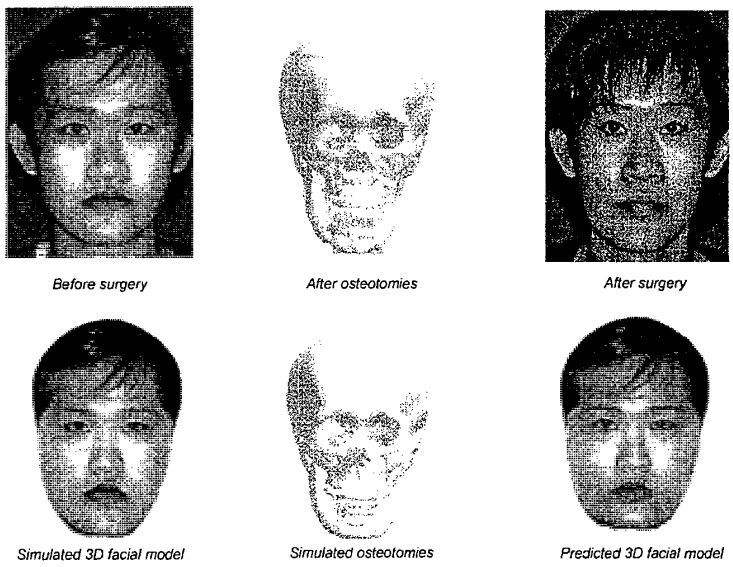


Fig. 13. Comparison between predicted facial models and color portraits (0° view).

struct a "fake" image of the postsurgical appearance of the patient before operation.

3-D imaging technology is now widely available and used to aid in the comprehension and application of volumetric data to diagnosis, planning, and therapy [15]. A 3-D computer system and virtual-reality environment bring the surgeon into Cyberspace to perform the tasks that he performs routinely. He may immerse into the responsive workbench to gain the same feelings as if he is in the real situation. The computer itself no longer means everything in the whole system, but rather acts as a "Daemon"—an intelligent server in the background, providing necessary information across multisensory interaction [9].

There are several studies on surgical planning for maxillofacial and craniofacial surgery [16]–[20]. Altobelli *et al.* [16] used the 3-D surface reconstruction from CT data to plan craniofacial operations. Cephalometric analysis was integrated with 3-D CT reconstruction to quantify the skeletal deformities and to assist in the design of the surgical procedure. Interactive techniques were developed to simulate osteotomies and skeletal movement in three dimensions on the computer-generated surface images.

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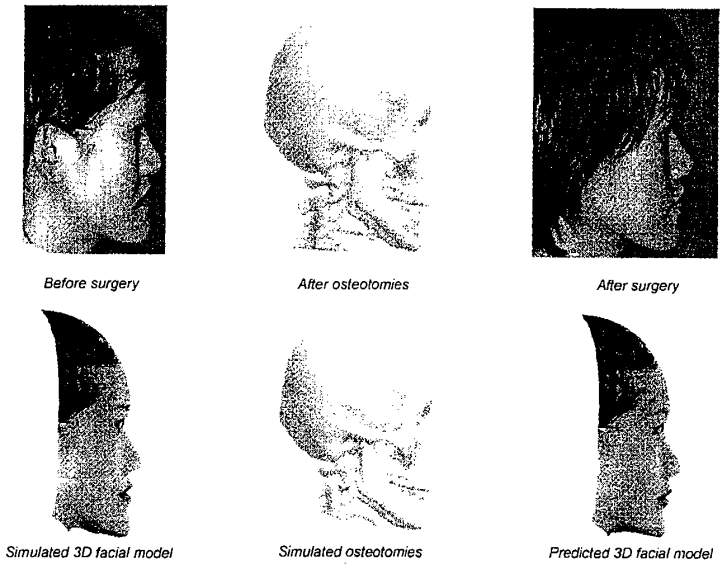


Fig. 14. Comparison between predicted facial models and color portraits (90° view).

It took about one or two days for bone surgery simulation on an extremely powerful high-end graphic workstation. 3-D soft-tissue prediction based on bone movement was not included.

Stereolithographic biomodeling is a modern technology that allows 3-D CT data to be used to manufacture solid plastic replicas of anatomical structures (biomodels) [21]–[23]. It can produce the life-sized deformed bone structures, so a surgeon can directly observe a patient's deformity and make surgical planning on the biomodel before operation. However, it needs an extremely expensive machine to fabricate this biomodel, and soft-tissue-change prediction is still not included.

Soft-tissue-change prediction is an important aspect in surgical planning, especially in orthognathic surgery. The orthognathic surgery is not only to correct the malfunctions and to relocate malpositioned bones, but also for aesthetic purposes. Currently, soft-tissue simulation are still mainly focused on the 2-D profile prediction (color video-imaging techniques) combining with cephalometric analysis in two recent decades [24]–[28], only a few studies involved in three- dimensional soft-tissue capturing and deformation [3]–[7], [10], [29]–[32]. Ayoub *et al.* [29], [30] designed a vision-based 3-D facial data capture system (photogrammetry) for the planning of maxillofacial operations. The facial images and a cephalogram were captured simultaneously, followed by a computer program to create a 3-D facial model, which was used to predict soft-tissue changes of orthognathic surgery. However, the 2-D cephalometric radiographs may not have enough information to simulation 3-D soft-tissue changes. The relationship between soft tissue and bone still remains a question.

From the methods discussed above, there is no virtual-reality-based 3-D system to make precise orthognathic surgical planning and soft-tissue predictions with a PC. The aim of this study is to combine 3-D visualization, virtual reality, color video-imaging technique, surgical planning, and simulation in order to solve the bone–soft-tissue relationship problem and provide the surgeon with an ideal virtual-reality workbench for orthognathic surgical planning, simulation, and soft-tissue prediction in a personal computer system. The workbench is designed not only for surgical planning, but for teaching purposes as well. This study has achieved the following general objectives:

- to create a 3-D virtual-reality workbench for surgical planning, simulation, and soft-tissue prediction for orthognathic surgery;
- to establish a 3-D surface reconstruction from sequential CT data;
- to generate an individual 3-D model from a generic mesh;
- to perform color texture mapping from three views (frontal, right-hand, and left-hand side) of portraits;
- to generate fast 3-D visualization, so multiple virtual osteotomies can be real-time performed;
- to deform individual facial model (mesh) after virtual operation, so as to achieve soft-tissue prediction;
- to obtain a final product—the quantitative osteotomy-simulated 3-D bone model and the precise soft-tissue-change predicted 3-D facial model with color photorealistic quality, which can be real-time visualized in three dimensions and a virtual-reality environment;
- all procedures operated in a conventional personal computer system with relatively low-cost virtual-reality devices, instead of an extremely expensive high-end virtual-reality graphics workstation.

Considering the cost and radiation of whole-skull CT scanning to the patient, this workbench is more likely to be suitable for the cases with complex maxillofacial deformity, such as asymmetric deformity, cleft palate, distraction osteogenesis, and trauma, where radiation and the cost of a CT scan need to be justified.

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Optical measurement of dental cast profile and application to analysis of three-dimensional tooth movement in orthodontics

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Abstract—Dental casts are frequently used for measuring the size, shape and position of a tooth. We have developed an optical apparatus for measuring a three-dimensional profile of a dental cast. The measurement is based on the triangular method which detects a laser spot on a cast by an image sensor. The apparatus is computer-controlled and designed to achieve a total measuring depth of 40 mm, a data acquisition time of 25 ms per point and a minimum scanning pitch of 0.1 mm. The depth and lateral resolutions are 0.05 and 0.1 mm, respectively, within a depth range of 25 mm. As a particular application of the apparatus, three-dimensional movement of teeth, including rotational movement, during orthodontic treatment, has been quantified by means of the superimposition of tooth profiles using a computer.

Key words: laser; image sensor; dental cast; three-dimensional measurement; tooth movement.

1. INTRODUCTION

A dental cast is capable of reproducing precisely tooth and palate shapes, and is widely used in dentistry not only for working on dental protheses but also for dental examination. Because of the problems involved in working within the mouth, tooth shape and position, providing fundamental diagnostic information in dentistry, are generally measured indirectly on a dental cast. This is called cast analysis and is most frequently carried out by using simple instruments such as a caliper and a ruler. These instruments, however, allow only one-dimensional measurement. In order to measure a cast in three dimensions, use of other instruments, using either a contacting mechanical or a non-contacting optical method, have also been attempted [1–3]; however, in most cases, since a structure is digitized by an operator point-to-point, little data can be obtained and important information concerning surface profiles is unavailable. As for the measurement of shape, stereophotogrammetry has been applied to the morphological study of the face, the tooth and the palate [4–6]. Although this method has been used successfully to measure three-dimensional shapes, it requires a sophisticated procedure and cannot automatically digitize the shape. A simpler, automatic measuring instrument using an optical probe and a computer has also been developed [7]. Unfortunately, this method does not meet the demands in spatial

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resolution required for the measurement of occlusal surface of teeth having a fine profile. This problem has led us to develop an automatic optical measuring system equipped with a laser and an image sensor and capable of greater precision [8].

Not only the shape, but also the positional change of a tooth is fundamental and important information in orthodontics. In daily practice, clinicians analyze tooth movement during orthodontic treatment in a one-dimensional way by measuring the distance between two teeth using a caliper, or in a two-dimensional way by tracing teeth on X-ray films taken at different stages of the treatment [9]. Once the three-dimensional shape of dental casts at the different stages is digitized into a computer, three-dimensional movement of a tooth can be obtained by numerical calculation. This paper describes an apparatus designed for the three-dimensional measurement of a dental cast and its application to the measurement of three-dimensional tooth movement during orthodontic treatment.

2. CONSTRUCTION OF THREE-DIMENSIONAL MEASUREMENT APPARATUS

Three-dimensional measurement using current apparatus is based on the triangular method, and employs an optical probe that is typically used for measuring distance and displacement. A few biomedical applications of this technique to the surface profile measurement have been published in recent years [10]. In our apparatus, as illustrated in Fig. 1, a small light spot is formed on a dental cast with a 0.6 mW He–Ne laser and a lens L_1 ($f=100$ mm). This lens is used to sharpen the laser beam to a point in order to raise the horizontal power of resolution, because the 0.8 mm diameter of the unfocused beam from the laser is too thick to measure the fine occlusal surface of a tooth. Scattered light from the spot is focused, with the other lens L_2 ($f=75$ mm), on to an image sensor (Sharp LZ2020), which has a one-dimensional array of 2048 photoelements (pixels) aligned at a pitch of 14 μm. Since the position of the spot on the array corresponds to the vertical position of the spot on the cast, the depth of the cast surface can be obtained. Scanning required for profile measurement is accomplished by moving the cast in a horizontal plane with an X–Y table, for which a conventional X–Y plotter (Graphtec WX4636) was substituted for ease of instrumentation.

The image sensor is placed on an optical W-axis making an angle of α (35°) with the incident optical Z-axis of the laser beam, and is also tilted by β (45°) with respect to the W-axis in such a way that the plane of the array coincides with the image plane of the spot. The latter geometrical arrangement is known in photogrammetry as the Scheimpflug condition, and in this case, $a \cdot \tan\alpha = b \cdot \tan\beta$, where a and b are distances from the lens L_2 of the object plane and the image plane, respectively.

The signals corresponding to the intensity of light which stimulates 2048 photoelements are read sequentially from the sensor synchronously with a 1 MHz clock, as illustrated in Fig. 2. In our prototype [8], the output signals from the photoelements around the spot were sent to a computer via an eight-bit A/D converter and then the position of the element having the peak intensity was examined. In the present apparatus, from the standpoint of data acquisition speed, only the positions of the rising and falling edges of the spot signal were transferred to the computer (MELCOM 70/25, 16-bit CPU, 112 kB memory) to obtain the peak in the following manner. The edges are detected by a voltage comparator and their positions are obtained by counting the 1 MHz clock from the beginning of a read-out cycle to the points where the edges are detected. The two counted values are stored in registers (RG1 and RG2) and transferred to the computer via a digital input immediately after

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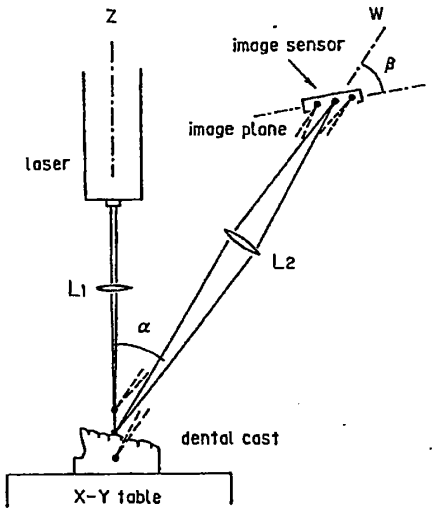


Figure 1. Configuration of the apparatus for three-dimensional measurement of dental casts. A light spot is formed on a dental cast with a laser and a lens L_1. The depth of the cast surface is determined from the position of the spot image formed by a lens L_2 onto a one-dimensional 2048-element image sensor. For alignment of the image plane and the sensor, the sensor is tilted by β. Cast scanning for profile measurement is accomplished by an *X-Y* table; α and β are 35 and 45 degrees, respectively.

the falling edge is detected. The center of the two edges is determined and defined as the peak position, because it almost coincides with the actual position of the peak. The peak position is then converted into the corresponding depth using the relationship obtained by the prior calibration procedure, as described later. The above process, including the cast scanning, for data acquisition is automatically repeated point-to-point by the computer. All the data are stored on a floppy disk.

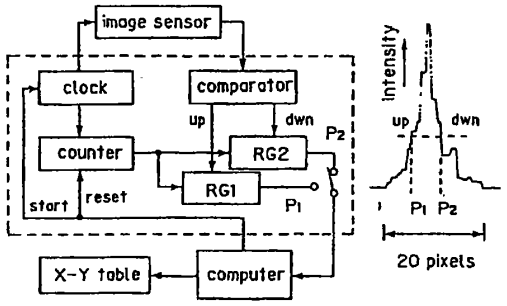


Figure 2. Output signal of the spot image from the image sensor and the block diagram of an interface for detecting a peak position. The output is distributed over about 20 pixels around the peak. The peak position was defined by the center of rising (up) and falling (down) edges of the comparated output. RG1 and RG2: registers for storing counted values; P1 and P2: edge positions.

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3. PERFORMANCE TEST OF THE APPARATUS

3.1. Depth and lateral resolutions

The relationship between the peak position of the sensor and the depth of an object surface was measured by moving, at longitudinal intervals of 0.01 and 0.5 mm, a spot on a plaster block fixed on a mechanical Z-stage. As shown in Fig. 3, the peak position of the spot has good correspondence to the amount of displacement of the block. Since the relation is slightly curvilinear in principle, as depicted by the lower data, the regression curve of the data, referred to as the calibration curve, was calculated and used to convert the peak position into depth. The depth resolution per pixel varied from 0.018 to 0.026 mm, depending on the depth range of ± 12 mm. To assess the accuracy of the measurement in depth we calculated the standard deviation of the linearized data from the linearized calibration curve. It was 0.024 mm, and 46 of the 50 data points were distributed with an error of less than 0.05 mm. The present apparatus is therefore able to detect a depth with an approximate accuracy of 0.05 mm.

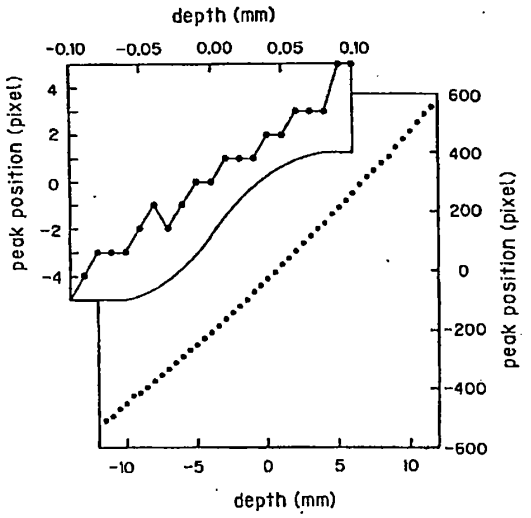


Figure 3. Peak position of the spot on the image sensor in relation to actual depth. Depth was changed by moving a plaster block at the interval 0.01 (upper) and 0.5 mm (lower). The lower was used to calibrate the apparatus.

Since the diameter of the laser beam primarily controls the lateral resolution, it should be as thin as possible within the range measured. For this purpose the 0.8 mm diameter beam from the laser was focused with the lens L_1, as mentioned earlier. Its focal length of 100 mm was chosen as a compromise between reciprocal relationship that the increase in the depth of a focus reduces blur outside a focal plane but results in blur, due to diffraction, at the focal plane. The diameter of the spot formed by the above lens can be estimated using the well-known formulas, for diffraction and for lens, as 0.19 to 0.21 mm within the measuring depth range of 25 mm, which allows measurement of casts with a desired horizontal resolution from top to bottom. In this

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connection it should be noticed that the maximum measuring depth range of the apparatus depending on the sensor length is 40 mm, when inferior horizontal resolution is allowable.

Actual lateral resolution was experimentally examined by measuring thin grooves that were cast on a plaster block using metal plates of known thickness. The widths of the grooves were 0.1 and 0.2 mm. As shown in Fig. 4, the results obtained by scanning at a pitch of 0.1 mm reveal that this apparatus attains a lateral resolution of at least 0.1 mm. Nevertheless, actual resolution is limited to the minimum scanning pitch of the plotter used.

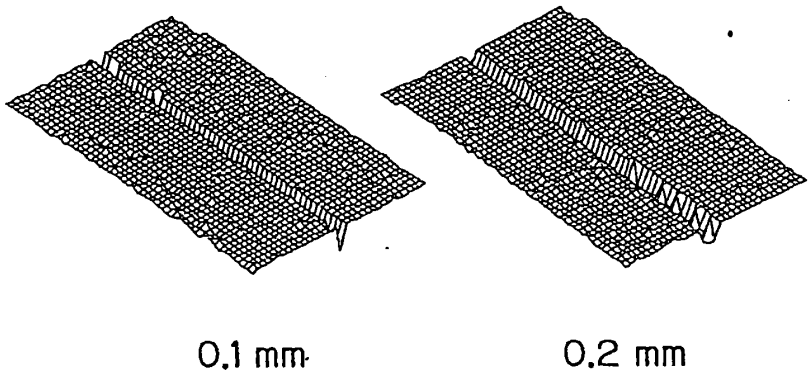


Figure 4. Measurements of thin grooves on a plaster block for the horizontal resolution test. Scanning pitch was 0.1 mm, and widths of grooves were 0.1 and 0.2 mm.

3.2. Three-dimensional measurement of dental casts

The three-dimensional shape of dental casts was measured in the following manner. A dental cast was fixed with pieces of double-sided adhesive tape on a platform (45 × 65 mm) supporting a plotter pen. The easiest way to scan a cast is to select one rectangular scanned area which covers all the teeth and the palate concerned. However, this method has the disadvantage of using more computer memory and also shows difficulty in identifying, within the computer, the boundaries between tightly connected teeth. To eliminate these problems, the scanned area illustrated in Fig. 5 was predetermined on each tooth and a palate, prior to the measurement, by moving a manually set window composed of a rectangle and two boundary lines. An operator can easily adjust the geometrical arrangement of this window with switches linked to the computer while observing the light spot excursion along the circumference of the area. After setting the scanned areas the apparatus automatically and successively digitizes teeth and palate profiles.

The time required for measuring a point was 25 ms, mostly occupied by mechanical scanning with the plotter. The data acquisition, except the scanning, required only 1 to 3 ms, depending on the spot position of the image sensor. A tooth and a palate were typically scanned at a pitch of 0.2 and 0.4 mm, respectively. The number of sampled

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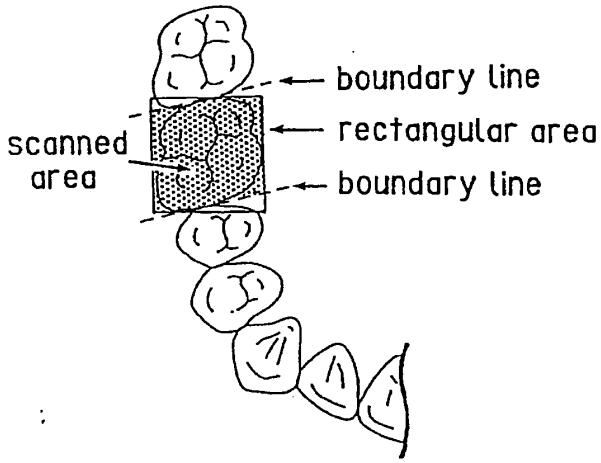


Figure 5. Set-up of a scanned area on a tooth. Rectangular area covering each tooth and two boundary lines separating tooth data from contiguous ones were manually set prior to automatic measurement.

data per tooth was about 2000 on the average, and it took about 50 s per tooth. A three-dimensional plot of a measured dental cast is shown in Fig. 6. The shape of the occlusal surface, which is necessary for the calculation of three-dimensional tooth movement, is almost completely measured, except the anterior lateral portion of the teeth. The lack of data in this portion is because the image sensor is placed on the upper posterior side above the dental cast.

4. APPLICATION TO MEASUREMENT OF THREE-DIMENSIONAL TOOTH MOVEMENT

When an orthodontic force is applied to a tooth over a long period of time the tooth moves, owing to resorption of the alveolar bone on the pressurized side and apposition of new bone on the opposite side. In orthodontics, tooth position and its change due to treatment are basic information. Although the tooth moves in a three-dimensional way, no established method of measuring this movement, including rotational movement, has been reported. We have applied the present apparatus to this kind of measurement.

Our principle of measuring the three-dimensional movement of a tooth is based on superimposition, within a computer, of three-dimensional tooth images serially measured at different stages of treatment. In order to calculate tooth movement by the superimposition, the three-dimensional position of two casts to be compared must be made coincident, because the position cannot be adjusted accurately when the shapes are digitized. For this purpose the palate profile details, which were found to be rather stable during orthodontic treatment as discussed later, were employed as a reference. Namely, the three-dimensional data of palates were numerically superimposed within the computer until the amount of mismatching evaluated from the averaged value of difference in depth was reduced to a minimum. After this, tooth movement from the initial stage of treatment to a certain stage was calculated from the superimposition of two corresponding teeth by repeating the same algorithm as that of the palates.

In order to represent changes in position of a tooth in three-dimensional space, six

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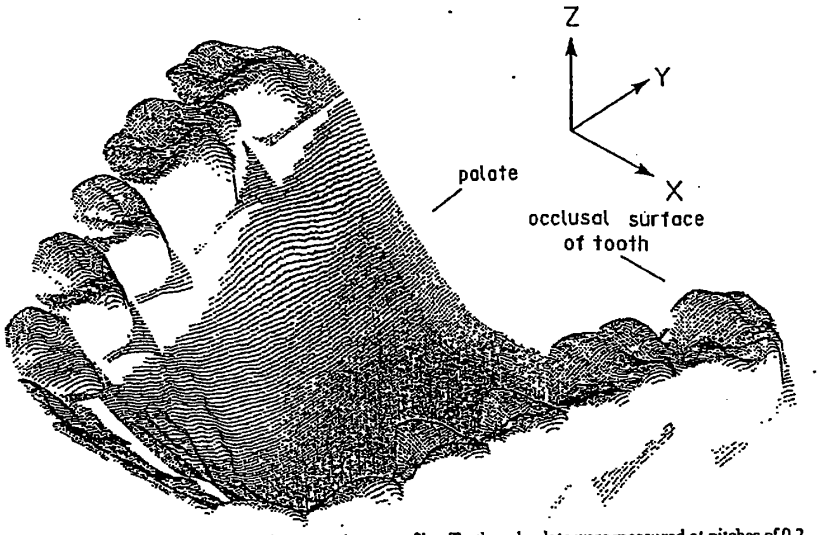


Figure 6. Three-dimensional plots of measured cast profiles. Teeth and palate were measured at pitches of 0.2 and 0.4 mm, respectively. Palate profiles were plotted in the same pitch as that of teeth after interpolating.

parameters are necessary. Those were defined, as illustrated in Fig. 7, by translations x, y and z, and by rotations ϕ, θ and ψ, which denote the tipping direction, the tipping angle and the rotation angle with respect to the Z-axis, respectively. For intuitional correspondence to tipping and rotation defined in dentistry, the present definitions of the angles were modified from Euler's angles conventionally used for describing the amount of rotation in three-dimensional space; i.e. ψ was redefined by $\phi+\psi$ of Euler's angles. According to this definition a tooth tips by θ to the direction of ϕ and 'then' rotates by ψ around the Z'-axis, as shown in Fig. 7. In this study the direction ϕ was defined by the angle not from the X-axis but from the Y-axis for symmetrical correspondence between right and left teeth. The coordinate system was fixed on each tooth of the initial stage and its origin was chosen at the centroid of the occlusal surface determined from the digitized tooth data.

The superimposition was achieved by searching a combination of the above six parameters, the movement by which resulted in the best matching. Mathematically it is regarded as a procedure searching a point of minimum of a function of six variables $u=f(x, y, z, \phi, \theta, \psi)$, which was defined in the present study by the averaged difference of data in depth when superimposed. Such a procedure is conducted using an iterative method of calculation, changing the value of one of the parameters back and forth, and repeating the same algorithm in turn on all parameters to reach the final minimum point. To check the accuracy of superimposition, and also the reproducibility of the shape measurement using the present apparatus, we repeated the measurement on the same dental cast and superimposed the data using the above procedure. The averaged difference obtained was only about 0.015 mm in depth and was comparable to the depth resolution of the apparatus. This result confirms no systematic error from measurement to superimposition. The error in movement calculated by the procedure

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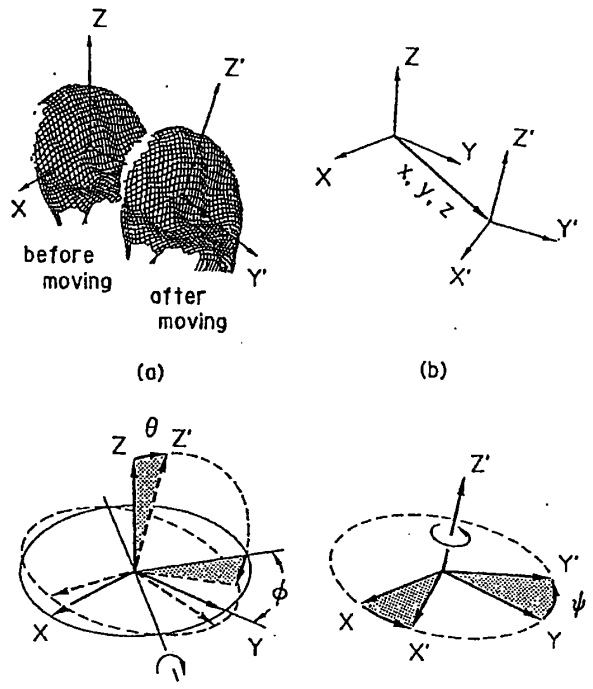


Figure 7. Coordinate system for calculating tooth movement by superimposition. (a) The coordinate system fixed on a tooth. The origin was chosen at the centroid of the occlusal surface data. (b) Translations denoted by x, y and z. (c) Tipping (left) and rotation (right). ϕ is direction of tipping, θ angle of tipping, and ψ rotation with respect to Z-axis. ϕ was defined as angle from Y-axis. See also axes in Fig. 6.

was also evaluated through a simulation study, in which measured data of a tooth were numerically moved within the computer by substituting random numbers for the parameters and then the superimposition was performed between the measured and the moved data. The 36 movements calculated in all showed sufficiently small errors, less than 0.1 mm in translation and 0.5 degrees in rotation. It should be noted that the error in translation is less than the scanning pitch 0.2 mm of a tooth because the procedure in the present study was designed to interpolate the superimposed data for raising the accuracy in calculating the movement.

Table 1 and Fig. 8 show an example of tooth movement in the maxillary arch before and after orthodontic treatment. The patient was a 12-year-old male suffering from an irregular set of teeth. The 21-month treatment using an orthodontic appliance was commenced after extracting the first premolars R4 and L4. The orthodontic force was applied so that the posterior teeth pulled the anterior ones. In this patient most of the teeth were displaced and tipped into a lingual site. The right lateral incisor R2, subject to the greatest orthodontic realignment, was retracted from the lingual site. The molar's movement to the anterior site, termed the movement of an anchor tooth in

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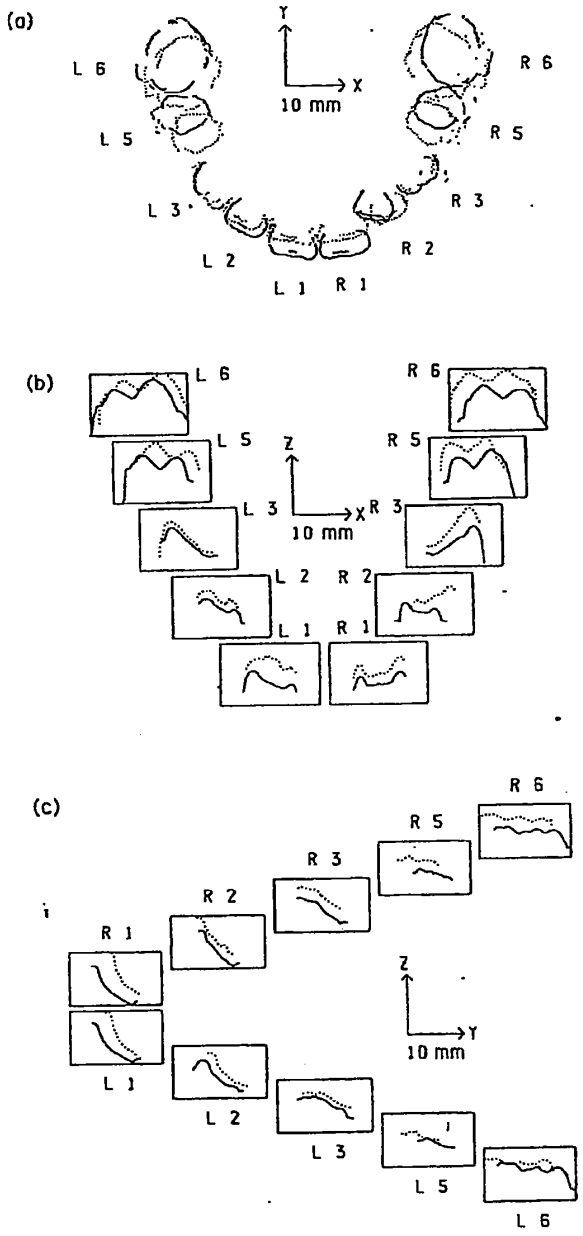


Figure 8. Graphical representation of tooth movement due to orthodontic treatment. Movements tabulated in Table 1 are illustrated. Solid and broken lines show edges or profiles before and after treatment, respectively. (a) Top view of teeth edges: (b) anterior view representing the cross-sections of occlusal surface at the center of each tooth; (c) lateral view of occlusal surface.

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Table 1.
Three-dimensional movement of teeth before and after 21 months' orthodontic treatment on a 12-year-old male suffering an irregular set of teeth

	Translation (mm)			Rotation (degrees)		
Tooth	x	y	z	ϕ	θ	ψ
R6	−2.4	−2.6	2.6	126.9	10.2	8.9
R5	−1.5	−2.8	2.9	127.9	8.6	−17.2
R3	−0.4	0.3	2.0	105.1	8.6	6.6
R2	2.1	−0.1	2.1	19.0	4.6	34.0
R1	−0.3	2.4	2.0	19.8	10.7	1.8
L1	−0.4	2.1	1.4	29.5	10.2	2.9
L2	−0.6	1.1	1.0	16.9	7.4	0.0
L3	−0.2	1.0	0.9	−50.0	5.3	6.0
L5	2.1	−3.0	1.4	−167.4	2.8	1.8
L6	1.8	−3.0	1.2	−146.3	9.9	−3.5

Teeth are serially numbered from the lateral incisor 1 to the first molar 6. R denotes right: L, left. R4 and L4 were extracted before treatment. See also Figs 7 and 8.

dentistry, was observed in this case, in which no additional appliances such as a holding arch or an extra-oral appliance for protecting the movement of the anchor were used. Time course analysis of tooth movement in other patients is now being conducted, and results suggest the usefulness of the present technique in allowing the movement of each tooth to be followed in conjunction with the applied force. On the other hand, it is almost impossible to detect the movement relative to the reference only by observing two casts with the eyes.

5. DISCUSSION

An optical apparatus for digitizing the three-dimensional shape of dental casts was developed and applied to the measurement of three-dimensional tooth movement. Although many instruments for three-dimensional measurement of a cast have been attempted, most of them require point-to-point manual operation for data acquisition, or a sophisticated procedure for conversion of a measured pattern to values in a coordinate system, as found in stereophotogrammetry and the Moire method. An apparatus using an optical probe, developed by Berkowitz *et al.* [7], was the first automatic measuring apparatus, to our knowledge, in dentistry. Though it was successfully applied to cleft palate cast analysis it has the limitation of the minimum detectable depth interval of 0.5 mm and horizontal resolution of about 1 mm under the total measuring depth range of 18 mm because of using the relationship between out-of-focusing and the depth. The accuracy of the present apparatus was at least 0.05 mm in depth and 0.1 mm in a horizontal plane within the depth range of 25 mm, which provided sufficient details of the occlusal surface.

Previous studies with respect to the movement of teeth for a long period of orthodontic treatment were restricted to one- or two-dimensional measurements. As for three-dimensional measurements, only the instantaneous translation and rotation, observed immediately after applying an orthodontic force to a tooth, have been

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measured using laser hologram interferometry [11–14]. This technique measures movement with the highest degree of sensitivity but is restricted to short-term observations. Our approach is based on superimposition within a computer after digitizing the shape of serial casts, and consequently enables long-term movement to be followed. Another method using superimposition, the two-dimensional measurement of tooth movement during orthodontic treatment, has recently been reported [15], where a cast and a holographic image representing different stages are superimposed within a plane by a mechanical X–Y stage.

In the method to obtain tooth movement using superimposition an immovable reference must be employed. To confirm the morphological stability of a palate used as the reference we evaluated its deformation during orthodontic treatments of 6–21 months in nine patients. Averaged discrepancy in depth before and after a treatment was only 0.05 to 0.13 mm, excluding the data around realigned teeth. Palate profile is thus appropriate for a reference, but application of measurement using this reference is at present restricted to the upper teeth by the presence of the tongue in the lower jaw.

Despite the above limitation the technique developed herein shows promise of providing an orthodentist with useful quantitative information so as to optimize treatment procedure by readjustment, for example, of the magnitude and direction of the applied force, and the antirotation and antitipping bends of an appliance, responding to the tooth movement due to treatment. Automatic digitization of cast shape will permit further application to computerization of cast analysis [16], which is now performed on manually digitized data.

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THREE-DIMENSIONAL MEASUREMENT OF DENTAL CAST PROFILES AND ITS APPLICATIONS TO ORTHODONTICS

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ABSTRACT

A computer-controlled apparatus for measuring dental cast profiles has been developed. This apparatus has been applied to the measurement of three-dimensional tooth movement during orthodontic treatments. The 3-D movements, including rotations, have been obtained by computer-aided 3-D registration between tooth profiles of casts serially taken at different stages of the treatment. Measurements over periods of 70 to 190 days on patients have revealed that we can quantify the difference in movements due to orthodontic therapeutics. A feasible application of this technique to the measurement of a contacting area of occlusal surface is discussed as well.

INTRODUCTION

In orthodontics, information concerning the positional change of a tooth is as fundamental and important as its shape. Although the tooth moves in a three-dimensional (3-D) way during orthodontic treatment, no established technique to measure this movement, including rotational movement, has been reported. The contacting area of occlusal surface is also an important information in orthodontic treatment.

In this paper, we briefly review our system designed for the 3-D measurement of dental cast profiles [1]. Then we describe the applications of the system to the 3-D measurement of tooth movement during orthodontic treatment and to the measurement of a contacting area of occlusal surface.

3-D MEASUREMENT OF DENTAL CASTS

We developed the apparatus for automatic measurement of dental cast profiles [1]. It achieved the depth and lateral resolutions of 0.05 and 0.1 mm within the depth range of 25 mm, respectively. The schematic diagram of the apparatus is shown in Fig.1. The depth is measured with an optical system composed of a laser and an image sensor. A small spot of laser beam is formed on a dental cast with a lens L_1. The position of the spot is detected by the image sensor which has a one-dimensional array of 2048 photoelements aligned in a pitch of 14 micrometers. An interface transfers the spot signal to a personal computer, in which the depth of the cast surface is obtained from the spot signal.

Scanning required for the profile measurement is accomplished by moving the cast in a horizontal plane with an X-Y table. Teeth and the palate were typically scanned at a pitch of 0.2 and 0.4 mm, respectively. The number of sampled data per tooth amounts to nearly 2000 on the average, and it takes about 1 min per tooth.

MEASUREMENTS OF 3-D TOOTH MOVEMENT

Our principle of measuring the 3-D movement of a tooth during orthodontic treatment is based on the registration of 3-D tooth images measured at different stages of treatment. Namely, tooth profiles taken at the initial stage of treatment are superimposed on those of a certain later stage. The superimposition which attains to the close matching of the images gives the actual movement of the tooth. The above procedure was carried out automatically with the aid of a computer.

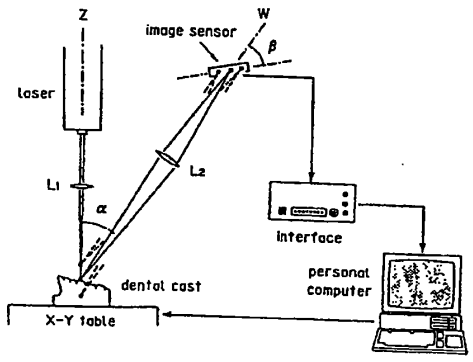


Fig. 1. Schematic diagram of an apparatus developed for the measurement of dental cast profiles.

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The tooth movement is represented by six parameters: three translations Δx, Δy and Δz, and three rotations ϕ, ρ and ψ which denote the tipping direction, the tipping angle and the rotation angle with respect to the Z-axis, respectively.

Figure 2 shows an example of the measurement, in which the canine movements during orthodontic treatment were examined over periods of 41 to 190 days [2]. The canines were moved to the posterior side by two types of springs conventionally used: an open single loop (spring A) and a closed loop with multiple helices (spring B). Spring A, which has less flexibility than spring B, has the greater ability to protect the rotation when incorporating the antirotation bend.

To demonstrate the above results, we have made a moving picture of teeth movement using computer graphics. One of the frames of the picture is shown in Fig.3. The moving picture can present the motion of teeth during a whole stage of treatment within a few second. Therefore, orthodontists can observe the dynamic change of tooth position. The image data between serial measurements are filled by interpolated data to make the picture smooth. The picture will be presented in a video tape on the meeting.

CONTACTING AREA OF OCCLUSAL SURFACE

A contacting area of occlusal surface is one of the most important information in dentistry and is desired to be measured quantitatively. We have conducted a preliminary study on the measurement of the contacting area, as another application of our apparatus. Profiles of mandibular and maxillary casts were measured by the apparatus and the occlusion of the teeth was simulated on the computer. We can observe the occlusions on a graphic display and calculate the distribution of distances between the upper and lower teeth.

CONCLUSIONS

These results suggest the usefulness of the present techniques in quantifying the action of a spring upon tooth movement and evaluating the teeth occlusions. This technique provides a useful tool for orthodontists to optimize a treatment procedure because they must readjust the force and bends of a spring in response to the tooth movement.

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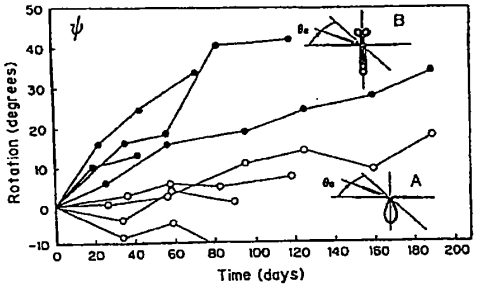


Fig. 2. Time course analysis of tooth movement during orthodontic treatment. Canine rotations around Z-axis are plotted. Open and closed circles show the movement by using springs A and B, respectively. The antirotation bend was 20 degrees in both springs.

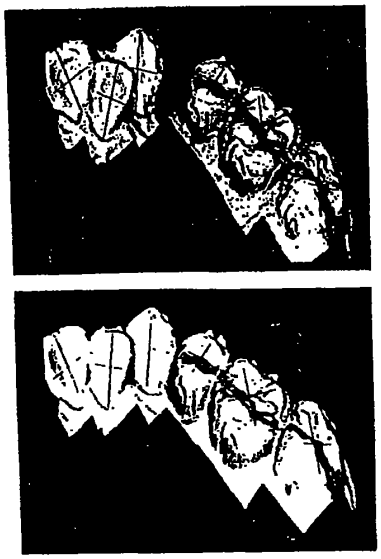


Fig. 3. Computer graphic display of cast profiles of the patient's maxilla. The upper panel shows the first frame of the moving picture and the lower the last one.

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A system for human jaw modeling using intra-oral images

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Abstract
A novel integrated system is developed to obtain a record of the patient's occlusion using computer vision. Data acquisition is obtained using intra-oral video camera. A modified Shape from Shading (SFS) technique using perspective projection and camera calibration is then used to extract accurate 3D information from a sequence of 2D images of the jaw. A novel technique for 3D data registration using Grid Closest Point (GCP) transform and genetic algorithms (GA) is used to register the output of the SFS stage. Triangulization is then performed, and a solid 3D model is obtained via a rapid prototype machine. The overall purpose of this research is to develop a model-based vision system for orthodontics that will replace traditional approaches and can be used in diagnosis, treatment planning, surgical simulation and implant purposes

Index Terms
Inspec

Controlled Indexing
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Non-controlled Indexing
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References

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Citing Documents

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A System for Human Jaw Modeling Using Intra-Oral Images

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Abstract— **A novel integrated system is developed to obtain a record of the patient's occlusion using computer vision. Data acquisition is obtained using intra-oral video camera. A modified Shape from Shading (SFS) technique using perspective projection and camera calibration is then used to extract accurate 3D information from a sequence of 2D images of the jaw. A novel technique for 3D data registration using Grid Closest Point (GCP) transform and genetic algorithms (GA) is used to register the output of the SFS stage. Triangulization is then performed, and a solid 3D model is obtained via a rapid prototype machine. The overall purpose of this research is to develop a model-based vision system for orthodontics that will replace traditional approaches and can be used in diagnosis, treatment planning, surgical simulation and implant purposes.**

Keywords—**Image Sequence Analysis, Shape Representation, Registration.**

I. Introduction

ORTHODONTIC treatment involves the application of force systems to teeth over time to correct malocclusion. In order to evaluate tooth movement progress, the orthodontist monitors this movement by means of visual inspection, intra-oral measurements, fabrication of plastic models (casts), photographs and radiographs, a process which is both costly and time consuming. Additionally, repeated acquisition of radiographs may result in undesired side effects. Obtaining a cast of the jaw is a complex operation for the orthodontist, an unpleasant experience for the patient and may not provide all the details of the jaw. Current technology in dental radiography can provide the orthodontist with 3D information of the jaw. This includes computer tomography (CT), tomosynthesis, tuned-aperture computer tomography (TACT) and localized computer tomography. While dental radiology is now widely accepted as a routine technique for dental examinations, the equipments are rather expensive and the resolution, being adequate for maxillofacial imaging, is still too low for 3D dental visualization. Furthermore, the dose required to enhance the resolution is unacceptably high. Recently, efforts have been devoted to computerized diagnosis in orthodontics.

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Bernard et al.[1] developed an expert system for orthodontic measurements. However, the cephalometric measurements that are fed to the expert system are still acquired manually from the analysis of X-rays and plaster models. Laurendeau et al.[2] presented a computer-vision technique for the acquisition of orthodontic data from cheap dental wafers. The system is only capable of obtaining the teeth imprints and not the whole 3D jaw model. Stereo photogrammetry has been used to obtain the 3D jaw information from the cast[3]. However user interaction is needed in such systems to determine the 3D coordinates of some points on the cast. Other systems that could measure the 3D coordinates have been developed using either mechanical contact[4] or traveling light principle[5].

In this paper we describe a novel system (shown in figure 1) that obtains the 3D model not from a cast but from the actual human jaw. The system consists of the several modules. First, a sequence of images are obtained from overlapping segments of the jaw using a small intra-oral calibrated camera. Accurate shape from shading (SFS), enhanced by using the calibrated camera perspective projection, is applied to obtain 3D representation of the segments. The resulting 3D points from each segment are merged/registered using a novel and fast registration technique. A priori information is also used to align the registered segments on the correct geometry of the jaw. Once the 3D cloud of points are obtained, a surface mesh is fitted to these points to obtain a closed contours model with no ambiguity and in a format suitable for the rapid prototype machine. Further processing is performed to separate individual 3D information for each tooth.

The originality of this work comes from the fact that data acquisition is performed directly on the human jaw using a small off-the-shelf CCD camera. The acquisition time is relatively short and is totally painless and not unpleasant to the patient, a marked improvement compared to the current practices. The acquired digital model can be stored with the patient data and can be retrieved on demand. These models can also be transmitted over a communication network to different remote dentists for further

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assistance in diagnosis. Dental measurements and virtual restoration could be performed and analyzed. Moreover, such a model will be a tremendous asset in dental training and teaching.

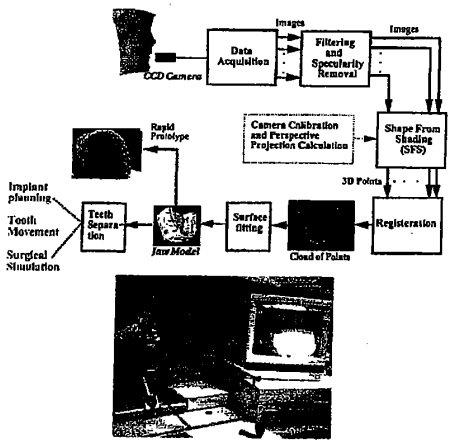


Fig. 1. (Up)System Overview. (Down)Dentist office setup to extract jaw model using a single CCD camera. We used a head model (called "Happy") that exactly resembles the human head and jaw.

II. Shape from Shading using Perspective Projection and Camera Calibration

Shape From Shading (SFS) has been primarily studied by Horn [6] and his colleagues at MIT. Since then there have been many recent developments in the algorithms[7][8][9]. Tsai and Shah [10] have described a linear technique to solve the SFS problem that is more suitable for our dental application because of its speed and accuracy . This is important because the reconstruction of the whole jaw requires the application of the SFS algorithm on more than 30 images. However, their approach, along with most of the suggested approaches referenced in the literature, use orthographic projection instead of perspective projection. In the case of real images, significant errors may occur when adopting the orthographic projection system instead of the perspective one. Errors may be magnified if the camera is near the object which is the case in the dental application. Some SFS approaches using perspective projection were found in the literature[11][12][13]. In these approaches the measurements obtained are not metric as they lack the information about the camera parameters. In this section we present a SFS approach that uses the linear approximation implemented by Tsai and Shah [10] and extend it to incorporate the camera perspective projection. A camera calibration process which takes into consideration both the intrinsic and the extrinsic camera parameters is done once before acquiring the sequence of images. To calibrate the camera, we can obtain the relation between the 3D coordinates $\mathbf{M} = \{X, Y, Z\}$ and image coordinates $\mathbf{m} = \{x, y\}$ as ; $s\vec{\mathbf{m}} = \mathbf{P}\vec{\mathbf{M}}$ where s is a scalar, $\vec{\mathbf{m}}$ and $\vec{\mathbf{M}}$ are the extended vectors $[\ \mathbf{m}^T\ 1]^T$ and $[\ \mathbf{M}^T\ 1]^T$, and $\mathbf{P}$ is called the camera calibration matrix. In general, $\mathbf{P} = \mathbf{A}\ [\mathbf{R}, \mathbf{t}]$ where $\mathbf{A}$ is a matrix containing all the camera intrinsic parameters and $\mathbf{R}, \mathbf{t}$ are the rotation matrix and translation vector. The matrix $\mathbf{P}$ has $3 \times 4 = 12$ elements but has only 11 degrees of freedom because it is defined up to a scale factor. The usual method of calibration is to use an object with known size and shape and extract the reference points from the object image. It can be shown that given N points ($N \geq 6$) in general position, the camera can be calibrated. The perspective projection matrix $\mathbf{P}$ could be decomposed as $[\mathbf{Bb}]$ where $\mathbf{B}$ is a 3×3 matrix and $\mathbf{b}$ is the translation vector.

$$s\vec{\mathbf{m}} = \mathbf{BM} + \mathbf{b}\ or, \quad (1)$$

$$\mathbf{M} = \mathbf{B}^{-1}(s\vec{\mathbf{m}} - \mathbf{b}) = s(x, y) \quad (2)$$

This is an equation of a line in the 3D space corresponding to the visual ray passing through the optical center and the projected point $\mathbf{m}$. By finding the scalar s, $s(x, y)$ will define a unique 3D point $\mathbf{M}$ on the object. Using the image brightness equation found in[10],

$$E(x, y) = R(p, q) = \frac{1 + p_l p + q_l q}{\sqrt{1 + p^2 + q^2}\sqrt{1 + p_l^2 + q_l^2}} \quad (3)$$

where p_l and q_l are the light source coordinates and p and q are the gradient along the X and Y at the object point $\mathbf{M}$, they can simply be written as,

$$p = s(x, y) - s(x - 1, y)\ and\ q = s(x, y) - s(x, y - 1) \quad (4)$$

which actually represents the gradient along a triangular surface patch. The brightness equation can now be written as a function of $s(x, y)$:

$$g(E(x, y), s(x, y), s(x - 1, y), s(x, y - 1)) = 0. \quad (5)$$

Using the Taylors series expansion of the above equation, we applied the Jacoby iterative method to obtain the 3D map, $s(x, y)$, which gives a unique scalar s to every point in the image thus defining a unique

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3D point on the object. At the nth iteration, $s^n(x,y)$, is as follows:

$$s^n(x,y) = s^{n-1}(x,y) + \frac{-g(s^{n-1}(x,y))}{\frac{d}{ds(x,y)}g(s^{n-1}(x,y))} \quad (6)$$

where

$$\frac{d}{ds(x,y)}g(s^{n-1}(x,y)) = \frac{-(p_l+q_l)}{\sqrt{1+p^2+q^2}\sqrt{1+p_l^2+q_l^2}} + \frac{(p+q)(pp_l+qq_l+1)}{\sqrt{1+p^2+q^2}\sqrt{1+p_l^2+q_l^2}} \quad (7)$$

Now assuming the initial estimate of $s^0(x,y) = 0$ for all pixels, the 3D map can be iteratively refined using equation (6). The output of applying this SFS algorithm to each jaw segment image will be an array of 3D points describing the teeth surface in this segment. However, there is no relation between the 3D points of a segment and the following one. Thus we needed a fast and accurate 3D registration technique to link the 3D points of all the segments and produce one set of 3D points describing the whole jaw surface. Details of our novel 3D registration using the Grid Closest Point (GCP) transform and Genetic Algorithms (GA) can be found in[14]. This technique was faster and more accurate than the existing techniques found in literature.

III. Results and discussion

Figure 2 shows two intra-oral images for two teeth segments and the resulting SFS surfaces. We then applied the 3D registration on the output of the SFS module directly. It took two minutes on the average to register two consecutive segments. This was still time consuming due to the fact that the 3D coordinates from each segment are uncorrelated. We enhanced the time to register these data by mounting the camera on a 3D digitizer arm as shown in figure 3. Using equation[1], we can obtain the location and direction of the optical center in the camera calibration process; $\mathbf{M}_{oc} = -\mathbf{B}^{-1}\mathbf{b}$, where $\mathbf{M}_{oc}$ is the location of the optical center of the camera relative to the origin of the world coordinate used in the camera calibration process. By mounting the camera on the digitizer arm while calibrating it, $\mathbf{M}_{oc}$ could always be referenced to the origin of the digitizer. The digitizer has five degrees of freedom which is suitable for the movement of the camera inside the oral cavity. For each segment, the transformation matrix corresponding to the new location of $\mathbf{M}_{oc}$ is calculated and the resulting 3D points are corrected accordingly.

This procedure has greatly enhanced the time required for registration. Yet the registration is still

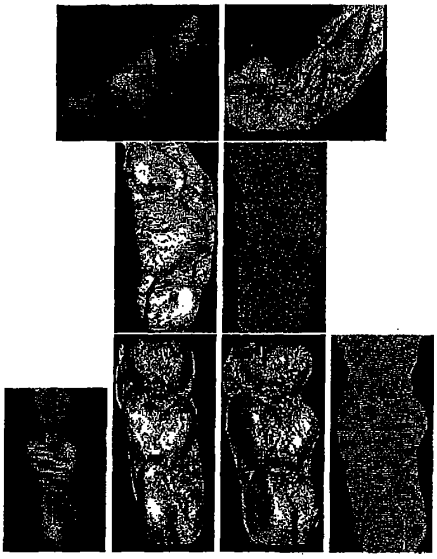


Fig. 2. The results of the SFS applied on two intra-oral images. Each 3D surface is shown from different view angles and the corresponding wire-frame



Fig. 3. The 3D digitizer used to track the camera position inside the oral cavity

an essential part of the process because it compensates for slight patient movement during the data acquisition and SFS errors. Using all of the abovementioned techniques and algorithms, a 3D model of the jaw was obtained. We started by taking a sequence of 16 images of the upper jaw of the head model. Filtering and specularity removal is then applied to the images. These images are then fed to the SFS and with the a priory information on the perspective projection parameters of the camera used, 3D surfaces representing each image are obtained. The data are then corrected using the transformation information from the digitizer arm. 3D registration is then performed and the output is shown on figure 4.

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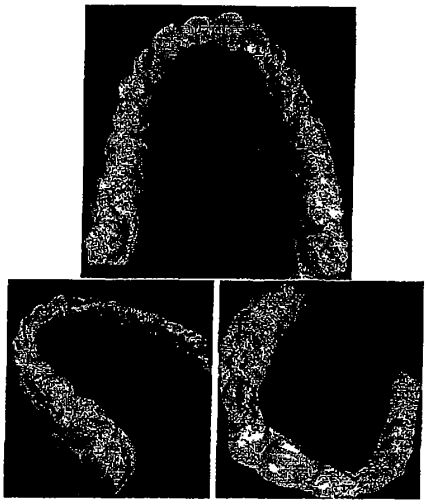


Fig. 4. The output of registering 16 images to obtain the upper jaw model. The model is shown here from different view angles

Taking into consideration the fact that the data was acquired directly from inside the oral cavity, which is a very restricted and hard to maneuver environment, the resulting jaw model is faithful enough to show all the information about the patient's actual jaw in a metric space. Both the time and convenience for the patient must be considered when comparing this result with the result of scanning a cast. Improvement of the results could be accomplished by incorporating a structured light system to obtain an initial 3D mesh that can improve the output of the SFS technique. Yet this will make the system more bulky and harder to maneuver inside the oral cavity.

IV. Conclusions and Future Work

The 3D reconstruction of the human jaw has tremendous applications. The model can be stored along with the patient data and can be retrieved on demand. The model can also be used in telemedicine because it can be transmitted over a communication network to different remote dentists for further assistance in diagnosis. Dental measurements and virtual restoration could be performed and analyzed. This paper describes the details of a complete system that acquires the jaw data directly from the oral cavity using small calibrated CCD intra-oral camera. The 3D metric information is obtained using a SFS and the calculated intrinsic and extrinsic camera parameters. Registration of the 3D surface segments is performed using the novel and fast GCP/GA technique. The described system is the first phase in a project to replace current orthodontics practices. The next phase includes the analysis and simulation of orthodontics operations. The authors have some preliminary results in this second phase which involves finite element analysis performed on the segmented teeth[15]. The results obtained can be further improved using an integrated system including photometric stereo vision and shape from shading. The stereo can be used to calculate the height of peculiar pixels (e.g. edges) and shape from shading can be used to estimate the normal vector of all pixels.

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RESEARCH ON A NEW ORTHODONTIC APPLIANCE: THE DYNAMIC POSITIONER (D.P.)

I. The D.P. Concept and Implementation of Transparent Silicone Resin (Orthocon)

By Osamu Yoshii, Head of the Kanto Teishin Hospital's Dental Department

Introduction

Using elasticity, primarily of a metal wire or rubber material (primarily natural rubber), to provide a corrective force to move teeth is well known in orthodontic treatment. However, the latter has various types of defects compared to the former in clinical or dental engineering, so it is primarily used as an attachment to an orthodontic appliance such as an intermaxillary rubber. Its use as an orthodontic appliance has at best been limited to the tooth positioner (a retainer used in the final stage of dynamic orthodontic treatment; it uses rubber to align the upper and lower jaw).

However, in recent years the progress in polymer materials has been astounding. Utilization of synthetic rubber (elastic polymer materials) developed in the area of elastomers has been actively incorporated into the area of orthodontic treatment. Rubber has characteristics which cannot be obtained with conventional metal wire, such as a large range of action and a constant light continuous force, and these properties are well suited for corrective force. So attempts are being made to introduce these new elastic materials which are required out of necessity when one seeks to ideally and biologically move teeth.

For example, rubber materials which are already commercially available as attachments for orthodontic appliances are rubber thread (elastic thread) and chain-shaped ringlets. These utilize a polyurethane resin (a synthetic rubber based on isocyanate) with superior physical properties, and it is well known that they are being used the in most advanced orthodontic clinical areas.

However, the author and others[1)2)3)] realized that it would be possible to create a dynamic orthodontic appliance which far surpassed conventional existing conceptions if there were an elastic material, or in other words an organic polymer material, which was colorless, transparent, odorless, tasteless, and which did not harm tissue, of course, and which had superior tensile strength and elongation, and which had virtually no loss of stress or permanent deformation over time, and which moreover could be worked without requiring a special apparatus or material. So first it was decided to begin research and development of a rubber material which satisfied the parameters required for orthodontic use. Next, various types of studies were carried out, with the objective of applying this to use in orthodontic clinics, regarding the concept and trial manufacture of a new orthodontic appliance to replace the conventional wire orthodontic appliance. Namely, this new dynamic orthopedic appliance completely dispensed with metal wires and bands and brackets, and moved teeth by a method which was simple and biological.

The dynamic positioner (D.P.) introduced herein is a completely new orthodontic appliance created from these perspectives. Serious development involved the

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cooperation of the Tokyo Dental College's Orthodontic Department, and took more than 10 years of basic and clinical research.

The so-called dynamic positioner is a removable orthodontic appliance made using an elastic polymer material (silicone, a rubber material utilizing a transparent, heat-cured silicone resin). It has the same recovery force as rubber, and can automatically move a tooth to the ideal position. It has a wide therapeutic range, from the start of orthodontic treatment until retention. These features and others make it an ideal dynamic orthodontic appliance.

Therefore, starting with this issue, I shall introduce its general concepts in alternating months. Under the general heading "Research on a New Orthodontic Appliance: The Dental Positioner (D.P.) will come I. The D.P. Concept and Implementation of A New Elastic Polymer Material (Orthocon), II. D.P. Manufacturing Procedure and Clinical Applications, and III. D.P. Test Cases and Results.

I. Summary of the New Orthodontic Appliance (D.P.)

1. D.P. Concept and Features

The D.P. is based on the basic principle of the tooth positioner (a retention appliance used in the final stage of dynamic orthodontic treatment to finish a narrow occlusal relationship) proposed by Kesling[4)5)6)] in 1945. However, tooth positioners made using hard natural rubber and the like were limited to static orthodontic appliances (retainers) which could be used only in the retention stage. In contrast, the D.P. uses soft synthetic rubber (silicone) which is very flexible, so its superior properties can be fully achieved. It is very different [from the older version] because it can be used continuously from the start of orthodontic treatment until retention, meaning that it is a dynamic orthodontic appliance which can be applied across the entire orthodontic treatment.

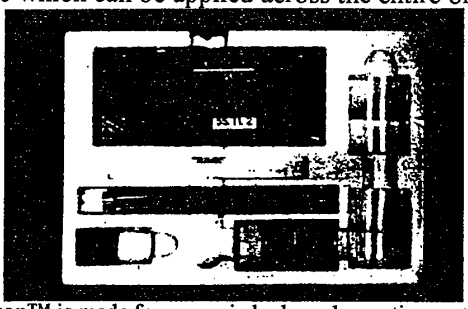


Figure 1. Orthocon™ is made from a main body and a coating material. There are three levels of rubber hardness (L, M, H).

Therefore a number of this appliance's features can be comprehensively listed as follows.

1) The D.P. completely dispenses with the conventionally used metal wires and bands and brackets, and is made entirely of soft, very flexible polymer material (silicone). It is an orthodontic appliance whose broad therapeutic range extends from the start of orthodontic treatment to retention. That is, the first feature of this appliance is that it can be continuously used, from dynamic treatment to static treatment.

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2) As shown in **Color Photo 1** (see pages 65~66 for Color Photos 1~10) the shape of the appliance resembles a rubber mouthpiece made to align the upper and lower jaw.

3) The system for using a D.P. to move teeth is as follows. The deformation of D.P. rubber obtained from a model (known as a set-up model) made by using a plaster model to realigning teeth which erupted in an incorrect position—that is, the rubber material's recovery force—is used for the corrective force, so the teeth can be ideally and automatically moved.

4) The D.P.'s rubber material is Orthocon (heat-cured silicone resin) newly developed by the author and others.[9)10)] As seen in **Color Photo 2**, it is very transparent, and tasteless and odorless, and has superior mechanical properties. Another benefit is that working it is easy.

5) Orthocon™ consists of a silicone resin main body and a silicone resin coating material, as shown in Figure 1. These can be made to achieve roughly three types of rubber hardness (light L, medium M, heavy H). They can be selected according to the use objective, and the strength of the corrective force can be adjusted at will by localized combinations of rubber hardness.

6) Patients may wear a D.P. intraorally only at night, and thereby move the teeth to the ideal position, namely in the direction they are realigned by the set-up model. Also, using a D.P. does not require any adjustment whatsoever by a technician, and there are no problems due to the appliance. As a result, a benefit is shorter chair time, and the number of visits by the patient is also reduced.

7) This appliance is a removable orthodontic appliance, so it can always be kept hygienic inside the oral cavity. Therefore it has biological benefits such as preventing the problems of conventional wire orthodontic appliances, namely loss of artificial substances, decayed teeth, gingivitis, etc.

8) The most effective period for beginning treatment is to use [the D.P.] before permanent dentition is complete. For example, it achieves superior therapeutic effects not found in other orthodontic appliances in guiding the eruption of permanent teeth.

9) Indications include mild maxillary protrusion or mandibular protrusion, and irregularities, deep overbite, etc. An additional clinical feature is that it can be combined with an extraoral retainer for application to patients with skeletal malocclusions.

Now I shall describe in a simple manner the principle of how a D.P. moves a tooth and the method thereof.

2. Principle of D.P. Tooth Movement

The fact that the D.P. movement principle is based on the basic concept of the tooth positioner proposed by Kesling has already been described. But there are a number of points which are different if a D.P. is used for dynamic treatment. These points will be described in detail in the section on clinical applications of the D.P., so here I shall confine myself to a brief summary of those points.

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First, a major point is that the D.P. treatment effect needs to be even stronger, so the tooth realignment is carried out aggressively (on the set-up model). This means introducing the concept of overcorrection (moving the teeth farther than the ideal position) when making the set-up model. In other words, the set-up model is made by moving teeth in the plaster model one level past the ideal realignment (so-called proper occlusion) so that the corrective force (rubber recovery force) applied to the teeth operates as a dynamic and continuous force. This is an extreme example, but as an example, in a case of mandibular protrusion this would be the concept of doing a tooth realignment which produced maxillary protrusion on the set-up model.

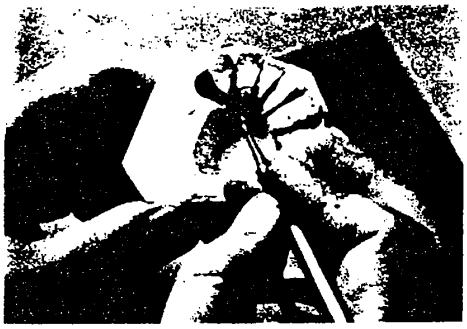


Figure 2. Malpositioned teeth are separated and realigned in their ideal occlusion. Depending on the case, the concept of overcorrection is introduced, and tooth realignment is carried out.

Now, as shown in Figure 2, in general malpositioned teeth are separated on the plaster model of a patient with a malocclusion, and the individual teeth are realigned in their ideal or previously described range, and a D.P. is made from the setup-model using Orthocon as shown in Figure 3. Next, when this D.P. is worn in an oral cavity with a malocclusion, rubber deformation occurs at the area where realignment occurred on the set-up model, and corrective force operates here, and the tooth begins to move.

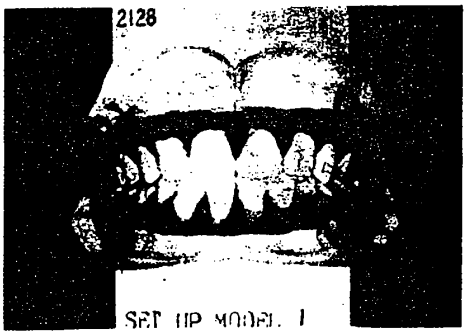


Figure 3. A set-up model with realignment completed. Depending on the case and treatment objective, it is necessary to make 2~3 of these at different stages.

Figure 4 shows the positional relationship of D.P. and teeth when using a D.P. for reversed occlusion. When treatment begins (Figure 4-1) a slight space is apparent between teeth and D.P., as is deformation of the D.P. After treatment (Figure 4-2), tooth

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movement due to the rubber's recovery force is complete, so the space has vanished and the D.P. has returned to its original shape. That is, to reach this sort of status the teeth move in accordance with the set-up model and dynamic orthodontic treatment ends.

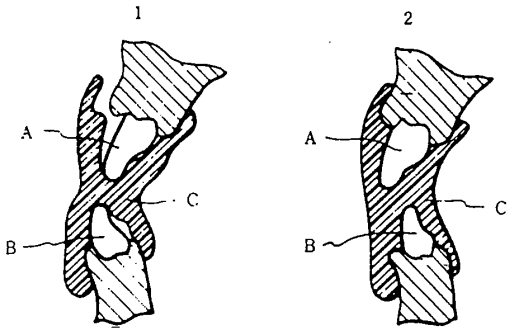


Figure 4. This shows the positional relationship (saggital cross-section) between D.P. and teeth in a case of reversed occlusion.

1) When treatment begins: The D.P. deforms, and a space appears between teeth and rubber.

2) When treatment ends: Tooth movement is complete, and the D.P. returns to its original shape, and the space vanishes.

(A): Maxillary central incisor (B): Mandibular central incisor (C): D.P.

Incidentally, Figure 5 shows optical investigation of D.P. deformation using a three-dimensional measurement method employing a laser beam, namely, the holographic Moiré shape displacement measurement method.[11)12)] This method was an experiment whose goal was to measure the amount of displacement of the D.P. on the model in response to a vertical load. It utilized the characteristics of a laser beam, namely, interference of the laser beam created from a fixed wavelength. First, the object's displacement was found using holographic interference fringes, and the object's shape was found from Moiré fringes; by photographing both of these at the same time it was possible to show the amount of displacement from [the original] shape. The amount of displacement is the rubber's recovery force operating on the tooth, namely, the corrective force.



Figure 5. Three-dimensional measurement using a laser beam, that is, investigating D.P. deformation using a holographic Moiré shape displacement measurement method. (Reversed occlusion)

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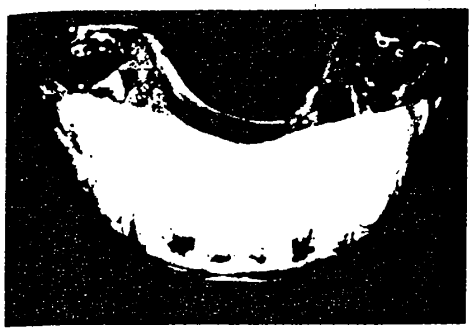
Now, I shall present actual cases and give a simple discussion of D.P. therapeutic effects and the set-up model method.

3. Therapeutic Effect of D.P. Used for Reversed Occlusion

For example, **Color Photo 3** shows a boy, 8 years 4 months old when he came to the clinic and was diagnosed, who presented primarily with reversed occlusion and mildly oblique teeth . (Case 2239)

After studying the details of this case, it was determined to be Angle Class III nonextraction exhibiting maxillary undergrowth and maxillary anterior lingual inclination. **Color Photo 4** shows superimposed profilograms often used in orthodontic diagnosis. This method is very convenient because the status of the malocclusion can be categorized and understood by pattern. In this case, the solid line is the patient's mandibulofacial pattern, and the dotted line is the average pattern for a Japanese boy of the same age. Examining this, one sees that this is a case of reversed occlusion (accompanying maxilla undergrowth) with the above-noted details.

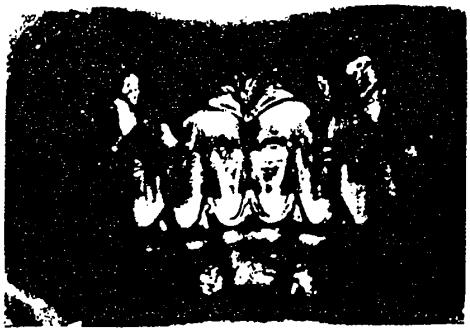
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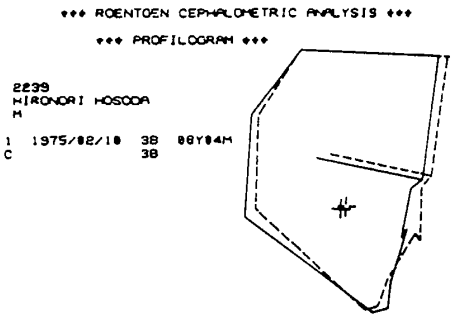
1. Dynamic positioner (D.P.) made using Orthocon (a heat-cured silicone resin).



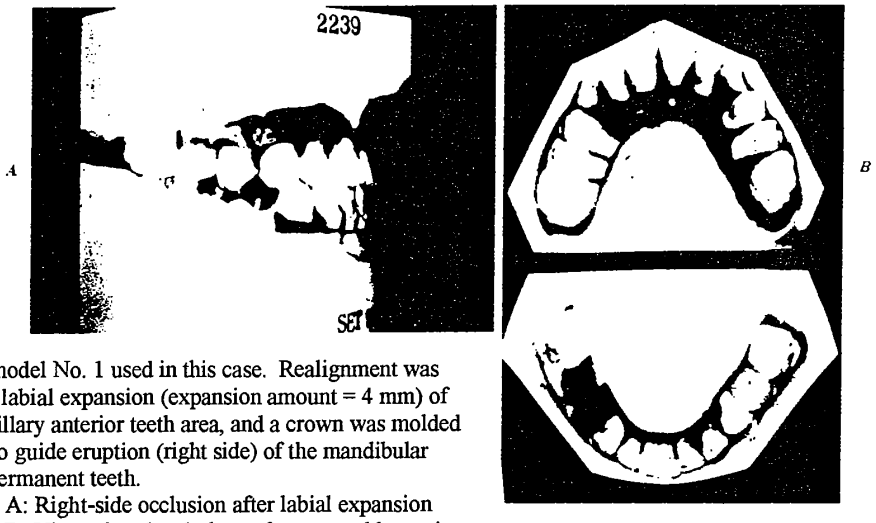
2. D.P. while being worn in oral cavity. It is highly transparent, so observing teeth and inside teeth is easy.



3. This case was a boy, age 8 years 4 months when diagnosed, presenting reversed occlusion. Nonextraction case, Angle Class III. (Case 2239)

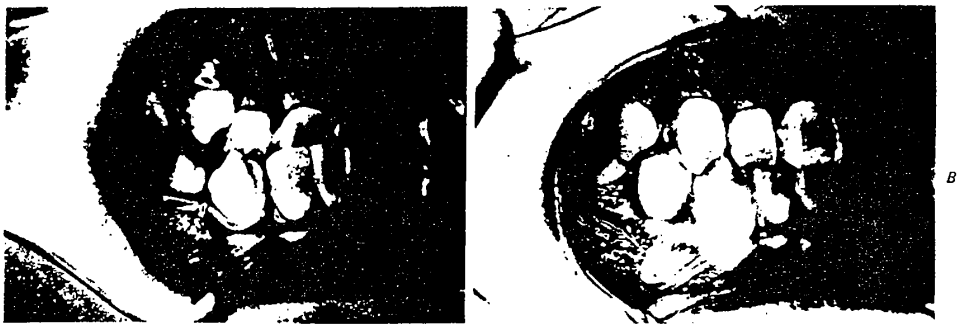


4. Profilogram obtained from lateral cephalometric radiograms. The solid line is the patient's pattern and the dotted line is the average pattern for a Japanese boy of the same age. This case shows maxilla anterior undergrowth and maxillary anterior teeth lingual inclination.



5. Set-up model No. 1 used in this case. Realignment was done by labial expansion (expansion amount = 4 mm) of the maxillary anterior teeth area, and a crown was molded in wax to guide eruption (right side) of the mandibular lateral permanent teeth.
A: Right-side occlusion after labial expansion
B: View of occlusal plane of upper and lower jaws

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6. Therapeutic effect of D.P. First, two dynamic positioners were made from the No. 1 set-up model (using L and M hardness rubber), and used for a dynamic treatment period of six months to correct the reversed occlusion. Then No. 2 was made for retention, and treatment ended after a total of one year four months. (Case 2239)
A: When treatment began (right side) B: When retention ended (right side)



7. Tooth positioner made of polyurethane resin.



8. Heat-cured silicone resin used in Orthocon main body. It is a material with the characteristic of becoming transparent after vulcanizing.



9. Additive type of silicone resin used for Orthocon coating material. It is viscous and highly transparent.



10. The operation of filling Orthocon can be easily done simply by filling the silicone resin in a flask.

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Now, when actually using a D.P. for orthodontic treatment it goes without saying that one must make a correct orthodontic diagnosis and appropriate treatment plan. This is a problem directly related to how well the set-up model is made. It is not exaggerating to say that this is the key which greatly affects the D.P. treatment result.

With this patient maxilla undergrowth was apparent, and the maxillary anterior teeth were somewhat lingually inclined, so the maxillary anterior teeth area was aggressively expanded in the labial direction (expansion amount = 4 mm), and labial impacted teeth 3|3 were realigned inside the dentition on set-up model No. 1 in order to correct this. In the lower jaw the remaining primary teeth were corrected, and then the extra space was utilized to move the mandibular anterior teeth area slightly in the lingual direction (**Color Photo 5**). The D.P.'s rubber material—that is, the type of Orthocon—was made using the most flexible Orthocon-L because of the basic principle of starting with a light corrective force.

The patient reported mild pain in the anterior area until the third day after he started wearing the D.P., but after that the pain vanished and the teeth began to move steadily. Subsequently, in the third month the overbite moved from edge-to-edge occlusion to the proper position, and treatment progressed excellently. Now, at this point in time it was necessary to change the hardness of the rubber because a stronger corrective force was required. Normally one uses set-up model No. 1 and makes a positioner using the next hardest rubber material, Orthocon-M. This is easy to make if one uses the flask used for Orthocon-L.

Now, three months after using a D.P. changed to harder rubber (M), the anterior teeth area's overbite relationship had improved to a completely normal position, and 3|3 too had been simultaneously guided within the dentition. At this point in time the lateral permanent teeth erupted, and were guided to the proper position by the addition of a tooth using the wax seen in **Color Photo 5**'s occlusal plane, and the initial-phase objectives were completed.

Next, set-up model No. 2 was made to combine both retention and finishing a narrow occlusion. The rubber material used this time was the hardest rubber material, namely Orthocon-H. **Color Photo 6** shows the therapeutic results of orthodontic treatment using a D.P. A is a photograph of the oral cavity when D.P. treatment began, and B shows it when retention was completed.

Incidentally, this case was treated as nonextraction mandibular protrusion, and the set-up models used were divided into two stages, No. 1 and No. 2, and orthodontic treatment ended after a total of one year four months. The effect of aggressively expanding the anterior teeth area 4 mm labially by means of set-up model No. 1 (using two types of rubber hardness, L and M, in the D.P.), which was used for dynamic treatment, is especially apparent.

Figure 6 shows superimposed lateral cephalometric radiograms before treatment (solid line) and after (dotted line). This shows that the maxillary anterior teeth incline labially and the mandibular anterior teeth have a slight lingual inclination. That is, I feel that this shows that the teeth movement pattern closely resembles the therapeutic effect achieved by three levels of intermaxillary securing (using three grades of rubber).

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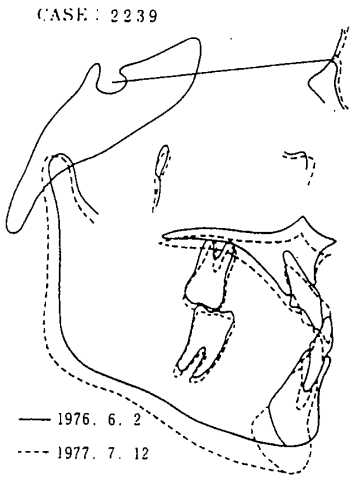


Figure 6. S-N overlay of pretreatment (solid line) and posttreatment (dotted line) lateral cephalometric radiograms.

Now I shall briefly discuss holographic Moiré set-up model experiments utilizing the characteristics of laser light beams (coherency), which were done with the goal of analyzing this phenomenon in more detail.

4. Holographic Moiré Shape Displacement Measurement Method Using Laser Beam

Holography, which was proposed by D. Gabor in 1948, is a new optical field which was completed in 1962 by Dr. Leith and Dr. Upatnieks of the University of Michigan after the appearance of laser light beams which could produce perfectly coherent light in 1960.

Incidentally, holographic interference measurement[13)14)] is a measurement method in which wave fronts before and after an object of some shape undergoes deformation are made to interfere, resulting in interference fringes corresponding to the amount of deformation. From this, the amount of displacement of the object can be found in three dimensions.

The story of Moire[15)16)] begins in 1874 when Lord Rayleih [sic] found that Moiré fringes were created if two linear groups with periodic structures were superimposed. Since then it has been applied to measuring the shape of rough-surfaced objects. This is known as Moiré topography. A light and dark pattern of lines is formed on an object by light passing through a reference grating consisting of transmissive areas and nontransmissive areas and placed directly in front of the object. This is the diffraction illumination type of contour Moiré fringe measurement, a feature of which is that an object's shape can be found in three dimensions.

Now, the object of this experiment was to measure the deformation of rubber when using a D.P. for reversed occlusion, so the amount of displacement from the D.P.'s [original] shape can be found by exposing holographic interference fringes and Moiré fringes on the same piece of film. This case used the set-up model shown in **Color Photo 3**, so a D.P. was made for tooth realignment using the set-up model shown in **Color Photo 5**. The laser apparatus was the FH-40 shown in Figure 7, which housed a 40 mW HeNe laser. The optical system was the grating (spacing 1 mm) shown in Figure 8; it was placed in front of the object being investigated in order to create Moiré fringes. A D.P. was inserted in the set-up model (**Color Photo 3**) before orthodontic treatment, and

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a vertical load (30 g) was applied, and displacement was measured. Figure 9 is a simple drawing representing these optical systems.



Figure 7. Shows inside of the laser apparatus (40 mW HeNe laser). Light rays traveling in a straight line indicate a laser beam.

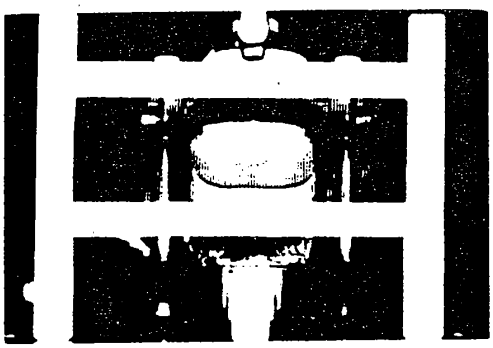


Figure 8. Grating for creating Moiré fringes. Grating pitch (between transmissive areas and non-transmissive areas) is 1 mm.

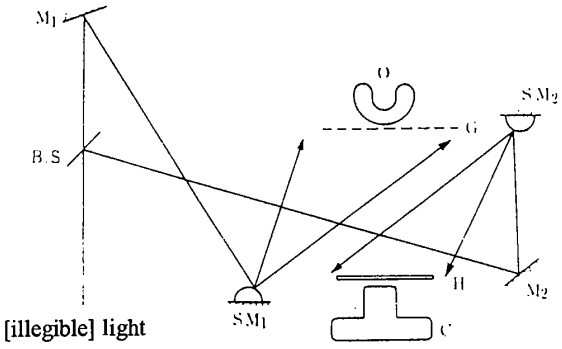


Figure 9. Optical system used in this experiment.
O: D.P.
G: Grating to create Moiré fringes.
H: Hologram photographic plate
C: Reimaging camera
M_1, M_2: Flat mirrors
B.S.: Half mirror
SM_1, SM_2: Spherical mirrors for scattering light beam

Now, before describing the experimental results, let us examine each fringe pattern. Figure 10 shows Moiré fringes indicating the shape. Figure 11 is holographic interference fringes indicating the amount of displacement caused by deformation. Superimposing and photographing these gives Figure 12, the holographic Moiré fringes. By analyzing each component from these fringe patterns one can quantitatively determine the D.P. deformation. The results discussed here are for the saggital area (cross-section AB), the canine area (cross-section CD), and the occlusal plane (cross-section EF).

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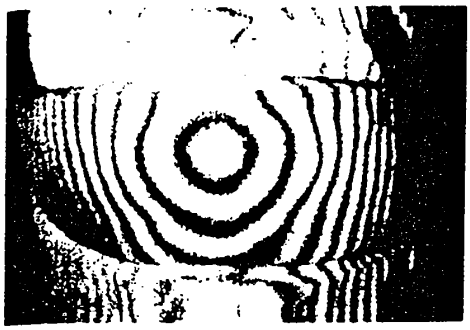


Figure 10. Measuring D.P. shape with Moiré fringes. The fringe pattern disperses in a doughnut shape from the D.P.'s forward-most tip (the center part of the midline).



Figure 11. D.P. holographic interference fringes utilizing a laser light beam. The amount of D.P. displacement can be measured from this fringe pattern.

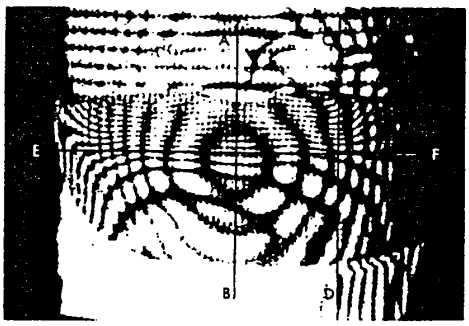


Figure 12. Composite photograph made by simultaneously photographing Moiré fringes and holographic interference fringes. The amount of displacement from the D.P. shape can be measured using this.

This experiment measured A-B (saggital cross-section), C-D (canine area cross-section), and E-F (occlusal plane cross-section).

Incidentally, in these analyses, calculations need to be made with optical system formulas from holographic or Moiré theoretical analysis.[17)]

1) Shape measurement using the contour Moiré fringe method uses the sort of optical system shown in Figure 13 and is as follows.

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Depth hN, from the grating, of Nth contour Moiré fringe is:

$$hN = bNP_0/(l-NP_0)$$

In this experiment,

$P_0 = 1.0$

$b = 420$

$l = 200$

$$hN = 420N/(200-N)\ (mm)$$

The pitch of contour Moiré fringes is about 2.1 mm.

2) Displacement measurement using the holographic double-exposure method uses the sort of optical system shown in Figure 14 and is as follows.

When displacement is simply D in the line of sight direction, optical path difference L before and after deformation is:

$$L = D(1 + \cos\theta)$$

Displacement amount DN indicating the Nth interference fringe's equal displacement line is:

$$DN = n\lambda/(1 - \cos\theta)$$

λ = wavelength = 0.63 μm

In this experiment, DN = 0.33N (μm).

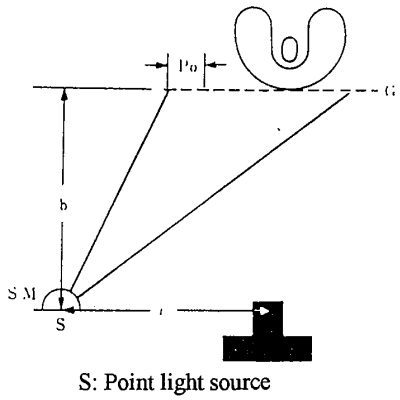


Figure 13. Optical system used in the contour Moiré fringe analysis method.

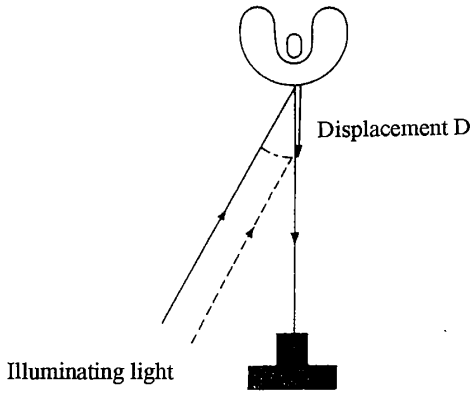


Figure 14. Optical system used in analysis using the holographic double-exposure method.

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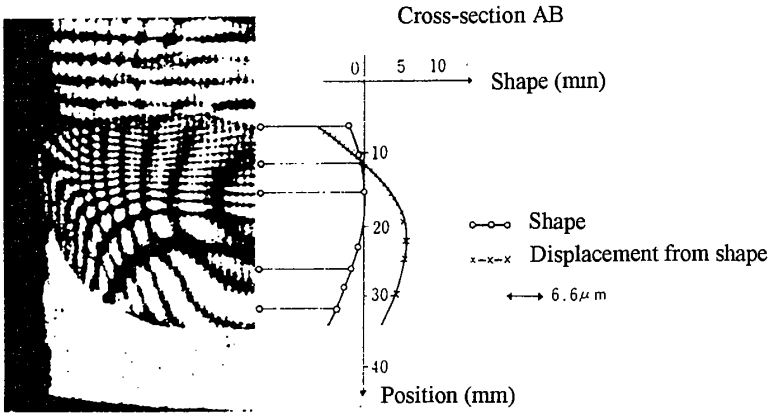


Figure 15. Result of analyzing displacement from D.P. shape (cross-section AB).

Analyzing the actual fringe pattern using these values leads to something like Figure 15 for cross-section AB, for example. That is, the deformation of D.P. caused by a vertical load creates a fringe pattern, and if this is transferred to a coordinate system and plotted, one can measure the amount of displacement from the [original] shape in the D.P. cross-section. In this case, we clearly see that D.P. deformation is such that in the maxillary anterior teeth area it displaces toward the tongue, and in the mandibular anterior teeth area it displaces toward the lips. The small amount of deformation in the maxillary anterior teeth area indicates that the plaster set-up model does not bite into the D.P. accurately so the load is small. From this one can infer that in the initial stage the same phenomenon would occur in an actual oral cavity.

Figure 16 shows the cross-sections in each area. The rubber's deformation shows displacement from the anterior teeth area to the canine area, and the upper jaw displaces toward the tongue, while the lower jaw expands toward the lips. This deformation occurs because the recovery force moves the actual tooth and becomes corrective force to treat the malocclusion, but this experiment indicates that it is necessary to change the shape of a conventional D.P.

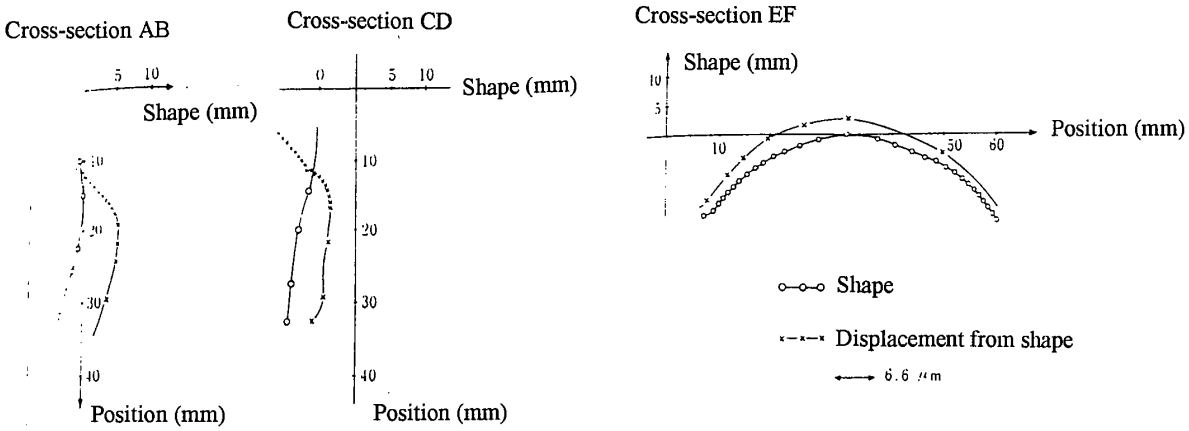


Figure 16. Shows shape and displacement from shape at each D.P. area.

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That is, if the appliance is not stably installed in the oral cavity in order to increase the D.P. effect, it becomes very difficult to achieve the objective of the initial phase. For example, in a case with pronounced irregularities (crowding), the D.P. cannot grip each tooth accurately if teeth are greatly realigned on the set-up model. In other words, the D.P. floats in the oral cavity, and when this happens the rubber's recovery force loses its anchor (unmoving teeth and surrounding mucosa) and is not fully transferred to the moving teeth, so the therapeutic effect is greatly weakened.

Therefore, as shown in Figure 17, the author and others have conceived of a method of altering the D.P. configuration as required. If tooth realignment involves a large amount of movement, the amount of rubber displacement too must naturally be large, so it is possible to resolve this by local adjustment of the orthodontic force using the cutting method. This shall be described in detail under clinical applications.



Figure 17. Clinical application of D.P. whose shape has been corrected (cutting method).

I shall now describe the new rubber material used in this appliance.

II. Implementation of New Elastic Polymer Material (Orthocon)

1. Rubber Material Conventionally Used in Tooth Positioners

The conventionally used rubber material is mainly natural rubber (1,4 polyisoprene). But long-term use of this material in the oral cavity is accompanied by stress diminishing over time, and decreases in mechanical properties such as tensile strength, rupture stress, etc. Moreover, sulfur in the unit is vulcanized, leading to a strong so-called rubber odor, and it cannot be used in a nervous patient. Also, the material is opaque and it is difficult to easily obtain natural rubber for tooth positioners (the material is made in the U.S.), so currently it is almost never used in this country.[18] Figure 18 shows tooth positioners made from various types of rubber materials generally used in the U.S. They are made from natural rubber (upper row) and polyurethane rubber (lower row).

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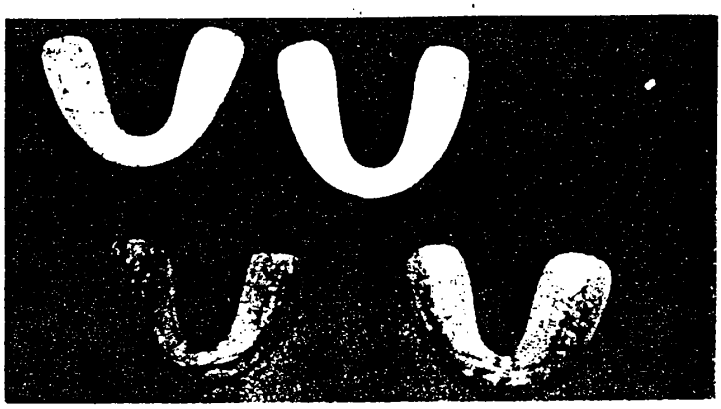


Figure 18. Tooth positioners made from various types of rubber materials used in the U.S. Upper row: natural rubber. Lower row: polyurethane rubber.

Therefore, as discussed at the beginning, the author and others first undertook the development of an organic polymer material which satisfied the requirements for an elastic material used in orthodontic treatment. As a result, they discovered a heat-cured polyol polymerized polyurethane resin, and made a prototype tooth positioner and used it in clinical applications.

2. Prototype Polyurethane Resin and Workability Issues

Polyurethane resin is a synthetic rubber whose main chain has isocyanate OCN <O> NCO. As seen in Figure 19, a first important feature is that stress diminution over time is slight, which is a requirement of particular importance for an orthodontic rubber material (Figure 19). Additionally, its mechanical properties are superior to those of other rubber materials, and it is very transparent, and of course it has no toxic effects on the body, and it is tasteless and odorless. Thus it is a rubber material with many clinical advantages.

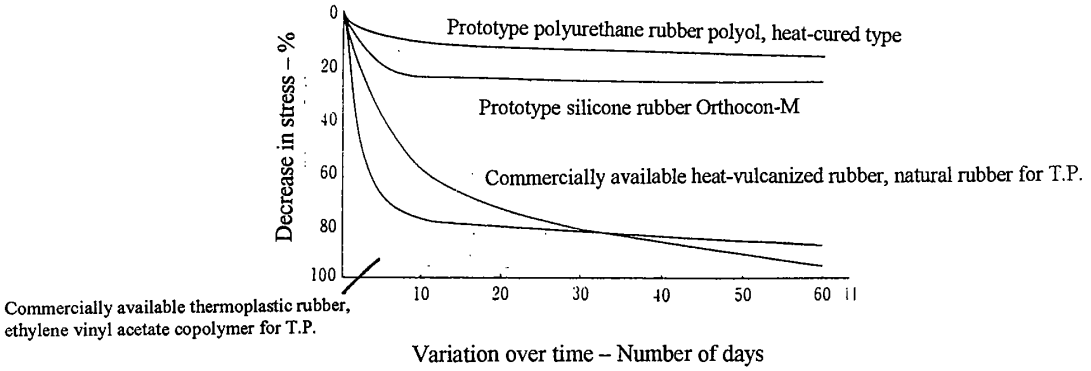


Figure 19. Decrease in stress over time of various types of rubber materials. (In water at 37°C, when stretched 100%)

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Color Photo 7 shows a prototype tooth positioner which was actually made. Based on ample clinical experience, it can move a tooth beyond the therapeutic range of a conventional tooth positioner, so it was named the "dynamic positioner" to distinguish it from an ordinary tooth positioner.[19] However, controlling a characteristic of this rubber (bubbling due to reaction with water)—the so-called CO_2 foaming phenomenon—requires the very complicated apparatus shown in Figure 20: a vacuum pump or a pressure pot or the like. Furthermore, polymerization takes a long time, and the manufacturing process is very complicated.

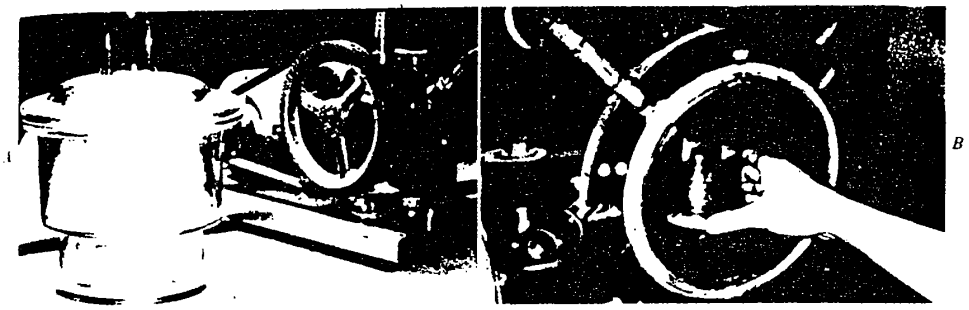


Figure 20. Various types of materials used to polymerize polyurethane resin.
A: Removing bubbles with a vacuum pump.
B: Suppressing foaming in a pressure pot (8 kg-cm^2).

Given this sort of situation, it would be rather difficult to manufacture it at an ordinary dental hospital, unless it were a university hospital, so it has not been widely used. Therefore additional studies were carried out in order to find a polymer material which was easy to work with and which moreover did not lose the various superior properties of polyurethane resin. The result was the development of the Orthocon (heat-cured silicone resin) reported herein, which we decided to introduce for clinical applications.

3. Implementation of a New Silicone Resin (Orthocon)

Orthocon is made from a heat-vulcanized type of silicone resin. This rubber material is a new rubber material which has been studied with regard to dental engineering, orthodontics, workability, etc. as an elastic material for use in dynamic positioners.[20)21)]

For example, the results of studies from an engineering perspective are as shown in Figure 21 and Figure 22. It exhibits values which are nearly the same as polyurethane resin. Also, its values for loss of stress are somewhat inferior when compared to polyurethane resin, as seen in Figure 19, but adequate for use. Also, the silicone resin used in the D.P.'s main body is a material which is very transparent, as shown in **Color Photo 8**, and is based on dimethylvinylpolysiloxane. In its unvulcanized state it is milky white and nontransparent, but it changes to transparent as shown in the Figure when heat vulcanized. A curing agent is already mixed in, so vulcanization (polymerization) is easy to do.

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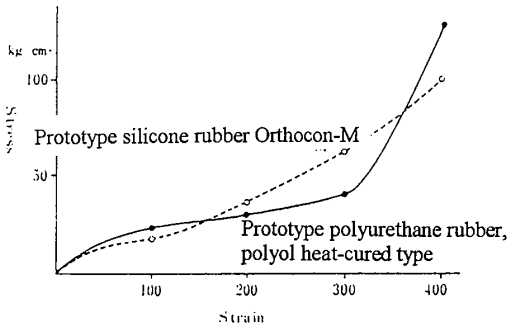


Figure 21. Comparison of stress-elongation curve of prototype rubber material.

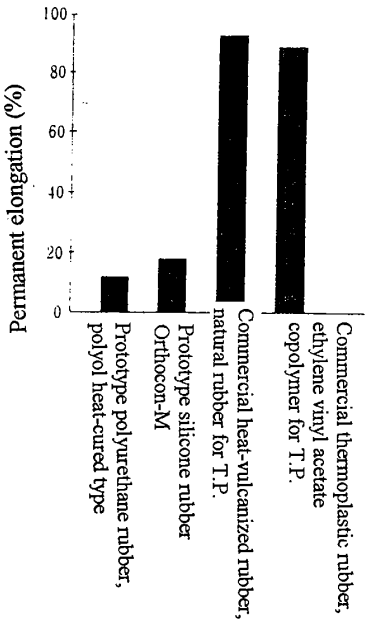


Figure 22. Permanent elongation of rubber materials. (Permanent elongation after 60 days in 37°C water and stretched 100%.)

The silicone resin of the main body has three levels of hardness (JIS standard): 40, 50, 60. Clinically these are classified as light L, medium M, and heavy H. They can be appropriately selected according to the period in which they are used for orthodontic treatment and the use objective. It is also possible to combine them. Meanwhile, the coating material on the D.P. main body is made from an additive type of double-liquid silicone resin (R.T.V.), and is a rather highly viscous material, as shown in **Color Photo 9**. The vulcanization parameters required are a primary vulcanization of the main body at 100°C for one hour, followed by secondary vulcanization (called post-vulcanization) at 180°C for two hours. Drying the coating material takes 30 minutes at 70~80°C, but this can be done in the course of the secondary vulcanization of the main body. I plan to describe the details of this when describing the D.P. manufacturing method.

With regards to workability, as shown in **Color Photo 10** the unvulcanized silicone resin is simply put in a flask and heated, so it is very easy to handle. I plan to describe this procedure in the next issue.

Conclusion

In the foregoing I described the D.P. concept and the general nature of Orthocon. Next time I shall describe the manufacturing procedure when actually using it, and clinical applications of the D.P.

(To be continued. References combined in final article.)

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昭和55年5月1日

類	価格
ハー，フック，フ	1,700
ド・エーカース	2,400
バークラスフ	2,800
スフ，バックアクション，	3,200
双子鉤単式	3,400
，双子鉤複式	4,400
所につき	2,200
	5,000
	2,200
コックアタッチメント	12,000
ックアタッチメント・1歯	1,500

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新しい矯正装置―ダイナミックポジショナー(D.P)―の研究

――I．D.Pの考案と透明シリコーン樹脂（オーソコン）の実用化――

吉井　修
（関東逓信病院歯科医長）

はじめに

矯正治療では，歯を移動するための矯正力を主に金属線やゴム材料（主に天然ゴム）の弾性に求めてきたことは周知の通りです．しかし，前者に比べて後者は，臨床上あるいは歯科理工学上種々な欠点を持つために顎間ゴムなどのような矯正装置の付加物として使用されているのが主であり，矯正装置としてはせいぜい tooth positioner（動的矯正治療の最終期から使用する上下顎を一本化したゴムによる保定装置）として用いられている程度にとどまっておりました．

ところで，近年の高分子材料の進歩発展にはめざましいものがあります．その中でも，エラストマーの一分野で開発された合成ゴム（弾性高分子材料）の利用が，矯正治療領域においても積極的にとり入れられようとしています．すなわち，従来の金属線では得られないゴムの特性，いいかえると range of action が大きく，しかも constant な light continous force が得られる性質を矯正力として大いに活用し，歯を理想的にしかも生物学的に移動しようとする必要性から要求された新しい弾性材料の導入といえましょう．

たとえば，矯正装置の付加物としてすでに市販されているゴム材料の中には，すぐれた物性を有するポリウレタン樹脂（イソシアナートを基材とした合成ゴム）を利用したゴム糸（elastic thread）やチェーン形態の成型物（ringlet）が，最近矯正臨床分野に使用されるようになったことからも頷けられます．

ところで筆者ら[1)2)3)]，もしゴム，いいかえれば有機系高分子材料の中で，無色透明，無味無臭で組織に対する為害性はもちろんなく，引張り強度や伸び率にすぐれ，経時的な応力の減衰や永久変形がほとんどないもので，しかも特別な装置や器材を必要とせずに技工操作が行えるような弾性材料があれば，従来の既成概念を乗り越えた動的矯正装置が生まれるに違いないとの発想を抱き，まず最初に，矯正用としての必要条件を満足するゴム材料の研究開発に着手いたしました．次いで，これを矯正臨床に応用する目的から，従来の線矯正装置にとって代わる新しい矯正装置，すなわち金属線やバンドならびにブラケット類を一切使用せず，歯を簡便な方法でしかも生物学的に動かすことのできる動的矯正装置の考案と試作について種々な検討を行ってまいりました．

ここに紹介しますダイナミック　ポジショナー（D.P と略す）は，そんな観点に立って実用化された全く新しい矯正装置であり，本体の開発には東京医科歯科大学矯正学教室の協力を得て10年有余の基礎的ならびに臨床的研究によって成し遂げられたものといえます．

いわば，ダイナミック　ポジショナーは，弾性高分子材料―オーソコン（透明な熱硬化型シリコ

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ーン樹脂を応用したゴム材料）—を利用して作られる可撤式の矯正装置である点，またゴムの復元力をフルに活かして歯を理想とする位置にオートマティックに移動することが可能である点，その治療範囲が矯正治療の開始から保定まで幅広く応用できるなどの点を特徴にもつ理想的な動的矯正装置といえるでしょう．

そこで，今月号から，「新しい矯正装置—ダイナミック　ポジショナー（D.P)—の研究」と題して，Ⅰ）D.P の考案と新しい弾性高分子材料（オーソコン）の実用化，Ⅱ）D.P の製作手順と臨床応用，Ⅲ）D.P の治験例とその効果について，その概要を隔月の本紙面に紹介してみたいと思います．

Ⅰ．新しい矯正装置（D.P）の概要

1. D.P の考案と特徴

D.P は，1945 年 Kesling[4)5)6)] により考案された tooth positioner（動的矯正治療の最終期から細かい咬合関係の仕上げを目的とした保定装置）の原理に基づくものであります．ところで，硬質な天然ゴムなどを使用して作られる tooth positioner は，その使用目的が保定期に使用する静的矯正装置（保定装置）に限られていたのに対して，この D.P はフレキシブルに富んだ軟質の合成ゴム（オーソコン）を利用することにより，その優れた特性を大いに活用できることから，矯正治療の開始から保定まで一貫して使用できるもの，いわば矯正治療の全般にわたって応用できる動的矯正装置である点が大きな違いといえましょう．

そこで，本装置の特徴のいくつかを総括的に列記してみると，以下の通りになります．

1) D.P は，従来から用いられてきた金属線やバンドならびにブラケット類を一切使用せず，全体がフレキシブルに富んだ軟質高分子材料（オーソコン）から作られます．その治療範囲は，矯正治療の開始から保定まで幅広く応用できる矯正装置です．すなわち，動的治療から静的治療へと継続して使用できる点がまず本装置の特徴として挙げられます．

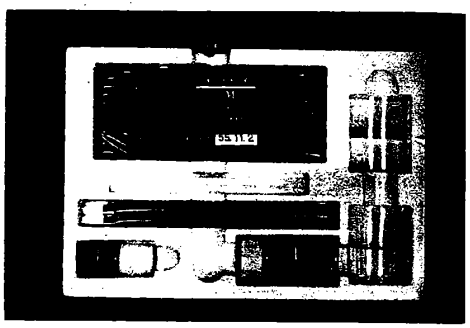


図1　オーソコン（製品名）は，本体と coating 材から作られていて，ゴムの硬度が 3 種類（L.M.H）あります．

2) 装置の形態は，***カラー 1**** に示すような上下顎を一体化したゴムで作られたマウスピースに似ています．

3) D.P による歯の移動様式は，石膏模型上で不正位に萌出した歯を再排列して作られる模型[7)8)]（set-up model と呼ぶ）から得られる D.P のゴムの変形，すなわちゴム材料の復元力を矯正力に活用することにより歯を理想的にしかもオートマティックに移動できる機能をもっています．

4) D.P のゴム素材は，筆者ら[9)10)]が新たに開発したオーソコン（熱硬化型シリコーン樹脂）で，***カラー2*** に示すように大変透明性に富み，無味無臭しかも機械的性質にすぐれ，また技工操作性が簡単であるなどの利点を持っています．

5) このオーソコン（製品名）は，図 1 に示すように本体のシリコーン樹脂と coating 材のシリコーン樹脂から成り立っていて，これらはおのおの 3 種類のゴムの硬さ（ライト-L，ミディアム-M，ヘビー-H）が得られるように作られています．使用目的によって選択することができるほかに，ゴムの硬さを部分的に組み合わせることも自由に調節すること

6) 患者は，夜間 D
けでよく，これに
置，すなわち set-
向に移動します．
ては，術者は一切調
るトラブルは皆無
から，チェアータ
り，特に患者の来院

7) 本装置は，可撤
で，口腔内は常に
す．これにより，
すなわち人為的な
の併発を防ぐなど
有しています．

8) 治療開始時期に
するまでの時期に
す．たとえば，永
矯正装置にはみら
発揮できます．

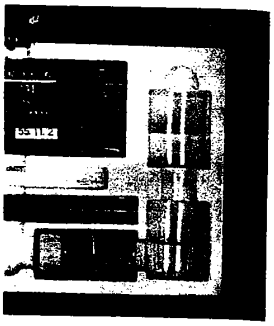
9) 適応症について
前突症，また乱杭
います．その他に
骨格系の不正咬合
上の特徴として挙



図2　不正位にある歯
咬合状態に再排列
over correction
行います．

* カラー *1*～*10* は 65ページ～66ページに掲載

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名)は，本体と coating 材から
ムの硬度が 3 種類 (L.M.H) あ

へと継続して使用できる点
徴として挙げられます．

カラー *1** に示すような上
ゴムで作られたマウスピー

移動様式は，石膏模型上で
歯を再排列して作られる模
odel と呼ぶ) から得られる
，すなわちゴム材料の復元
することにより歯を理想的
ティックに移動できる機能

は，筆者ら[9][10] が新たに開
(熱硬化型シリコーン樹脂)
すように大変透明性に富
も機械的性質にすぐれ，ま
単であるなどの利点を持っ

(製品名) は，図 1 に示す
コーン樹脂と coating 材の
ら成り立っていて，これら
のゴムの硬さ (ライト-L，
ビー-H) が得られるよう
．使用目的によって選択す
かに，ゴムの硬さを部分的

ージ～66ページに掲載

に組み合わせることにより矯正力の強さを自由に調節することもできます．

6) 患者は，夜間 D.P を口腔内に装着するだけでよく，これによって歯は理想とする位置，すなわち set-up model で再排列した方向に移動します．また，D.P の使用にあたっては，術者は一切調節を必要とせず，装置によるトラブルは皆無といえましょう．このことから，チェアータイムが短縮できる利点があり，特に患者の来院回数も少なくてすみます．

7) 本装置は，可撤式の矯正装置でありますので，口腔内は常に衛生的に保つことができます．これにより，従来の線矯正装置の弊害，すなわち人為的な実質欠損やむし歯，歯肉炎の併発を防ぐなど生物学的にもすぐれた点を有しています．

8) 治療開始時期については，永久歯列が完成するまでの時期に使用するのが最も効果的です．たとえば，永久歯の萌出誘導には，他の矯正装置にはみられないすぐれた治療効果が発揮できます．

9) 適応症については，軽度な上顎前突や下顎前突症，また乱排歯や過蓋咬合などに適しています．その他に，顎外固定装置との併用で骨格系の不正咬合者にも応用できる点が臨床上の特徴として挙げられます．

さて，実際に D.P がどのように歯を動かすかといった移動原理とその方法を簡単に述べるとしましょう．

2. D.P による歯の移動原理

D.P の移動原理については，Kesling が考案した tooth positioner の基本概念に準じている点については前述した通りですが，動的治療を目的として使用する D.P の場合は，いくつかの異なる点を挙げることができます．この点については，D.P の臨床応用の章で詳しく述べるとして，ここでは簡単にその要点だけを述べるとしましょう．

まず，D.P の治療効果をより一層高める必要から，歯の再排列 (set-up model) は積極的に行うことが大きなポイントといえましょう．このことは，set-up model 製作時に over correction (理想的位置より過度に歯を移動すること) の概念を導入することを意味します．いいかえると，石膏模型上で理想的な再排列 (いわゆる正常咬合) を行った状態から一段と大きく歯を移動し，set-up model を製作することであり，これにより歯に加わる矯正力 (ゴムの復元力) は動的に，しかも持続性のある力として活用できるわけです．たとえば，端的な例ですが，下顎前突の症例の場合，set-up model 上では上顎前突の状態になるよう歯の再排列を行うという概念がこれにあたります．

さて，一般的には図 2 で示すように不正咬合者

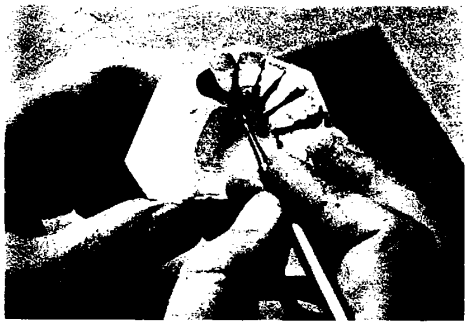


図 2 不正位にある歯を分割し，その個体の理想的な咬合状態に再排列を行います．症例によっては，over correction の概念を導入し，歯の再排列を行います．

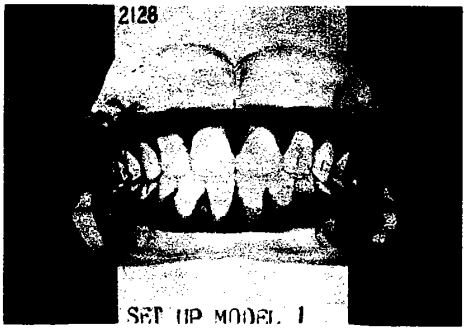


図 3 再排列を完了した set-up model です．症例や治療目的によっては，段階別に 2～3 個製作する必要があります．

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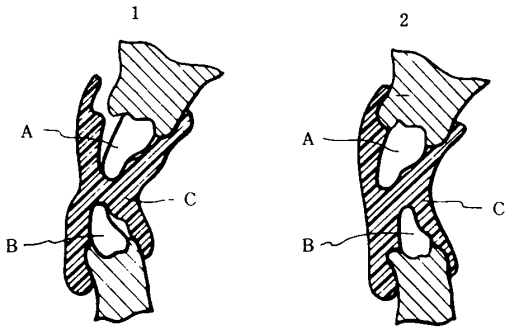


図4 反対咬合の症例に用いた場合の D.P と歯の位置的関係（正中横断面）を示したものです．
1） 治療開始時：D.P が変形を起こし，歯とゴム面に空隙が認められます．
2） 治療終了時：歯が移動を完了し，D.P は元の形に戻ると同時に空隙も消失します．
(A)：上顎中切歯，(B)：下顎中切歯，(C)：D.P

の石膏模型上で不正位にある歯を分割し，その個体の理想的もしくは前述した要領で歯を再排列し，図3で示すような模型（set-up model）からオーソコンを使用して D.P を製作します．次いで，この D.P を不正咬合を有する口腔内に装着しますと，装着と同時に set-up model 上で再排列を行った部位にゴムの変形が生じ，ここに矯正力が働き，歯が移動を開始します．

図4は，反対咬合者に D.P を用いた場合の D.P と歯の位置的関係を図で示したものですが，治療開始時（図4－1）の状態では歯と D.P の間に空隙が認められると同時に，D.P の変形が認められます．治療後（図4－2）は，ゴムの復元力により歯が移動を完了しますから空隙は消失し，D.P の形態も元の形に戻ります．すなわち，このような状態になりますと，set-up model の通りに歯が移動し，動的矯正治療が終了したことを意味します．

ところで，これらの D.P の変形を光学的に調べたのが図5で示すレーザー光線を応用した3次元計測法，すなわちホログラフィー・モアレ形状変位測定法[11)12)]です．この方法は，D.P の垂直荷重に対する変位量を模型上で測定することを目



図5 レーザー光線を応用した3次元計測法，すなわちホログラフィー・モアレ形状変位測定法により D.P の変形を調べたものです（反対咬合の症例）．

的とした実験で，レーザー光線の持つ特性，いいかえると一定波長から生ずるレーザー光線の干渉性を利用したものです．まず，物体の変位量はホログラフィー干渉縞から，また物体の形状はモアレ縞からとらえ，この両者を同時撮影することにより形状からの変位量として表わすことができます．この変位量が歯を動かすゴムの復元力，すなわち矯正力になるわけです．

さて，次に，実例を示しながら，D.P の治療効果や set-up model の方法について簡単にお話ししましょう．

3. 反対咬合に用いた D.P の治療効果

たとえば，**カラー3** は反対咬合と軽度な八重歯を主訴として来院した初診時年齢が8歳4カ月の男子です（Case 2239）．

症例の詳細な検討を行った結果，本症例は上顎骨の劣成長と上顎前歯の舌側傾斜を示す Angle class Ⅲ の非抜歯症例と決定されました．**カラー4** は，矯正診断を行うに際しよく使用されるプロフィログラムの重ね合わせです．これにより不正咬合者の形態をパターンにより分類，把握することができる点で大変便利な方法といえます．本症例の場合，実線が患者の顎顔面骨のパターンであり，点線が同年代の日本人男子の平均的パターンであります．これをみても，本症例が上記した内容を持つ不正咬合者（上顎骨の劣成長を伴う）で



1 オーソコン(熱
作したダイナミッ



3 症例は，反対咬
4カ月の男子で，
例です（Case 22



5 本症
排列は，
を行い，
めワッ
A：
B：

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用した3次元計測法，すなわ
モアレ形状変位測定法により
ものです（反対咬合の症例）．

ザー光線の持つ特性，いい
生ずるレーザー光線の干渉
まず，物体の変位量はホ
ら，また物体の形状はモア
両者を同時撮影することに
として表わすことができま
動かすゴムの復元力，すな
です．
示しながら，D.P の治療効
方法について簡単にお話し

いた D.P の治療効果

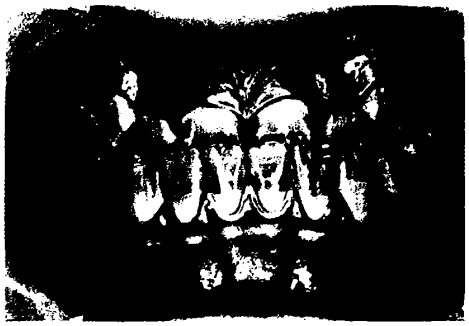
は反対咬合と軽度な八重歯
初診時年齢が8歳4カ月の
．
行った結果，本症例は上顎
の舌側傾斜を示す Angle
に決定されました．**カラー**
に際しよく使用されるプロ
っせです．これにより不正
ンにより分類，把握するこ
単な方法といえます．本症
の顎顔面骨のパターンであ
な人男子の平均的パターン
ても，本症例が上記した内
上顎骨の劣成長を伴う）で



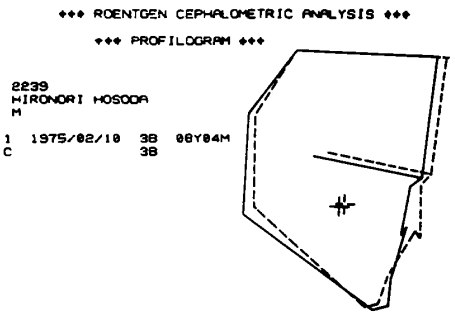
1 オーソコン（熱硬化型シリコーン樹脂）を用いて製作したダイナミック・ポジショナー（D.P）．



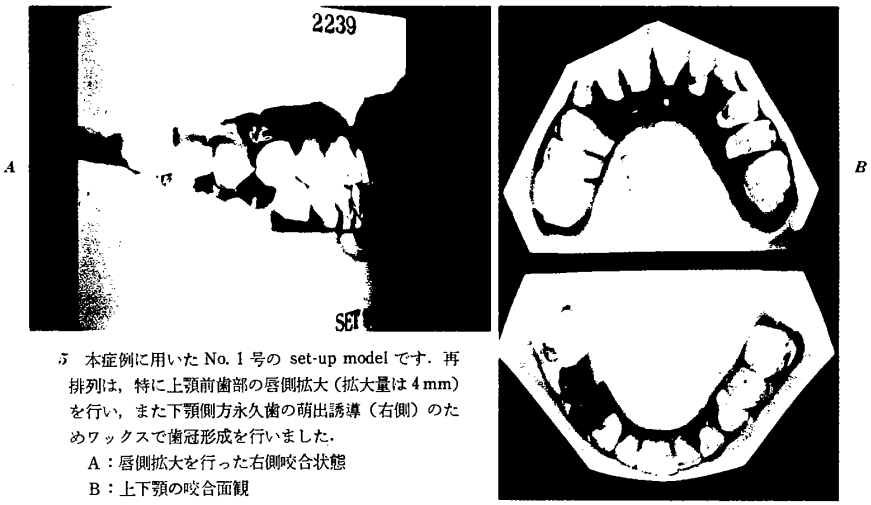
2 D.P の口腔内装着時の状態で，透明性が高いので歯や歯肉の観察が容易です．



3 症例は，反対咬合を主訴とした初診時年齢が8歳4カ月の男子で，Angle class Ⅲ を呈した非抜歯症例です（Case 2239）．



4 側貌頭部X線写真から求めたプロフィログラムで，実線が患者のパターン，点線が同年代の日本人男子の平均的パターンです．これにより，本症例は上顎骨前方発育成分が劣成長であり，上顎前歯の舌側傾斜を示した症例といえるでしょう．



5 本症例に用いた No. 1 号の set-up model です．再排列は，特に上顎前歯部の唇側拡大（拡大量は4mm）を行い，また下顎側方永久歯の萌出誘導（右側）のためワックスで歯冠形成を行いました．
A：唇側拡大を行った右側咬合状態
B：上下顎の咬合面観

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6 D.Pによる治療効果です．まず，No. 1号の set-up model から D.P を2個製作（ゴムの硬さをLとM使用）し，動的治療期間に6カ月間を要し，反対咬合を改善しました．その後，保定を目的としてNo. 2号を製作し，通算1年4カ月で治療を終了した症例です（Case 2239）．
A：治療開始時（右側）　B：保定終了時（同側）



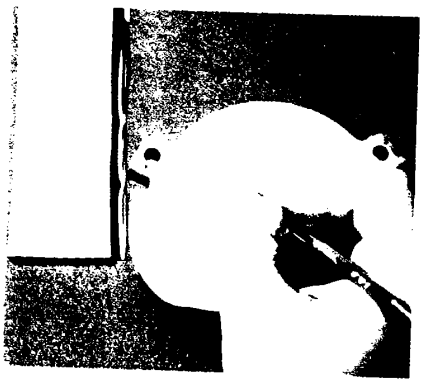
7 ポリウレタン樹脂で試作した tooth positioner



8 オーソコンの本体に用いる熱硬化型シリコーン樹脂．加硫後は透明体に変わる特性を持った材料である．



9 オーソコンの coating 材に用いる付加型のシリコーン樹脂．粘度の高い透明体である．



10 オーソコンの填入操作は，フラスコ中にシリコーン樹脂を充填するだけで簡単に作ることができます．

あることが頷けられま

さて，実際に D.P を
時には，正しい矯正診
ることはいうまでもあ
のように set-up mode
関係してくる問題であ
く左右する鍵であると
りません．

この症例の場合には
れ，しかも上顎前歯が
ので，No. 1 号の set
する目的から上顎前
拡大（拡大量は 4 mm
歯列内に再排列しまし
は，残存乳臼歯を整理
大いに活用して下顎前
移動させ，再排列を行
のゴム材料，すなわち
的に最初は弱い矯正力
吹らかいオーソコン
した．

D.P 装着後，3日目
歯部に訴えましたが，
は順調に移動を開始し
月目で切端咬合位か
は良好な経過をとり
ムの硬さを変える必
り強い矯正力が要求
No. 1 号の set-up r
いゴム材料，オーソ
す．この製作には，
ラスコを利用すれば

さて，ゴムの硬さ
してみると3カ月後
に正常位に改善され
導されてきました．
出してきましたが，
すワックスによる歯
誘導され，初期の目

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B

ムの硬さをLとM使
Jとして No. 2 号を製



いる熱硬化型シリコーン樹
わる特性を持った材料であ



よ，フラスコ中にシリコー
簡単に作ることができま

あることが頷けられます．

さて，実際に D.P を使用して矯正治療を行う時には，正しい矯正診断と適切な治療方針を立てることはいうまでもありません．このことは，どのように set-up model を製作したらよいか直接関係してくる問題であり，D.P の治療効果を大きく左右する鍵であるといっても決して過言ではありません．

この症例の場合には，上顎骨の劣成長が認められ，しかも上顎前歯が舌側にやや傾斜していますので，No. 1 号の set-up model でこの点を改善する目的から上顎前歯部を積極的に唇側方向に拡大（拡大量は 4 mm）し，$\frac{3}{3}$ の唇側低位歯を歯列内に再排列しました．また下顎におきましては，残存乳臼歯を整理した後，余剰なスペースを大いに活用して下顎前歯部をわずかに舌側方向に移動させ，再排列を行いました（**カラー 5**）．D.P のゴム材料，すなわちオーソコンの種類は，原則的に最初は弱い矯正力から開始する立場から一番軟らかいオーソコン-L を使用して製作いたしました．

D.P 装着後，3 日目まで患者は軽度な痛みを前歯部に訴えましたが，その後は痛みも消失し，歯は順調に移動を開始いたしました．その後，3 カ月目で切端咬合位から被蓋は正常位に移り，治療は良好な経過をとりました．さて，この時点でゴムの硬さを変える必要があります．すなわち，より強い矯正力が要求されるためです．通常は，No. 1 号の set-up model を利用して一段上の硬いゴム材料，オーソコン-M を使用し，製作します．この製作には，オーソコン-L で使用したフラスコを利用すれば容易に作ることができます．

さて，ゴムの硬さを（M）に変えた D.P を使用してみると 3 カ月後に，前歯部の被蓋関係は完全に正常位に改善され，同時に $\frac{3}{3}$ も歯列内に誘導されてきました．この時点で，側方永久歯が萌出してきましたが，**カラー 5** の咬合面にみられますワックスによる歯の添加により正常な位置へと誘導され，初期の目的を完了することができました．

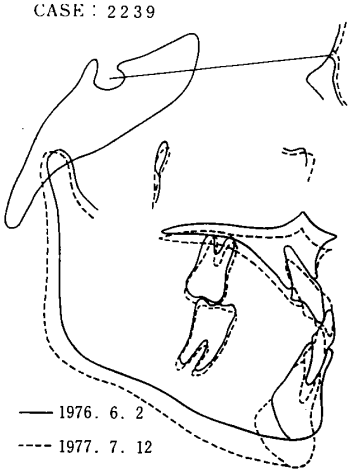


図 6　側貌頭部X線規格写真の術前（実線）と術後（点線）の S-N 重ね合わせです．

次いで，保定を兼ねた細かい咬合の仕上げを目的として No. 2 号の set-up model を製作しました．この時使用しますゴム材料は，通常一番硬いゴム材料，すなわちオーソコン-H を使用します．**カラー 6** は，D.P を使用して矯正治療を行った治療結果で，A は D. P による治療開始時の状態，B は保定を終了した時点の口腔内写真です．

ところで，本症例は非抜歯の下顎前突症例として治療を進めたものですが，使用した set-up model は No. 1 と No. 2 の 2 段階に分けて，通算 1 年 4 カ月で矯正治療を終了した症例です．特に，動的治療を目的に行った No. 1 号の set-up model（使用した D.P のゴムの硬度は，L と M の 2 種類）では，前歯部の唇側拡大を 4 mm と積極的に行った効果がはっきりと現われています．

図 6 は，側貌頭部X線規格写真の術前（実線）と術後（点線）の重ね合わせですが，これをみますと上顎前歯は唇側方向に傾斜し，また下顎前歯はわずかに舌側に傾斜しているのが認められます．すなわち，このことから歯の移動様式はこの場合，3 級の顎間固定（3 級ゴムの使用）で行った治療結果とよく似ていることがおわかりいただ

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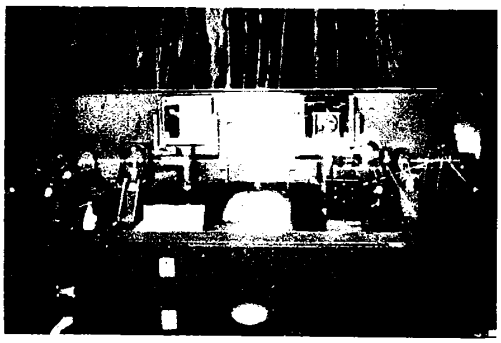


図7　レーザー装置(He-Ne レーザー 40mW を内蔵)の内部を示したものです．直線に走る光線が，レーザービームを表わしています．

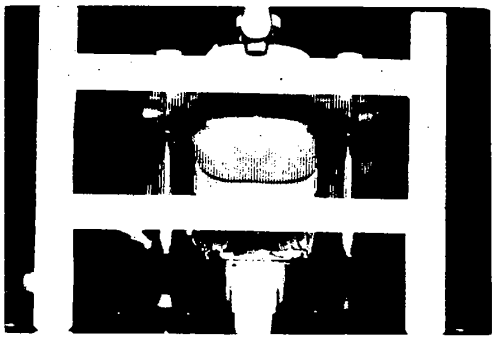


図8　モアレ縞を作るための格子で，格子間隔（透過部と不透過部）は1mmです．



図10　D.P の形状を測定す端（正中線上の中央部様が分散しています．

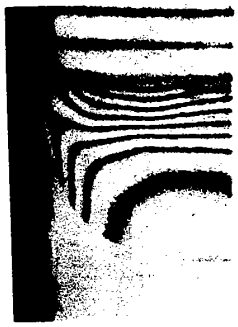


図11　レーザー光線の干フィー干渉縞です．を測定することがで

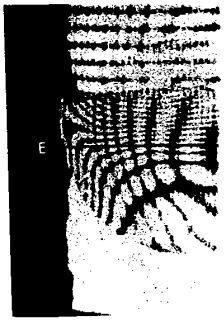


図12　モアレ縞とホロた合成写真．これ量が測定できます．本実験では，A—B断面)，E—F（咬合しました．

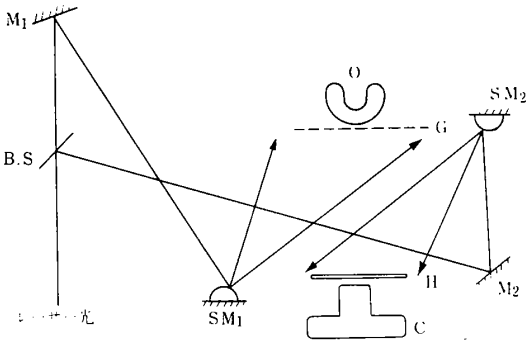


図9　本実験に使用した光学系です．
O：D.P
G：モアレ縞作成用格子
H：ホログラム乾板
C：再生像撮影カメラ
M_1，M_2：平面ミラー
B.S：ハーフミラー
SM_1，SM_2：光束発散用球面ミラー

けると思います．

さて，この現象をより詳細に分析する目的で行われたレーザー光線の特性（コヒーレント）を利用したホログラフィー・モアレの模型実験について簡単に述べてみましょう．

4.　レーザー光線によるホログラフィー・モアレ形状変位測定法

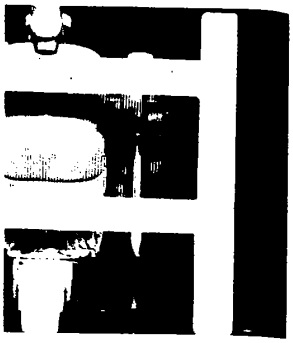
1948年，D. Gabor によって提唱されたホログラフィー理論は，1960年に完全なコヒーレント光が得られるレーザー光線が出現するようになってから Michigan 大学の Leith, Upatnieks 両博士によって1962年に完成された新しい光学分野といえます．

ところで，ホログラフィー干渉測定[13)14)]とは，物体のある状態からそれが変形を受けた時の変形前後の波面を干渉させ，変形量に応じた干渉縞を得ることから物体の変位量を3次元的にとらえることができる測定法です．

また，モアレ[15)16)]については，1874年に Lord Rayleih が，2つの周期的な構造を持つ直線群を重ねるとモアレ縞が発生することをつきとめて以来，大きな粗面物体の形状測定に応用されてきました．これが Moire Topography と呼ばれるもので，物体の直前に置かれた透過部および不透過部からなる基準格子を通過する光により物体上に黒白の縞模様を形成します．これが格子照射型の等高線モアレ縞計測法であり，物体の形状を3次元的にとらえることが特徴として挙げられます．

さて，本実験には，反対咬合に D.P を使用した場合のゴムの変形を測定する目的から，ホログ

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ための格子で，格子間隔（透過
1mmです．

した光学系です．

生成用格子
ム乾板
影カメラ
面ミラー
ミラー
光束発散用球面ミラー

変形量に応じた干渉縞を
位量を3次元的にとらえる
す．
ついては，1874年に Lord
期的な構造を持つ直線群を
生することをつきとめて以
形状測定に応用されてきま
Topography と呼ばれるも
かれた透過部および不透過
通過する光により物体上に
ます．これが格子照射型の
であり，物体の形状を3次
特徴として挙げられます．
反対咬合に D.P を使用し
測定する目的から，ホログ

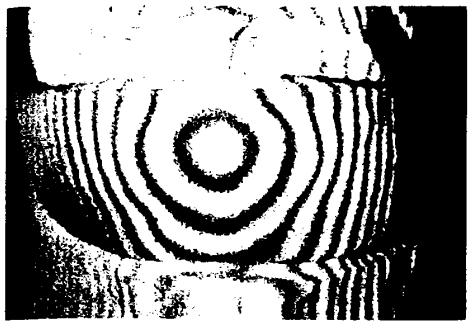


図10 D.P の形状を測定するモアレ縞で，D.P の最先端（正中線上の中央部）からドーナッツ型に縞模様が分散しています．



図11 レーザー光線の干渉を利用した D.P のホログラフィー干渉縞です．この縞模様から D.P の変位量を測定することができます．

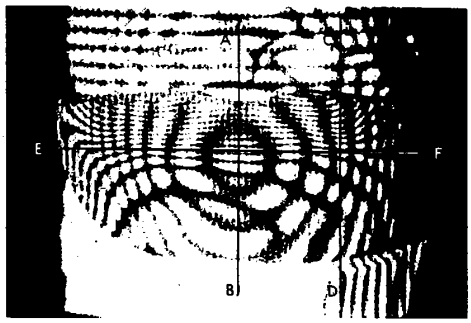


図12 モアレ縞とホログラフィー干渉縞を同時撮影した合成写真．これにより，D.P の形状からの変位量が測定できます．
本実験では，A—B（正中部断面），C—D（犬歯部断面），E—F（咬合面の断面）について測定いたしました．

ラフィー干渉縞とモアレ縞を同一フィルム上に露光させることにより，D.P の形状からの変位量をとらえたものです．症例は，***カラー3*** で示した模型を使用したもので，歯の再排列は***カラー5*** で示した set-up model を使用し，D.P を製作しました．レーザー装置は，図7で示します He-Ne レーザー 40mW を内蔵した FH-40 を使用し，光学系は，図8で示しますモアレ縞を作るための格子（間隔1mm）を被検物体の前に設置し，矯正治療を行う前の模型（***カラー3***）に D.P を装着し，垂直荷重（30g）をかけてその変位量を測定いたしました．図9はこれらの光学系を簡単な図で表わしたものです．

さて，実験結果について述べる前に，各縞模様について見てみますと，図10は形状を表わすモアレ縞であり，図11は変形から生ずる変位量を表わすホログラフィー干渉縞で，これらの両者を同時撮影したものが図12のホログラフィー・モアレ縞です．そこで，これらの縞模様からおのおのの成分を解析することによって D.P の変形を定量的にとらえることができます．ここでは，正中部（AB断面），犬歯部（CD断面），咬合面（EF断面）について測定した結果を述べてみます．

ところで，これらの解析には，ホログラフィーまたはモアレの理論解析[17]から光学系の数式にあてはめて計算する必要があります．

1） 等高線モアレ縞法による形状測定では，図13に示すような光学系から以下の通りになります．

N番目等高線モアレ縞の格子からの深さ hN は

$$hN=\frac{bNP_0}{l-NP_0}$$

本実験では $P_0=1.0$

$b=420$

$l=200$

$$hN=\frac{420N}{200-N}\text{(mm)}$$

等高線モアレ縞間隔は約 2.1mm となります．

2） ホログラフィー二重露光法による変位測定では，図14に示すような光学系から以下の通りに

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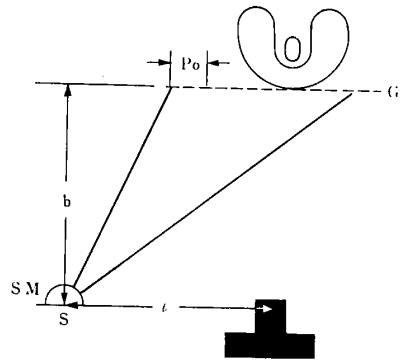


図13 等高線モアレ縞の解析法に用いた光学系です.

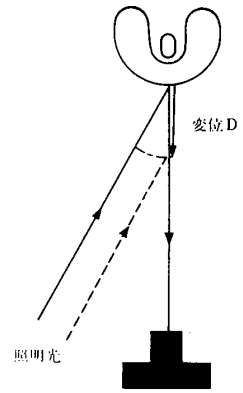


図14 ホログラフィー二重露光法による解析法に用いた光学系です.

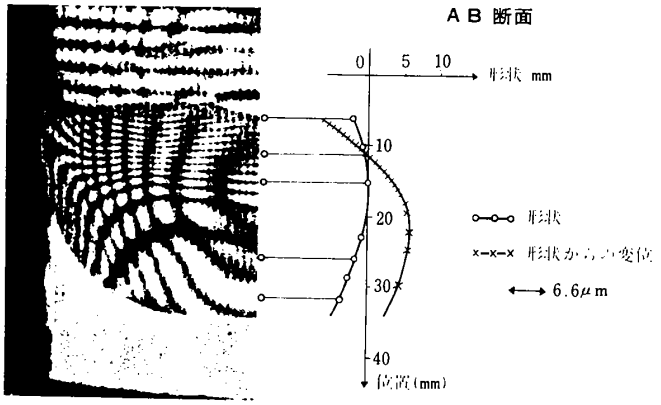
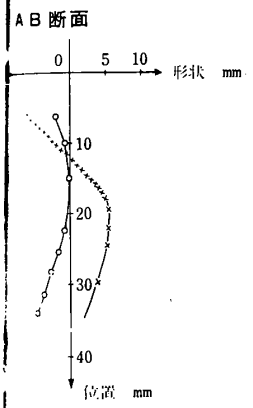


図15 D.P の形状からの変位量を解析した結果（AB 断面）です.



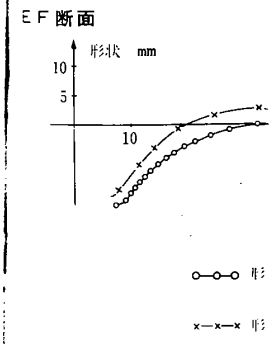


図16 D.P の各部位に
示したものです.

なります.

視線方向にDだけ変位したとすると変形前後の光路差Lは

$$L=D(1+\cos\theta)$$

N番目の干渉縞等変位線の示す変位量DNは

$$DN=\frac{n\lambda}{1-\cos\theta}$$

λ=波長　0.63 μm

本実験では

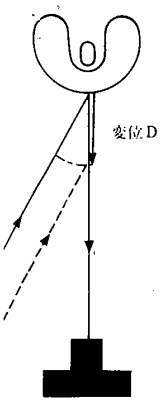
$DN=0.33N$（μm）となります.

これらの数値から，実際に縞模様を解析してみると，たとえばAB断面については図15のようになります. すなわち，垂直荷重によって D.P が変形を起こした状態を，縞模様を座標に置きその数をプロットしますと，D.P の断面の形状からの変位量が測定できます. この場合，D.P の変形は，上顎前歯部において舌側方向に変位し，また下顎前歯部においては唇側方向に変位しているのがはっきり認められます. 上顎前歯部にその変位量が少ないのは，荷重が小さいために D.P の中に石膏模型が的確に嚙み込んでいない状態を表わしています. このように初期においては，実際の口腔内において同一の現象が生じるものと推測できます.



図17 D.P の形態修正
態の臨床応用です

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二重露光法による解析法に用い

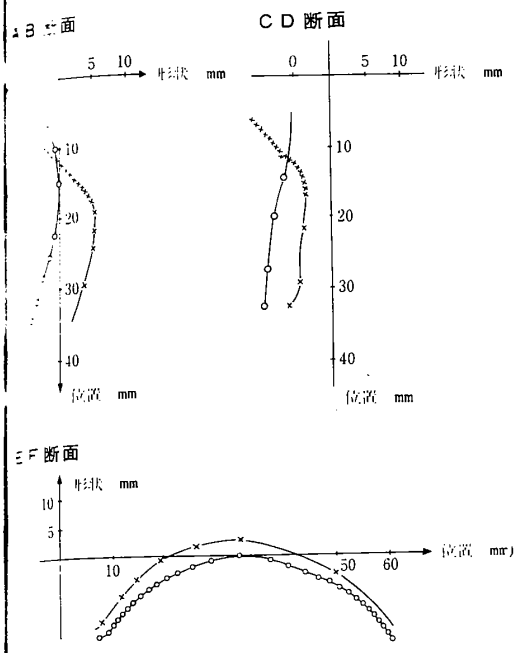


図16 D.P の各部位における形状と形状からの変位を示したものです.

垂直荷重によって D.P が
，縞模様を座標に置きその
と，D.P の断面の形状から
す．この場合，D.P の変形
て舌側方向に変位し，また
唇側方向に変位しているの
す．上顎前歯部にその変位
が小さいために D.P の中
み込んでいない状態を表わ
に初期においては，実際の
現象が生じるものと推測で

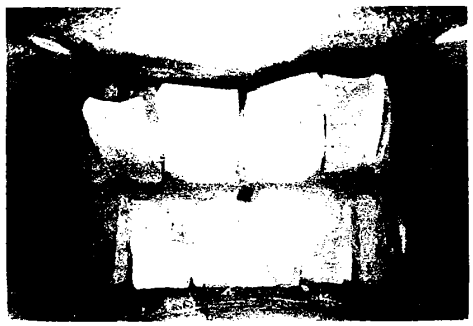


図17 D.P の形態修正（cutting method）を行った状態の臨床応用です.

図16は，各部位の断面を表わしたものですが，前歯部から犬歯部に至っては，共に上顎が舌側方向に変位し，逆に下顎は唇側方向に拡大したゴムの変形を認めることができます．この変形，すなわち復元力が実際の歯を移動し，不正咬合を治療する矯正力になるわけですが，本実験などから従来の D.P の形態を変える必要があることが認められました．

すなわち，D.P の効果を高めるためには，装置が口腔内で安定した状態で装着されていなければ初期の目的を達成することがはなはだ困難であるということです．たとえば，乱排歯の著しい症例（叢生）の場合は，set-up model 上で大きく歯を再排列した場合に D.P が的確に各歯を把握することが不可能となります．いいかえれば，口腔内で D.P が浮き上がった状態になっているわけで，こうなりますとゴムの復元力が固定源（不動歯ならびに周囲粘膜面）をかいして充分に移動歯に伝達されず，したがって治療効果も大変薄くなるわけです．

そこで，筆者らは，図17のように必要に応じて D.P の形態を変える方法を考案いたしました．特に歯の再排列の移動量が大きい場合は，当然のことながらゴムの変位量も大きくなりますので，切り込み法（cutting method）を用いることにより矯正力を部分的に調節することで解決することが可能となりました．このことについては，臨床応用のところで詳しく述べることとします．

さて，この辺で本装置に用いる新しいゴム素材について述べるとしましょう．

Ⅱ．新しい弾性高分子材料（オーソコン）の実用化

1．従来から使用されてきた tooth positioner のゴム材料

従来から使用されてきたゴム材料は，主に天然ゴム（1,4 polyisoprene）が使用されてきましたが，この材料は長期間の口腔内の使用において，経時的応力の減衰や引張り強さ，ならびに破断応

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図18 米国で使用されている各種ゴム材料から作られた tooth positioner です．
（上段）天然ゴム，（下段）ポリウレタンゴム

力等の機械的性質が低下するばかりか，硫黄を主体に加硫することから，いわゆるゴム臭が強く，神経質な患者には使用できないという欠点が認められてきました．また，材質が不透明であることや tooth positioner 用の天然ゴム（米国製）を容易に入手することが困難であるなどの理由から，本邦においてはほとんど普及しない状態で現在に至っています[18]．図18は，従来から米国において使用されてきた各種ゴム材料から作られた tooth positioner を示したもので，材質は天然ゴム（上段）とポリウレタンゴム（下段）により製作されたものです．

そこで，冒頭でも述べた通り，筆者らはまず矯正治療に具備する弾性材料の条件を充たす有機系高分子材料の開発に取り組み，その結果，熱硬化型ポリオール重合ポリウレタン樹脂を見出し，tooth positioner の試作を行い，臨床応用を行ってきました．

2. 試作ポリウレタン樹脂と技工操作性の問題

ポリウレタン樹脂は，主鎖にイソシアナート OCN ⟨○⟩ NCO を持つ合成ゴムであり，図19の通り，特に矯正ゴム材料として要求される条件の1つである経時的応力の減衰が少ない点がまず特徴として挙げられます（図19）．その他に，機械的性質が他のゴム材料に比較してすぐれている点，また大変透明性に富んでいる点，もちろん

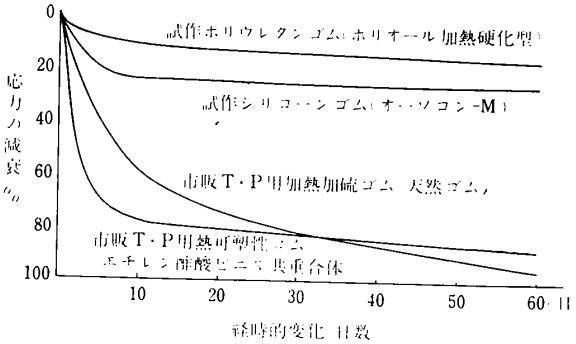


図19 各種ゴム材料の経時的応力の減衰（37 C温水中，100%の伸張時）

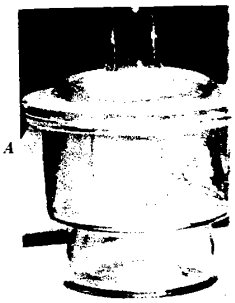


図2(

生体に対する為害性もな
の臨床的利点も兼ね備え
ます．

カラー7 は，実際に
です．多くの臨床経験
tioner の治療範囲を越
ことをつきとめ，特に
分けて考える立場から
付けました[19]．しかし，
と反応すると発泡する
泡現象を抑えるために
な装置，たとえば真空
となり，その上，重合
の欠点があり，また製
たことは否定できませ

こんな状況に置かれ
ならともかくも，一般
するのが困難であり，
そこで，技工操作性が
ン樹脂が持つすぐれた
な高分子材料を見出
果，今回報告するオー
ン樹脂）を開発し，臨
きるようになりました

3. 新しいシリ
の実用化

オーソコンは，加

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ner です.

取り組み，その結果，熱硬化
ポリウレタン樹脂を見出し，
試作を行い，臨床応用を行っ

レタン樹脂と技工操作性

は，主鎖にイソシアナート
O を持つ合成ゴムであり，図

ゴム材料として要求される条
的応力の減衰が少ない点がま
られます（図19）．その他に，
ム材料に比較してすぐれてい
性に富んでいる点，もちろん

化型）

60日

張時）

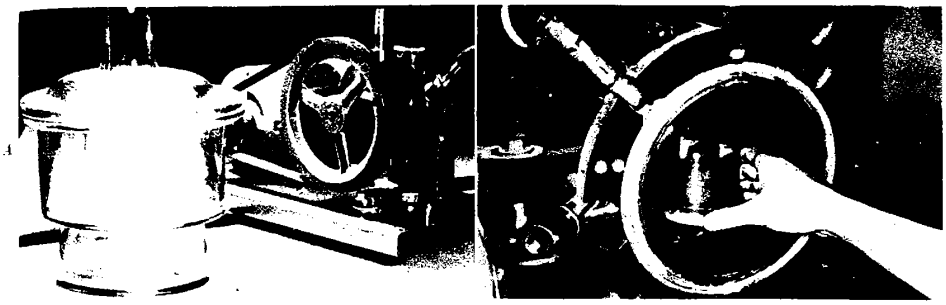


図20　ポリウレタン樹脂を重合するために用いる各種器材．
A：真空ポンプで脱泡を行う．
B：加圧釜（8kg/cm²）で発泡現象を抑える．

生体に対する為害性もなく，無味無臭であるなどの臨床的利点も兼ね備えたゴム材料であるといえます．

カラー7 は，実際に試作した tooth positioner です．多くの臨床経験から，従来の tooth positioner の治療範囲を越えた歯の移動が可能であることをつきとめ，特にこれを tooth positioner と分けて考える立場から dynamic positioner と名付けました[19]．しかし，このゴムの持つ特性（水と反応すると発泡する現象），いわゆる CO_2 の発泡現象を抑えるためには，図20に示す大変大掛りな装置，たとえば真空ポンプや加圧釜などが必要となり，その上，重合時間に長時間を要するなどの欠点があり，また製作過程が甚しく繁雑であったことは否定できません．

こんな状況に置かれていましたから，大学病院ならともかくも，一般歯科医院ではなかなか製作するのが困難であり，普及には至りませんでした．そこで，技工操作性が簡便で，しかもポリウレタン樹脂が持つすぐれた種々な特性を損わないような高分子材料を見出すための再検討を行った結果，今回報告するオーソコン（熱硬化性シリコーン樹脂）を開発し，臨床応用に導入することができるようになりました．

3. 新しいシリコーン樹脂（オーソコン）の実用化

オーソコンは，加熱加硫型のシリコーン樹脂か

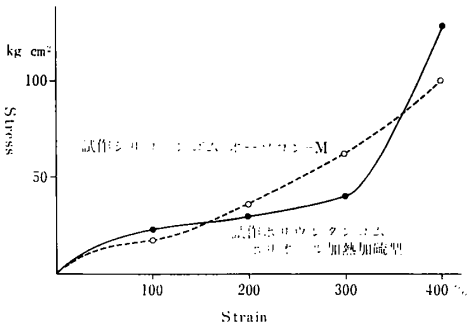


図21　試作したゴム材料の応力—伸び曲線の比較

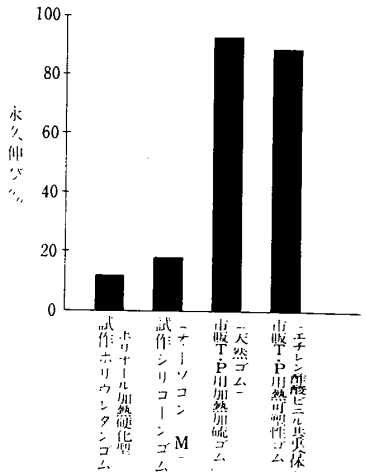


図22　各種ゴム材料の永久伸び
（37°C温水中，100%の伸張時の60日後の永久伸び）

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ら作られたものです．このゴム材料は，特にD.Pに使用する弾性材料として歯科理工学的，矯正学的，技工操作性などの観点から検討された新しいゴム素材です[20)21)]．

たとえば，理工学的立場から検討した結果は，図21と図22に示してある通り，ほぼポリウレタン樹脂に近似した値を示しています．また，応力減衰の値は，図19で示した通りポリウレタン樹脂と比較するとやや劣りますが，使用には充分であります．また，D.Pの本体に使用しますシリコーン樹脂は，***カラー8*** で示す通り大変透明性に富んでいる材料で，ジメチルビニルポリシロキサンをベースとしたものです．未加硫の状態では，乳白色の不透明体ですが，加熱加硫を行うと図のように透明体に変化します．硬化剤は，すでに練り込まれた状態ですので，加硫方法（重合）も簡単に行うことが可能となりました．

この本体のシリコーン樹脂は，硬度（JIS 規格）が40，50，60台の3段階に分かれていて，臨床的にライト-L，ミディアム-M，ヘビー-Hと分類されています．矯正治療の使用時期や使用目的によって使い分けることが可能ですし，またこれを組み合わせて使用することもできます．一方，D.Pの本体に coatingする塗布材は，付加型の2液性のシリコーン樹脂（R.T.V）より作られていて，***カラー9*** に示すようなやや粘度の高い材料からできています．加硫条件は，本体が第1次加硫として100°C 1時間，その後第2次加硫（後加硫ともいう）として180°C 2時間を要します．また，coating 材の乾燥には，70°～80°C 30分を要しますが，これは本体の第2次加硫を行う時に含まれる加硫操作の過程で行うことができます．この辺の細かい点については D.P の製作法のところで述べる予定になっています．

技工操作性については，***カラー10*** で示します通り，未加硫のシリコーン樹脂をフラスコ内に填入し，加熱するだけでよいことから，操作性はきわめて簡単といえるでしょう．この操作手順についても次号で述べる予定です．

おわりに

以上，D.Pの考案とオーソコンについてその概要を述べましたが，次回は，実際に使用する場合の製作手順と D.P の臨床応用について述べてみたいと思います．

（つづく．文献は最終回に一括掲載）

ペリオ臨
P.I
ペリ
院長さん
おすすめ
すべての
必ず炎症に
そこで、歯
の対象にな
ン等の外科
で、大半の
■講演は、
理解で
あなたの
日
会
受
申
方
150 東京都渋
氏　名
現住所
〒□□□
*

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Nippon Dental Review
Vol. 454, P. 107-130 (August 1980)

RESEARCH ON A NEW ORTHODONTIC APPLIANCE: THE DYNAMIC POSITIONER (D.P.)

II. The D.P. Manufacturing Procedure and Clinical Applications

By Osamu Yoshii, Head of the Kanto Teishin Hospital's Dental Department

Introduction

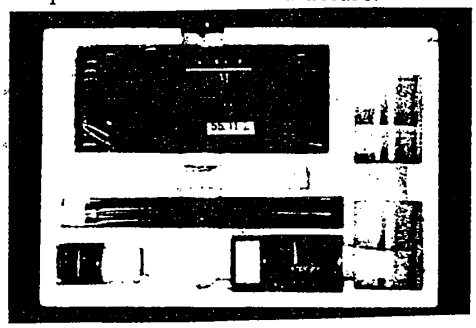
Last time (No. 452, June 1980) I provided an overview of the dynamic positioner conceived of by myself and others. (It is a removable orthodontic device used from the start of orthodontic treatment through retention, which dispenses entirely with metal wires and brackets and which uses a rubber material's recovery force to automatically move a malpositioned jaw or tooth to the ideal position.) I also reported on the prototype manufacture and implementation of a transparent heat-cured silicone resin (Orthocon) for making a D.P., and the basic research thereon.

This time I intend to focus on technique through which this D.P. is actually manufactured, from an orthodontic work perspective, and to introduce the D.P. manufacturing procedure and to briefly summarize the status of the newly conceived D.P. and its clinical applications.

First, to appropriately explain the procedure for making a D.P. made using Orthocon™, it should be divided into four items:

1. From taking an impression to making a set-up model
2. The bite registration method and important points when realigning
3. From making a working model to D.P. investment
4. From Orthocon filling to finishing

These matters shall be described with pictures, and introduced in sequence while describing important points about the manufacture.



Orthocon™ consists of a main body and coating material. It is made from a set of three types of hardness (hardness increases L, M, H) so that rubber hardness can be selected according to the D.P. use objective and treatment system.

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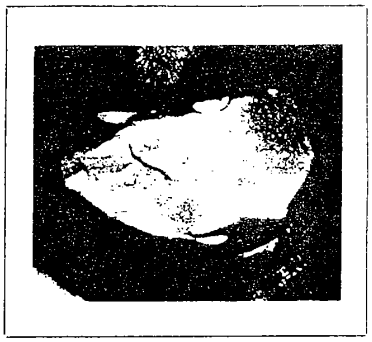
A dynamic positioner (D.P.) made using Orthocon (a heat-cured silicone resin). It is made from a rubber material which is very transparent, tasteless and odorless, and which has excellent mechanical properties.

I. D.P. Manufacturing Procedure (1~57)

1. From Taking an Impression to Making a Set-up Model

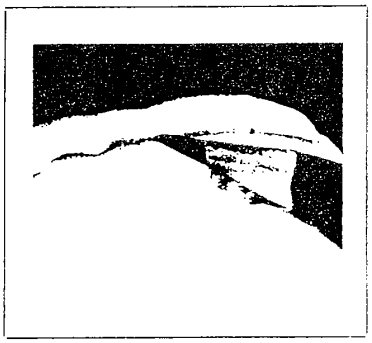
1. Taking an Impression

An impression is taken of the upper and lower jaw of a patient with malocclusion using an alginate impression material. A point to be careful about at this time is the necessity to capture as precisely as possible the gingivobuccal fold and the rearmost molar's back edges. This method uses the cement spatula which is generally used, and if plenty of previously prepared impression material is packed into the aforesaid area, a clear impression can be obtained.



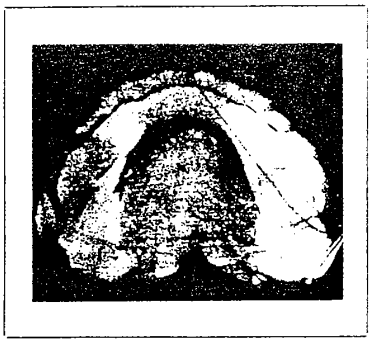
2. Inscribing Split Lines

After taking an impression, split lines are inscribed at the upper and lower jaws' impression inner surfaces (labial surfaces). This operation establishes the horizontal split needed when making the set-up model to be described later. That is, it establishes the reference surface for separating the dental arch portion and the base portion on the plaster model. The inscription position varies somewhat depending on the case, but in general is a horizontal line inscribed by pencil at a location about 5~8 mm above each dental neck line.



3. Primary Plaster Injection

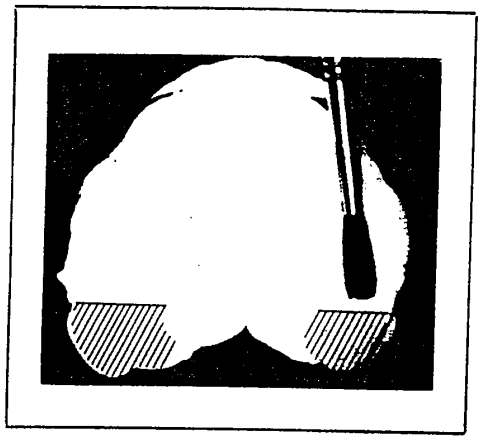
After the splint lines are inscribed comes plaster injection. First, soft plaster is poured in up to the split line as a primary plaster injection. A point to be careful about in this operation is extending the plaster and piling it on as far back behind the dental arch as possible. This operation makes it possible for the plaster model to be removed as a single block when separating it from the mold.



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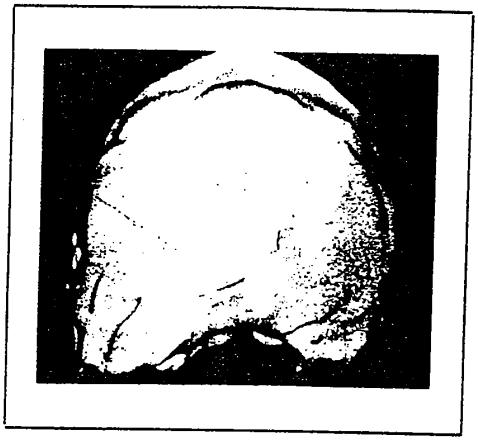
4. Coating with Plaster Release Agent

After the primary plaster hardens, a release agent (a generally used plaster release agent) is spread on the plaster surface with a brush. A point to be careful about in this operation is absolutely not applying the release agent to the rearmost molar's extension area (the area indicated by slanted lines). This is because the objective of this operation is to link the primary and secondary plaster (dental arch portion and base portion) in this extension area.



5. Secondary Plaster Injection

After applying the release agent, hard plaster (which should be colored) is poured in as a secondary plaster injection. The operation ends when the plaster fills the usual region. After the plaster hardens, the plaster model is carefully extracted. The dental arch and base area were previously linked at the rearmost teeth's back edges, so the plaster model can be easily removed from the impression surface as a single block.



6. Trimming the Plaster Model

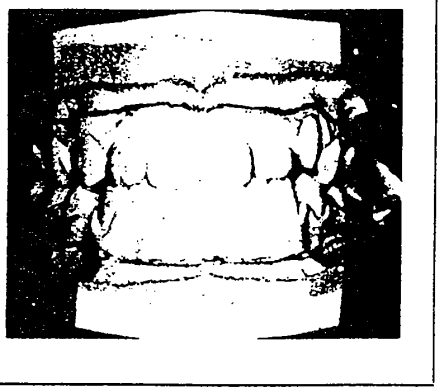
After separating the mold, surplus parts are carefully trimmed using the sort of plaster trimmer shown in the photo. First, peripheral surplus plaster is trimmed to match the configuration of the dentition. Then the previously noted link area (extension area) is carefully shaved off.



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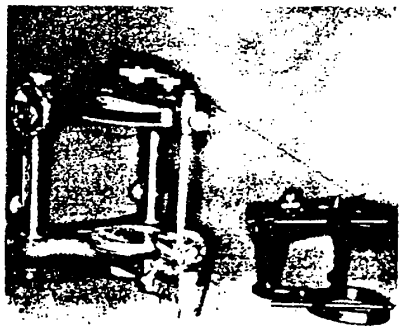
7. Completed Upper and Lower Jaw Plaster Model

The sort of procedure described above makes a plaster model of the upper and lower jaws for making a set-up model. After trimming ends, the dental arch model may fall out from the split line, so special caution is required in handling the plaster model. Furthermore, the split lines shown on the model are reinscribed in order to clarify their locations.



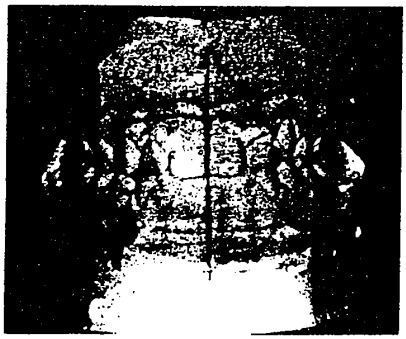
8. Selection of Articulator

When selecting an articulator a generally used one is sufficient, but it should be one capable of reproducing the jaw position, depending on the D.P. use objective and case specifics, and it should be one which can check jaw movement. For example, if used in the final stage of orthodontic treatment, it needs to be one capable of fine adjustment in order to study the occlusal relationship of the narrow part of the teeth. Here I shall introduce the articulators used by the author and others. The one on the left is a semi-adjustable Hanau (H2-XPR) articulator. The one on the right is a flat articulator (Unity) which is widely used because it is easy to operate in clinics.



9. Mounting the Plaster Model on the Articulator

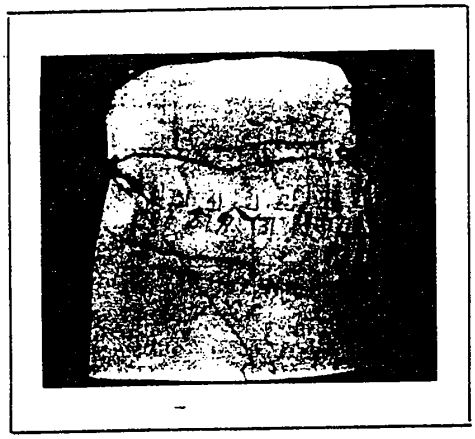
Generally speaking, there are two methods of mounting on an articulator. In one method it is mounted with the occlusal vertical dimension elevated (about 4 mm) in the patient's oral cavity (including the construction bite). The other method is to mount it in an intercuspal relationship. The former is used primarily for functional malocclusions or in cases where realignment involves overcorrection (extra tooth movement), which is often done in dynamic orthodontic treatment. The latter is used in the stage when dynamic orthodontic treatment ends. The first mounting method will be described later; here I shall describe the procedure for using the second mounting method.



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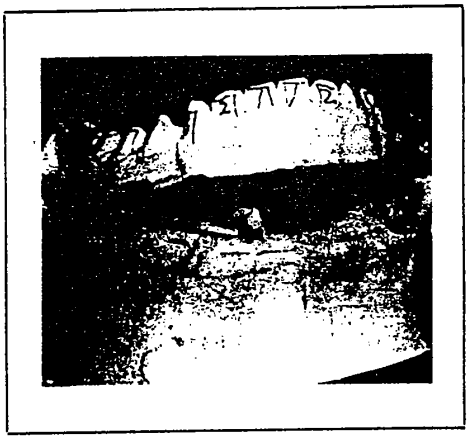
10. Dental Notation Inscription

With the plaster model of the upper and lower jaws in an intercuspated position, it is mounted on a Unity, and then the dental notation is written in pencil on the labial surface for all teeth. This is a preparatory operation which must be done before going to the next step (splitting the teeth).



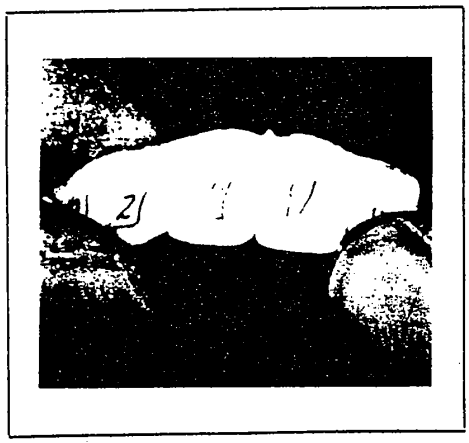
11. Horizontal Splitting of the Dental Arch

After inscribing the dental notation, the dental arch area is separated from the base area. First, a chisel is applied to the previously described split line and a light external force is applied and it is split from the base area. A release agent was previously applied to the split area, so this operation is easy. The essence of this is to separate the dental arch of the upper and lower jaws from the base.



12. Vertical Splitting of the Dental Arch

Now we shift to vertical splitting of the teeth. First, according to the basic principle of realignment (start from the dentition on one side), the blade of an electric saw is applied to the interproximal surface between the central and lateral incisors on both jaws, and cuts it vertically. The cutting direction is from the root toward the crown along a line extended along the interproximal surface. Splitting between the central and lateral incisors results in two unilateral dental arches; one is used for the splitting operation for set-up model realignment, and the other unilateral dental arch is temporarily returned to the articulator and secured in its original position with wax.



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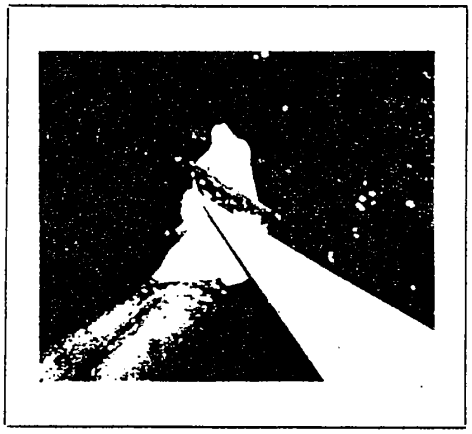
13. Vertical Splitting of Individual Teeth

As with the previously described operation, splitting individual teeth which are malpositioned is done by cutting from the root and stopping before the contact point. Then splitting each tooth is done by lightly holding it with the fingers. The decision about the split location and the number of teeth split varies according to how the set-up model is made. In other words, these factors are determined according to the D.P. treatment objective and treatment system.



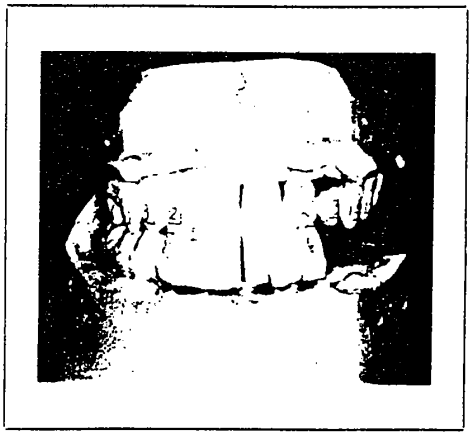
14. Root Trimming

After the tooth splitting operation ends, the plaster around the tooth root area is removed for 1~2 mm using a chisel to prepare for tooth realignment. The amount removed varies according to the tooth movement amount and movement direction. In cases where teeth are rotated or conspicuously crowded, it is necessary to remove a substantial 4~4 mm.



15. Tooth Realignment (From Unilateral Dental Arch)

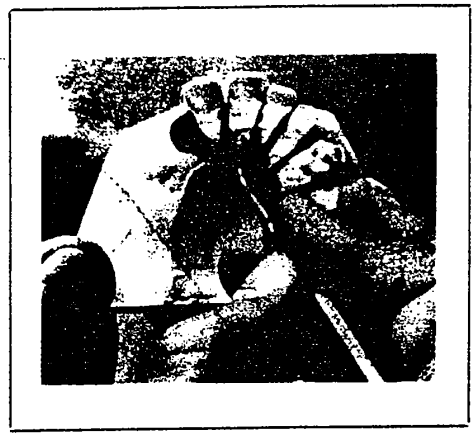
The method of realigning teeth is the most important point in the course of making a D.P. In other words, it is not exaggerating to say that the orthodontic treatment effect largely depends on the realignment method. These points are complicated and vary according to the case, so they will be described next time in the case reports. Here I shall describe the basic work operation. The general basic principle is that realignment starts from one side of the dentition, and moved teeth are temporarily mounted with utility wax.



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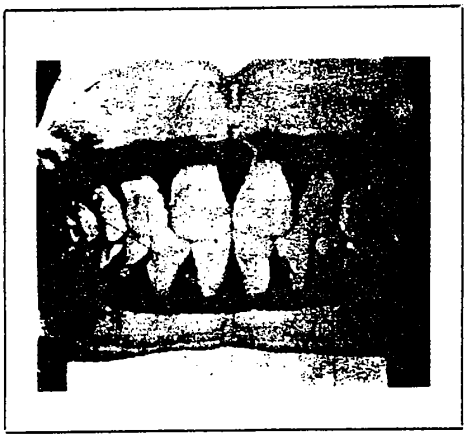
16. Tooth Realignment (Move to Opposite Side)

After realignment of one side ends, realignment then shifts to the opposite side. The reason for doing it from one side of the dentition in this manner is that the reference point for moved teeth is found from the dentition on the opposite side, and realignment is done by quantitatively finding the movement amount and movement direction. It is difficult to describe the amount of movement of individual teeth in simple terms, but from ample clinical experience the author and others have determined that the maximum movement amount for one tooth is 4 mm.



17. Completed Set-up Model

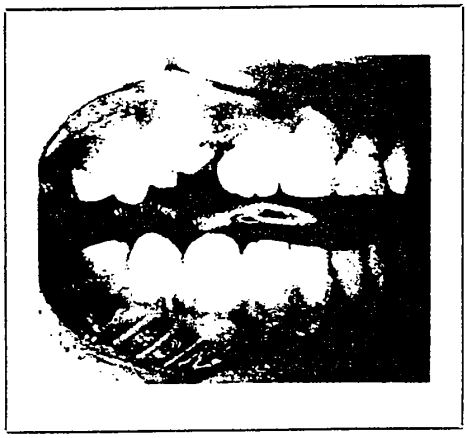
In a set-up model with a completed ideal realignment of teeth, the gingiva are molded by the usual method using paraffin wax (in essence the same as when making a prosthesis) and the model is finished. The set-up model shown in the photo is one in which all of the teeth are moved, but depending on the case there may be instances in which some are moved; this is determined by the D.P. treatment system. Next, an occlusal elevation (about 4 mm) is provided in the completed set-up model. This occlusal elevation is done with the articulator, and is done in order to register the wax bite used in the working model described later.



2. **The Bite Registration Method And Important Points When Realigning**

18. Registering a Bite With Construction Bite

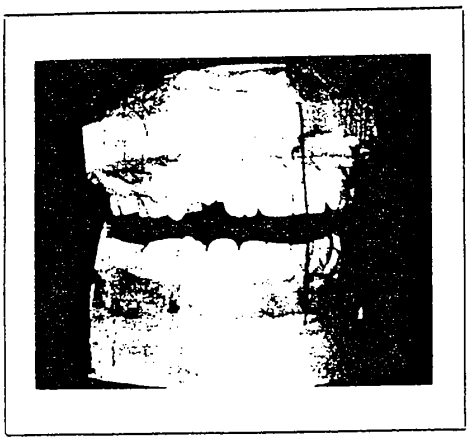
In cases in which the cause of malocclusion is believed to occur due to functional factors, a bite is taken with the construction bite (in the same sense as when making an F.K.O.) and a D.P. is made. That is, this is a method in which the mandible is moved from a temporary position to its latent proper position by artificial means. The picture shows a case diagnosed as functional reverse occlusion. The mandible is artificially shifted to a distal position (to the rear) and the bite is registered (anterior teeth 4 mm inter-incisal space).



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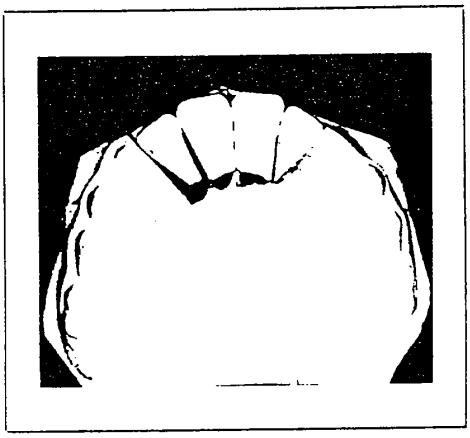
19. Articulator Mounting with Construction Bite

The wax bite registered in the case in Photo 18 is clamped in the plaster model and mounted on the articulator. This sort of method is generally used for articulator mounting in cases involving functional reversed occlusion. After mounting, the articulator's stopper or center pin is secured so that the articulator's vertical distance does not change. Then the wax bite registered from the patient is removed. Now teeth realignment (making a set-up model) begins with this open position.



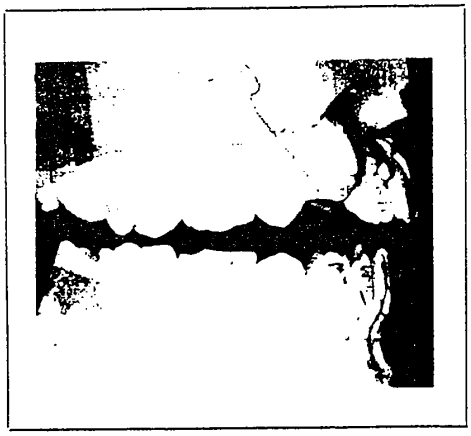
20. Realignment Using Construction Bite

The case in Photo 18 was diagnosed as functional reversed occlusion accompanying lingual inclination of the maxillary anterior teeth area. Therefore on set-up model No. 1 the maxillary anterior area in particular was aggressively expanded toward the lips (expansion amount = 3 mm) and realigned. This was a partial realignment carried out in the first stage in order to eliminate the harmful effect of premature contact, and was a method which utilizes the rubber's recovery force and muscle functional force for corrective force.



21. Set-up Model with Open Position

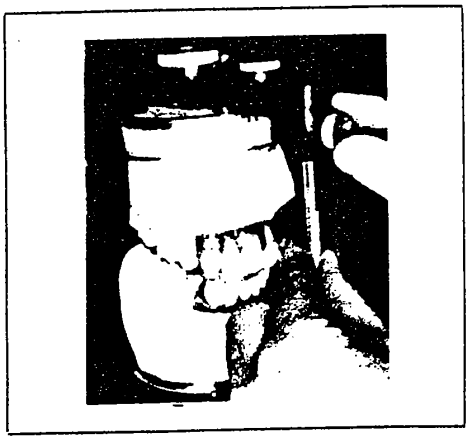
When making a set-up model with a construction bite, realignment is completed with the open position shown in the photo (the case from 18). This is a new method not seen in conventional methods. Also, in cases which do not present functional malocclusion, set-up models are often made with an opening. This is because the bite is taken in the position which is the patient's habitual closing motion (anterior teeth inter-incisal space 4 mm), and realignment is performed with the same sort of operation. If the set-up model has been completed, the wax bite for the working model (D.P. bite) is taken on the set-up model without changing the occlusal vertical dimension.



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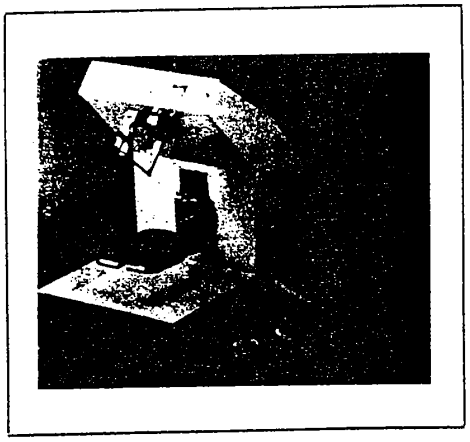
22. Articulator Mounting with Intercuspation

The method of articulator mounting in an intercuspated state conforms to the tooth positioner manufacturing method proposed by Kesling. That is, after realignment is completed, occlusal elevation is provided on the articulator (4 mm at the anterior area) and the wax bite for the working model is registered. Incidentally, a recognized defect resulting from providing occlusal elevation on the articulator in this method (hinged rotary motion) is that the subject's jaw orientation (particularly the vertical relationship) does not coincide, but at present it is a widely used method because tooth realignment can be studied with a construction bite when realigning.



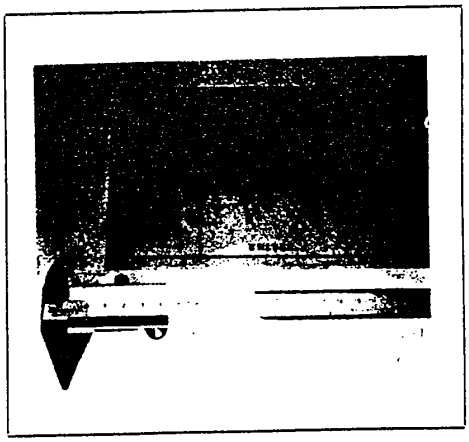
23. Electric Saw Used in Realignment

Vertical splitting of teeth requires an electric saw with a thin blade. The electric saw shown here is one developed especially for D.P. manufacture, so it is one which can cut the tooth from the dental arch safely and precisely. In addition, manual saws and disk-shaped cutters are commercially available, but for these uses one should use a saw that can work efficiently and quickly.



24. Materials Needed for Realignment

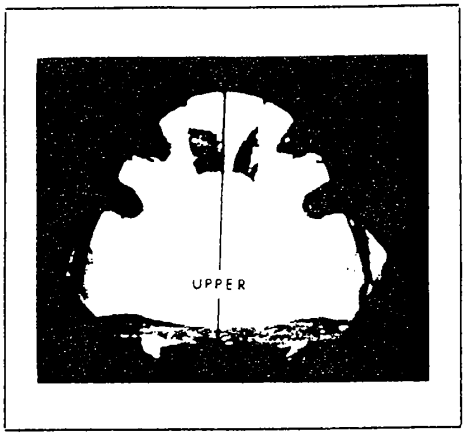
The materials used in a tooth realignment operation are a ruler, calipers, and an arch symmetry chart to check dentition symmetry. Using these materials makes it possible to precisely understand tooth movement when realigning.



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25. How to Use Arch Symmetry Chart

The arch symmetry chart is used to study the amount of tooth movement and dentition symmetry when making a set-up model. The photo shows various studies of dental arch status and symmetry after completion of the set-up model. This chart is very convenient, especially when determining the location of unerupted teeth or forming crowns (guiding an erupted tooth).

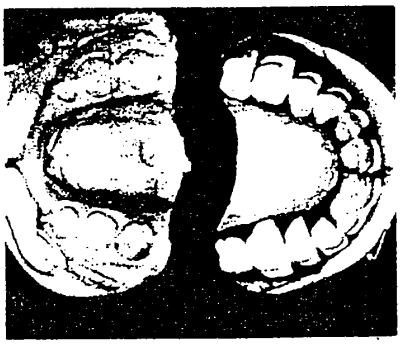


3. **From Making a Working Model to D.P. Investment**

26. Set-up Model Impression Taking

In order to make a working model after the set-up model is complete, an impression of the set-up model is taken by the usual method using alginate impression material. When doing so, the set-up model needs to be first immersed in water so that the plaster has an adequate moisture content.

The picture shows the impression taken from the upper jaw of a set-up model.



27. Making the Working model

After the impression is taken, hard plaster or ultrahard plaster is poured into the impression's inner surface and the working model is made. After the plaster hardens, the plaster models of the upper and lower jaw taken from the impression surface are trimmed of excess along the shape of the dental arch, and the working model is finished.

The picture shows the maxillary plaster model removed from the impression surface.

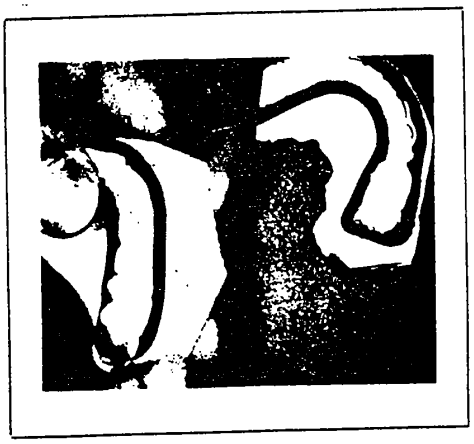


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28. Determining Outline and Boxing

The outline of the D.P. is established on the plaster model of the upper and lower jaws. The range for setting the outline varies greatly according to each case, but usually is drawn with a pencil and avoids the narrow bands located about 5~8 mm above the dental neck line. After the lines are drawn, a casting wax with diameter 2.5 mm is used and secured on the outline as shown in the photo for boxing

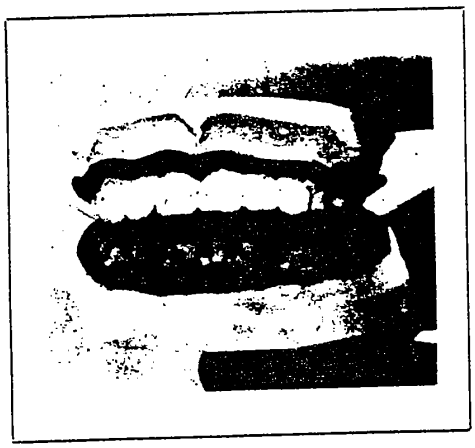
The photo shows upper and lower jaw working models being boxed.



29. Wax Bite for Working model

Next, the wax bite is bitten by the working model, and the upper and lower jaw molds are linked by wax. When doing so, the wax bite used is the wax bite registered on the set-up model as shown in 17.

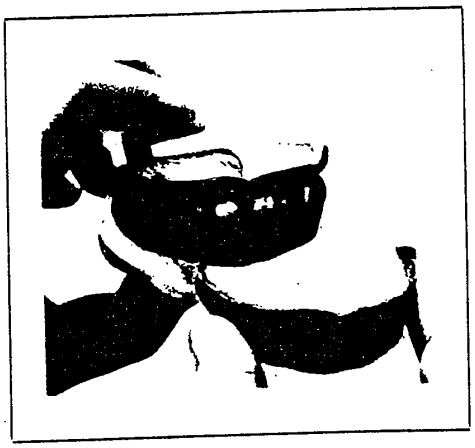
This photo shows the wax bite registered in 17 secured in the model.



30. Labial Surface Wax Formation

Now we shift to D.P. wax formation. First, a sheet of paraffin wax is softened, and this is placed on the boxed casting wax, and the paraffin wax is cut off along the shape of the outline using a chisel, and the D.P. labial surface is made.

The photo shows paraffin wax removal and D.P. labial surface formation.

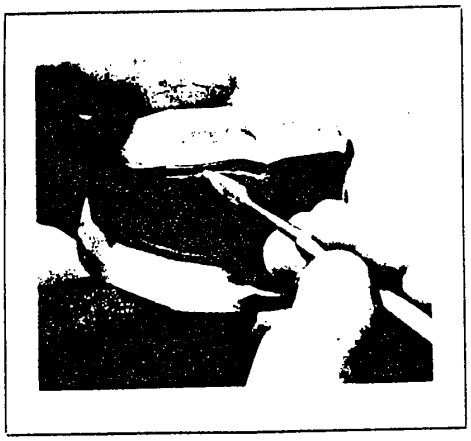


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31. Labial Surface Wax Operation

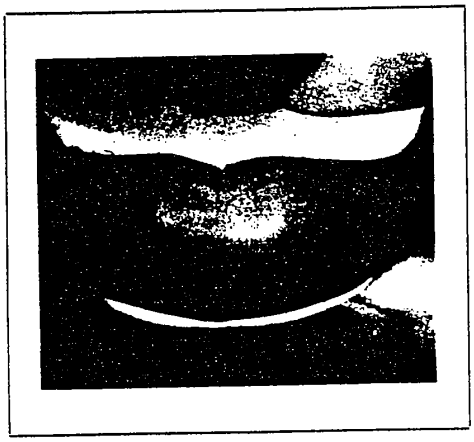
Next, the removed paraffin wax is connected to the boxed casting wax to make the D.P. labial surface. After the labial surface wax operation is complete, next comes lingual surface wax formation, and wax is piled up in the shape of the D.P.

The photo shows connecting the labial surface paraffin wax to the casting wax using a spatula.



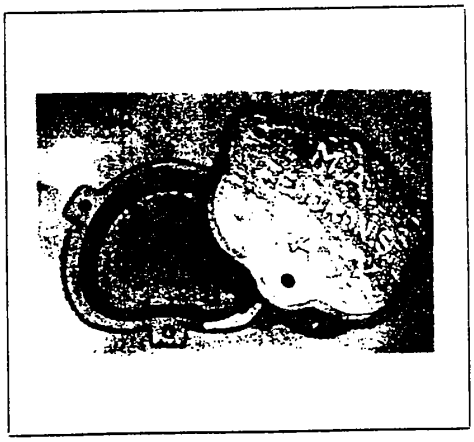
32. Completion of D.P. Wax Formation

The photo shows the status when D.P. wax formation is completed. At this time it is necessary to finish the wax surface by making it as smooth as possible. Then the base is trimmed and cut away to the precise outline of the plaster model.



33. Flask for Making Prosthesis

After wax formation ends comes the operation of working model investment using a flask. The investment operation uses a flask of the sort generally used for making a prosthesis (one divided into an upper and lower cover).

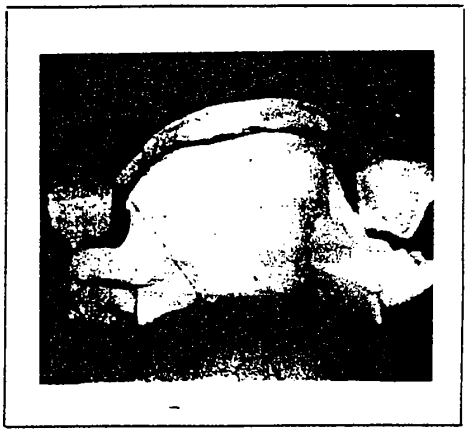


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34. Working model Investment Operation

In the working model investment operation the maxillary dentition is oriented downward and invested in the flask (lower cover) using soft plaster. When doing so, the formation of air bubbles at the wax surface formed on the model should be avoided by investing the surrounding area using leftover plaster.

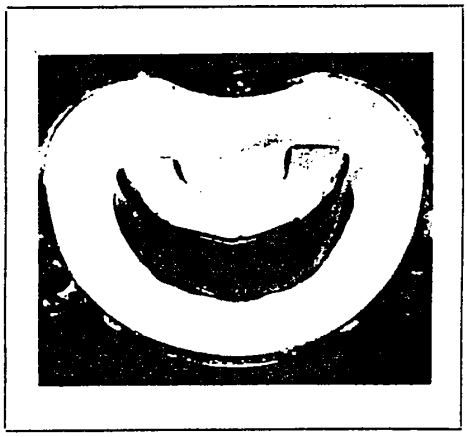
The photo shows primary investment with plaster around the working model.



35. Coating with Release Agent

After the maxillary dentition is invested in the flask's lower cover, a release agent is applied. First, the release agent is uniformly applied to the plaster surface (invested soft plaster) outside the model (mandibular dental arch's base surface).

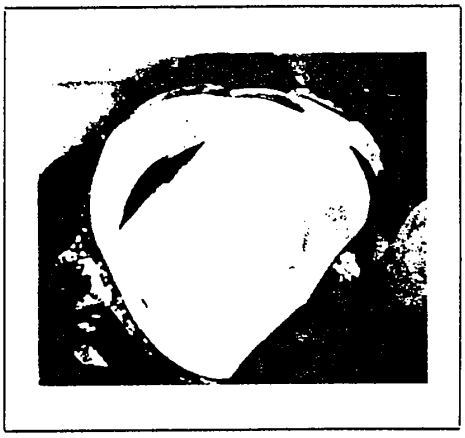
The photo shows completion of primary investment.



36. Completion of Working model Investment

After coating with the release agent, the working model is completely invested in the flask's upper cover using soft plaster. The formation of air bubbles in this investment operation can be prevented if plaster is injected atop a vibrator.

The photo shows secondary investment atop a vibrator.

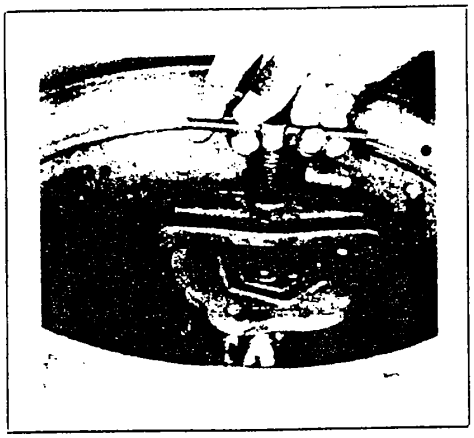


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37. Sprue Hole Operation

After the plaster hardens, a sprue hole is made in order to remove the paraffin wax inside the flask. Usually the flask is immersed in 60°C water for about five minutes, and the wax inside softens.

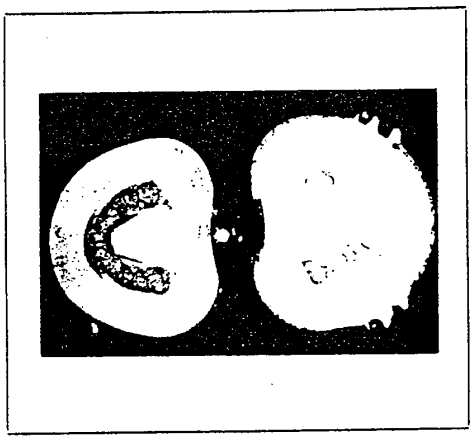
The photo shows the flask inserted in warm water.



38. Completion of Sprue Hole Operation

After the wax softens, the flask is removed from the warm water and the flask's upper cover and lower cover are separated. Then the softened wax is gently removed with a chisel, and wax is completely removed by an ordinary sprue hole operation.

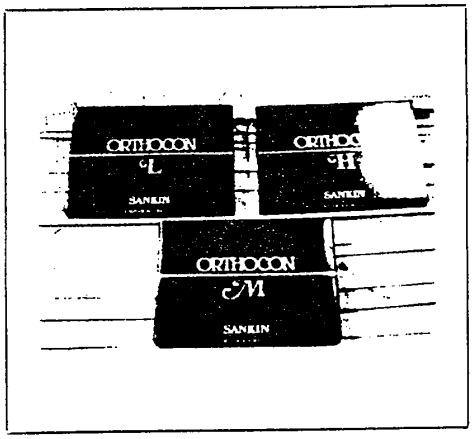
The photo shows the inside of the upper and lower jaw flask at completion of the sprue hole operation.



4. **From Orthocon Filling to Finishing**

39. Orthocon Selection

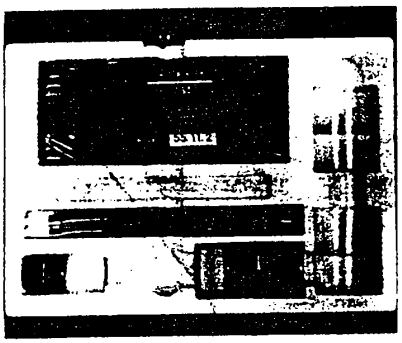
As described previously, Orthocon comes in a set of three rubber hardnesses: light-L, medium-M, and heavy-H. First, before filling with Orthocon, the type of Orthocon is selected according to the D.P. use objective and treatment system. For example, if the D.P. is to be used from the start of dynamic treatment, the basic principle is to use light-L, the softest material. Rubber hardness is gradually increased (M to H) while observing the treatment results.



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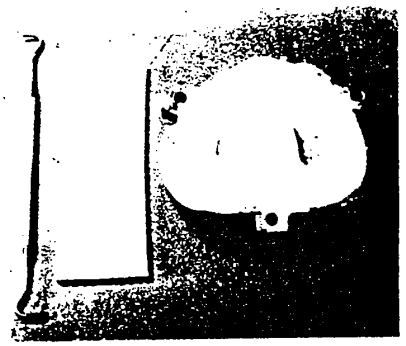
40. Facts about Orthocon

Orthocon consists of a heat-cured silicone resin (high grade) used for the main body and a room-temperature polymerized silicone resin (low grade) used for the coating material. The kit includes a stirring rod, brush, and stirring container. One Orthocon box can make four dynamic positioners.



41. Orthocon Filling Preparation

The Orthocon filling operation requires an upper and lower jaw flask with sprue hole completed, the Orthocon main body, and a filling rod (a tool used when filling the main body).



42. Orthocon Main Body Filling Operation

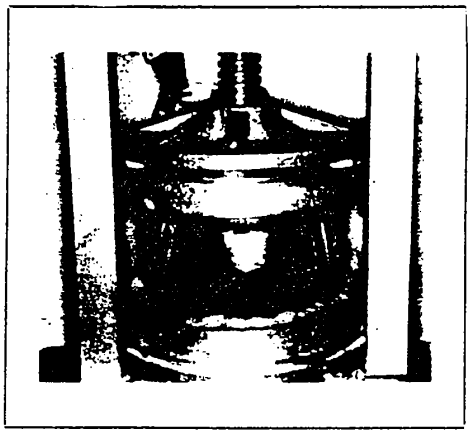
Next, the Orthocon main body (unvulcanized silicone resin with a curing agent already kneaded in) is loaded inside the flask. First, as shown in the photo, Orthocon formed in a rod-like shape is packed in from the maxillary dentition's labial surface using the filling rod. This must be done carefully because the maxillary labial surface has a narrow space between teeth and investment plaster surface.



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43. Trial Pressurizing

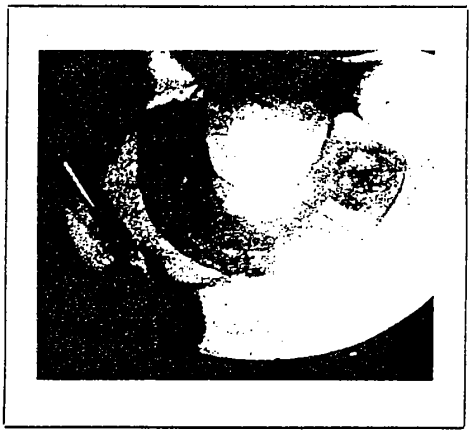
After the Orthocon has been put into the upper and lower jaw flask, it undergoes trial pressurization in a press in order to remove excess silicone resin. This operation closely resembles making a prosthesis, where a thin polyethylene film is interposed in the flask between top and bottom. Usually one or two trial pressurizations is sufficient.



44. Removal of Excess Silicone Resin

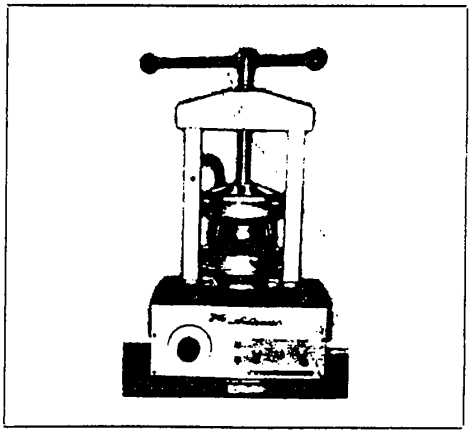
After trial pressurization ends the flask is split and the excess silicone resin (Orthocon main body) is completely removed using a chisel.

The photo shows removal of excess silicone resin squeezed out by the trial pressurization operation.



45. Orthocon Primary Vulcanization

Vulcanizing the Orthocon main body is divided into primary vulcanization and secondary vulcanization (post-vulcanization). Secondary vulcanization shall be described later; here I shall describe the primary vulcanization operation. First, after excess silicone resin is removed, a dry polymerizer like that shown in the photo (for making prostheses) is used, and primary vulcanization takes one hour at 100°C.



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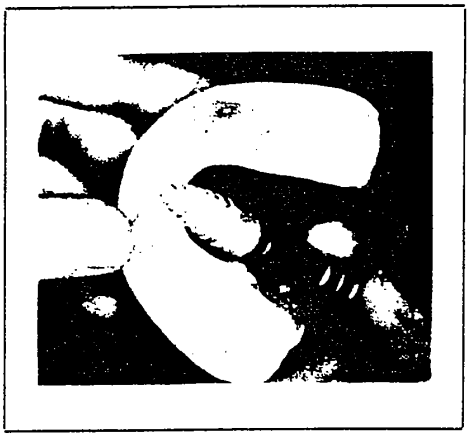
46. D.P. Release

After primary vulcanization ends, the D.P., which has become rubbery, is removed from the flask. This operation is done carefully by hand, as shown in the photo. Now, in clinical cases in which a second D.P. (made with different rubber hardness) is required, the mold is immediately refilled and another D.P. is made. The author and others prepare two dynamic positioners with different hardnesses when starting dynamic treatment and start treatment.



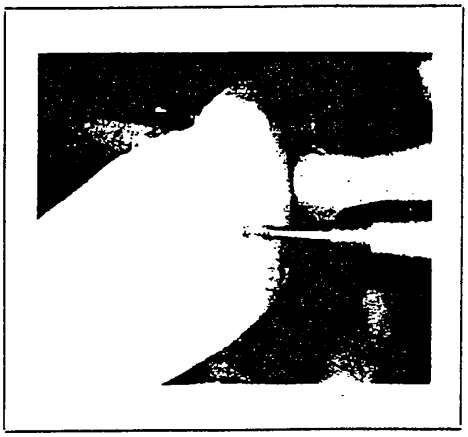
47. D.P. Polishing

After release from the mold, the surface of the formed D.P. is simply polished. Polishing at this stage can be adequately done using a rough paper cone, etc. The surface will be finished by a treatment method (coating with a coating material) to be described later.



48. Air Hole Perforation

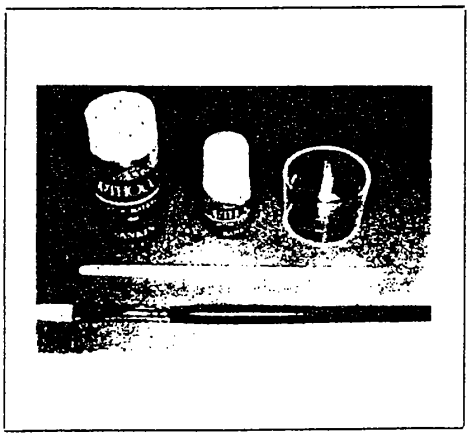
An air hole is provided in the D.P. surface. An air hole is usually made in the center of the D.P. using a thick fissure bar, but in cases involving special nasal problems it is necessary to provide three air holes, one in the center and at the left and right canines.



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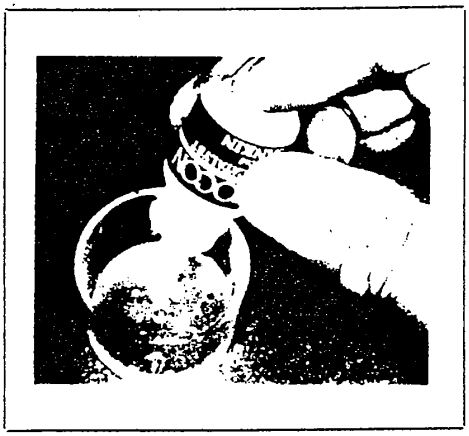
49. Preparing to Apply Coating Material

The Orthocon coating material consists of two liquids: a silicone resin base material and a catalyst. The kit also includes a container for mixing these resins, a brush, and stirring rod. These are readied to prepare for application.



50. Mixing the Coating Material

First, the coating material's base material is placed in the stirring container, and then an appropriate amount of the catalyst is added. The mixing ratio (weight ratio) is base material and catalyst 10:1. That is, 10% of the catalyst is added, relative to the base material. In general, the base material comes up to the third mark on the container, and 12~13 drops of catalyst are added to make the coating material for one case.



51. Stirring the Coating Material

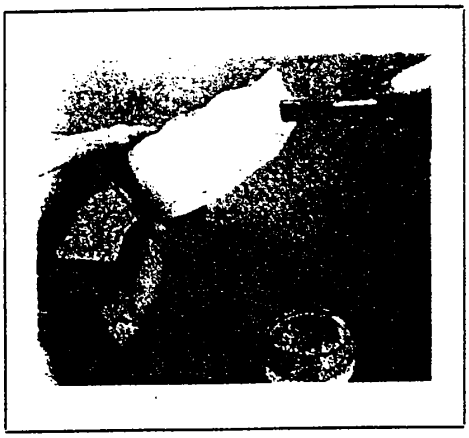
The silicone base material and catalyst placed in the stirring container are stirred for a few seconds. This prepares the coating material. Polymerization time at room temperature is very slow compared to other silicone resins, so the application operation can be done slowly.



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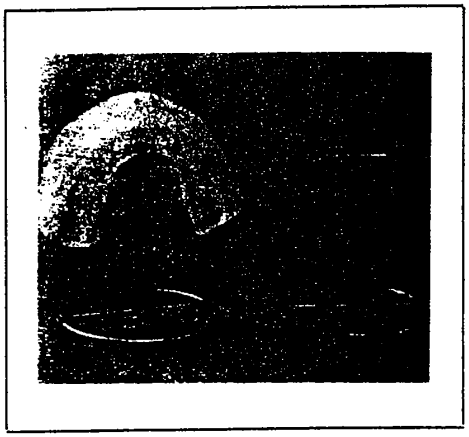
52. Applying the Coating Material

The prepared coating material is applied by slowly moving the brush from the D.P.'s labial surface to the lingual surface. When doing so, put enough coating material on the brush and apply it so that the D.P. surface is uniformly covered. A single application is sufficient.



53. Special D.P. Stand

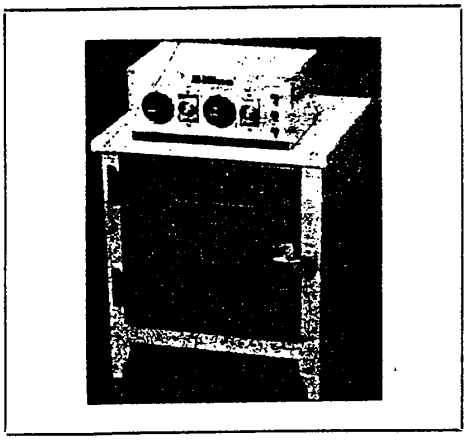
When coated with the coating material the D.P. becomes very transparent. Incidentally, this operation is a method conceived of using hints obtained from the D.P. surface treatment method using a polyurethane resin which the author and others proposed earlier. After the coating is applied, the D.P. is secured on the special D.P. stand using the air hole.



54. Use of Dryer

After the coating material has been applied, the D.P. is placed in a dryer, and the coating material is dried and secondary vulcanization (post-vulcanization) of the Orthocon main body continues.

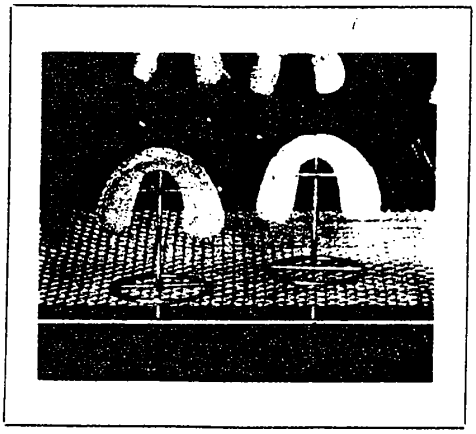
The photo shows an Air Bus™ newly developed for this operation. It is a dryer designed so that temperature and timer operate automatically.



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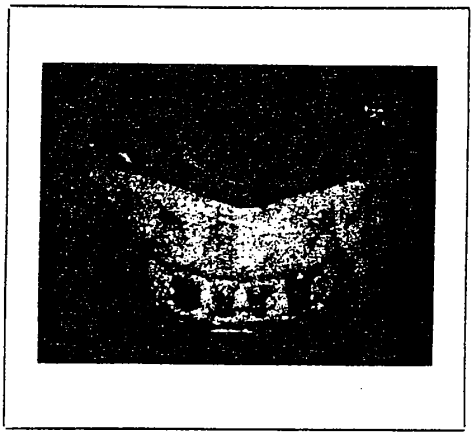
55. Drying the Coating Material, and Secondary Vulcanization of Orthocon

The D.P., mounted on its stand, is heated inside the dryer in order to dry the coating material and carry out secondary vulcanization (known as post-vulcanization) of the silicone resin. First and initially, in order to dry the coating material, heating begins at room temperature and rises to about 70°C, and in 40 minutes the coating is dried. Then the temperature inside the dryer is raised to 180°C and the Orthocon main body undergoes secondary vulcanization for two hours. This operation is carried out in order to heighten the silicone resin's mechanical properties.



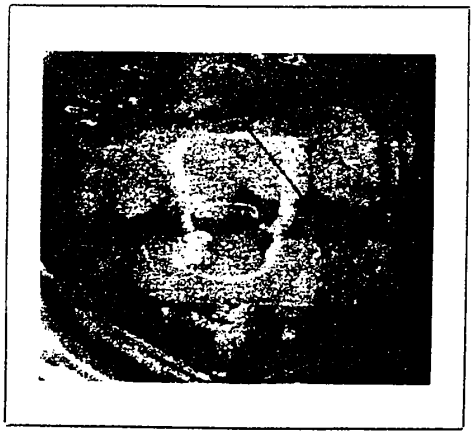
56. D.P. Completion

The photo shows a D.P. which has completed secondary vulcanization. It has superior mechanical properties, and overall is a milky white, but highly transparent, and has a smooth surface. This is the completed D.P.



57. Installing D.P. in Oral Cavity

When installing the D.P. in the oral cavity, it is first boiled for about 10 minutes to sterilize it. Since the D.P. is transparent, observing the teeth and the tissue around them is easy. This has great significance for orthodontic clinics.



In the foregoing I gave a brief introduction of the D.P. manufacturing process and points to be aware of when making it. Next I want to introduce the latest configuration of the D.P.

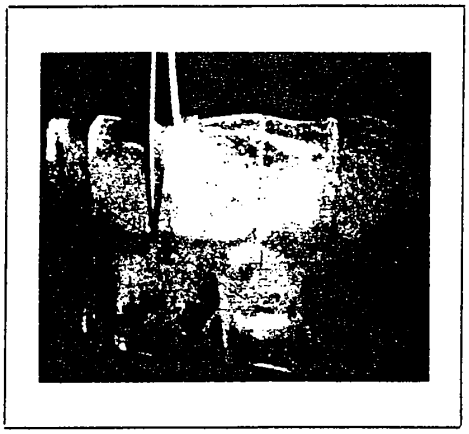
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II. New D.P. Configuration and Clinical Applications (58~68)

The effect of D.P. treatment depends largely on the amount of movement of the teeth realigned on the mold. That is, the method of making the set-up model becomes an important key to obtaining superior treatment results. Incidentally, in an earlier report the author and others advocated the necessity of aggressive tooth realignment (maximum movement amount 4 mm). However, if teeth are moved a large amount on the set-up model, naturally it will not be possible to wear the D.P. in a stable position in the mouth. The significance of this has already been provided by the principle that tooth movement distance when realigning and D.P. stability are inversely correlated. Suppose we examine, from an orthodontics perspective, an instance in which a tooth is moved a great deal when realigning. It becomes an orthopedic appliance which ignores the basic principle of orthodontic treatment, namely, the action and reaction of orthodontic force, so one can not hope to achieve a therapeutic result. Therefore the author and others partially modified the conventional configuration (tooth positioner), and combined it with other orthodontic appliances (for example, extraoral retainers), and thereby studied ideal and biological movement of the tooth, and used it for many malocclusions. As a result, we found that it is necessary to modify the D.P. configuration according to the type of malocclusion. Here I shall introduce D.P. modification methods and new D.P. configurations, and briefly note their clinical applications.

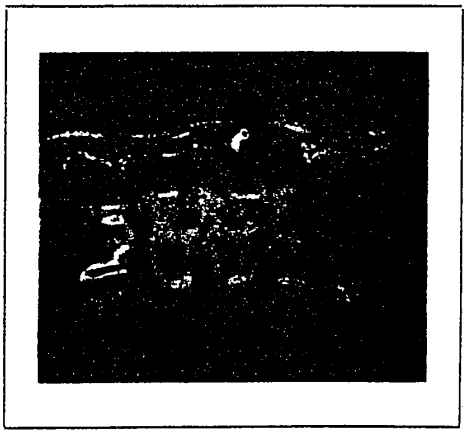
58. Crowding: Labial Surface Modification

In cases with pronounced crowding, a cut is made in the crowding area and the corrective force is partially divided, and a light orthodontic force is applied to the tooth. As shown in the photo, this method involves inserting scissors proximal to the crowding area and inserting a cut with their tip. The author and others call this method the "cutting method"; it is widely used in clinics.



59. Crowding: Lingual Surface Modification

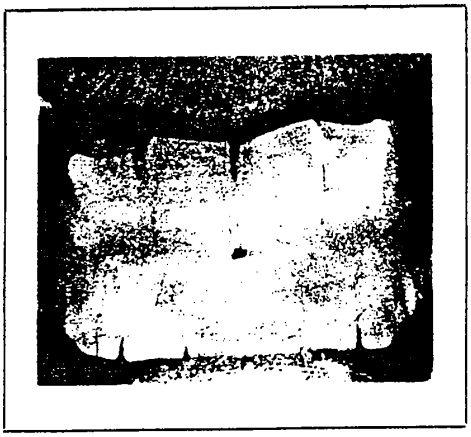
In cases with crowding, a cut is inserted at the region shown in Photo 58 when the tooth exhibits pronounced linguoversion. Usually just a vertical cut is inserted, but when the linguoversion is pronounced a V-shaped horizontal cut is inserted, and a rubber flap is formed. This rubber flap applies continuous corrective force to the tooth, and moves it to the ideal position.



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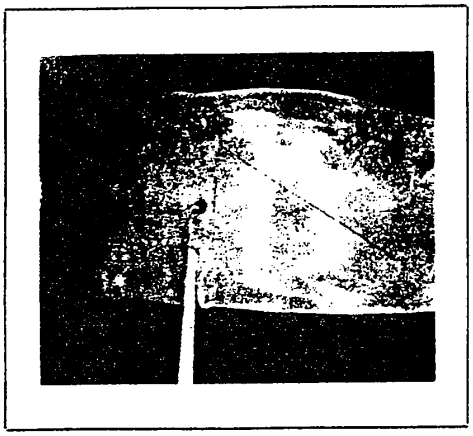
60. Crowding: Being Worn in Oral Cavity

This is the situation when a D.P. modified by the cutting method is worn in the oral cavity. A divided rubber piece inclines toward the lips at an anterior tooth in labioversion. Thus the corrective force applied to the tooth changes to a light continuous force, and the tooth moves biologically. Clinically, this is an application method generally used when starting dynamic treatment. Cuts are made by the same method in the molar region when there is a large amount of movement on the set-up model.



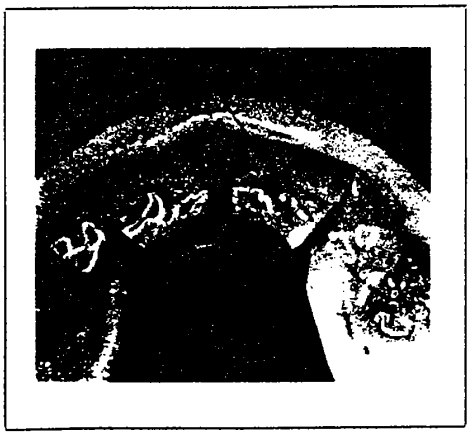
61. Mandibular Protrusion: Labial Surface Modification

In cases of mandibular protrusion, the cutting method is applied and a cut is inserted at the mandibular anterior labial surface. In general, cuts are inserted between the mandibular central incisors and distally and proximally to the lateral incisors on both sides.



62. Mandibular Protrusion: Lingual Surface Modification

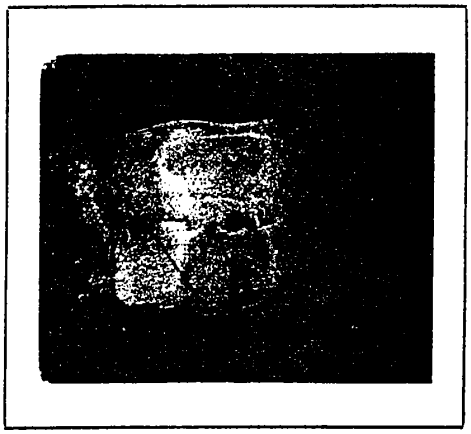
In cases of mandibular protrusion, when the amount of tooth movement when realigning is particularly large, a cut needs to be inserted at the maxillary anterior area lingual surface. In this case, a vertical V-shaped cut is inserted in the saggital area and the lateral incisor distal surface. Also, depending on the circumstances, a V-shaped horizontal cut may be inserted in the same manner as in Photo 59.



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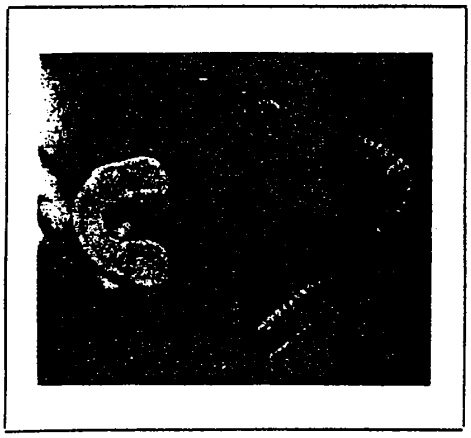
63. Mandibular Protrusion: Being Worn in Oral Cavity

When a D.P. modified in this manner is worn in the patient's oral cavity, a reverse V-shaped space appears at the area where the cut was inserted. In instances of skeletal mandibular protrusion this method must be used because the amount of movement on the set-up model is large.



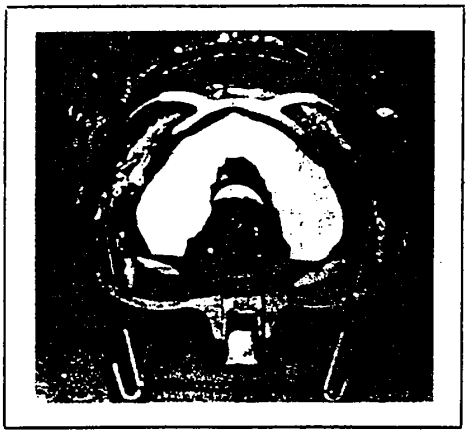
64. Maxillary Protrusion: D.P. with Headgear

In cases with pronounced maxillary protrusion, a new type of D.P. is used which has headgear directly encased in the D.P. Naturally it is secured behind the head or neck. In cases with mixed dentition arches this effectively achieves the D.P. effect and produces superior therapeutic results.



65. Maxillary Protrusion: How to Invest Headgear

The flask investment method for a D.P. with headgear is to invest it in the flask with the headgear attached as shown in the photo. Two cut holes are provided in the rear of the flask, and the headgear's outerbow is externally exposed from that groove. The Orthocon filling method is the same as the generally used method.



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66. Maxillary Protrusion: Being Worn in Oral Cavity

The photo shows a D.P. with headgear being worn in the oral cavity. When there is crowding in the maxillary anterior area, it may be necessary to apply the cutting method as described in 61 and insert a cut. This case shows a situation in which the D.P. is used with cuts at two locations distal to both maxillary lateral central incisors.



67. D.P. for One Jaw

A D.P. for one jaw is used in instances in which the improper area is limited to one jaw. It is particularly useful if used as a retainer after dynamic treatment.



68. D.P. for One Jaw Being Worn in Oral Cavity

The photo shows a D.P. for one jaw being worn in the oral cavity. It is effective for mild single-jaw malocclusions, and is particularly useful if used in cases in which mandibular anterior teeth shift to the rear, which often occurs after dynamic treatment.



In the foregoing, I introduced the D.P. manufacturing procedure and described newly conceived D.P. configurations and clinical applications. Next time I want to focus on therapeutic effects and case reports using these dynamic positioners.

(To be continued. References combined in final article.)

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編集
執筆
B5判
定価 5,000円
〒200円

監修
執筆
B5判
定価 3,000円
〒200円

著
A5判
定価 3,500円
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著
A5判
定価 2,500円
〒200円

著
B5判
カラー76葉
定価 4,200円
〒200円

著
B5判
定価 7,000円
〒240円

編集
執筆
A4判
定価 3,500円
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Nippon Dental Rev.
V. 454 p. 107-130

新しい矯正装置　ダイナミック　ポジショナー(D.P)　の研究

——Ⅱ．D.Pの製作手順と臨床応用——

吉井　修（よしい　おさむ）
（関東逓信病院歯科医長）

はじめに

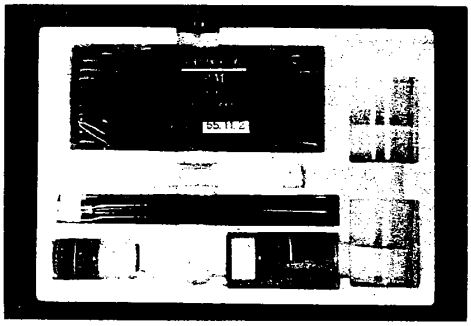
前回（No.452　55年6月号）は，筆者らが考案したダイナミック　ポジショナー（矯正治療の開始から保定まで，金属線やブラケット類を一切使用せず，ゴム素材の復元力を利用して不正位にある顎や歯を理想とする位置にオートマチックに動かすことができる可撤式の矯正装置）の概要とこれを製作するための透明な熱硬化型シリコーン樹脂（オーソコン）の試作と実用化，ならびにこれらの基礎的な研究について報告した．

今回は，矯正技工の立場から，実際にこのD.Pをどのようにして製作するかといった技工操作に焦点を合わせて，D.Pの製作手順の紹介と新しく考案したD.Pの形態ならびに臨床応用についてその概要を簡単に紹介してみたい．

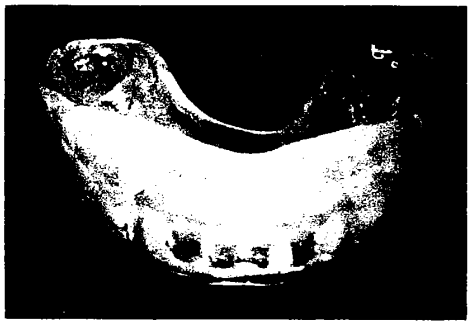
まず，オーソコン(製品名)を使用して製作するD.Pの製作手順を説明する便宜上

1. 印象採得から set-up model の製作まで
2. 咬合採得法と再排列時の要点について
3. 作業用模型の製作から D.P の埋没操作まで
4. オーソコンの充塡操作から仕上げまで

の4項目に分けて，その内容を図解し，また製作上の注意点などを述べながら順次紹介してみよう．



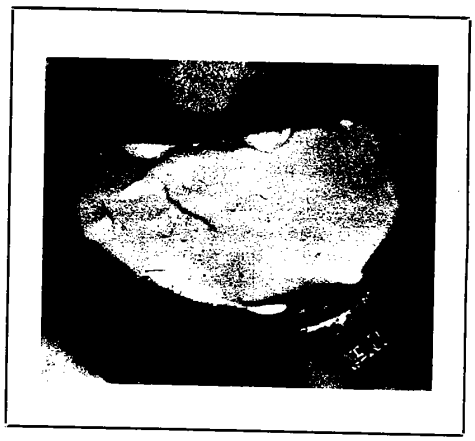
オーソコン(製品名)は，本体と coating 材から成り，D.P の使用目的や治療方針によってゴムの硬さを選択できるように3種類（L.M.Hと硬度が増す）のセットから作られている．



オーソコン（熱硬化型シリコーン樹脂）を用いて製作したダイナミック　ポジショナー(D.P)，大変透明性に富み，無味無臭，しかも機械的特性に優れたゴム素材から作られている．

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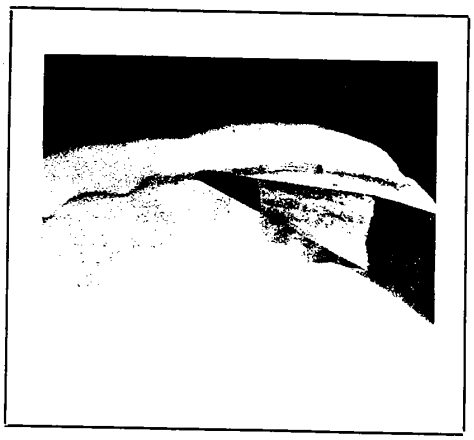
〔I〕D. P の製作手順 (*1*～*57*)



1. 印象採得から set-up model の製作まで

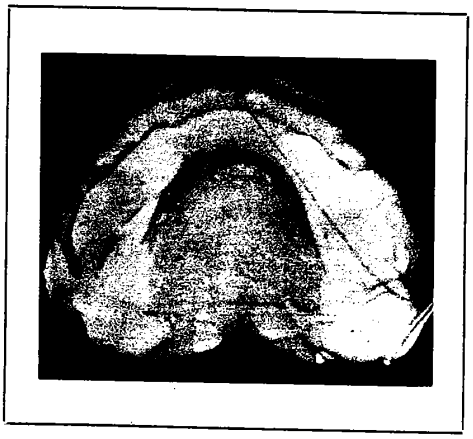
1 印象採得

不正咬合者の上下顎をアルジネート印象材を用いて印象採得を行う．この時注意する点は，特に頬移行部と最後臼歯部後縁をできるだけ正確に採得する必要がある．この方法には，一般に用いられているセメントスパチュラなどを使用して，あらかじめ余分な印象材を上記部位に装塡しておくと明瞭な印象が得られる．



2 分割線の記入

印象採得後，上下顎の印象内面（唇側面）に分割線を記入する．この操作は，後述する set-up model の製作時に必要となる水平的分割，すなわち，石膏模型上で歯列弓の部分と基底部を分離するための基準面の設定として行われる．記入部位は，症例によって多少異なるが，一般的に各歯頸線上約5～8 mm の位置に水平線として鉛筆で記入する．



3 第1次石膏注入

分割線を記入したのち，石膏注入に移る．まず，第1次石膏注入として軟石膏を分割線まで流し込む．この操作で注意する点は，できるだけ歯列弓の後方部位まで石膏を延長して盛り上げる．この操作は，離型時に石膏模型を一塊のブロックとして取り出すための便宜的操作といえる．

4 石膏分離材の塗布

第1次石膏硬化後，石膏
用いられている石膏分離材
の操作で注意する点は，最
線で示した部分）には絶対
ことである．この操作は，
と第2次石膏（歯列弓の
る目的があるためである．

5 第2次石膏注入

分離材塗布後，第2次
（着色した石膏がよい）
る要領で石膏を盛り上げ
化後，石膏模型を慎重に
臼歯部後縁で歯列弓と基
っているので，石膏模型
容易に印象面から取り出

6 石膏模型のトリミン

離型後，図で示すよう
て余剰な部分を慎重にト
初に歯列の形態に合わせ
リミングする．つづいて
長部分）を注意しながら

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ip model の製作まで

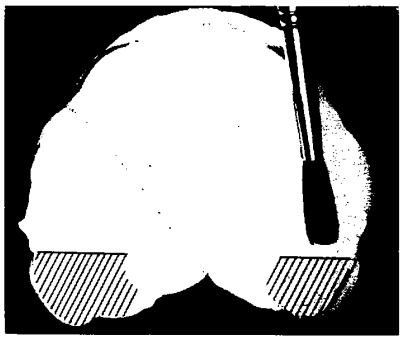
ルジネート印象材を用
時注意する点は，特に
縁をできるだけ正確に
方法には，一般に用い
ュラなどを使用して，
上記部位に装填してお
う．

印象内面（唇側面）に分
作は，後述する set-up
る水平的分割，すなわ
部分と基底部を分離す
て行われる．記入部位
るが，一般的に各歯頸
水平線として鉛筆で記

石膏注入に移る．まず，
石膏を分割線まで流し込
点は，できるだけ歯列弓
長して盛り上げる．この
型を一塊のブロックとし
操作といえる．

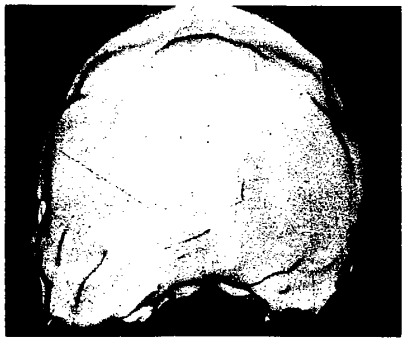
4 石膏分離材の塗布

第1次石膏硬化後，石膏表面に分離材（一般に用いられている石膏分離材）を筆で塗布する．この操作で注意する点は，最後臼歯の延長部分（斜線で示した部分）には絶対に分離材を塗布しないことである．この操作は，この延長部分で第1次と第2次石膏（歯列弓の部分と基底部）を連結する目的があるためである．



5 第2次石膏注入

分離材塗布後，第2次石膏注入として硬石膏（着色した石膏がよい）を流し込み，通常行われる要領で石膏を盛り上げ操作を終了する．石膏硬化後，石膏模型を慎重に取り出す．すでに，最後臼歯部後縁で歯列弓と基底部が結合した状態になっているので，石膏模型は一塊のブロックとして容易に印象面から取り出すことができる．

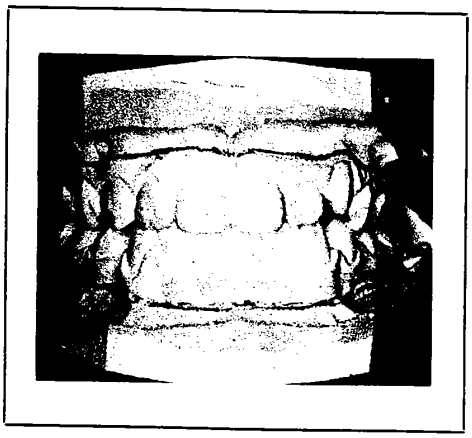


6 石膏模型のトリミング

離型後，図で示すような石膏トリーマーを用いて余剰な部分を慎重にトリミングする．まず，最初に歯列の形態に合わせて周囲の余剰な石膏をトリミングする．つづいて，前記した結合部分（延長部分）を注意しながら削り落とす．

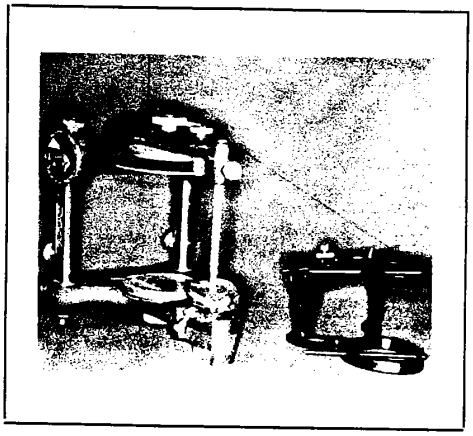


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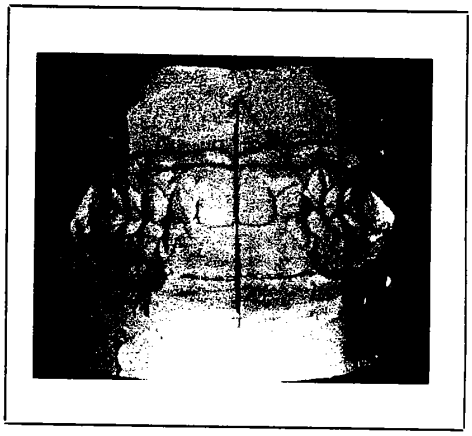
7 完成した上下顎石膏模型

以上のような手順で set-up model 製作用の上下顎石膏模型を製作する．トリミングを終了した石膏模型は，分割線から歯列弓の模型が脱落する状態になるので，その取り扱いには特に注意が必要である．なお，模型上に示した分割線は，その位置を明示する意味からのちに再記入したものである．



8 咬合器の選択

咬合器の選択は，一般的に用いられているもので十分であるが，D.P の使用目的や症例によっては顎位の再現性の可能なもの，また顎運動をチェックできるものが望ましい．たとえば，矯正治療の最終段階に使用する場合などでは，細部の歯の咬合関係を検討する目的から微調節のできるものが必要となる．ここで，筆者らが使用している咬合器を紹介してみよう．左側は，半調節型の Hanau（H2-XPR）の咬合器，右側は，臨床的にその操作が簡便であるという理由から広く普及している平線咬合器（Unity）である．



9 石膏模型の咬合器付着

咬合器への付着方法は，大別すると２種類の方法がある．一方は，患者の口腔内で咬合高径を挙上（約 4 mm）した状態（構成咬合位を含む）で付着する方法，他方は，咬頭嵌合位で付着する方法である．前者は，主に機能的不正咬合者を対象とする場合，また，動的矯正治療中にしばしば行う over correction（過度の歯の移動）を再排列時に行う症例などに用いられ，後者は，動的矯正治療を終了する段階に用いられる．前者の付着方法については後述することにして，ここでは，後者の付着方法で行った手順について述べる．

10 歯式の記入

上下顎の石膏模型を咬
Unity の咬合器に付着した
側面に歯式を鉛筆で記入す
ップ（歯の分割操作）に入
準備の操作となる．

11 歯列弓の水平的分割

歯式の記入後，基底部
する．まず，前述した分
な外力を加えて基底部か
部位には分離材が塗布し
容易に行える．このよう
弓を基底部から分離する．

12 歯列弓の垂直的分割

これより，歯の垂直的
列を行う原則（片側歯列
上下顎両側中切歯隣接面
的に切り込みを入れる．
向から歯冠方向に向けて
る．両側中切歯間で２分
うは，一方を set-up m
た分割操作に使われ，他
器上に戻し，元の位置に

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…膏模型

…set-up model 製作用の上…る．トリミングを終了した…ら歯列弓の模型が脱落する…取り扱いには特に注意が必…上に示した分割線は，その…らのちに再記入したもので…

…般的に用いられているもの…の使用目的や症例によって…なもの，また顎運動をチェ…しい．たとえば，矯正治療…場合などでは，細部の歯の…的から微調節のできるもの…筆者らが使用している咬合…左側は，半調節型の Hanau…右側は，臨床的にその操作…由から広く普及している半…ある．

…付着

…は，大別すると2種類の方…者の口腔内で咬合高径を半…態（構成咬合位を含む）で…，咬頭嵌合位で付着する方…に機能的不正咬合者を対象…的矯正治療中にしばしば行…度の歯の移動）を再排列時…いられ，後者は，動的矯正治…いられる．前者の付着方法…とにして，ここでは，後者…順について述べる．

10 歯式の記入

上下顎の石膏模型を咬頭嵌合位の状態で，Unity の咬合器に付着したのち，すべての歯の唇側面に歯式を鉛筆で記入する．これは，次のステップ（歯の分割操作）に入る前に必ず行われる前準備の操作となる．



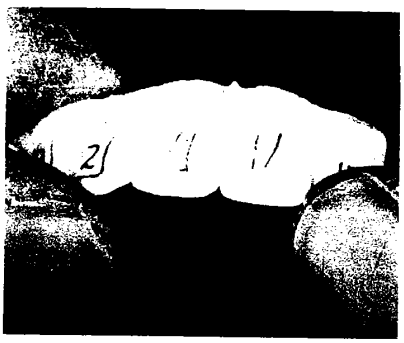
11 歯列弓の水平的分割

歯式の記入後，基底部から歯列弓の部分を分離する．まず，前述した分割線に彫刻刀をあて軽度な外力を加えて基底部から分割する．すでに分割部位には分離材が塗布してあるので，この操作は容易に行える．このような要領で，上下顎の歯列弓を基底部から分離する．

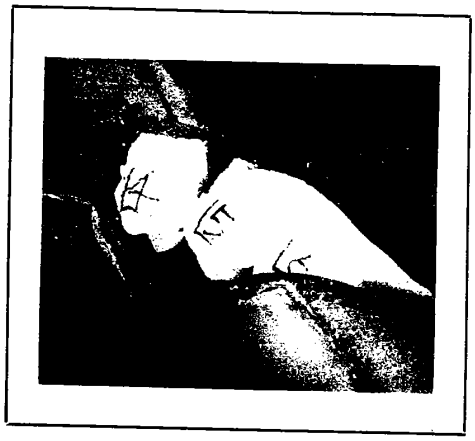


12 歯列弓の垂直的分割

これより，歯の垂直的分割に移る．まず，再排列を行う原則（片側歯列から開始する）に従って，上下顎両側中切歯隣接面に電動鋸の刃を当て垂直的に切り込みを入れる．切り込む方向は，歯根方向から歯冠方向に向けて隣接面延長線上で行われる．両側中切歯間で2分割された2個の片側歯列弓は，一方を set-up model の再排列を目的とした分割操作に使われ，他の片側歯列弓は一時咬合器上に戻し，元の位置にワックスで固定される．

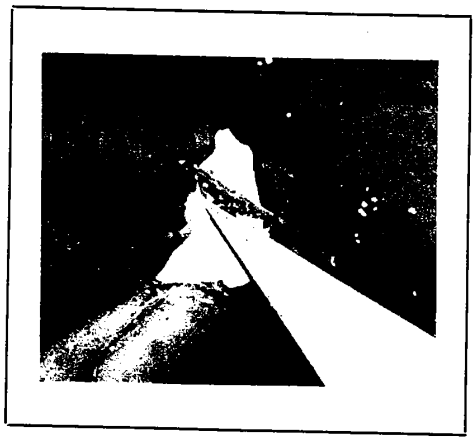


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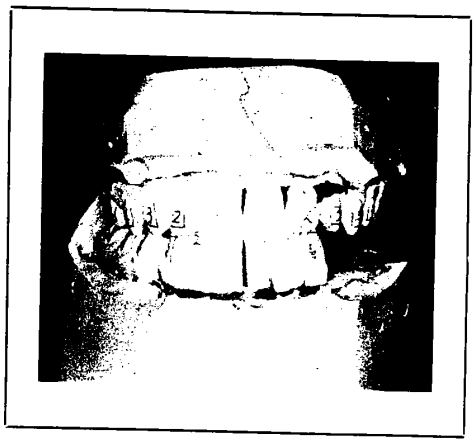
13 個々の歯の垂直的分割

不正位にある個々の歯の分割操作は，前記した操作と同様に，歯根方向から切り込みを入れて，contact point の手前で止める．その後，各歯の分割は，指をもって慎重に行う．分割部位や分割する歯数の決定は，どのような set-up model を製作するかによって異なる．換言すれば，D.P の治療目的や治療方針によってこれらは決定される．



14 歯根部のトリミング

歯の分割操作を終了したのち，歯の再排列の前準備として歯根部周囲の石膏を 1 ～ 2 mm 彫刻刀を用いて削剝する．この削剝量は，歯の移動量や移動方向によって異なる．特に，捻転歯や叢生の著しい症例などでは，4 ～ 5 mm と大きく削り取ることも必要となる．



15 歯の再排列（片側歯列弓から）

歯の再排列の方法は，D.P の製作過程の中で最も重要なポイントといえる．換言すれば，この再排列の方法によって矯正治療の効果が大きく左右されるといっても過言ではない．これらの点については，症例によって種々様々であるので次回の症例報告で述べることとして，ここでは，あくまでも基本的な技工操作について述べてみよう．一般的な原則として，再排列は片側の歯列から開始され，移動歯はユーティリティ・ワックスで仮着される．

16 歯の再排列（反対側に

片側歯列の再排列が終了し
対側の再排列に移る．この
う理由は，移動歯の基準点
め，移動量や移動方向を定
を行うためである．個々の
一言で表現することは難し
の臨床経験から 1 歯の最大
ている．

17 完成した set-up mod

歯の理想的な再排列を
は，通常の方法（義歯製作
フィン・ワックスを用いて
げる．図に示した set-up
たものであるが，症例に
る場合もあり，これらは
て決定される．次に，完
で咬合挙上（約 4 mm）を
咬合器上で行われ，後述
る wax bite を採得する

2. 咬合採得法と再排

18 構成咬合位による

不正咬合の原因が，機
たと思われる症例では，
時と同じ意味）で咬合採
る．すなわち，下顎骨を
が潜在的に有している
動する方法である．図
された症例で，下顎を
動して咬合採得（前歯
ているところである．

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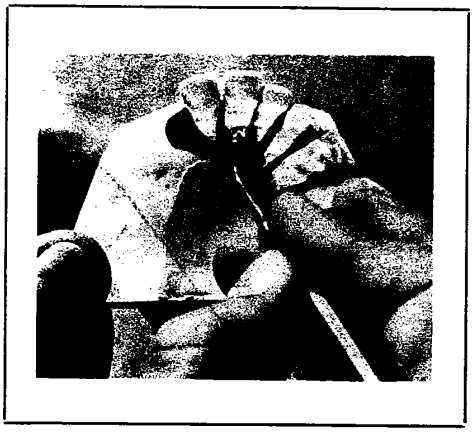
分割
歯の分割操作は，前記した
刃から切り込みを入れて，
で止める．その後，各歯の
宜に行う．分割部位や分割
ような set-up model を製
う．換言すれば，D.P の治
ってこれらは決定される．

グ
ったのち，歯の再排列の前
の石膏を 1～2 mm 彫刻刀
の削剝量は，歯の移動量や
う．特に，捻転歯や叢生の
4～5 mm と大きく削り取

歯列弓から）
D.P の製作過程の中で最
える．換言すれば，この再
正治療の効果が大きく左右
ではない．これらの点につ
重々様々であるので次回の
として，ここでは，あくま
について述べてみよう．
排列は片側の歯列から開始
ィリティ・ワックスで仮着

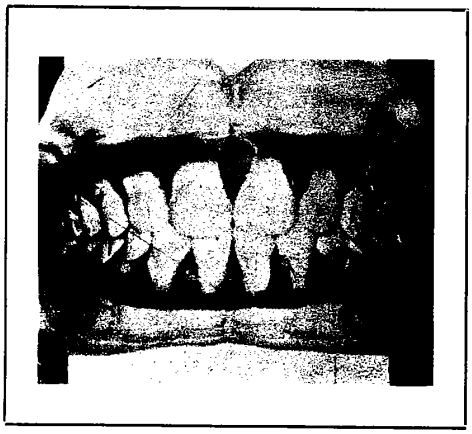
16 歯の再排列（反対側に移る）

片側歯列の再排列が終了したのち，つづいて反対側の再排列に移る．このように片側歯列から行う理由は，移動歯の基準点を反対側の歯列に求め，移動量や移動方向を定量的にとらえて再排列を行うためである．個々の歯の移動量については一言で表現することは難しいが，筆者らは，多くの臨床経験から 1 歯の最大移動量を 4 mm と決めている．



17 完成した set-up model

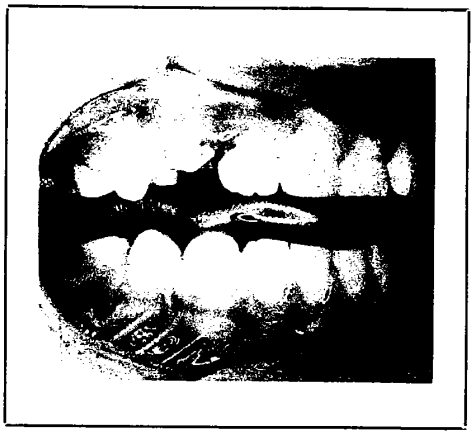
歯の理想的な再排列を完了した set-up model は，通常の方法（義歯製作時と同じ要領）でパラフィン・ワックスを用いて歯肉形成を行い，仕上げる．図に示した set-up model は全歯を移動したものであるが，症例によっては部分的に移動する場合もあり，これらは D.P の治療方針によって決定される．次に，完成した set-up model 上で咬合挙上（約 4 mm）を行う．この咬合挙上は，咬合器上で行われ，後述する作業用模型に使用する wax bite を採得するために行う．



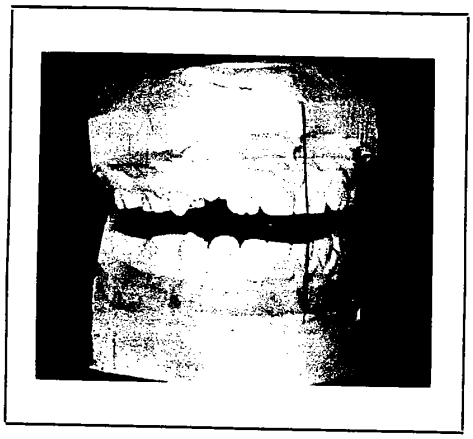
2. 咬合採得法と再排列時の要点について

18 構成咬合位による咬合採得

不正咬合の原因が，機能的因子によって発現したと思われる症例では，構成咬合位（F.K.O 製作時と同じ意味）で咬合採得を行い D.P を製作する．すなわち，下顎骨を仮性の位置からその個体が潜在的に有している正常位に人為的な手段で移動する方法である．図は，機能的反対咬合と診断された症例で，下顎を人為的に遠心位（後方）に移動して咬合採得（前歯部切端間で 4 mm）を行っているところである．

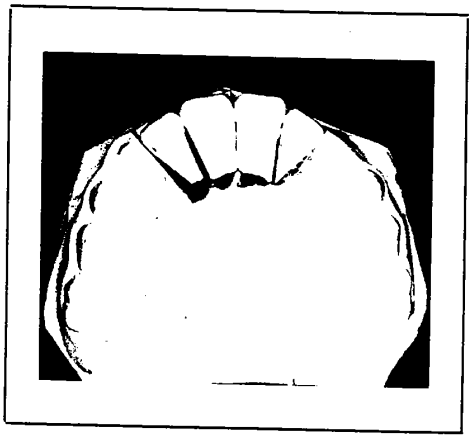


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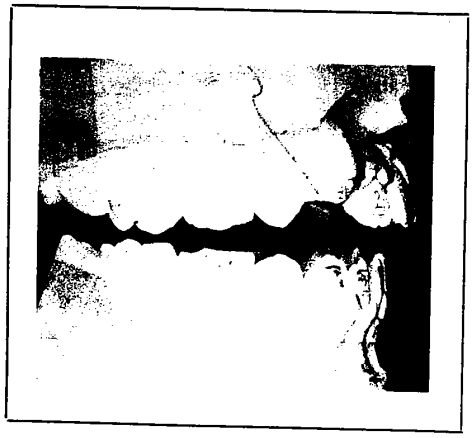
19 構成咬合位による咬合器付着

18 の症例で採得した wax bite を石膏模型に嚙ませて咬合器に付着したところである．一般的に，機能的不正咬合を対象とする症例では，このような方法で咬合器に付着される．付着後，咬合器の垂直的距離が変わらないように咬合器のストッパーまたはセンターピンを固定する．そのあとで，患者から採得した wax bite を除去する．さて，歯の再排列（set-up model の製作）は，この開口位の状態で開始される．



20 構成咬合位による再排列

18 の症例は，上顎前歯部の舌側傾斜を伴う機能的反対咬合と診断された症例である．このことから，No. 1 の set-up model 上では，特に上顎前歯部を積極的に唇側拡大（拡大量 3 mm）し，再排列を行った．これは，早期接触の障害を排除する目的から，第 1 段階で行われる部分的再排列であり，ゴムの復元力と筋の機能力を矯正力として求めた方法といえる．



21 開口位の状態で行われる set-up model

構成咬合位で set-up model を製作する場合，図に示すような開口位の状態で再排列を完了する（*18* の症例）．これは，従来の方法ではみられない新しい方法といえる．また，機能的不正咬合を示さない症例についても，しばしば開口位の状態で set-up model を製作する場合がある．この時は，患者の習慣性開口運動時のある位置（前歯部切端間で 4 mm）で咬合採得を行い，同様な操作で再排列を行う．Set-up model が完成したなら ば，咬合高径を変えずに作業用模型の wax bite（D.P の bite）を set-up model 上で採得する．

22 咬頭嵌合位による咬

咬頭嵌合位の状態で咬
Kesling が考案した toot
準じたものといえる．す
のちは，咬合器上で咬合
を行い作業用模型の wax
ろで，この方法では，咬
回転運動）を行う結果，
関係）とは一致しない欠
列時に咬頭嵌合位の状態
るなどの理由から，現在
法である．

23 再排列時に使用され

歯の垂直的分割には，
要となる．ここに示す電
用として開発されたもの
に，しかも的確に切断で
える．この他に，手動式
削器が市販されているが
は能率的に，しかも短時
い．

24 再排列時に必要な器

歯の再排列操作に用い
スの他に歯列の対称性を
chart が必要である．こ
て，再排列時の歯の移動

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咬合器付着

wax bite を石膏模型に
ったところである．一般的
対象とする症例では，この
付着される．付着後，咬合
うないように咬合器のスト
ピンを固定する．そのあと
wax bite を除去する．さ
› model の製作）は，この
る．

再排列

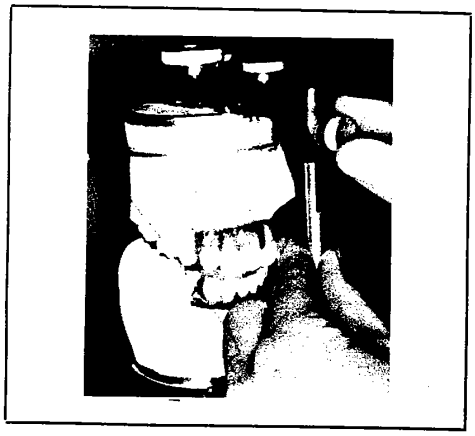
前歯部の舌側傾斜を伴う機
た症例である．このこと
model 上では，特に上顎
拡大（拡大量 3 mm）し，再
早期接触の障害を排除す
で行われる部分的再排列で
筋の機能力を矯正力として

われる set-up model

model を製作する場合，
の状態で再排列を完了する
従来の方法ではみられな
また，機能的不正咬合を
，しばしば開口位の状態
する場合がある．この時
運動時のある位置（前歯部
採得を行い，同様な操作
p model が完成したなら
作業用模型の wax bite
p model 上で採得する．

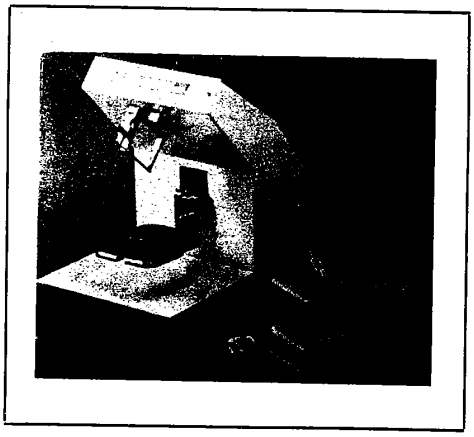
22 咬頭嵌合位による咬合器付着

咬頭嵌合位の状態で咬合器に付着する方法は，Kesling が考案した tooth positioner の製作法に準じたものといえる．すなわち再排列を完了したのちは，咬合器上で咬合挙上（前歯部で 4 mm）を行い作業用模型の wax bite を採得する．ところで，この方法では，咬合器上で咬合挙上（喋番回転運動）を行う結果，生体の顎位（特に垂直的関係）とは一致しない欠点が認められるが，再排列時に咬頭嵌合位の状態で歯の再排列が検討できるなどの理由から，現在でも広く普及している方法である．



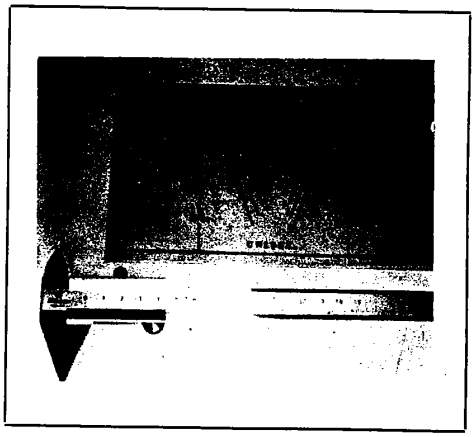
23 再排列時に使用される電動鋸

歯の垂直的分割には，薄い刃をもつ電動鋸が必要となる．ここに示す電動鋸は，特に D.P 製作用として開発されたもので，歯列弓から歯を安全に，しかも的確に切断できる機能をもった鋸といえる．この他に，手動式の鋸やディスク形態の切削器が市販されているが，これらの使用については能率的に，しかも短時間に処理できるものがよい．

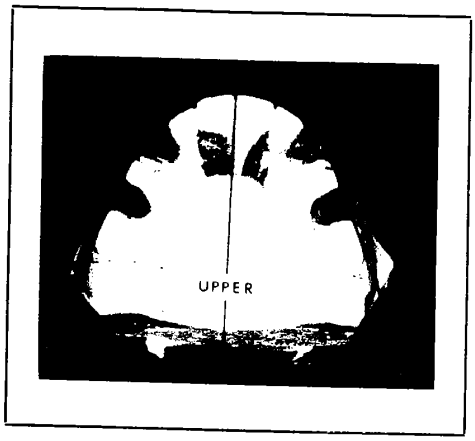


24 再排列時に必要な器材

歯の再排列操作に用いる器材には，定規，ノギスの他に歯列の対称性を調べる arch symmetry chart が必要である．これらの器材の使用によって，再排列時の歯の移動量を正確に把握できる．

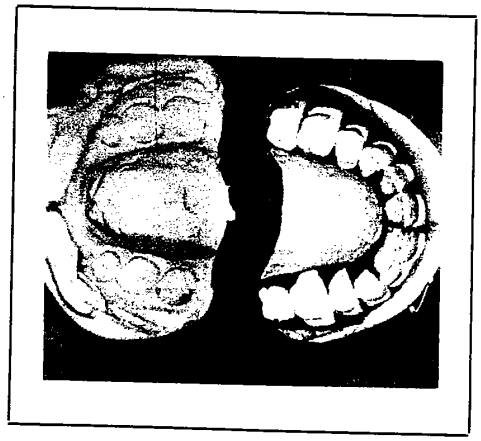


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25 Arch symmetry chart の使用法

この arch symmetry chart は，set-up model 製作時に歯の移動量や歯列の対称性を検討する目的で使用される．図は，set-up model 完成後，歯列弓の形態や対称性を種々検討しているところである．特に，未萌出歯の位置の決定や歯冠形成（萌出歯の誘導を行う目的）を行う時などは，この chart は大変便利である．

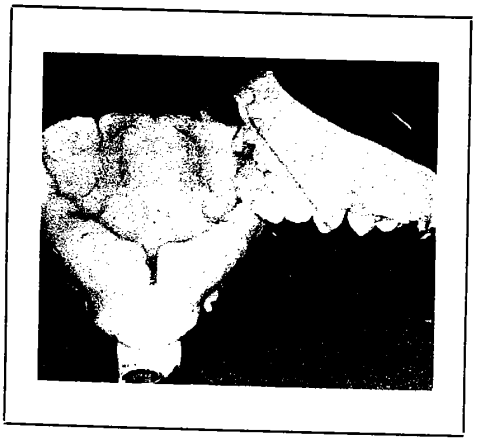


3. 作業用模型の製作からD.Pの埋没操作まで

26 Set-up model の印象採得

Set-up model 完成後，作業用模型の製作を目的として，アルジネート印象材を用いて通法に従い set-up model の印象採得を行う．この時，あらかじめ set-up model を水中に浸して，十分な水分を石膏に与えておくことが必要である．

図は，上顎の set-up model から印象採得を行っているところである．



27 作業用模型の製作

印象採得後，印象内面に硬石膏または超硬石膏を流し込み，作業用模型を製作する．石膏硬化後，印象面から取り出した上下顎の石膏模型を歯列弓の形態に沿って余剰な部分をトリミングし作業用模型に仕上げる．

図は，印象面から取り出した上顎の石膏模型を示す．

28 外形線の設定と box

上下顎の作業模型上で，る．外形線の設定範囲は，なるが，通常，歯頸線上小帯などを避けて鉛筆で 2.5mm のキャスティンク図に示すように外形線上

図は，boxing を行っ を示す．

29 作業用模型の wax

次に，作業用模型上に下顎の模型をワックスでする wax bite は，***17*** model 上で採得した wa

図は，***17***で採得した したところである．

30 唇側面のワックス

これより，D.P のワッ パラフィン・ワックスを ing したキャスティン 刻刀を用いてパラフィ 態に沿って切り抜き，I

図は，パラフィン・ の唇側面を形成してい

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chart の使用法
y chart は，set-up model
歯列の対称性を検討する目
，set-up model 完成後，
を種々検討しているところ
歯の位置の決定や歯冠形成
目的）を行う時などは，この
る．

作からD.Pの埋没操作まで

の印象採得
後，作業用模型の製作を目
ト印象材を用いて通法に従
印象採得を行う．この時，あ
el を水中に浸して，十分な
くことが必要である．
p model から印象採得を行
．

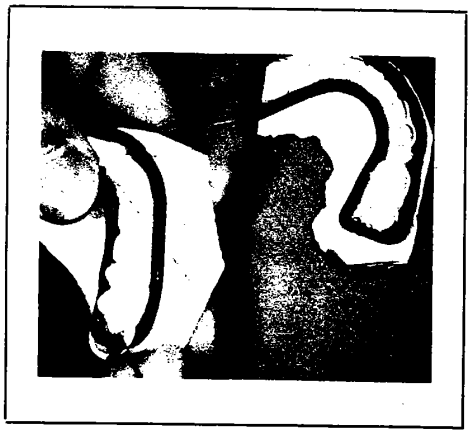
作
面に硬石膏または超硬石膏
模型を製作する．石膏硬化
した上下顎の石膏模型を歯
剰な部分をトリミングし作

り出した上顎の石膏模型を

28 外形線の設定と boxing

上下顎の作業模型上で，D.P の外形線を設定する．外形線の設定範囲は，各症例によって多少異なるが，通常，歯頸線上約5～8 mm の位置に各小帯などを避けて鉛筆で記入する．記入後，直径2.5mm のキャスティング・ワックスを利用して，図に示すように外形線上に固定し boxing を行う．

図は，boxing を行っている上下顎作業用模型を示す．



29 作業用模型の wax bite

次に，作業用模型上に wax bite を噛ませ，上下顎の模型をワックスで連結する．この際，使用する wax bite は，***17*** で述べたように set-up model 上で採得した wax bite を使用する．

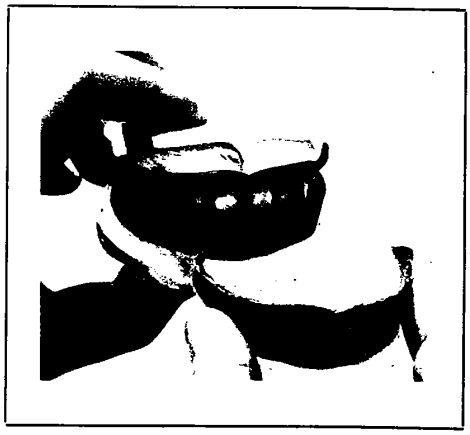
図は，***17*** で採得した wax bite を模型上に固定したところである．



30 唇側面のワックス形成

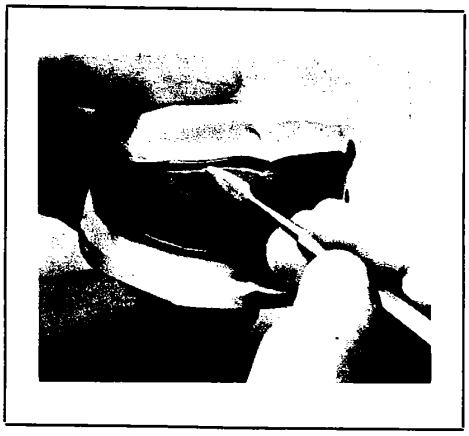
これより，D.P のワックス形成に移る．まず，パラフィン・ワックスを1枚板化し，これを boxing したキャスティング・ワックス上に置き，彫刻刀を用いてパラフィン・ワックスを外形線の形態に沿って切り抜き，D.P の唇側面を製作する．

図は，パラフィン・ワックスを切り抜き D.P の唇側面を形成しているところである．





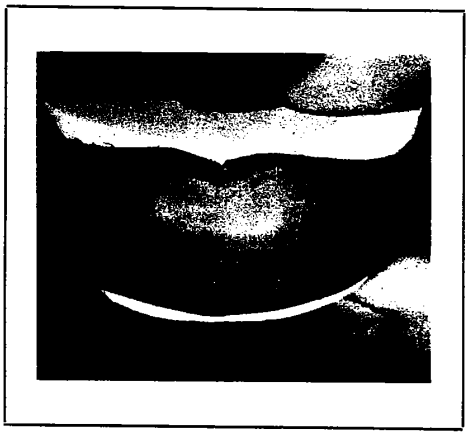
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31 唇側面のワックス操作

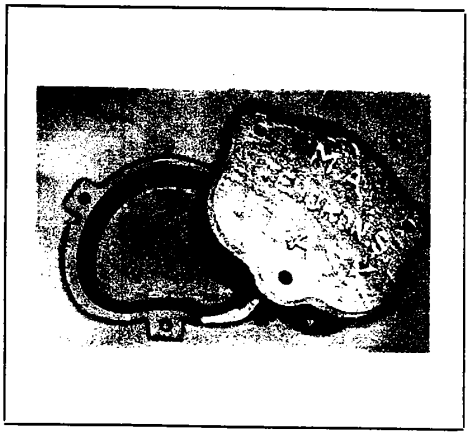
次に，切り抜いたパラフィン・ワックスを boxing したキャスティング・ワックスと連結し，D.P の唇側面を作る．唇側面のワックス操作完了後，つづいて舌側面のワックス形成に移り，D.P の形態にワックスで盛り上げる．

図は，唇側面のパラフィン・ワックスをキャスティング・ワックスにスパチュラを用いて連結しているところである．



32 D.P のワックス形成完了

図は，D.P のワックス形式を完了した状態を示す．この時，ワックス表面はできるだけ滑沢に仕上げる必要がある．その後，石膏模型の外形線ぎりぎりまで基底部をトリーマーで削り落とす．



33 義歯製作用のフラスコ

ワックス形成終了後，フラスコを用いて作業用模型の埋没操作に移る．使用するフラスコは，一般に用いられている総義歯製作用（上下蓋に2分割できるもの）のフラスコを利用して埋没操作を行う．

34 作業用模型の埋没

作業用模型の埋没方
け，フラスコ内（下蓋）
る．この時，模型上で
気泡の発生を防ぐ目的
膏を利用して周囲を埋
図は，作業用模型の
没を行っているところ

35 分離材の塗布

フラスコ下蓋に上顎
材の塗布を行う．まず
面）以外の石膏表面（
を均一に塗布する．
図は第1次埋没を完

36 作業用模型の埋

分離材塗布後，軟
全に上蓋フラスコ内
は，バイブレーター
発生を防ぐことがで
図は第2次埋没を
るところである．

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ス操作

ラフィン・ワックスを box-
グ・ワックスと連結し，
唇側面のワックス操作完了
ワックス形成に移り，D. P
り上げる．
フィン・ワックスをキャス
スパチュラを用いて連結し

形成完了

ス形式を完了した状態を示
表面はできるだけ滑沢に仕
の後，石膏模型の外形線ぎ
リーマーで削り落とす．

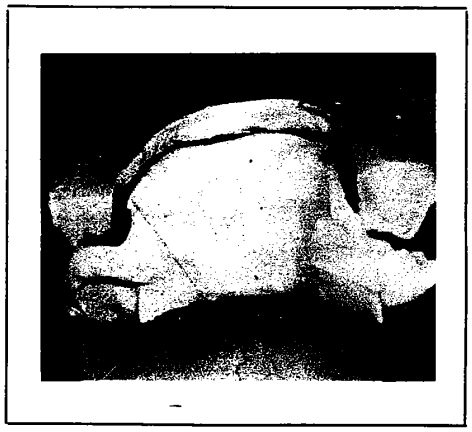
ラスコ

，フラスコを用いて作業用
．使用するフラスコは，
義歯製作用（上下蓋に2分
スコを利用して埋没操作を

34 作業用模型の埋没操作

作業用模型の埋没方法は，上顎歯列を下に向け，フラスコ内（下蓋）に軟石膏を用いて埋没する．この時，模型上で形成したワックス表面には気泡の発生を防ぐ目的から，あらかじめ残った石膏を利用して周囲を埋没しておくとよい．

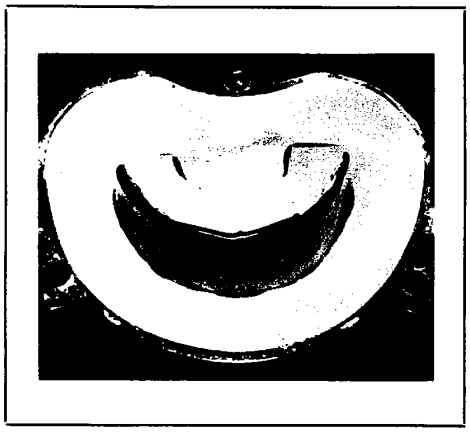
図は，作業用模型の周囲に石膏をつけ第1次埋没を行っているところである．



35 分離材の塗布

フラスコ下蓋に上顎歯列を埋没したのち，分離材の塗布を行う．まず，模型（下顎歯列弓の基底面）以外の石膏表面（埋没した軟石膏）に分離材を均一に塗布する．

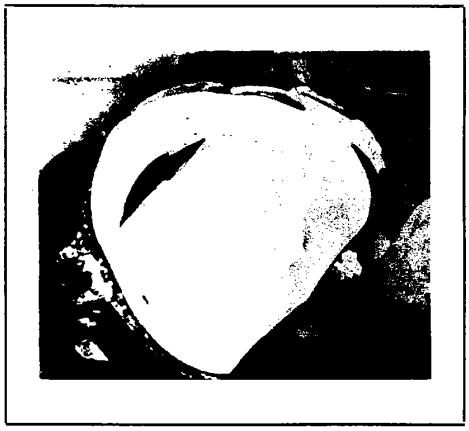
図は第1次埋没を完了したところである．



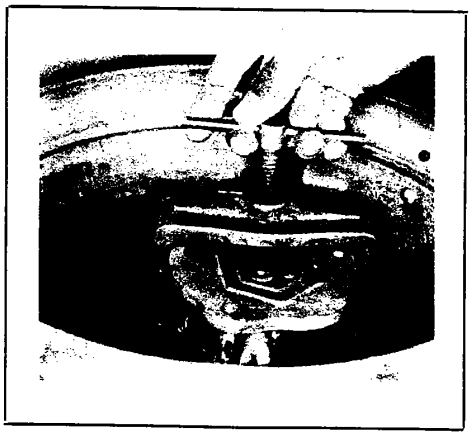
36 作業用模型の埋没完了

分離材塗布後，軟石膏を用いて作業用模型を完全に上蓋フラスコ内に埋没する．この埋没操作には，バイブレーター上で石膏注入を行うと気泡の発生を防ぐことができる．

図は第2次埋没をバイブレーター上で行っているところである．



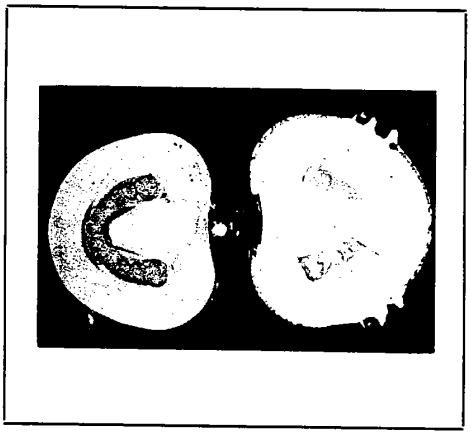
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37 流ロー操作

石膏硬化後，フラスコ内部のパラフィン・ワックスを除去する目的で流ロー操作を行う．通常，60°Cの温水中にフラスコを約5分間浸漬し，内部のワックスを軟化する．

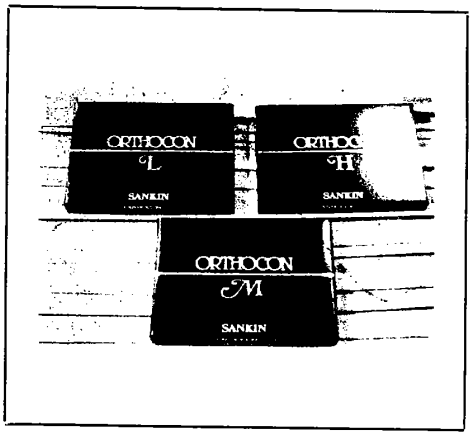
図は，温水中にフラスコを入れているところである．



38 流ロー操作完了

ワックス軟化後，フラスコを温水中より取り出し，フラスコの上蓋と下蓋を分割する．その後，軟化したワックスを彫刻刀で慎重に除去し，通常の流ロー操作で完全にワックスを排除する．

図は，流ロー操作を終了した上下顎のフラスコ内部を示している．



4. オーソコンの充填から仕上げ操作まで

39 オーソコンの選択

オーソコンは，前回述べたように，3種類のゴムの硬さから3種のセット（ライト-L，ミディアム-M，ヘビー-H）が作られている．まず，オーソコンの充填操作を行う前にD.Pの使用目的や治療方針に従ってオーソコンを選択する．たとえば，動的治療の開始時からD.Pを使用する場合，原則的に一番軟質なライト-Lを使用し，治療効果を検討しながらゴムの硬さ（MからH）を順次高めていく．

40 オーソコンの内容

オーソコンの内容は，シリコーン樹脂（上段）と重合型シリコーン樹脂（撹拌棒，筆，撹拌容器がオーソコン1箱から，4る．

41 オーソコンの充填

オーソコンの充填操作上下顎のフラスコ，オー（本体を充填する時に使

42 オーソコン本体の

次に，オーソコン本まれている未加硫シリに充填する．まず，格図で示す要領で，上顎用いて充填する．特に膏面との空隙が狭い

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スコ内部のパラフィン・ワッ
で流ロー操作を行う．通常，
ラスコを約5分間浸漬し，内
する．
ラスコを入れているところで

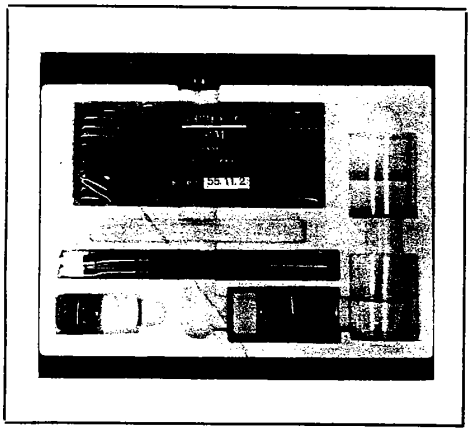
フラスコを温水中より取り出
と下蓋を分割する．その後，
彫刻刀で慎重に除去し，通常
にワックスを排除する．
を終了した上下顎のフラスコ

充填から仕上げ操作まで

択
引述べたように，3種類のゴ
ット（ライト-L，ミディア
作られている．まず，オーソ
う前にD.Pの使用目的や治療
ンを選択する．たとえば，
う D.P を使用する場合，原
イト-Lを使用し，治療効果
)硬さ（MからH）を順次高

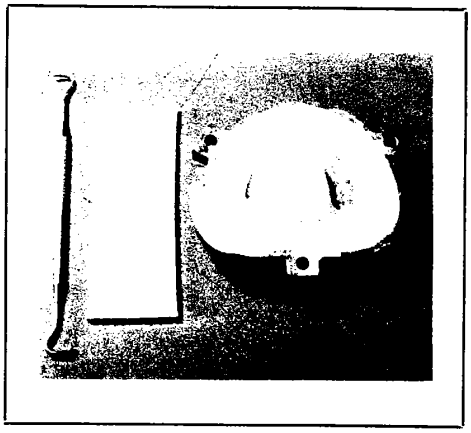
40 オーソコンの内容

オーソコンの内容は，本体に用いる熱硬化型シリコーン樹脂（上段）と coating 材に用いる常温重合型シリコーン樹脂（下段）から成り，また，撹拌棒，筆，撹拌容器がセットされている．このオーソコン1箱から，4個の D.P が製作できる．



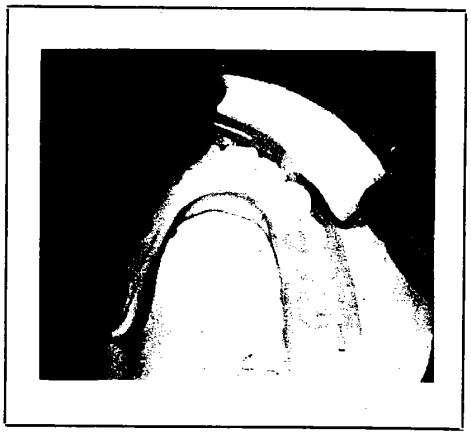
41 オーソコンの充填準備

オーソコンの充填操作には，流ローを完了した上下顎のフラスコ，オーソコンの本体，充填棒（本体を充填する時に使用する器具）を用意する．

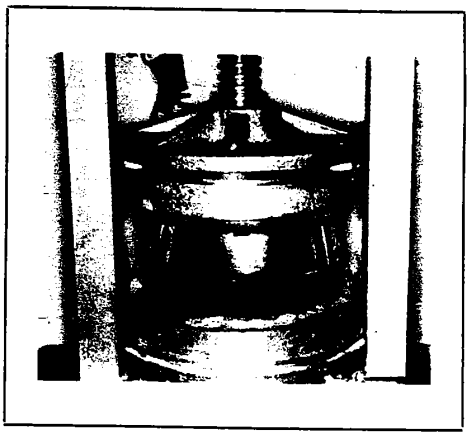


42 オーソコン本体の充填操作

次に，オーソコン本体（すでに硬化剤が練り込まれている未加硫シリコーン樹脂）をフラスコ内に充填する．まず，棒状に成型されている本体を図で示す要領で，上顎歯列の唇側面から充填棒を用いて充填する．特に上顎唇側面は，歯と埋没石膏面との空隙が狭いので慎重に行う必要がある．

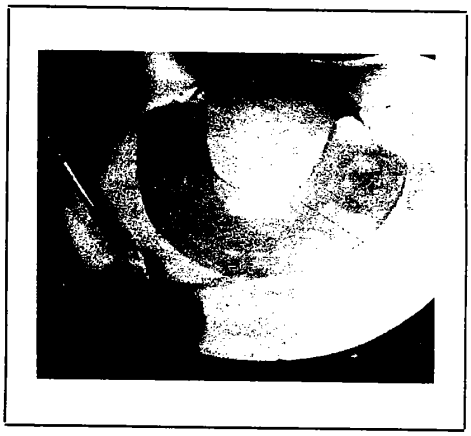


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43 試圧操作

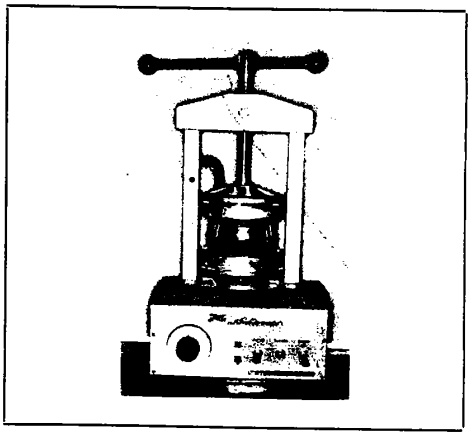
上下顎のフラスコにオーソコンを充塡したあと，過剰なシリコーン樹脂を除去する目的からプレス器で試圧する．この操作は，義歯製作時とよく似ている操作で，上下のフラスコ内に薄いポリエチレン・フィルムをはさんで行われる．試圧は，一般に1～2回行えば十分である．



44 余剰なシリコーン樹脂の除去

試圧を終了したフラスコを分割し，余剰なシリコーン樹脂（本体）を彫刻刀を用いてすべて除去する．

図は，試圧操作によってはみ出た余剰なシリコーン樹脂を除去しているところである．



45 本体の第1次加硫

本体の加硫は，第1次加硫と第2次加硫（後加硫）とに分けて行う．第2次加硫については後述するとして，ここでは第1次加硫の操作について述べてみよう．まず，余分なシリコーン樹脂を除去したのち，図に示すような乾熱重合器（義歯製作用）を用いて，100°C，1時間で第1次加硫を行う．

46 D.P の離型

第1次加硫完了後，フラたD.Pを離型する．この操指で慎重に取り出す．さて(ゴム硬度を変えて製作すは，直ちに再充塡を行いらは，動的治療の開始時にるD.Pを用意して，治療を

47 D.P の研磨

離型後，成型された D.する．この段階の研磨はなどを用いて行う程度でついては，後述する方法仕上げる．

48 空気孔の穿孔

D.P の表面に空気孔をは D.P の中央に太いするが，特に鼻疾患を部と左右犬歯部に3カ

図は，フィッシャー央に空気孔を穿孔して

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にオーソコンを充塡した点
ン樹脂を除去する目的からプ
この操作は，義歯製作時とよ
上下のフラスコ内に薄いポリ
をはさんで行われる．試圧は，
ば十分である．

ーン樹脂の除去
フラスコを分割し，余剰なシリ
を彫刻刀を用いてすべて除去

よってはみ出た余剰なシリコ
いるところである．

加硫
第1次加硫と第2次加硫（後加
う．第2次加硫については後述
では第1次加硫の操作について
ド，余分なシリコーン樹脂を除
ドするような乾熱重合器（義歯製
00°C，1時間で第1次加硫を

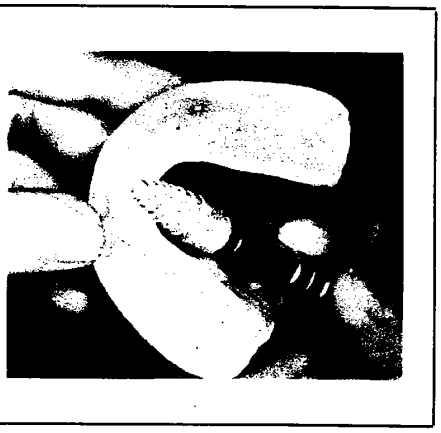
16 D.P の離型

第1次加硫完了後，フラスコからゴム状にな
たD.Pを離型する．この操作は，図に示す通り，
所で慎重に取り出す．さて，臨床上2個目の D.P
ゴム硬度を変えて製作する）を必要とする場合に
は，直ちに再充塡を行い D.P を製作する．筆者
らは，動的治療の開始時に2個のゴム硬度の異な
るD.Pを用意して，治療を開始している．



17 D.P の研磨

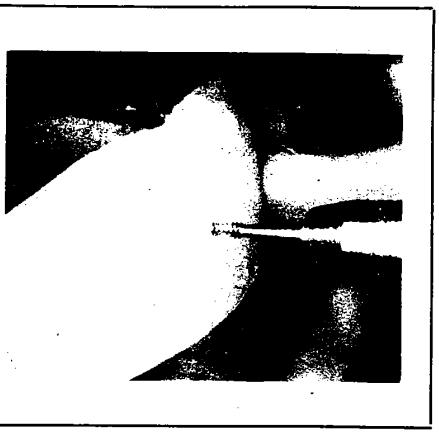
離型後，成型された D.P の表面を簡単に研磨する．この段階の研磨は，荒いペーパー・コーンなどを用いて行う程度で十分である．表面処理については，後述する方法（coating 材の塗布）で仕上げる．



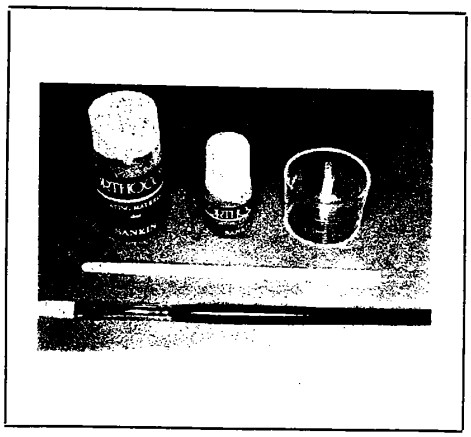
18 空気孔の穿孔

D.P の表面に空気孔を設ける．一般に，空気孔は D.P の中央に太いフィッシャー・バーで穿孔するが，特に鼻疾患を伴う症例の場合には，中央部と左右犬歯部に3カ所設ける必要がある．

図は，フィッシャー・バーを用いて D.P の中央に空気孔を穿孔しているところである．

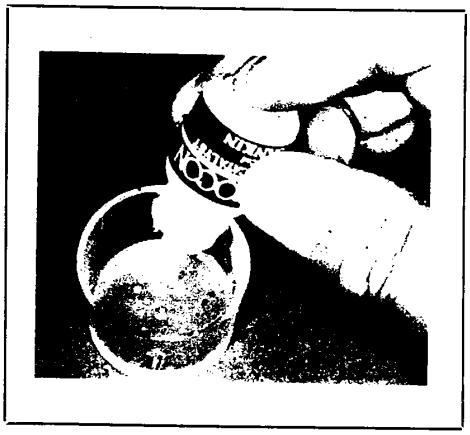


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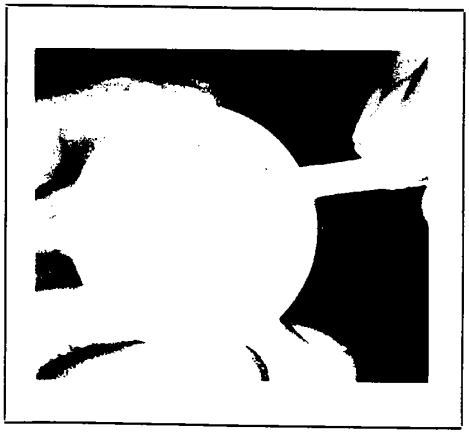
49 Coating 材の塗布準備

オーソコンの coating 材は，2液性で基材のシリコーン樹脂と触媒とに分かれている．また，セットの中には，これらの樹脂を配合する容器，筆，撹拌棒が含まれている．塗布準備としてこれらを用意する．



50 Coating 材の配合

まず，撹拌容器に coating 材の基材を取り，つづいて触媒を適量加える．配合比（重量比）は，基材と触媒を 10：1 の比率で配合する．すなわち，基材に対して 10 %の触媒を加えることになる．一般には，基材を容器の3目盛までとり，触媒を12～13滴加えると1症例分の coating 材の配合になる．



51 Coating 材の撹拌

撹拌容器に入れたシリコーン基材と触媒を撹拌棒で数秒間撹拌する．これで，coating 材の用意ができる．常温時における重合時間は，他のシリコーン樹脂に比べて大変遅いので，塗布操作はゆっくり行える．

52 Coating 材の塗布

用意された coating 材舌側面へと筆をゆっくり動時，筆に十分な coating 均一になるように塗布する操作で十分である．

53 D.P 専用スタンド

Coating 材を塗布するく高くなる．ところでこ考案したポリウレタン樹処理法からヒントを得て塗布後，D.P 専用のスタD.P を固定する．

54 乾燥器の使用

Coating 材塗布後，章て coating 材の乾燥と本を継続して行う．

図は，この操作のためバス（製品名）で，温度ィクに連動するように調

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布準備
ng 材は，2液性で基材のシ
に分かれている．また，セ
の樹脂を配合する容器，筆，
．塗布準備としてこれらを

oating 材の基材を取り，つ
る．配合比（重量比）は，
の比率で配合する．すなわ
%の触媒を加えることにな
容器の3目盛までとり，触
1症例分の coating 材の配

リコーン基材と触媒を攪拌
これで，coating 材の用意
ける重合時間は，他のシリ
変遅いので，塗布操作はゆ

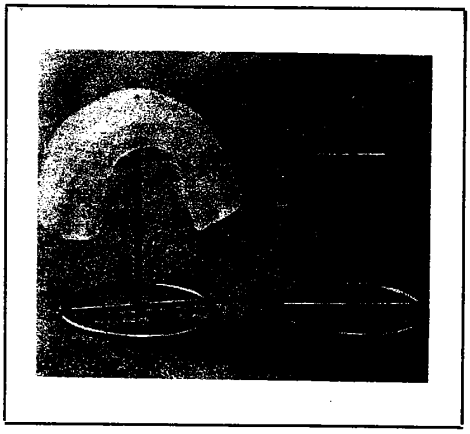
52 Coating 材の塗布

用意された coating 材を，D.P の唇側面から舌側面へと筆をゆっくり動かして塗布する．この時，筆に十分な coating 材をつけ D.P の表面に均一になるように塗布する．塗布は，1回の塗布操作で十分である．



53 D.P 専用スタンド

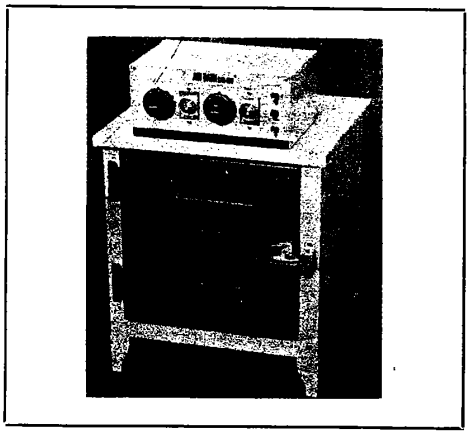
Coating 材を塗布すると D.P の透明性は著しく高くなる．ところでこの操作は，以前筆者らが考案したポリウレタン樹脂を用いた D.P の表面処理法からヒントを得て考案した方法といえる．塗布後，D.P 専用のスタンドに空気孔を利用して D.P を固定する．



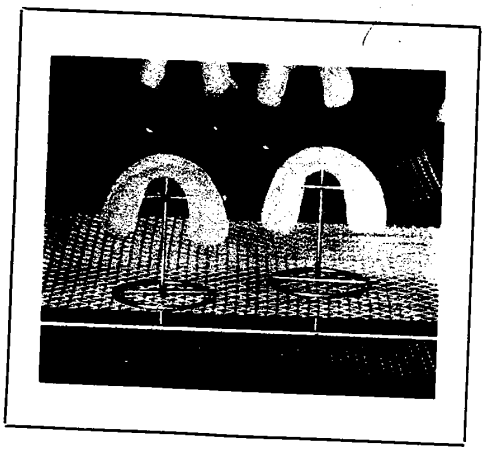
54 乾燥器の使用

Coating 材塗布後，乾燥器の中に D.P を入れて coating 材の乾燥と本体の第2次加硫（後加硫）を継続して行う．

図は，この操作のために新たに開発したエアーバス（製品名）で，温度とタイヤーがオートマティクに連動するように設計された乾燥器である．

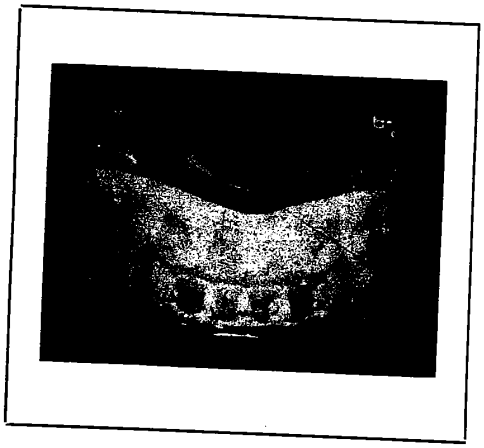


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55 Coating 材の乾燥と本体の第2次加硫

スタンドに固定された D.P は，coating 材の乾燥とシリコーン樹脂の2次加硫（後加硫ともいう）を行う目的で乾燥器の中で加熱する．まず最初に，coating 材の乾燥のために，常温から加熱を開始し約 70°C，40分で coating 材の乾燥を行う．その後，引き続き乾燥器内の温度を180°C に上げて，2時間で本体の第2次加硫を行う．これは，シリコーン樹脂の機械的性質を高める目的から行う操作である．



56 D.P の完成

図は，第2次加硫を完了した D.P である．機械的性質に優れ，全体は乳白色であるが透明性の高い，しかも滑沢な表面を有する D.P がここに完成する．



57 D.P の口腔内装着

口腔内装着時には，消毒の意味で，前もって D.P を約10分間煮沸する．D.P は透明体であるので歯や歯周組織の状態が容易に観察できる．これは矯正臨床上，大変大きな意味をもつことといえる．

以上で，D.P の製作法と製作時の注意点などを簡単に紹介した．次に，D.P の新しい形態について紹介しよう．

D.P の治療効果は，
動量により，その効果
なわち，優れた治療効
set-up model の製作法
る．ところで，筆者ら
列を積極的に行う必要
する）を提言した．し
歯の移動量が大きけれ
は口腔内で安定した状
の意味は，再排列時の
性が反比例する理論か
を大きく移動して再排

58 【叢生の症例】唇
叢生の著しい症例の
込みを入れて部分的に
力を歯に与える．この
生部位の隣接面に鋏を
入れる．筆者らはこの
呼んで，広く臨床面に

59 【叢生の症例】舌
叢生のある症例で，
ような場合にも ***58*** で
る．一般には，垂直的
あるが，舌側転位の状
型の水平的切り込みを
る．この ゴムの弁が歯
て，歯を理想的な位置

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乾燥と本体の第２次加硫
された D.P は，coating 材の
脂の２次加硫（後加硫ともい
燥器の中で加熱する．まず最
乾燥のために，常温から加熱
0分で coating 材の乾燥を行
き乾燥器内の温度を180°C に
体の第２次加硫を行う．これ
の機械的性質を高める目的か

を完了した D.P である．機械
は乳白色であるが透明性の高
面を有する D.P がここに完成

着
よ，消毒の意味で，前もって
する．D.P は透明体であるの
態が容易に観察できる．これ
大きな意味をもつことといえ

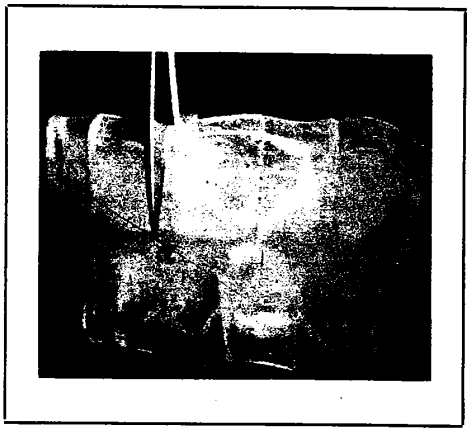
作法と製作時の注意点などを
に，D.P の新しい形態につい

〔II〕D.P の新しい形態と臨床応用 (*58*～*68*)

D.P の治療効果は，模型上で再排列した歯の移動量により，その効果が左右されるといえる．すなわち，優れた治療効果を得るためには，特に set-up model の製作法が重要な鍵を握る要素となる．ところで，筆者らは前回の報告で，歯の再排列を積極的に行う必要性（最大移動量を４mm とする）を提言した．しかし，set-up model 上での歯の移動量が大きければ，当然のことながら D.P は口腔内で安定した状態に装着できなくなる．この意味は，再排列時の歯の移動距離と D.P の安定性が反比例する理論からもうなずける．仮に，歯を大きく移動して再排列を行った場合を矯正学の立場から検討してみると，矯正治療上の原則，すなわち矯正力の作用，反作用の原理を無視した矯正装置となり，したがって治療効果も期待できなくなる．そこで筆者らは，従来の形態（tooth positioner.）を一部修正すること，また，他の矯正装置との組み合わせ（たとえば顎外固定装置）を行うことにより，歯を理想的にしかも生物学的に移動することを検討し，多くの不正咬合者に用いている．その結果，不正咬合のタイプによって D.P の形態を修正する必要性を認めた．ここで，D.P の修正法や新しい形態の D.P の紹介，およびその臨床応用について簡単に列記してみよう．

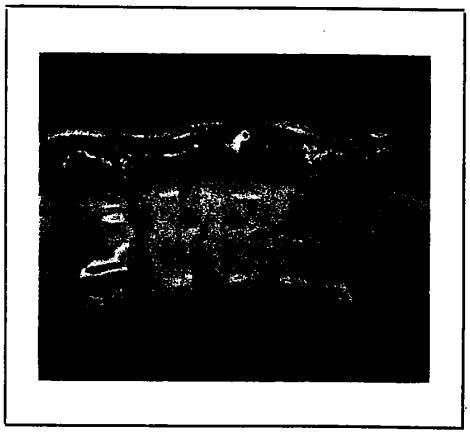
58 【叢生の症例】唇側面の修正

叢生の著しい症例の場合には，叢生部位に切り込みを入れて部分的に矯正力を分断し，弱い矯正力を歯に与える．この方法は，図に示すように叢生部位の隣接面に鋏を入れ，切端まで切り込みを入れる．筆者らはこの方法を cutting method と呼んで，広く臨床面に応用している．

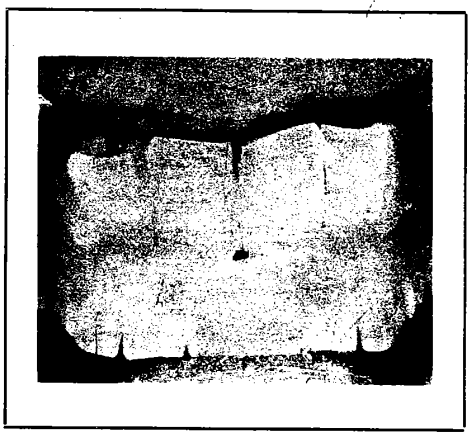


59 【叢生の症例】舌側面の修正

叢生のある症例で，歯が著しく舌側転位を示すような場合にも *58* で示す要領で切り込みを入れる．一般には，垂直的に切り込みを入れるだけであるが，舌側転位の状態が著しい場合には，V字型の水平的切り込みを入れて，ゴムの弁を形成する．このゴムの弁が歯に持続性の矯正力を与えて，歯を理想的な位置に動かすことができる．

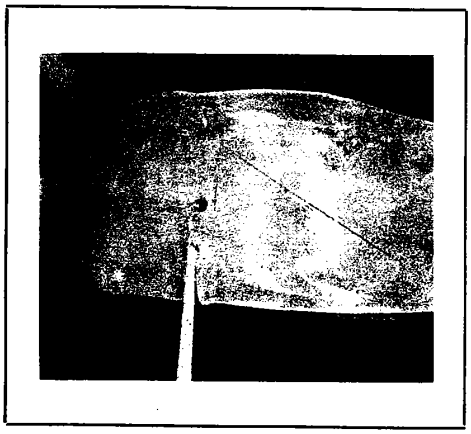


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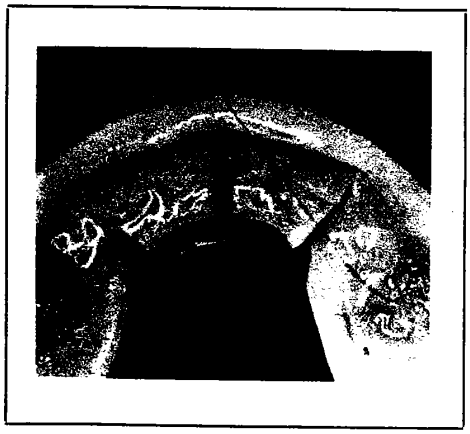
60 【叢生の症例】口腔内装着時の状態

Cutting method を行った D.Pを口腔内に装着した状態である．唇側転位を示す前歯では，分断されたゴム片が唇側方向に傾斜してくる．これにより歯に加わる矯正力は，持続性のある弱い矯正力（light continuous force）に変わり，生物学的に歯を移動できる．臨床的には，動的治療開始時に行うのが一般的な応用法といえる．また，臼歯部においても set-up model の移動量が大きな場合には，同様な方法で切り込みを行う．



61 【下顎前突の症例】唇側面の修正

下顎前突の症例では，下顎前歯唇側面に cutting method を応用して切り込みを入れる．一般的には，下顎中切歯間と両側側切歯遠心隣接面に切り込みを入れる．



62 【下顎前突の症例】舌側面の修正

下顎前突の症例で，特に再排列時の歯の移動量が大きい場合，上顎前歯部舌側面に切り込みを入れる必要がある．この場合，垂直的にV字型の切り込みを正中部ならびに側切歯遠心面に入れる．また，場合によっては ***59*** の場合と同様にV字型の水平的切り込みを入れる場合がある．

63 【下顎前突の症例】

このような修正を加に入れると，切り込みを空隙が発生する．特に，は，set-up model上での方法は必ず行われる．

64 【上顎前突の症例】

著しい上顎前突の症headgear を直接埋めを使用する．当然のこまたは頸部に求める．どには，効果的に D.Fた治療効果を示す．

65 【上顎前突の症例

Headgear を付けた図に示すような形態てフラスコ内に埋没すは，フラスコの後部2の溝から外部に露出さは，一般的に行われる

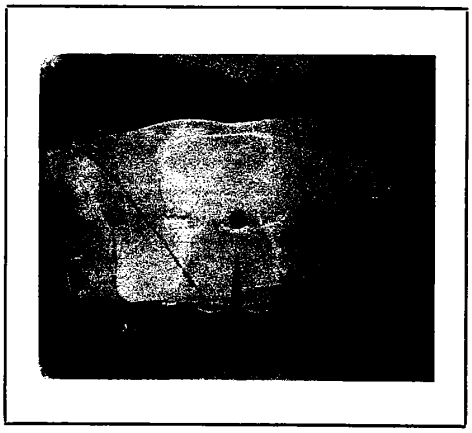
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腔内装着時の状態
行った D.Pを口腔内に装着
転位を示す前歯では，分断
向に傾斜してくる．これに
は，持続性のある弱い矯正
force）に変わり，生物学的
床的には，動的治療開始時
用法といえる．また，臼歯
model の移動量が大きな場
切り込みを行う．

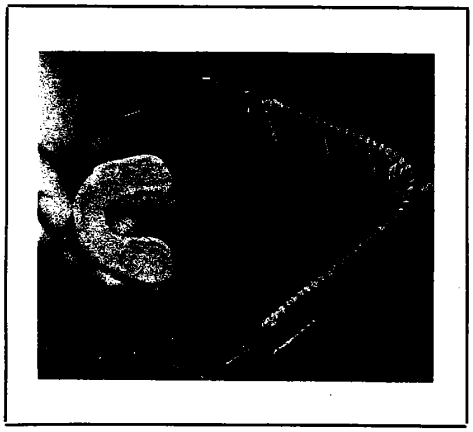
】唇側面の修正
と，下顎前歯唇側面に cutting
り込みを入れる．一般的に
側側切歯遠心隣接面に切り

】舌側面の修正
特に再排列時の歯の移動量
前歯部舌側面に切り込みを入
場合，垂直的にV字型の切
に側切歯遠心面に入れる．
と *59* の場合と同様にV字型
れる場合がある．

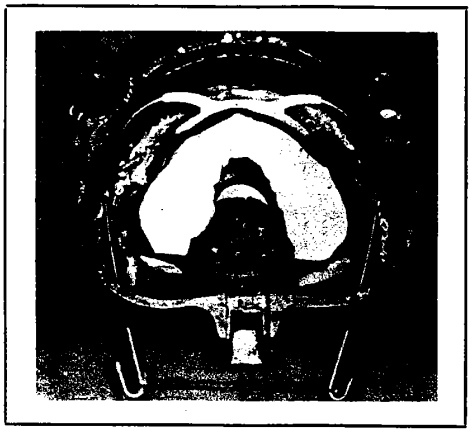
63 【下顎前突の症例】口腔内装着時
このような修正を加えた D.P を患者の口腔内に入れると，切り込みを入れた部位に逆V字型の空隙が発生する．特に，骨格性下顎前突の場合には，set-up model上での移動量が大きいためこの方法は必ず行われる．



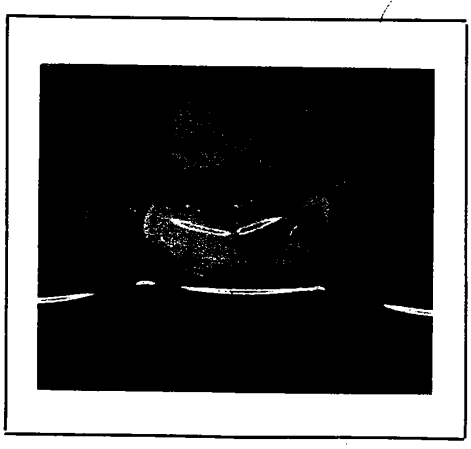
64 【上顎前突の症例】Headgear 付き D.P
著しい上顎前突の症例の場合は，D.P の中に headgear を直接埋め込んだ新しい形態の D.P を使用する．当然のことながら，固定源は後頭部または頸部に求める．特に，混合歯列弓の症例などには，効果的に D.P の作用が発揮され，優れた治療効果を示す．



65 【上顎前突の症例】Headgear の埋没法
Headgear を付けた D.P のフラスコ埋没法は，図に示すような形態で Headgear を付けた状態でフラスコ内に埋没する．Headgear の outerbow は，フラスコの後部2カ所に切り口を設けて，その溝から外部に露出させる．オーソコンの充塡法は，一般的に行われる方法と同様である．

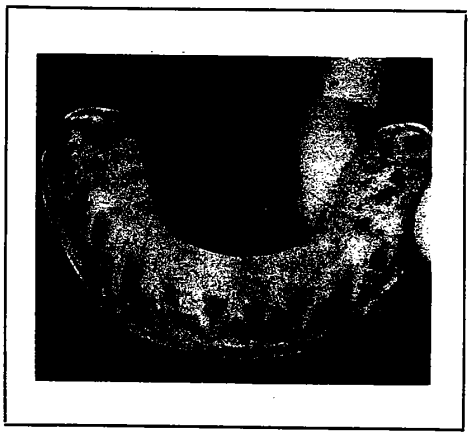


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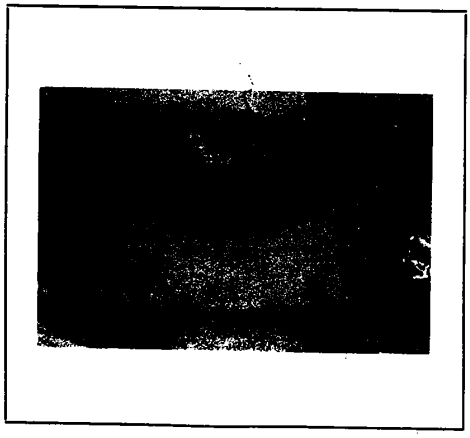
66 【上顎前突の症例】口腔内装着時

Headgear 付き D.P を口腔内に装着したところを示している．上顎前歯部で叢生などが認められた場合には，***61*** で述べたように cutting method を応用して切り込みを入れる場合がある．この症例では，切り込みを上顎両側中切歯の遠心部に 2 カ所入れて使用した状態を示している．



67 片顎用の D.P

片顎用の D.P は，不正部位が片顎に限られている場合に使用される．特に，動的治療後の保定装置として使用すると便利である．

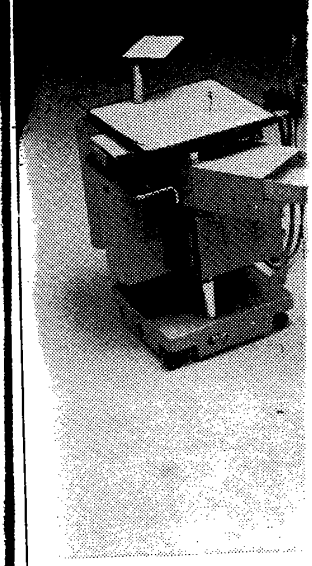


68 片顎用 D.P の口腔内装着時

片顎用の D.P を口腔内に装着した状態を示した．わずかな片顎の不正咬合などに有効であり，特に，動的治療後にしばしば生ずる下顎前歯の後戻りの症例などに使用すると便利である．

以上，D.P の製作手順の紹介と新しく考案した D.P の形態と臨床応用について述べた．次回は，これらの D.P を用いた治療効果と治験例を中心にして述べてみたい．

（つづく　文献は最終回に一括掲載）

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RESEARCH ON A NEW ORTHODONTIC APPLIANCE: THE DYNAMIC POSITIONER (D.P.)

III. The General Concept of the D.P. Method and Its Therapeutic Effect. Part 1. Dental and Functional Reversed Occlusion Case Reports

By Osamu Yoshii, Head of the Kanto Teishin Hospital's Dental Department

Introduction

Dynamic positioner (abbreviated as D.P. herein) is the general term a new removable orthodontic appliance (Figure 1) which utilizes the superior recovery force of a rubber material for orthodontic force and which is intended to move a malpositioned jaw or tooth to the ideal location—the individual's proper occlusion, as used in the broadest sense. Moreover, it is a therapeutic tool which has the clinical feature that it can be used from the start of orthodontic treatment to the finish (after retention), so this means the advent of a new orthodontic treatment method.

Incidentally, the author previously published articles about the D.P. in this journal and provided an overview of it as follows.

I. The D.P. Concept and Implementation of Transparent Silicone Resin (Orthocon) (No. 452, June 1980)

II. D.P. Manufacturing Procedure and Clinical Applications (No. 454, August 1980)

Now, when this new orthodontic appliance is actually used in a clinical setting its concept and technique are completely different from that of the conventional orthodontic method (using the elasticity of a fine metal wire to move teeth), so the author gave this treatment method a new name—the D.P. method (Dynamic Positioner system)—and used it on many malocclusions and studied its clinical effectiveness from many angles. As a result, extremely improved treatment effects were realized, and ample clinical experience yielded advantages in use which could not be achieved with conventional treatment methods.

Therefore this time I want to describe the general concept of the D.P. method. That is, exactly what effect can be expected from it, and what sort of treatment is best. I also want to focus on actual clinical aspects and describe important points about the D.P. method and its therapeutic results and so forth.

First, as a clinical overview, I want to describe when D.P. treatment begins and indications therefor, its positioning in orthodontic treatment, and how to create and achieve treatment objectives. Therapeutic results are described according to type of malocclusion. In this report, I take up cases reports, primarily of mild malocclusions, and briefly introduce their progress and therapeutic effects, etc.

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Figure 1. Dynamic positioner made using Orthocon™ (heat-cured transparent silicone resin). Utilizing the superior recovery force of silicone rubber material, it is possible to create a dynamic orthodontic appliance which automatically moves teeth to the ideal position. The author named this new treatment method the D.P. method.

I. General Overview of D.P. Method

1. When to Begin Treatment

In general, orthodontic treatment begins as soon as the practitioner diagnoses malocclusion, so this is greatly influenced by the patient's awareness of and demands for orthodontic treatment.

However, if I were to describe when to begin D.P. treatment from the standpoint of performing orthodontic treatment, the period in which to achieve the best D.P. therapeutic effect is the period before permanent teeth occlusion is completed, namely, from deciduous dentition to mixed dentition (about age 3 until around age 10). A number of reasons can be listed for using a D.P. during this period; typical clinical ones are:

1) This is the period during which an individual's growth and development are greatest, so it is possible to carry out treatment while controlling mandibulofacial growth to some extent.
2) During the period while deciduous teeth are being replaced by permanent teeth so-called "leeway space" is available for treatment.
3) The eruptive force of erupting permanent teeth can be utilized as orthodontic force, and teeth can be guided to the correct position (guided eruption).
4) In discrepancy cases D.P. can be used along with serial extraction. In particular, guided eruption of subsequent permanent teeth can be done at the same time as treating a malpositioned tooth.
5) Realigning the set-up model is partial. In particular, the anterior teeth and posterior teeth are handled at different stages, in accordance with the treatment objectives, so the D.P.'s so-called anchorage (nonmoving teeth and peripheral mucosa) can be reliably obtained.
6) It is easy to obtain patient cooperation and guarantee the use period with a D.P.

Therefore I shall next attempt to describe the D.P. treatment period and positioning in actual clinical terms.

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2. Treatment Positioning and Significance

Miura,[22] when planning orthodontic treatment, advocated dividing it into various stages—significance, treatment period, measures and objectives, devices and methods, etc.—and called this the orthodontic treatment long-term treatment planning method.

Incidentally, when the D.P. is positioned in orthodontics, it is positioned within the major roles of:

1) Preventive orthodontics
2) Interceptive orthodontics
3) Limited corrective orthodontics

(according to the U.S. Dental Student Education Network). Moreover, if used in combination with other orthodontic appliances, it is completely satisfactory for extensive corrective orthodontics, so it can be widely used in all phases of orthodontic treatment.

Next, if we attempt to position the D.P. in the orthodontic treatment long-term treatment planning method, it is an orthodontic appliance which is fully effective in each phase:

1) Primary dynamic treatment phase
2) Primary growth guidance phase (anterior teeth replacement period)
3) Secondary dynamic treatment phase
4) Secondary growth guidance phase (lateral teeth replacement period)

If problems are eliminated in this period, it becomes possible to obtain individual proper occlusion subsequently merely by managing the occlusion. Of course, the point that it can also be used in tertiary dynamic treatment is as previously described, but the treatment period and objectives for the D.P. itself are within the range of 1)~4) as described above.

To describe the significance of this in greater detail, during the course of growth and development of an individual's mandibulofacial cranial bones, [the practitioner] monitors and guides the permanent teeth over the long period from replacement of the anterior teeth to replacement of the lateral teeth. While doing so, [he] corrects problems such as functional impediments, growth inhibiting factors, improper skeletal patterns, etc., using comparatively simple appliances and methods, and sets [teeth and bones] on the proper development course. Here lie the essential significance and positioning of the D.P. This, in other words, echoes the meaning and objective of orthodontic treatment itself.

3. Necessity of Early Treatment, and D.P. Effects

There are many variations in orthodontic treatment, according to the extent and type of problem, and it goes without saying that treatment needs to begin as soon as possible after the problem is recognized.

Cases of reversed occlusion in particular exhibit an abnormal configuration and functional impediments, so the necessity of early treatment is strongly recognized, compared to other so-called cosmetic malocclusions. For example, we often experience dental or functional reversed occlusions which can be easily treated if treatment is undertaken at an early stage but which have the risk of shifting to skeletal reversed occlusions if the problem is left alone over a long period. Treating a problem and then treating a pronounced skeletal reversed occlusion resulting therefrom is very difficult, and may sometimes require invasive measures. In this sense, the essential objective of

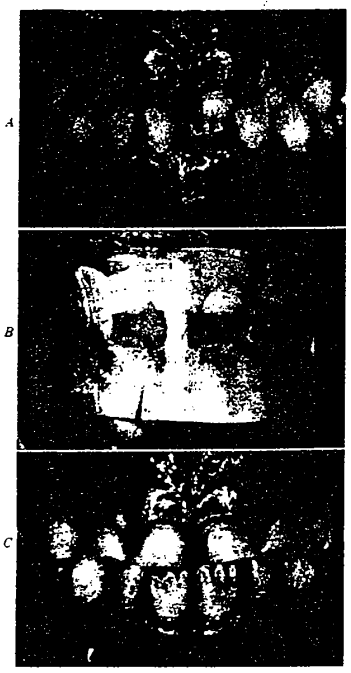
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orthodontic treatment in cases of reversed occlusion and the like is to eliminate the problem as soon as possible and obtain an individual proper occlusion.

Now I shall introduce two cases (reversed occlusion) treated with the D.P. method at an early stage, and advocate the necessity of early treatment using a D.P.

Figure 2 is a case in which the goal of the primary dynamic treatment phase was improving the anterior teeth overbite. It is a deciduous reversed occlusion (female, age 5) undergoing so-called early treatment. Figure 2-A shows when D.P. treatment began, Figure 2-B shows the D.P. being worn with the cutting method, and Figure 2-C shows the situation in the fourth month, when overbite correction ended. This case has now entered the primary growth guidance phase, and the eruption and guidance of subsequent permanent teeth is being managed with a D.P.

Figure 3 is a case of functional reversed occlusion (6 years 5 months, female). The target of the secondary dynamic treatment phase was the anterior reversed occlusion. Figure 3-A is when the D.P. method began, and Figure 3-B is at the end of orthodontic treatment (age 11). The anterior overbite relation was corrected by D.P. No. 1 (requiring five months), after which lateral permanent teeth eruption in the secondary growth guidance phase was managed by D.P. No. 2 while finishing an individual proper occlusion.



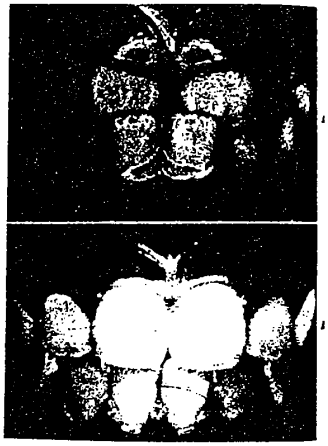


Figure 3. Case of functional reversed occlusion. Six years 5 months when diagnosed. Female.
A: When initially diagnosed
B: At end (age 11)
Example of a case in which the anterior crossbite was corrected in the fifth month by the D.P. method. In the subsequent secondary growth guidance phase, occlusion was managed by D.P. and individual proper occlusion was established.

Figure 2. Case of deciduous reversed occlusion. Initial diagnosis at age 5, female. (One case of early orthodontic treatment)
A: When initially diagnosed
B: D.P. being worn (cutting method)
C: Fourth month (enter primary growth guidance phase)
Example of a case in which the anterior overbite relation was corrected in the fourth month by the D.P. method. Subsequent permanent tooth eruption was guided with a D.P.

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The results of these two cases indicate that if an early-phase problem can be swiftly corrected, at least it can be addressed without allowing the problem to worsen, or subsequent orthodontic treatment can be performed easily and effectively even if [the patient] shifts to the permanent dentition stage.

4. Indications

It is difficult to say in simple terms what indications point to what kind of cases, but the following matters can be pointed out as a general overview.

First, the main therapeutic target of the D.P. method is malocclusion which is thought to be caused by dental and functional factors. Malocclusions exhibiting skeletal factors can be included in these indications in mild cases, of course, but in cases exhibiting a pronounced skeletal pattern it is necessary to combine and use a D.P. with other orthodontic appliances (for example, an extraoral retainer). There, the main element in selecting indications must be first and foremost a detailed case analysis and a precise orthodontic diagnosis derived therefrom. This also has a great impact on the set-up model realignment method, so this study must be undertaken seriously.

Another important element in studying D.P. indications is fully understanding the D.P. structure and how it works. The structure of the D.P. is such that it connects the upper and lower jaws via a layer of rubber at the occlusal plane, so when it is first used the strongest corrective force is the orthodontic force transmitted to the teeth. Moreover, the area where the orthodontic force is initially created is the incisal side of the anterior area, and at the molars it acts strongly upon the region near the occlusal plane. That is, in the initial phase, inclined movement is apparent, while in the intermediate phase and final phase the movement pattern shifts to tooth movement.

Also, because of the appliance's structure the tooth movement effect is highly effective for horizontal movement (labial or buccolingual, mesiodistal) and weakly effective for vertical movement (up/down).

Here the following sorts of categories can be applied when trying to select D.P. indications based on general malocclusion categories.

1) Dental maxillary protrusion, mandibular protrusion
2) Functional maxillary protrusion, mandibular protrusion
3) Mild skeletal maxillary protrusion, mandibular protrusion
4) Crowding (often cases with extraction)
5) Deep overbite
6) Crossbite

Various other cases may be applicable in addition to those listed above, but here these are selected from the ordinary category system.

5. How to Create Treatment Objectives

Thus far I have described the clinical positioning and significance of the D.P. in general terms, but from this section onward I want to shift to the treatment issue of how the D.P. is actually used.

If using the D.P. for orthodontic treatment, it goes without saying that it is necessary to do the customary detailed case analysis and establish a precise orthodontic

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diagnosis and treatment goals. The nature and type of malocclusion determine the D.P. treatment system and its use objective, so this treatment goal must be carefully studied. The major points which must be considered when formulating a treatment objective and system include:

1) Skeletal problems (In this case, use in combination with extraoral retainer. Headgear for maxillary protrusion, chin cap for mandibular protrusion.)
2) Functional problems (Can be treated with D.P. alone. Make D.P. utilizing construction bite.)
3) Discrepancy type (Apply serial extraction method and combine with other orthodontic appliances.)
4) Individual tooth problems (D.P. combined with other orthodontic appliances as required.)

Here I shall describe the therapeutic objective in reversed occlusions and important points in using the D.P.

When treating reversed occlusion in the mixed dentition stage, the cause of the problem and the treatment system can be considered as follows.

1) If accompanied by maxilla undergrowth: Correct overbite by aggressive labial and lateral expansion using D.P.
2) If accompanied by mandible overgrowth: Quickly correct the overbite relation using D.P., and then suppress mandibular growth and development using a chin cap.
3) If accompanied by a functional mesial orientation of the mandible: Remove functional impediment using D.P., and quickly correct overbite.
4) If accompanied by discrepancy: Correct the overbite relation while applying serial extraction, and then in the final stage use an all-band appliance (usually finishing within six months) and obtain individual proper occlusion.

Now, once the treatment goals and D.P. application have been decided upon, next one must determine how to proceed with treatment, namely, what sort of D.P. use method and system to use.

6. How to Proceed with the D.P. System

In the D.P. method (dynamic positioner system) planning the use objective and set-up model based on the treatment goal begins with studying the case. In general, treatment of a case in the mixed dentition stage proceeds along the following general lines.

1) First stage: Quickly correct the incorrect relation of the anterior teeth using the D.P., and then shift to the growth guidance stage and observe the eruption of lateral permanent teeth.
2) Second stage: While guiding the eruption of permanent lateral teeth with the D.P., deal with skeletal growth and development. (In extraction cases, do serial extraction at this point.)
3) Third stage: If individual proper occlusion cannot be achieved, use D.P. for retention and stop. (In extraction cases, correct the final occlusal relation with D.P. and an all-band appliance. For example, correct the

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inclination of small molars and canines. In general, do the edgewise method using D.B.S.)

Cases of reversed occlusion are also handled by the aforesaid method, and their set-up models are also made based on this.

Now I would like to describe how the D.P. is used in clinical use, and to describe important points about using it.

First, when beginning treatment, two separate dynamic positioners are made from the same set-up model (ones with different rubber hardness, for example Orthocon-L and M), and the way of beginning treatment is the usual method. A feature of this way of proceeding is to aggressively move the teeth on the set-up model and to adjust the corrective force so that the hardness of the rubber used and the D.P.'s shape modification (Figure 4) gradually change.

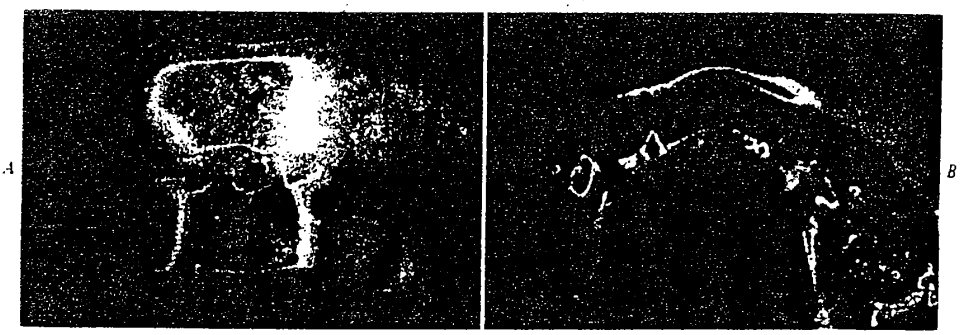


Figure 4. D.P. Shape Modification (for reversed occlusion)
The corrective force is adjusted by the hardness of the rubber used and modifying the shape (cutting method). This results in a highly active orthodontic force always being applied to the teeth.
A: A D.P. being worn in the oral cavity of a patient with reversed occlusion. A reversed V-shaped space can be seen in the D.P.'s mandibular labial surface.
B: Shows maxillary lingual surface of D.P. used in the same case.

In the commonly used method, the set-up model is remade once in the sixth month while monitoring the course of treatment, and two dynamic positioners are made at a time. That is, treatment proceeds in a system wherein D.P. replacement occurs every three months.

Benefits of this method include:

1) Some of the set-up model work can be eliminated.
2) A constant light corrective force is continuously applied to the teeth, and teeth can be moved to the biological and ideal position.
3) When treatment begins, one D.P. can be modified. Therefore teeth are moved without causing pain in the patient.
4) Depending on the progress of treatment, a second D.P. with a different rubber hardness (usually one with harder rubber) can be substituted at the proper time, and a fixed continuous highly active orthodontic force can be applied to the teeth.
5) D.P. loss or appliance breakage or the like can be dealt with quickly.

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Treatment in the clinic can proceed very rationally, and high treatment effects can be expected.

7. Adjustment of Orthodontic Force

When beginning orthodontic treatment, it is necessary to move teeth using the lightest possible force; this is called for from a biological standpoint. The necessity of using a light force and moreover a continuous force is a basic concept in moving teeth in modern orthodontic treatment.[23)24)]

Incidentally, the D.P.'s corrective force comes from utilizing rubber recovery force, as described earlier, and the magnitude of this force can be controlled by the methods described below.

1) Adjust it by the amount of movement of the teeth realigned on the set-up model.
2) Adjust it by selection of the type of Orthocon, that is, the rubber hardness (light L, medium M, heavy H). Also, the D.P. force's operating effect can be partially changed by partially changing the rubber hardness when making the D.P.
3) Insert a cut in the D.P. (cutting method)[25)], and change its shape, thereby partially alleviating the corrective force and adjusting its force.

In practice, on the clinical level, 1) and 2) are determined by the treatment system or objective, and are operations which are carried out in the course of making the D.P. 3) is an adjustment method which is strictly limited to when orthodontic treatment begins, and is an operation carried out in order to avoid causing various problems in the patient.

In summary, D.P. adjustment is virtually unnecessary, except when treatment begins, and teeth begin to move automatically in the ideal direction. This feature is quite different from conventional orthodontic treatment with wires.

Here I shall attempt to describe D.P. shape modifications which are often carried out when starting to use a D.P. in cases of reversed occlusion.

This operation is a method which is proposed from the biological standpoint of not applying a strong corrective force directly to the tooth when beginning treatment. The necessity of this is determined from the case and the amount of tooth movement on the set-up model. In general, it is used in many cases in order to lessen the rubber's recovery force.

Figure 5 shows a modification method (the cutting method) used in a reversed occlusion case. The cut on the mandibular anterior labial surface is made distal and proximal to the lateral incisors at both sides, and in some cases a cut may be made between the mandibular central incisors (Figure 5-A). Lingual surface modification is done using a surgical knife or scissors to make a vertical V-shaped cut at the saggital area of the maxillary anterior palate and at the lateral incisor's distal surface (Figure 5-B). When a D.P. modified in this manner is worn in a patient's oral cavity, a reverse V-shaped space appears at the area with the cut (labial surface). As a result, the corrective force applied to the teeth is a continuous light force and the tooth moves biologically (Figure 5-C). Also, if the case is skeletal reversed occlusion, the amount of movement on the set-up model is large, so a horizontal cut is made in the rubber's lingual surface to form a rubber flap, and the orthodontic force applied to the maxillary anterior incisor area is alleviated (Figure 5-D).

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Figure 5. How to modify shape of D.P. used in reversed occlusion. This operation weakens the orthodontic force when beginning treatment and makes teeth move biologically.

A: Modification of labial surface
B: Modification of lingual surface
C: D.P. with modification being worn
D: When modifying for skeletal reversed occlusions, etc., a horizontal V-shaped cut is made in the D.P.'s lingual surface to form a rubber flap.

8. Patient Cooperation and Cautions in Use

A D.P. is a removable orthodontic appliance, so patient cooperation is absolutely required. This is a problem common to removable orthodontic appliances. No matter how advanced the treatment system or therapeutic device, if the patient dislikes it not even the initial objectives will be achieved. This means that it is not exaggerating to say that patient cooperation is the most important and necessary requirement when using the D.P. method clinically.

First, in order to obtain the patient's cooperation, one must fully explain the significance of the D.P. used and the objective and how it works and the benefits of using it and so forth. The patient himself, of course, and also the mother must be made to understand. Also, one must not neglect patient education when monitoring progress after the D.P. is installed (generally at an interval of once a month). That's because the mother's guidance and diligent attitude are important factors in achieving a high therapeutic effect with the D.P.

Now, next I want to describe some important points in using it.

As regards the period the D.P. is used, the longer the period the greater the effect, but it puts restrictions on the patient's lifestyle, so usually it is used primarily at night (the period from when the patient returns home until the next morning). That is, the patient needs to be ordered to use it about 12 hours a day, including bedtime. Of course this time

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slot is the conditional upon doing dynamic treatment with the D.P. After the treatment objectives of the initial phase are completed, treatment shifts to the guidance phase (monitoring), during which D.P. usage may be required as needed (in this case, changing to using it only when asleep) or it may become a case in which progress is monitored without using any appliance whatsoever.

To install the D.P., first the D.P. is inserted on the maxillary dentition, and then the mandible slowly bites into the D.P. It is not necessary to apply a biting motion for a few minutes after installing it; applying a light occlusal pressure to the D.P. is sufficient. This is because teeth are more effectively moved by applying a continuous light orthodontic force than an excessive orthodontic force.

It is also important to instruct [the patient] to clean the oral cavity well with a brush before and after using the D.P., and to keep the D.P., especially its inner surface, clean.

If patients experience a large amount of saliva while using it, the lingual surface of the D.P. should be removed as much as possible. In some cases the problem may be resolved by modifying the shape of the D.P. The occlusal vertical dimension (usually an aperture of 4 mm) can be lowered to make swallowing motion easier, or the shape can be modified so it doesn't feel like a foreign object to the patient.

Now, [the patient] must be instructed to bring the D.P. and not forget it when visiting the clinic. This is not because the practitioner has to adjust the D.P., which almost never happens. It is because of the need to monitor the progress of treatment and move ahead with treatment. Have cracks developed in the D.P.? Is the D.P. being used correctly? (When a D.P. is used often its transparency decreases and it changes to somewhat nontransparent.) When is it time to shift to the next treatment stage? (When one realizes that spaces created by the D.P. orientation have vanished, it is time to move to the next stage.)

9. Responsibilities and Viewpoints of the Dentist and Dental Technician

A D.P. is a device which obtains its principles of movement from teeth realigned on a set-up model. It is a treatment device whose orthodontic treatment is modified by the nature and details of the lab work, so the duties and responsibilities of the dentist and technician need to be more clearly defined. First, making the set-up model is a task performed by the dentist, who understands the D.P. concept. Even if the technician were to participate in this operation, serious problems would remain from a medical practices standpoint if the method of realigning the teeth were not done under the direction and guidance of the practitioner.

However, the technician can work without problems from after the set-up model is made until D.P. finishing, since this is no different whatsoever from making a prosthesis. In short, after a D.P. exists as an orthodontic appliance treating an actual malocclusion, all responsibility for those actions belongs to the dentist.

In the future the D.P. will become more common as an orthodontic treatment device, and it will be used to treat many patients with malocclusions, so it will be necessary to clearly define the work responsibilities of the dentist and technician, and to move ahead with mutual understanding of each other's perspective.

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II. Case Reports of Reversed Malocclusion Using the D.P. Method

Now I want to introduce case reports of reversed malocclusions treated using the D.P. method. The case reports reported herein are two cases (nonextraction) of mild reversed occlusion during the mixed dentition stage thought to arise from dental and functional factors. Furthermore, introduction of each case and explanation of the therapeutic effect is summarized at the end.

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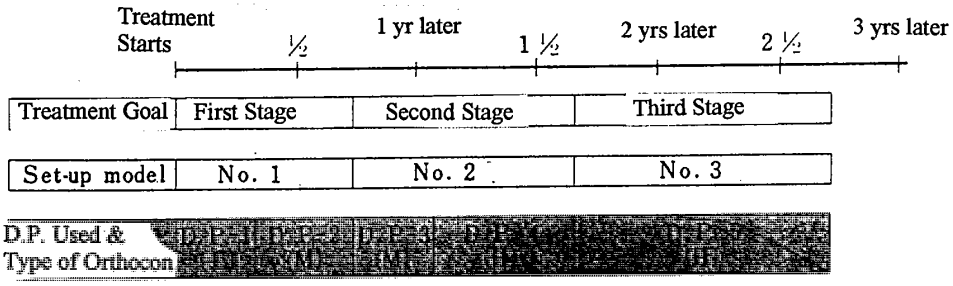
Case No. 1: Dental Reversed Occlusion Accompanying Traumatogenic Occlusion of $\overline{|1}$; Age 8 years 5 months; Male

Diagnosis: Anterior crossbite accompanying cuspal interference to $\overline{|1}$. Angle Class III

Treatment system: Nonextraction using D.P. method.

D.P. Treatment Objectives:
First stage: Remove impediment due to premature contact of $\frac{|1}{|1}$, and correct anterior teeth misalignment.
Second stage: Guide eruption of lateral permanent teeth.
Third stage: Shift to retention.

Treatment Progress



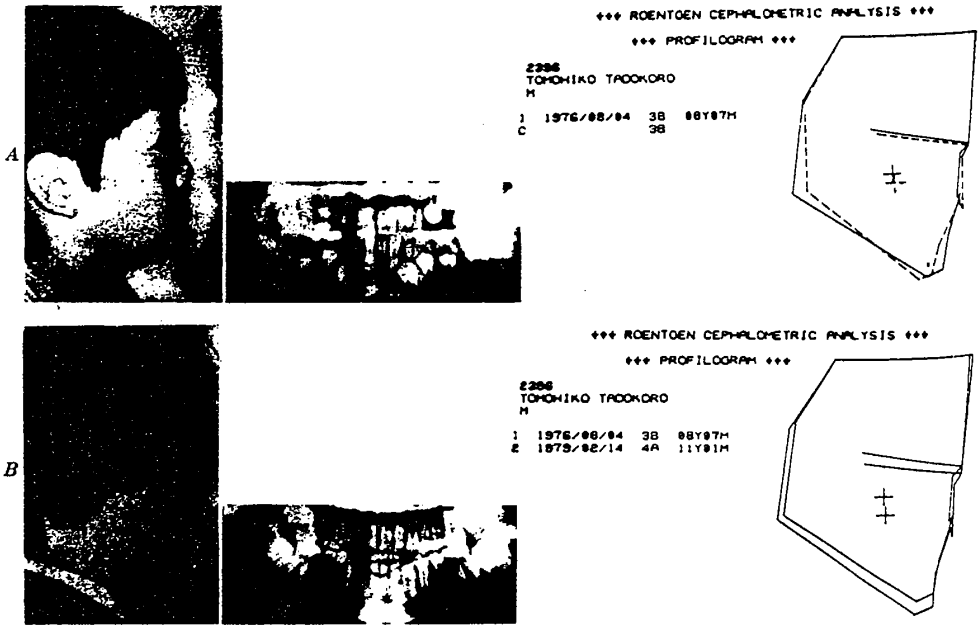


Figure 6. Case 1's profile view (left), panoramic X-ray view (center), and profilogram obtained from cephalometric radiograms (S-N superimposed using NEAC 3200 computer image analysis system).
A: Before treatment B: After treatment

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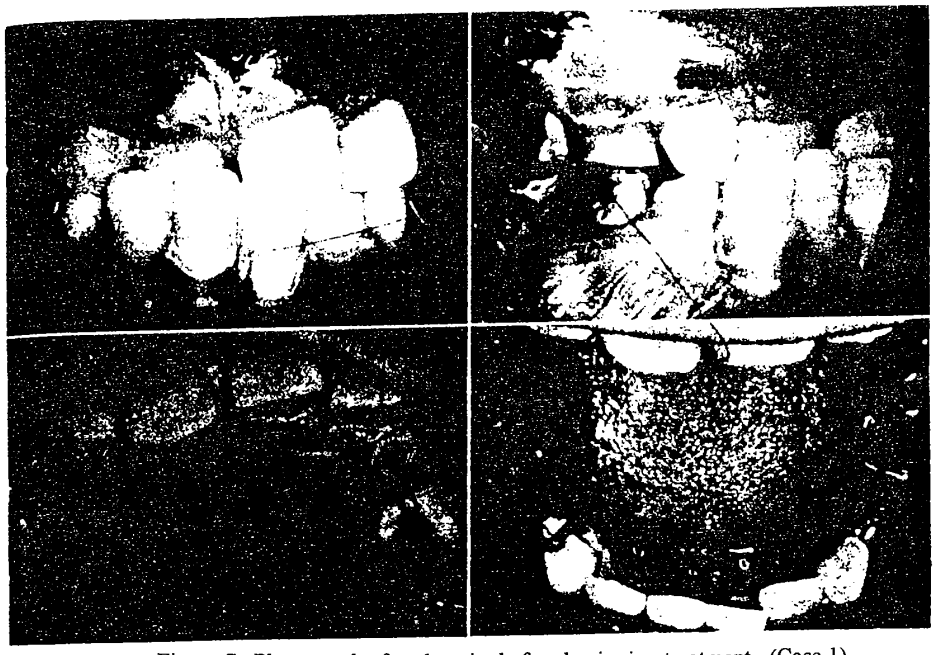


Figure 7. Photograph of oral cavity before beginning treatment. (Case 1)

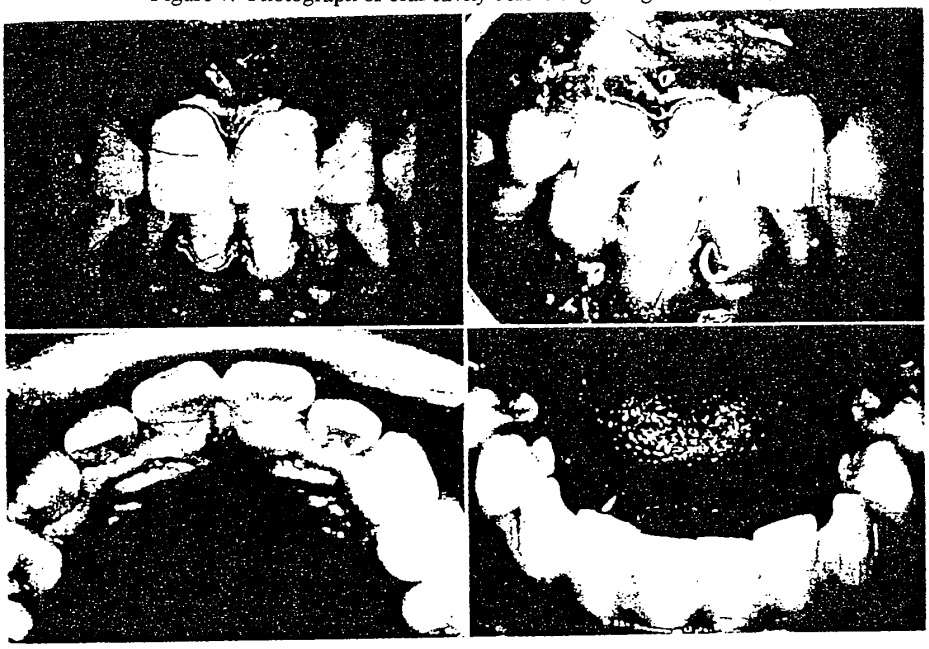


Figure 8. Photograph of oral cavity after treatment using D.P. ended (Case 1). Dynamic treatment for 9 months, lateral tooth eruption guidance for 11 months, retention for one year.

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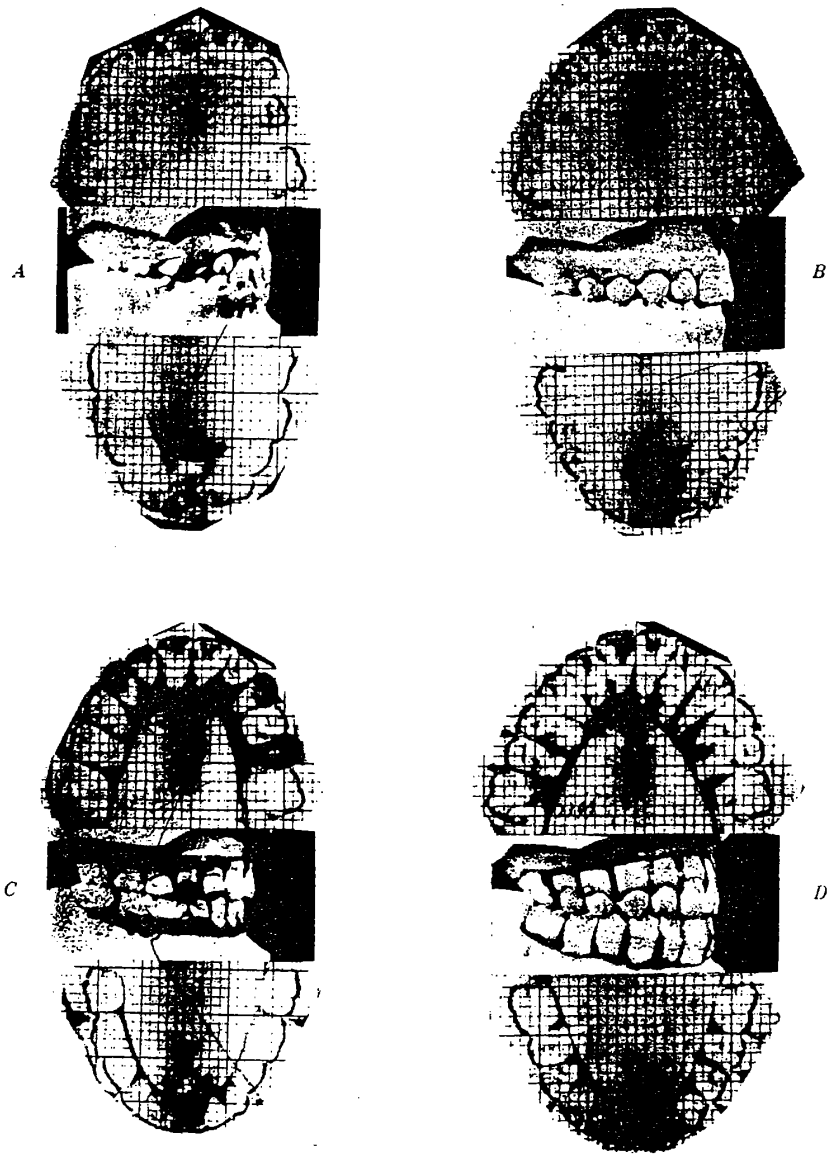


Figure 9. Photographs of Case 1's plaster models and set-up model's occlusal plane grid (1 unit = 2mm).
A: Before treatment B: After treatment C: No. 1 set-up model D: No. 3 set-up model

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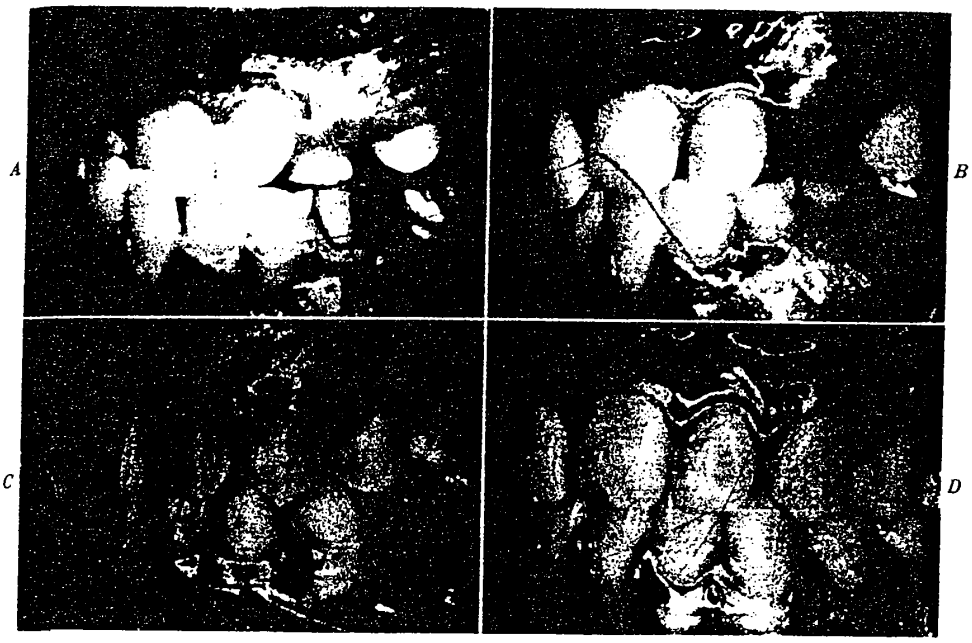


Figure 10. Case 1's treatment progress. A: When treatment began. B: Five months later. C: One year later. D: Two years one month later.

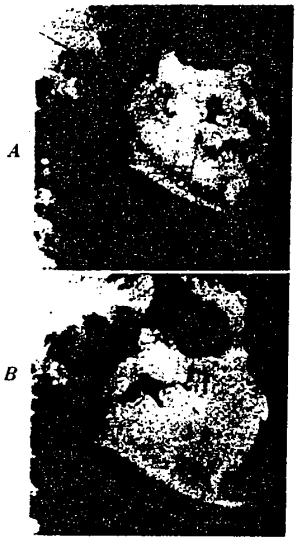


Figure 11: Trimmed maxillomandibular relation, from lateral cephalometric radiogram.
A: Before treatment B: After treatment

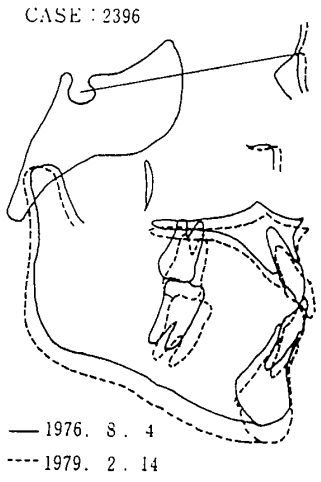


Figure 12. Superimposed (S-N criterion) of lateral cephalometric radiogram: Solid line = before treatment, dotted line = after treatment.

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Case No. 2: Reversed Occlusion with Anterior Deviated Mandible Due to Functional Factors; Age 8 years 11 months; Female

Diagnosis: Functional reversed occlusion; mandible shifted forward due to premature contact of anterior teeth. Angle Class III

Treatment system: Nonextraction using D.P. method.

D.P. Treatment Objectives:
First stage: Correct reverse overbite relationship caused by cuspal interference from anterior teeth.
Second stage: Obtain space for eruption of maxillary lateral permanent teeth through lateral expansion.
Third stage: Shift to retention.

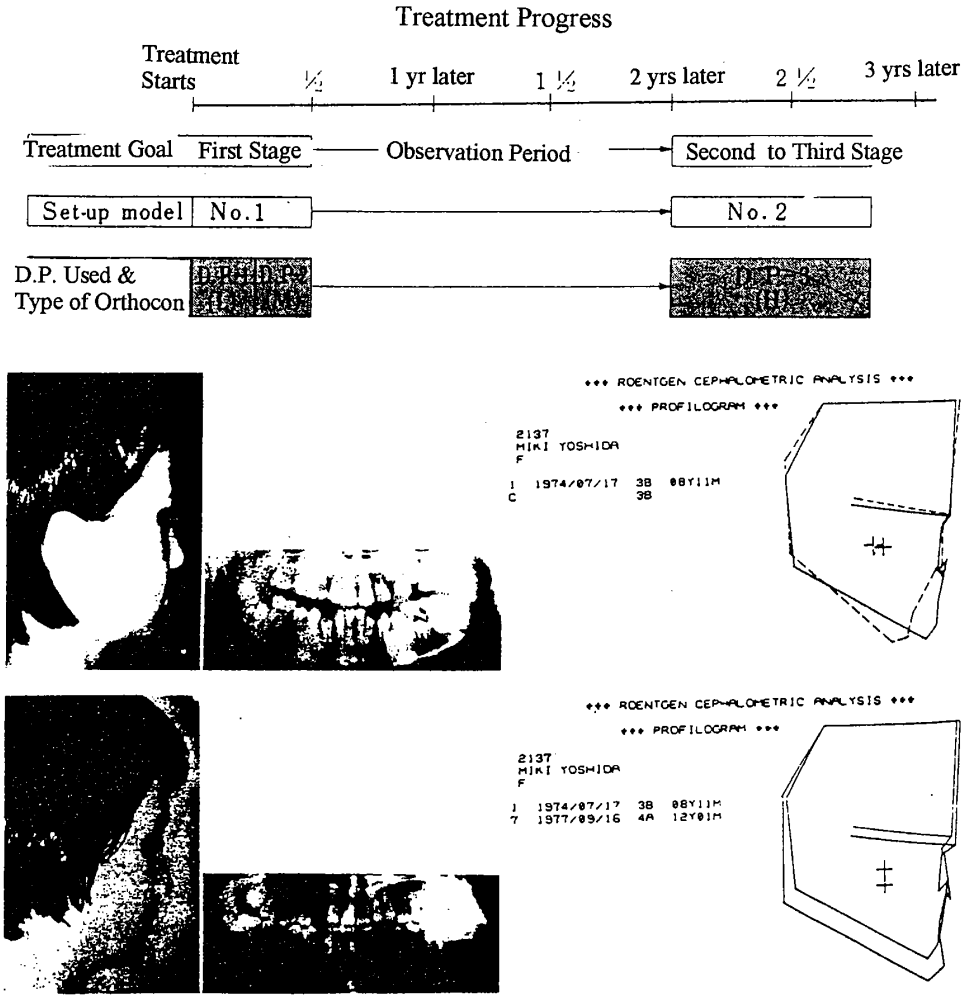


Figure 13. Case 2's profile view (left), panoramic X-ray view (center), and profilogram obtained from cephalometric radiograms (right).
A: Before treatment B: After treatment

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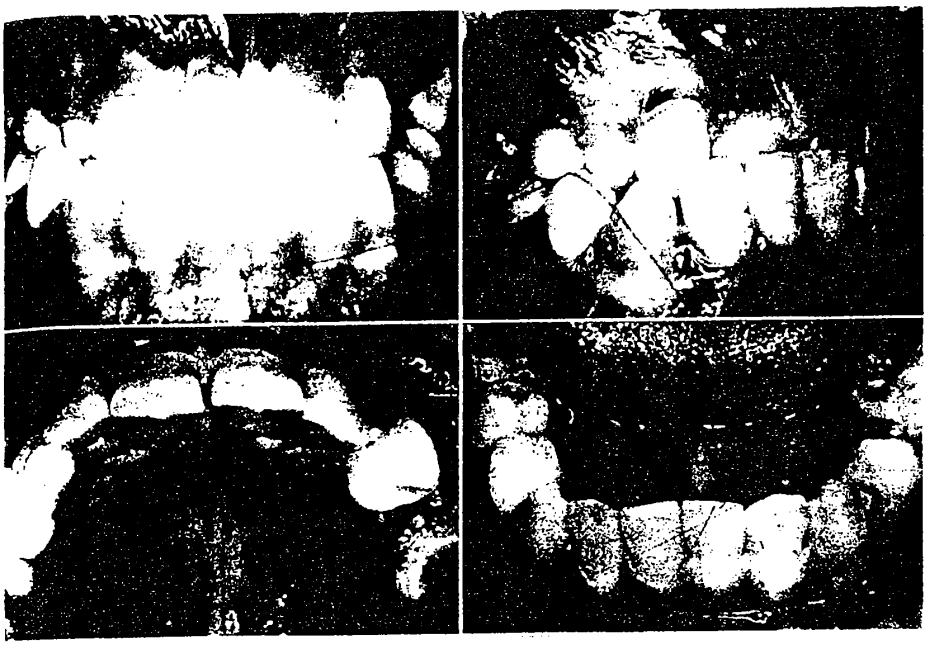


Figure 14. Photograph of oral cavity before beginning treatment. (Case 2)

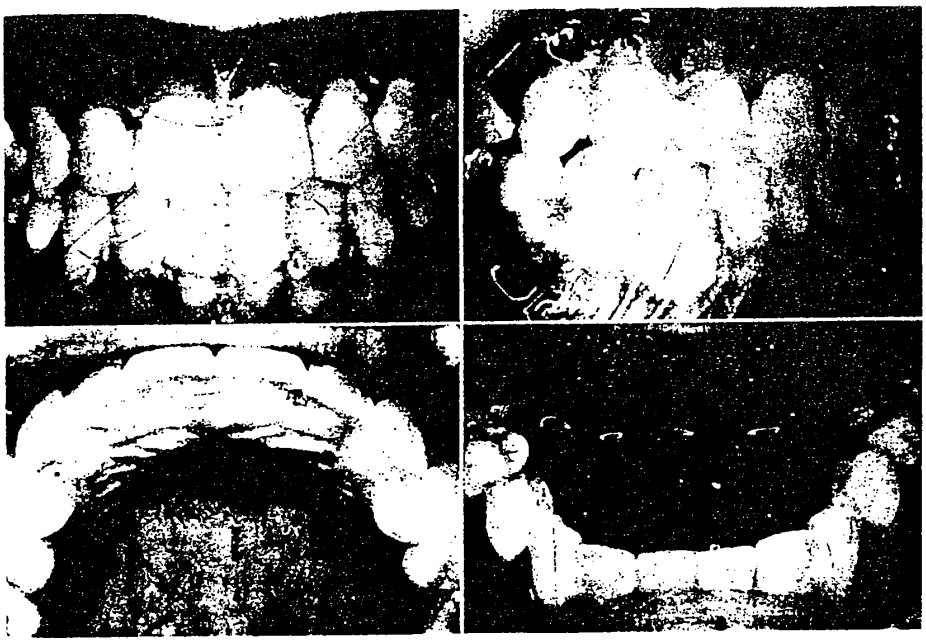


Figure 15. Photograph of oral cavity after treatment using D.P. ended (Case 2). Dynamic treatment for 9 months, observation for 1 year 6 months, retention for 6 months.

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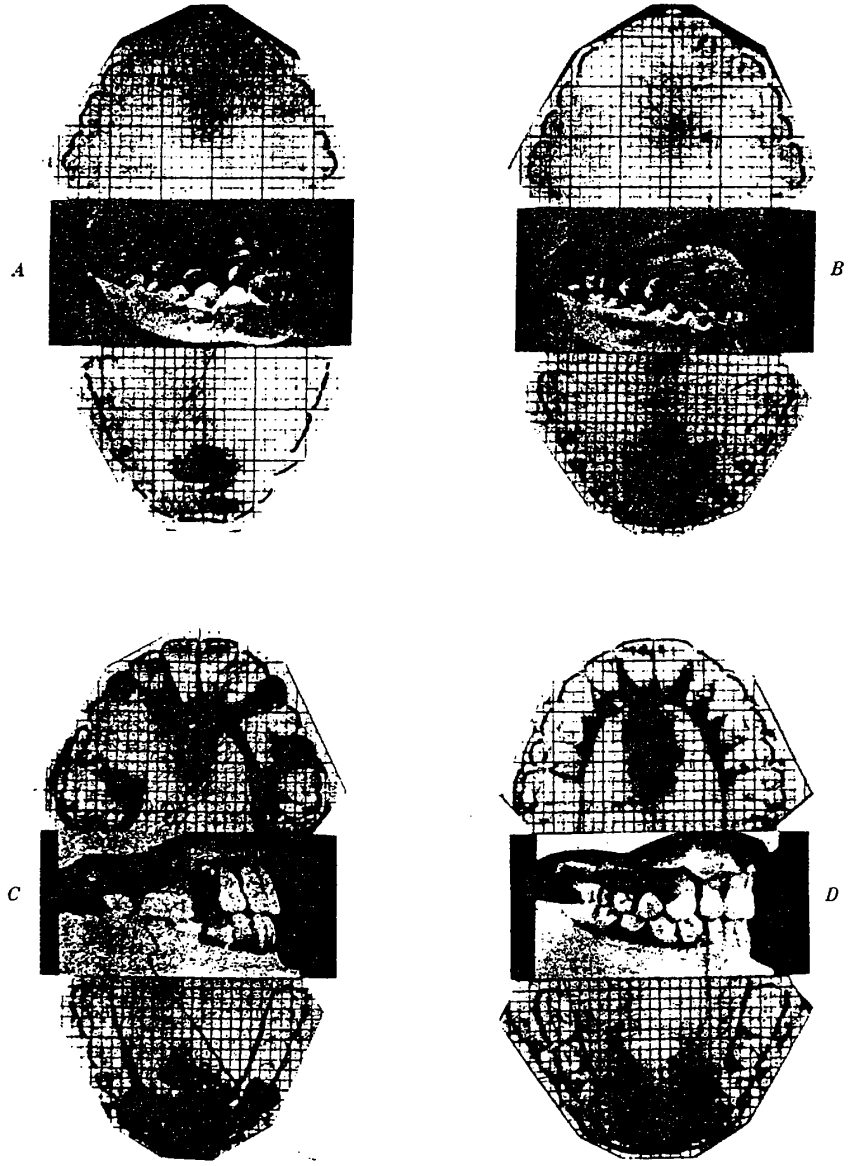


Figure 16. Photographs of Case 2's plaster models and set-up model's occlusal plane grid (1 unit = 2mm).
A: Before treatment B: After treatment C: No. 1 set-up model D: No. 2 set-up model

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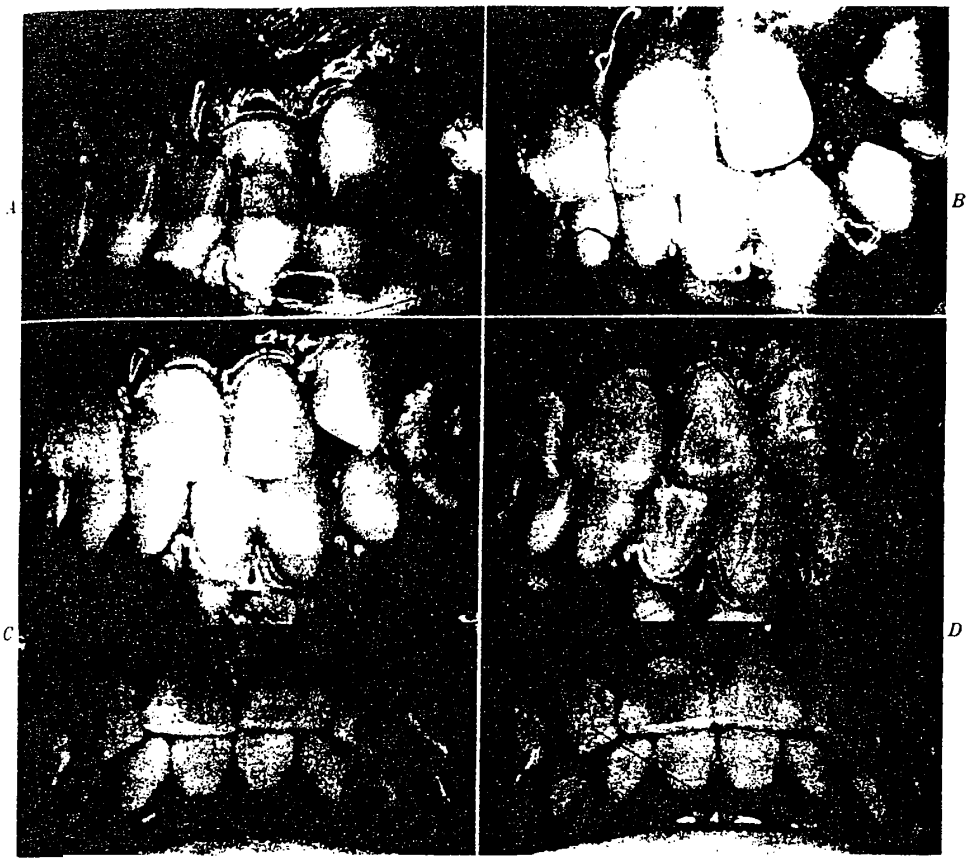


Figure 17. Case 2's treatment progress. A: When treatment began. B: Three months later. C: One year 6 months later. D: Two years 10 months later.

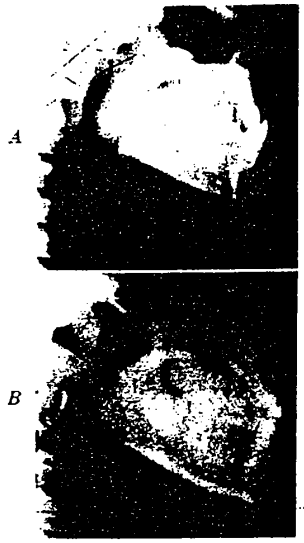


Figure 18: Trimmed maxillomandibular relation, from lateral cephalometric radiograms.
A: Before treatment B: After treatment

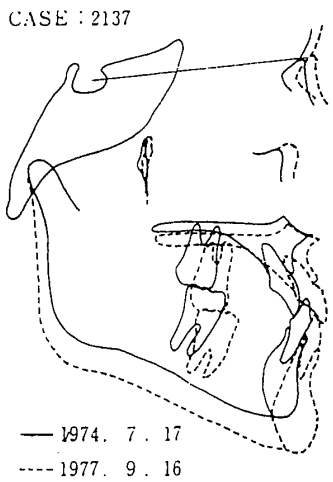


Figure 19. Superimposed (S-N criterion) of lateral cephalometric radiograms. Solid line = before treatment, dotted line = after treatment.

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Case No. 1: Dental Reversed Occlusion Accompanying Traumatogenic Occlusion of $\overline{1}$; Age 8 years 5 months; Male (Figures 6~12)

Patient: Age 8 years 5 months; Male

1) Status Praesens

Facial impression: In profile no pronounced abnormalities apparent, but a slight rollback was visible at the lower lip (Figure 6-A).

Occlusal impression: This case was dental age III B with three anterior teeth exhibiting reversed occlusion; the left maxillary central incisor was wedged between the mandibular central incisor and lateral incisor (Figure 7). Also, the left mandibular central incisor was receding into the gingiva due to traumatogenic occlusion. The midline was such that the mandible was deviated slightly to the left of the maxilla.

The molar occlusal relationship was Angle class III. It was felt that there was enough room for the eruption of lateral teeth on the upper and lower jaws, even after considering the panoramic X-ray in Figure 6-A. This case seemed to be one which included functional elements, since if the lower jaw were made to retract, a construction bite could be obtained.

Cephalometric radiogram analysis impression: The main impression was that the maxilla was almost correct, but the mandible was anteriorly deviated, and moreover the mandibular plane angle was small, so the lower jaw was rotating forward and up (see profilogram in Figure 6-A).

2) Diagnosis and Treatment System

Angle Class III was diagnosed: dental reversed occlusion due to the lower jaw's functional anterior position Treatment was commenced as nonextraction using the D.P. system.

3) D.P. Treatment Goals

The D.P. treatment goals were divided into three stages.

First stage: Remove impediment due to premature contact of anterior teeth, and at the same time correct anterior teeth reversed occlusion and irregularities.

Second stage: Guide eruption of lateral permanent teeth.

Third stage: Shift to retention.

Furthermore, set-up models were aligned and made in three stages based on this treatment objective.

4) Treatment Progress

Treatment progressed as shown in Figure 10. Two D.P.s were used in the first stage (Orthocon L and M), and the initial objectives were achieved in about five months. As shown in Figure 9-C, a set-up model was made which expanded the maxillary anterior teeth about 2.5 mm toward the labial direction and at the same time shifted the mandibular anterior teeth about 1.5 mm in the lingual direction. Then, in order to guide the eruption of the lateral permanent teeth, the set-up model used in the second stage was made. Dynamic treatment required nine months, lateral teeth eruption guidance 11 months, and retention one year, and then treatment ended. Set-up models were made for

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three stages, and a total of five individual D.P.s were used before orthodontic treatment ended in this case.

5) Treatment Results and Evaluation

Figure 7 and Figure 8 show the actual oral cavity before and after treatment. Figure 9 shows views of the patient's occlusal plane before and after treatment, and side views of the set-up models made at each stage. Figure 12 is a superimposition of lateral cephalometric radiograms before and after treatment, showing the changes. In order to investigate the tooth movement effect, occlusal plane grid views before and after treatment were superimposed (using the distal surfaces of the left and right first molars as the reference surface) (Figure 20). Table 1 also shows typical values for angular analysis of cephalometric radiograms.

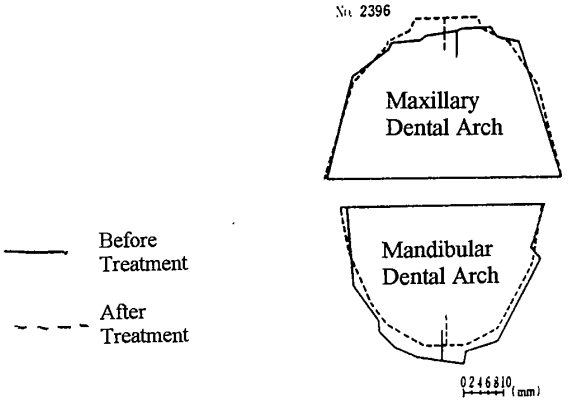


Figure 20. Superimposing Case 1's occlusal surface grid views (using the first molar's distal surface as the reference surface.)

Table 1. Analytical Values for Lateral Cephalometric Radiograms (Case 1)

	Before	After
SNA	79. 83	79. 98
SNB	80. 08	78. 53
ANB	−0. 25	1. 45
MP-SN	31. 29	32. 75
Go.A	113. 19	114. 66
$\underline{1}$ to SN	97. 38	105. 22
$\bar{1}$ to MP	93. 66	86. 59

To list the points where changes are most clearly apparent from these treatment results:

1) Movement of the anterior teeth in the upper and lower jaws underwent the greatest change.
2) The effect of the set-up models is accurately manifested in the treatment results, producing the occlusal relationship sought in the realignment.

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3) $\overline{1}$'s traumatogenic occlusion was corrected, and effects were obtained which satisfied the objectives of the orthodontic treatment.

4) Mandibulofacial cranial growth and development was set on the correct course.

These points show that in orthodontic treatment of dental reversed occlusion the D.P. method is a treatment system which can achieve a greater therapeutic effect by fully realizing its functions. Also, the effect of this treatment is to correct malocclusion in the initial stage and then continue to guide the eruption of lateral permanent teeth while obtaining individual proper occlusion, so it is highly evaluated as a new method with effects not seen in conventional orthodontic treatment methods.

Case No. 2: Reversed Occlusion with Anterior Deviation Due to Functional Factors; Age 8 years 11 months; Female (Figures 13~19)

1) Status Praesens

Facial impression: In profile no pronounced abnormalities apparent (Figure 13-A).

Occlusal impression: This case was dental age III B, a reversed occlusion of all anterior teeth, a so-called classic mandibular protrusion (Figure 14). In particular, it presented an overbite (5 mm) with shallow overclosure, and the midline of the lower jaw was deviated about 2 mm to the right of the upper jaw. The molar occlusal relationship was Angle Class III (Figure 18-A).

The maxillary dental arch provided inadequate space for eruption of the lateral teeth, as seen in Figure 13-A's panoramic X-ray view (about ½ the space needed for the eruption of $\underline{|3}$ in particular).

Also, if the lower jaw could be artificially shifted to the rear, the ends of the upper and lower central incisors could be brought into incisal contact, providing a so-called construction bite. For this reason the case was considered to include functional factors.

Cephalometric radiogram analysis impression: The mandible was anteriorly positioned, and the mandibular plane angle was small and the lower jaw was rotated forward and upward (see profilogram in Figure 13-A).

2) Diagnosis and Treatment System

This case was diagnosed as Angle Class III, a classic functional reversed occlusion caused by functional factors. It was decided to treat this case as nonextraction using the D.P. system.

3) D.P. Treatment Goals

As with Case 1, a treatment plan was created which divided the treatment objectives into three stages.

First stage: Eliminate intercuspal interference at anterior teeth and first do overbite correction.

Second stage: Expand the side to create room for eruption of maxillary lateral teeth. Guide $\underline{|3}$ into the dental arch by doing so.

Third stage: Shift to retention.

Manufacture of set-up models proceeded according to these treatment objectives.

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4) Treatment Progress

As shown in Figure 17, two individual D.P.s were used in the first stage, and in about three months the overbite correction which was the initial objective was accomplished. The pattern of occlusion was stable after this, so the case was entrusted to natural progress, with no orthodontic appliance used, and was monitored. During the 18-month monitoring period all of the lateral permanent teeth erupted, and the maxillary left canine erupted slightly buccally from the dental arch as expected. Therefore treatment shifted to the second stage, with the goal of guiding |3 into the dental arch, and the lateral permanent teeth were laterally expanded and |3 was guided into the dentition. Orthocon H was used for hard D.P. rubber, and after six months |3 had been guided into the dentition. Dynamic treatment totaled nine months for the first stage and second stage, and observation lasted 18 months, and the retention period was six months before treatment was complete.

5) Treatment Results and Evaluation

Examining Figure 14 and Figure 15 we see a great improvement. In cases presenting reversed occlusion due to this sort of functional factor the therapeutic effect is determined by first improving the overbite. After the overbite is corrected, this sort of case maintains a proper occlusal relationship even if other measures are taken subsequently. Among the various therapeutic effects, the following are apparent.

(1) In reversed occlusions accompanying functional factors, short-term overbite correction is necessary; the D.P. effect is superior in this.

(2) It also works effectively in lateral expansion.

Figure 21 shows superimposed occlusal plane views, and Table 2 shows the results of analyzing angles from cephalometric radiograms (before and after treatment).

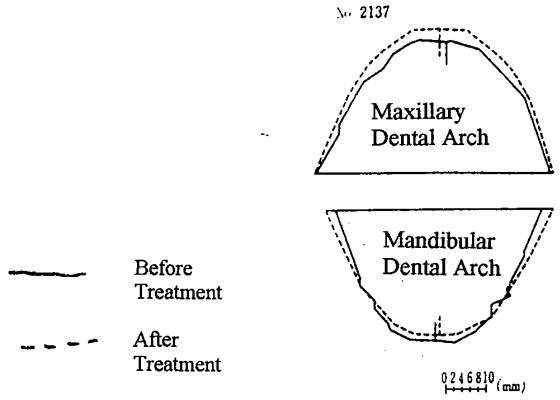


Figure 21. Superimposing Case 2's occlusal plane grid views.

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Table 2. Analytical Values for Lateral Cephalometric Radiograms (Case 2)

	Before	After
SNA	81. 17	82. 27
SNB	83. 71	82. 08
ANB	−2. 53	0. 19
MP-SN	28. 42.	29. 49
Go. A	123. 41	123. 33
$\underline{1}$ to SN	104. 79	111. 99
$\overline{1}$ to MP	84. 45	77. 16

Conclusion

This time I have briefly introduced the important points when actually using this in an orthodontic clinic, namely, the positioning and significance of the D.P. method in orthodontic treatment, when to begin treatment, indications, how to proceed with treatment, objectives, etc. I have also presented two case reports of using the D.P. method in so-called mild reversed occlusions (nonextraction cases, mixed dentition stage, cases believed due to dental and functional factors), and reported on the treatment progress and therapeutic effects.

As this shows, the D.P. method is a completely new concept and technique which exceeds the limits of conventional orthodontic treatment and uncovers new possibilities for the field of dental orthodontics. A point which is particularly significant on the orthodontic clinical front is that its effects are best realized in the period when growth and development is most vigorous (the period when switching from deciduous teeth to permanent teeth). This suggests that using the D.P. method will make it possible to move teeth on a biological level, which is the essence of orthodontic treatment itself.

Next time I plan to present case reports of skeletal reversed occlusions, and discuss the therapeutic effects of extraction and nonextraction cases and how to proceed therein, etc.

(To be continued. References combined in final article.)

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新しい矯正装置—ダイナミック ポジショナー(D.P)—の研究

——Ⅲ. D.P 法の概念とその治療効果——

その1. 歯性ならびに機能性反対咬合の治験例

吉井 修
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はじめに

ダイナミック ポジショナー(以下 D.P と略す)は,ゴム素材が本来有している優れた復元力を矯正力に利用して,不正位にある顎や歯を理想とする位置——いわゆる広義に用いられる個性正常咬合——に移動する目的をもった新しい可撤式矯正装置(図1)の総称であり,しかも矯正治療の開始から終了(保定後)まで一貫して使用できる臨床上の特徴を有する治療器具であるところから,新しい矯正治療法の出現を意味するものといえる.

ところで,筆者はこれまで本誌上において,D.Pの内容を以下の通り,

Ⅰ. D.P の考案と透明シリコーン樹脂(オーソコン)の実用化(No. 452, 55年6月号)

Ⅱ. D.P の製作手順と臨床応用(No. 454, 55年8月号)

に掲載し,その概要を紹介した.

さて,この新しい矯正装置を実際の臨床の場で使用する場合,従来の治療法(細い金属線の弾力を利用して歯を移動する方法)とはその概念や術式などがまったく異なるところから,筆者はこの治療法を新たに D.P 法(Dynamic Positioner system)と名づけて多くの不正咬合者に使用し,その臨床的効果をさまざまな角度から検討している.その結果,きわめて優れた治療効果を発揮することや,従来の治療法では得られない使用上の利点を多くの臨床経験から得ている.

そこで,今回はこの D.P 法の概念,すなわち,その効果ははたしてどこまで期待できるのか,また,どのように治療を進めていったらよいかなど,実際の臨床面に焦点を合わせながらD.P法の要点やその治療効果などについて述べてみよう.

まず,臨床的概念として,D.Pの治療開始時期や適応症,矯正治療上の位置づけと意義,治療目標のたて方や進め方について述べ,治療効果は,不正咬合の種類に分けて報告する関係で,今月号は主に軽度な反対咬合の治験例を取り上げてその経過や治療効果などを簡単に紹介してみたい.



図1 オーソコン(熱硬化型透明シリコーン樹脂)を用いて製作したダイナミック ポジショナー.シリコーンゴム素材の優れた復元力を利用して,歯を理想的な位置にオートマティックに移動できる動的矯正装置である.筆者はこの新しい治療法を D.P 法と名づけた.

Ⅰ. D.P 法の一般的

1. 治療開始時期

一般に矯正治療の開始時期は,を診査した時点から開始され,患者側の矯正治療に対する認って大きく影響されるものといところで,矯正治療を行う立治療開始時期を述べるとすれば,が完成されるまでの期間,すた混合歯列期(3歳ごろから10歳開始するのが最も D.P の治療時期といえる.この時期に D.していくつかの点を挙げるこの代表的なものについては

1) 個体の成長発育が最も旺とから,顎顔面の成長をあルしながら治療を進めるこ

2) 乳歯と永久歯の交換時期わゆる leeway space など.

3) 萌出永久歯の萌出力を利し,歯を正しい位置に誘導(萌出誘導).

4) Discrepancy case につ用しながら連続抜去法が行部位の歯を治療しながら後導を同時に行うことができ

5) Set-up model の再排列特に,治療目標に従って階別に分けて行うことがのいわゆる固定源(非移を確実に得ることができ

6) D.P に対する患者の協が容易に得られる.

などが臨床上考えられる.

そこで,実際の臨床面にお期と位置づけをどのように考述べてみよう.

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ック

究

果——

治験例

井　修
東逓信病院歯科医長）

治療法では得られない使用上の
経験から得ている．
この D.P 法の概念，すなわち，
てどこまで期待できるのか，ま
療を進めていったらよいかな
に焦点を合わせながらD.P法の
果などについて述べてみよう．
念として，D.Pの治療開始時期
療上の位置づけと意義，治療目
方について述べ，治療効果は，
分けて報告する関係で，今月号
咬合の治験例を取り上げてその
どを簡単に紹介してみたい．



熱硬化型透明シリコーン樹脂）を用い
ミック　ポジショナー．シリコーン
復元力を利用して，歯を理想的な位
ックに移動できる動的矯正装置であ
新しい治療法を D. P 法と名づけた．

Ⅰ．D.P 法の一般的概念

1. 治療開始時期

一般に矯正治療の開始時期は，術者が不正咬合者を診査した時点から開始されるものであるから，患者側の矯正治療に対する認識度や要求度によって大きく影響されるものといえるだろう．

ところで，矯正治療を行う立場にたって D.P の治療開始時期を述べるとすれば，特に永久歯咬合が完成されるまでの期間，すなわち乳歯列期から混合歯列期（3歳ごろから10歳前後）の範囲内に開始するのが最も D.P の治療効果を発揮できる時期といえる．この時期に D.P を用いる理由としていくつかの点を挙げることができるが，その代表的なものについては

1) 個体の成長発育が最も旺盛な時期であることから，顎顔面の成長をある程度コントロールしながら治療を進めることが可能である．
2) 乳歯と永久歯の交換時期に認められる，いわゆる leeway space などを治療面に活かせる．
3) 萌出永久歯の萌出力を矯正力として利用し，歯を正しい位置に誘導することができる（萌出誘導）．
4) Discrepancy case については，D.P を使用しながら連続抜去法が行える．特に，不正部位の歯を治療しながら後続永久歯の萌出誘導を同時に行うことができる．
5) Set-up model の再排列が部分的に行える．特に，治療目標に従って前歯群と臼歯群を段階別に分けて行うことができることから，D.P のいわゆる固定源（非移動歯と周囲粘膜面）を確実に得ることができる．
6) D.P に対する患者の協力と使用時間の確保が容易に得られる．

などが臨床上考えられる．

そこで，実際の臨床面において D.P の治療時期と位置づけをどのように考えたらよいかを次に述べてみよう．

2. 治療上の位置づけと意義

三浦[22]は，矯正治療を計画するにあたり，意義，治療時期，処置と目標，装置と方法などを各段階に分けて，これを矯正治療の長期治療計画法として唱えた．

ところで，D.P を矯正治療学の面で位置づけた場合，その主な役割は

1) 予防矯正（Preventive orthodontics）
2) 抑制矯正（Interceptive orthodontics）
3) 限局矯正治療（Limited corrective orthodontics）——米国の歯学部学生教育要綱から——

の範囲内に位置づけられる．しかも，他の矯正装置との併用ならびに組み合わせを行えば，いわゆる広範囲な矯正治療（Extensive corrective orthodontics）の役割も十分に満たしてくれることから，矯正治療全般に幅広く使用できるものと考えられよう．

次いで，D.P を矯正治療の長期治療計画法に位置づけて考えてみると

1) 第1動的治療期
2) 第1成長誘導期（前歯群交代期）
3) 第2動的治療期
4) 第2成長誘導期（側方歯群交代期）

の各時期にその効果をフルに発揮できる矯正装置であり，この時期に不正を解消すればそれ以降は咬合の管理を行うだけで個性正常咬合を獲得できる可能性を示すものである．もちろん，第3動的治療にも使用することができる点については前述した通りであるが，D.P 本来の治療時期と目的は上記した1）～4）までの範囲内にあるといえよう．

この意味をもうすこし詳しく述べてみると，個体の顎顔面頭蓋骨の成長発育過程の中で，前歯群の交代から側方歯群の交代まで永久歯を長期にわたって監視・誘導しながら，機能的障害，発育抑制因子，skeletal pattern の不正などに対して比較的簡単な装置と処置によって不正を直し，正常な発育軌道にのせることが D.P 本来の意義と位置づけであると結論づけられる．これは，取りも直さ

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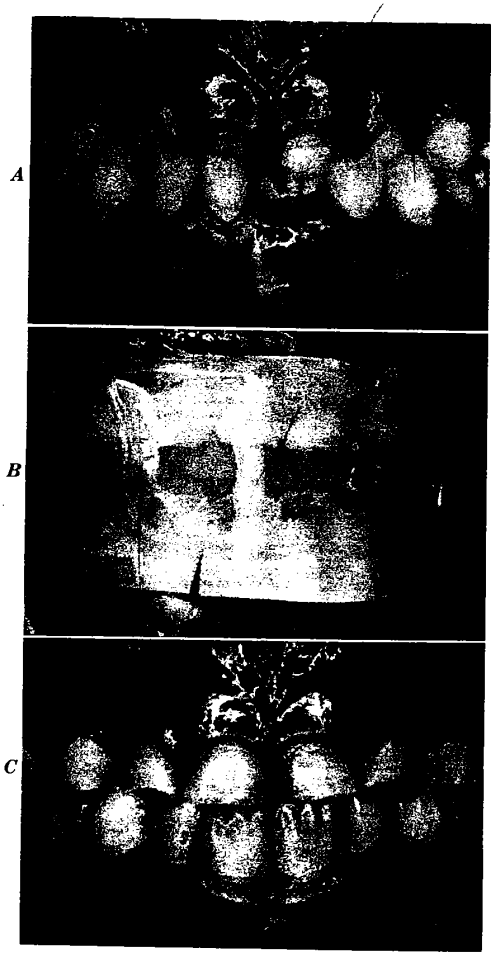


図2　乳歯反対咬合の症例．初診時5歳，女子（早期矯正治療の1例）
A：初診時　B：D.P（cutting 法を行う）の装着時
C：4カ月目（第1成長誘導期に入る）
D.P 法で前歯部の被蓋関係を4カ月で改善し，後続永久歯の萌出を D.P で誘導している治療例である．

ず矯正治療本来の意味と目的に共鳴したものとして受けとめることができる．

3. 早期治療の必要性と D.P の効果

矯正治療は，その不正の程度や種類によって多少の差はあるにせよ，不正を認めた時点からできるだけ早い時期に開始する必要があることはいうまでもない．

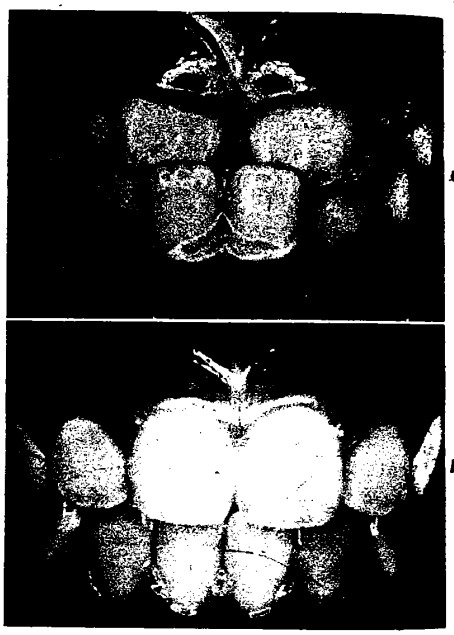


図3　機能性反対咬合の症例．初診時6歳5カ月，女子
A：初診時　B：終了時（11歳）
D.P 法で anterior cross bite を5カ月で改善した後，第2成長誘導期に咬合の管理を D.P で行い個性正常咬合を獲得した1治験例である．

特に反対咬合の場合には，他のいわゆる外観上の不正咬合などに比較して特異な形態と機能障害を示すことから，早期治療の必要性を強く認める．たとえば，初期の段階で処置を加えれば容易に治療ができる歯性あるいは機能性反対咬合も，その不正状態を長期に放置すれば顎性の反対咬合に移行してしまう危険性があることはしばしば経験する．不正を放置し，その結果生じた著しい顎性の反対咬合に対する処置は大変困難を期し，場合によっては観血的処置を加えなければならない状態にしてしまう．このような意味から，反対咬合の症例などはできるだけ早い時期にその不正を解消し，個性正常咬合を獲得することが矯正治療本来の目的ではないだろうか．

ここで，早期治療を D.P 法で行った2症例（反対咬合）を紹介しながら，D.P 必要性を提唱したい．

図2は，第1動的治療期か
を目的として開始した症例で，
を行った乳歯反対咬合（5歳，
2-Aが D.P 法開始時，図2-
hod を行って製作した D.P
被蓋改善を終了した4カ月
作，第1成長誘導期に入り，
萌出誘導を管理している．

図3は，第2動的治療期か
を治療する目的で行った機能
カ月，女子）の治験例である
開始時，図3-B が矯正治療
歳）である．前歯部の被蓋関
改善（5カ月を要す）した
側方永久歯の萌出管理を D
個性正常咬合に仕上げた症

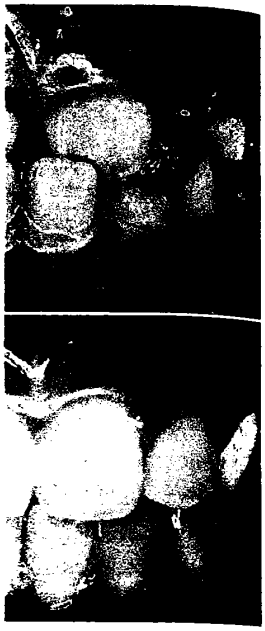
この2症例の治療結果か
不正を速やかに改善すれば，
を増悪させずに完治するこ
は永久歯列期に移行しても
易かつ効果的に行える可能
である．

4. 適

適応症とはどのような症
現することは難しいが，一
の内容を示すことができよ

まず，歯性ならびに機能
えられる不正咬合が，D.P
る．顎性を示す不正咬合
であればもちろん適応症
が，著しい skeletal patte
矯正装置（たとえば顎外
み合わせが必要となる．
る要素とは，まず第1に，
から得られる正確な矯正
るだろう．また，これは
方法にも大きく影響され

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の症例．初診時6歳5カ月，女

：終了時（11歳）
ior cross bite を5カ月で改善
誘導期に咬合の管理を D.P で行
獲得した1治験例である．

合には，他のいわゆる外観上
及して特異な形態と機能障害
期治療の必要性を強く認め
の段階で処置を加えれば容易
うるいは機能性反対咬合も，
に放置すれば顎性の反対咬合
性があることはしばしば経
，その結果生じた著しい顎
な処置は大変困難を期し，場
処置を加えなければならない
このような意味から，反対咬
るだけ早い時期にその不正を
を獲得することが矯正治療
だろうか．
こ D.P 法で行った2症例（反

対咬合）を紹介しながら，D.P による早期治療の必要性を提唱したい．

図2は，第1動的治療期から前歯部の被蓋改善を目的として開始した症例で，いわゆる早期治療を行った乳歯反対咬合（5歳，女子）である．図2-Aが D.P 法開始時，図2-B が cutting method を行って製作した D.P の装着時，図2-C が被蓋改善を終了した4カ月目の状態である．現在，第1成長誘導期に入り，D.P で後続永久歯の萌出誘導を管理している．

図3は，第2動的治療期から前歯部の反対咬合を治療する目的で行った機能性反対咬合（6歳5カ月，女子）の治験例である．図3-Aが D.P 法開始時，図3-B が矯正治療を終了した時点（11歳）である．前歯部の被蓋関係は，D.P-1号で改善（5カ月を要す）した後，第2成長誘導期に側方永久歯の萌出管理を D.P-2号で行いながら個性正常咬合に仕上げた症例である．

この2症例の治療結果から得たものは，初期の不正を速やかに改善すれば，少なくとも不正状態を増悪させずに完治することができるか，もしくは永久歯列期に移行してもその後の矯正治療を容易かつ効果的に行える可能性を示してくれたことである．

4. 適　応　症

適応症とはどのような症例を指すのか一言で表現することは難しいが，一般的な概念として以下の内容を示すことができよう．

まず，歯性ならびに機能性因子が原因すると考えられる不正咬合が，D.P 法の主な治療対象となる．顎性を示す不正咬合については，軽度な症例であれば もちろん 適応症に 入れることが できるが，著しい skeletal pattern を示す症例では他の矯正装置（たとえば顎外固定装置）との併用や組み合わせが必要となる．そこで，適応症を選択する要素とは，まず第1に，詳細な症例分析とそこから得られる正確な矯正診断に他ならないといえるだろう．また，これは set-up model の再排列方法にも大きく影響されることなので，慎重に検討する必要がある．

D.P の適応症を検討する他の要素として，D.P の構造とその作用機序を十分に理解しておくことが大切である．D.P の構造は，咬合面間に一層のゴム面を介して上下顎が連結した形態から成り立っているので，使用開始時に最も強く矯正力が歯に伝達され矯正力を発揮する．しかも，矯正力の発生部位は初期において前歯部で切端側に，また臼歯部では咬合面に近い部位に強く作用する．すなわち，初期においては傾斜移動が認められ，中期から末期にかけて歯体移動に移行する移動形式をとる．

また，歯の移動効果については，装置の構造上水平的移動（唇舌的または頬舌的，近遠心的）には効果が高いが，垂直的移動（上下的）には効果が薄いといえる．

ここで，一般的な不正咬合の分類を基に D.P の適応症を選択してみると，以下のように分類できる．

1) 歯性上顎前突，下顎前突
2) 機能性上顎前突，下顎前突
3) 軽度な顎性上顎前突，下顎前突
4) 叢生（多くの場合抜歯症例となる）
5) 過蓋咬合
6) 交叉咬合

以上の他に種々な症例に応用できるが，ここでは一般的な分類法から選択した．

5. 治療目標のたて方

これまで一般的な概念として，D.P の臨床上の位置づけや意義などについて述べてきたが，この章からは実際にどのようにして D.P を使用するのかといった治療面に話題を移していきたい．

D.P で矯正治療を行う場合，一般的に行われる詳細な症例分析，正確な矯正診断ならびに治療目標を確立することの必要性はいうまでもない．この治療目標は，不正咬合の性格やタイプによって D.P の治療方針やその使用目的が決定づけられる要素となるだけに，慎重に検討されなければならない．その要点は

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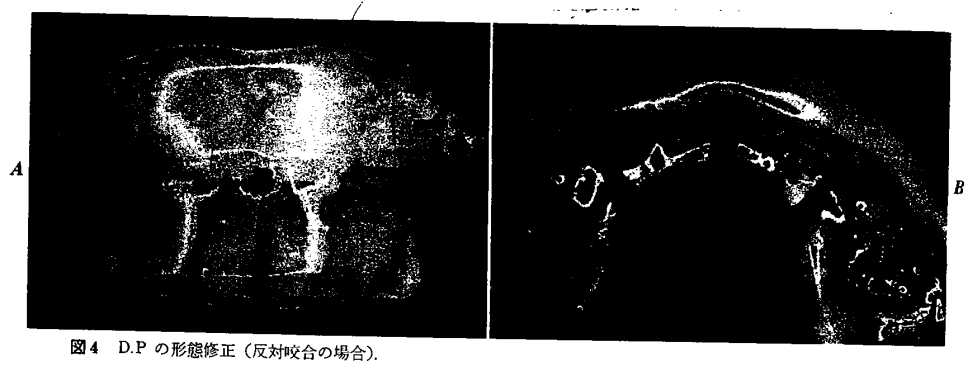


図4 D.P の形態修正（反対咬合の場合）.
矯正力の調節は，使用するゴム硬度の種類と形態修正（cutting 法）によって行う．これにより，常に活性化の高い矯正力を歯に与えることができる.
A：反対咬合者の口腔内に D.P を装着した時点．D.P の下顎唇側面に逆V字型の空隙が認められる.
B：同じ症例に用いた D.P の上顎舌側面を示す.

1) 骨格型の不正（この場合は顎外固定装置として上顎前突ならば head gear を，下顎前突の場合は chin cap の併用か組み合わせを行う）
2) 機能型の不正（D.P だけで治療することが可能，構成咬合位を利用して D.P を製作する）
3) Discrepancy 型（連続抜去法の適用と他の矯正装置との組み合わせ）
4) 個々の歯の問題（D.P と必要によっては他の矯正装置との組み合わせ）

などを考慮に入れ治療目標と方針を確立する.

ここでは，特に反対咬合の治療目標と D.P の使用上の要点について述べておこう.

混合歯列期の反対咬合に対処する場合，不正の要因と治療方針は以下のように考える.

1) 上顎骨の劣成長をともなう場合：D.P による積極的な唇側，側方拡大により被蓋改善を行う.
2) 下顎骨の過成長をともなう場合：D.P により速やかに被蓋関係を改善した後，chin cap により下顎の成長発育を抑制する.
3) 下顎骨の機能的近心位をともなう場合：D.P により機能的障害を除去し，速やかに被蓋改善を行う.
4) Discrepancy をともなう場合：連続抜去法を適用しながら被蓋関係を改善した後，最終段階で全帯環装置（一般には6カ月以内で終了する）を使用し，個性正常咬合を獲得する.

さて，治療目標と D.P の適用が決まれば，次にどのように治療を進めるかといった，いわば D.P の使用方法ならびにその方針などを決めなければならない.

6. D.P法の進め方

D.P法（Dynamic Positioner system）は，治療目標に準じてその使用目的と set-up model の設計を，症例に合わせて検討することから始まる．一般に混合歯列期の症例では以下の要領で治療が進められる.

1) 第1段階：前歯群の不正関係を D.P で速やかに改善した後，成長誘導期に移行し側方永久歯の萌出を観察する.
2) 第2段階：側方永久歯の萌出を D.P で誘導しながら顎骨の成長発育に対処する（抜歯症例の場合は，この時点で連続抜去を行う）.
3) 第3段階：個性正常咬合が獲得できたならば，D.P で保定を行い終了する（抜歯症例の場合は，D.P と全帯環装置で最終的な咬合関係の改善，たとえば小臼歯部，犬歯部の歯軸

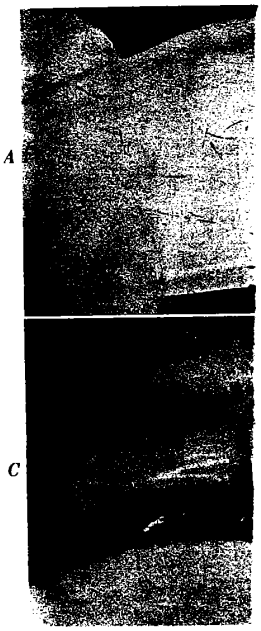


図5 反対咬合に用
的に移動するこ
A：唇側面の
D：顎性の反
ゴムの角

の傾斜を改善する.

いた Edgewise 法で
反対咬合の症例も上記
れるし，set-up model も
れる.

さて，臨床使用にあた
使用していくか，使用上
よう.

まず，治療開始時にあ
el から2個の D.P（ゴム
とえば オーソコン-L と
たることが一般的な治療
進め方の特徴は，set-up
積極的に行い，矯正力の
度と D.P の形態修正（
ていくという考え方にた

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行う．これにより，常に

型の空隙が認められる．

をともなう場合：連続抜去法
被蓋関係を改善した後，最終
装置（一般には6カ月以内で終
用し，個性正常咬合を獲得す

D.P の適用が決まれば，次
を進めるかといった，いわば
びにその方針などを決めなけ

D.P法の進め方

Positioner system）は，治療
使用目的と set-up model の設
て検討することから始まる．
症例では以下の要領で治療が

前歯群の不正関係を D.P で速
後，成長誘導期に移行し側方
観察する．
側方永久歯の萌出を D.P で誘
骨の成長発育に対処する（抜歯
この時点で連続抜去を行う）．
個性正常咬合が獲得できたなら
定を行い終了する（抜歯症例の
全帯環装置で最終的な咬合関
えば小臼歯部，犬歯部の歯軸

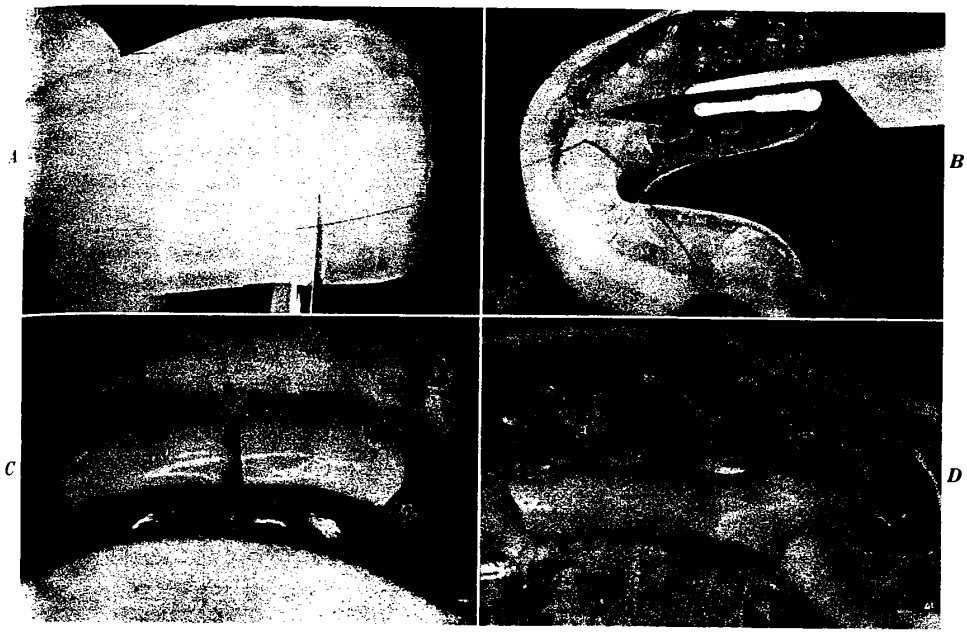


図5 反対咬合に用いられる D.P の形態修正法．この操作により，治療開始時に矯正力を弱め歯を生物学的に移動することができる．
A：唇側面の修正　B：舌側面の修正　C：修正を加えた D.P 装着時
D：顎性の反対咬合などに用いられる修正法で，D.P の舌側面にV字型の水平的切り込みを入れて，ゴムの弁を形成する．

の傾斜を改善する．一般には，D.B.S. を用いた Edgewise 法で行う）．

反対咬合の症例も上記した進め方に従って行われるし，set-up model もこれらに準じて製作される．

さて，臨床使用にあたって D.P をどのように使用していくか，使用上の要点について述べてみよう．

まず，治療開始時にあたって同じ set-up model から2個の D.P（ゴム硬度が異なるもの，たとえばオーソコン-LとM）を製作し，治療にあたることが一般的な治療法の進め方である．この進め方の特徴は，set-up model 上で歯の移動を積極的に行い，矯正力の調節は使用するゴムの硬度と D.P の形態修正（図4）によって順次変えていくという考え方にたったものである．

一般的に行われている方法では，治療経過を観察しながら set-up model は6カ月に1回再製作し，D.P は2個ずつ製作する．すなわち，D.P の交換は3カ月ごとに行っていく方針で治療を進めていく．

この方法の利点は

1) set-up model の技工操作が一部省略できる．
2) 常に弱い矯正力を継続的に歯に与えることができ，歯を生物学的に理想的な位置に移動することが可能となる．
3) 治療開始時に一方の D.P に修正が加えられる．このことにより，患者に疼痛を与えず歯の移動が行える．
4) 治療の進行状況によって，ゴム硬度が異なるもう一方の D.P（通常はゴム硬度が一段高

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い材質で作られる）を寸時のうちに交換し，歯に一定の持続した活性化の高い矯正力を与えることができる．

5) D.P の紛失や装置の破損などに速やかに対処できる．

などがあり，臨床上きわめて合理的に治療を進めることができ，かつ高い治療効果が期待できる．

7. 矯正力の調節

矯正治療を開始する場合は，できるだけ弱い力（light force）を用いて歯を移動することが必要であり，これは生物学的な立場から唱えられている．このことは近代矯正治療の歯の移動様式が，弱い力でしかも持続性のある力（continuous force）を矯正力に用いる必要性を基本的な概念[23)24)]としていることからも頷ける．

ところで，D.P の矯正力は前述した通り，ゴムの復元力を活用することによって得られるものであり，その力の大きさは以下に述べる方法によってコントロールされる．

1) Set-up model 上で再排列される歯の移動量によって調節する．

2) オーソコンの種類，すなわちゴム硬度（ライト-L，ミディアム-M，ヘビー-H）を選択することによって調節する．また，D.P製作時に部分的にゴム硬度を変えることにより，D.P の力の作用効果を部分的に変える．

3) D.P に切り込み（cutting method）[25)]を入れ，形態を修正することによって矯正力を部分的に緩衝し，その力を調節する．

実際の臨床面においては，1)と2)は治療方針や目的によって決定づけられる性質のものであり，D.P 製作過程において行われる操作といえる．また，3)はあくまでも矯正治療開始時に限って行われる調節法であり，患者に種々な障害を与えないという理由から行われる操作である．

要するに，D.P の調節は治療開始時以外にはほとんど行う必要がなく，歯は理想とする方向にオートマティックに移動を開始する点が従来の線矯正治療法と比べて異なる大きな特徴の1つとして挙げられよう．

ここで，反対咬合の症例に D.P を開始する時にしばしば行われる D.P の形態修正について述べてみたい．

この操作は，治療開始時に強い矯正力を直接歯に与えない生物学的な立場から考案された方法であり，症例や set-up model 上での歯の移動量によってその必要性は決定されるものである．一般的には，ゴムの復元力を緩衝させる目的から多くの症例に用いられている．

図 5 は，反対咬合の症例に用いられる修正法（cutting method）を示したものである．下顎前歯唇側面の切り込みは両側側切歯遠心隣接面に，また症例によっては，下顎中切歯間に切り込みを入れる場合がある（図 5 -A）．舌側面の修正は，上顎前歯口蓋側の正中部ならびに側切歯遠心側に，垂直的なV字型の切り込みを外科用メスまたは鋏を用いて行う（図 5 -B）．このような修正を加えた D.P を患者の口腔内に装着すると，切り込みを入れた部位（唇側面）に逆V字型の空隙が発生する．これにより，歯に加わる矯正力は持続性のある弱い力となって歯を生物学的に移動することができる（図 5 -C）．また，症例が顎性の反対咬合の場合は，set-up model 上での移動量が大きいので，舌側面のゴムに水平的な切り込みを入れてゴムの弁を形成し，上顎前歯切端部に加わる矯正力を緩衝する（図 5 -D）．

8. 患者の協力と使用上の注意

D.P は可撤式の矯正装置であることから，患者の協力がぜひとも必要となる．これは可撤式矯正装置の共通した問題であり，どんなに優れた治療方針や治療器具であっても，患者側がこれを無視するようであっては，初期の目的さえ達成できない．その意味で患者の協力は，D.P 法を行う場合，臨床上最も重要な必要条件になるといって過言ではない．

まず患者の協力を得るためには，患者本人にはもちろんのこと，母親にも使用する D.P の意味や目的，その作用機序や使用上の利点などを十分に説明し，理解させることである。着後の経過観察時（一般に月1る）においても患者教育は決し．D.P の高い治療効果を得るでの母親の指導性と毅然たる態きく左右する要因となるからて

さて，次に使用上の注意点に。

D.P の使用時間は，可及的に発揮できるものであるが，もあるので，通常は夜間の使用（就寝時までの時間帯）に主体を，使用時間は就寝時を含め者に命じる必要性がある．もは D.P で動的治療を行ってであり，初期の治療目的が完期間）に移行した時点では，せたり（この場合は就寝時の切の装置を使用せず経過をによってはある．

D.P の装着の仕方は，まず入れ，その後ゆっくり下顎をませるだけでよい．装着後にをさせる必要はなく，軽い咬状態で十分である．それは，も持続した弱い矯正力（ligh歯に与えた方が効果的に移からである．

また，D.P の使用前後はうがくと同時に，D.P の周囲に保つよう指導しておくこ

また，使用中に多量の唾は，D.P の舌側面をできるだけては嚥下運動を容易に行．高径（通常は 4 mm の開D.P の異物感を患者に与え方法で解決する．

さて，来院時には D.P ことを命じる．その理由は

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説明し，理解させることである．そして，D.P 装着後の経過観察時（一般に月1回の間隔で約束する）においても患者教育は決して怠ってはいけない．D.P の高い治療効果を得るためには，家庭内での母親の指導性と毅然たる態度がその効果を大きく左右する要因となるからである．

さて，次に使用上の注意点について述べてみよう．

D.P の使用時間は，可及的に長いほどその効果を発揮できるものであるが，患者の生活上の制約もあるので，通常は夜間の使用（患者の帰宅後から翌朝までの時間帯）に主体がおかれる．すなわち，使用時間は就寝時を含めて1日12時間前後患者に命じる必要性がある．もちろん，この時間帯は D.P で動的治療を行っている期間の使用条件であり，初期の治療目的が完了し，誘導期（観察期間）に移行した時点では，必要によって使用させたり（この場合は就寝時のみの使用に変える），一切の装置を使用せず経過を観察する場合も症例によってはある．

D.P の装着の仕方は，まず上顎歯列に D.P を入れ，その後ゆっくり下顎を D.P の中に噛み込ませるだけでよい．装着後に数分間噛みしめ運動をさせる必要はなく，軽い咬合圧を D.P に加える状態で十分である．それは，一過性の矯正力よりも持続した弱い矯正力（light continuous force）を歯に与えた方が効果的に移動できるという理由からである．

また，D.P の使用前後はよく口腔内をブラシでみがくと同時に，D.P の周囲や，特に内面を清潔に保つよう指導しておくことも大切である．

また，使用中に多量の唾液を流出する患者には，D.P の舌側面をできるだけ削除し，場合によっては嚥下運動を容易に行えるように D.P の咬合高径（通常は4mm の開口位）を下げることや D.P の異物感を患者に与えないような形態に修正する方法で解決する．

さて，来院時には D.P を忘れずに持参させることを命じる．その理由は，術者は来院時に D.P を調節することはほとんどないが，治療経過を観察しながら，D.P に亀裂が生じていないか，正しく D.P が使われているか（よく D.P を使用している場合には D.P の透明度が低下し，やや不透明に変化する），次の治療段階にいつごろ移ったらよいか（D.P の変位によって生じた空隙が消失したことが認められたら次の段階に進む）などを検討しながら治療を進めていくために必要だからである．

9. 歯科医と歯科技工士の責任と立場

D.Pは，set-up model 上で行われる歯の再排列にその移動原理を求めたものであり，矯正治療を間接的に技工室内で行う性質と内容を持った治療器具である以上，歯科医と技工士の責任と分担をより明確にしておく必要がある．まず set-up model の製作に関しては，D.P の概念からこの操作は歯科医が行う仕事であるといえる．仮に技工士がこの操作に加わったとしても，歯の排列法は術者の監督ならびに指導下で行われなければ，医療行為の立場から重大な問題を残すことになる．

しかし，set-up model 製作後から D.P の仕上げまでは，義歯を作る操作と何ら変わらないなどの理由から，この範囲は技工士が行うことに問題はない．つまり，D.P が実際の不正咬合を治療する矯正装置として存在する以上，その行為の責任はすべて歯科医側にあるといえる．

今後，D.P を矯正治療器具としてより普遍化し，多くの不正咬合者を治療していく立場からも，歯科医と技工士は仕事の分担を明確に区別し，お互いの立場を認識しながら進む姿勢がぜひとも必要である．

Ⅱ．D.P 法による反対咬合の治験例

ここで，D.P 法による反対咬合の治験例を紹介してみたい．今回報告する症例は，一般に軽度な反対咬合と考えられる，歯性ならびに機能的因子によって生じた混合歯列期の2症例（非抜歯症例）である．なお，各症例の紹介ならびに治療効果についての説明は，末尾に一括して掲載した．

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症例1　$\overline{1}$に外傷性咬合をともなう歯性反対咬合　8歳5カ月　男子

診断：$\overline{1}$に咬頭干渉をともなう anterior cross bite.　Angle Ⅲ級

治療方針：D.P 法による非抜歯症例.

D.P の治療目的

第1段階：$\frac{1}{1}$の早期接触による障害の除去と前歯部乱排歯の改善.

第2段階：側方永久歯の萌出誘導.

第3段階：保定に移る.

治療経過

治療開始　½　1年後　1½　2年後　2½　3年後

治療目的	第1段階	第2段階	第3段階
Set-up model	No. 1号	No. 2号	No. 3号
使用した D.P.と矯正	D.P-1 (L)	D.P-2 (M)	D.P 3 (M)	D.P-4 (H)	D.P-5 (H)

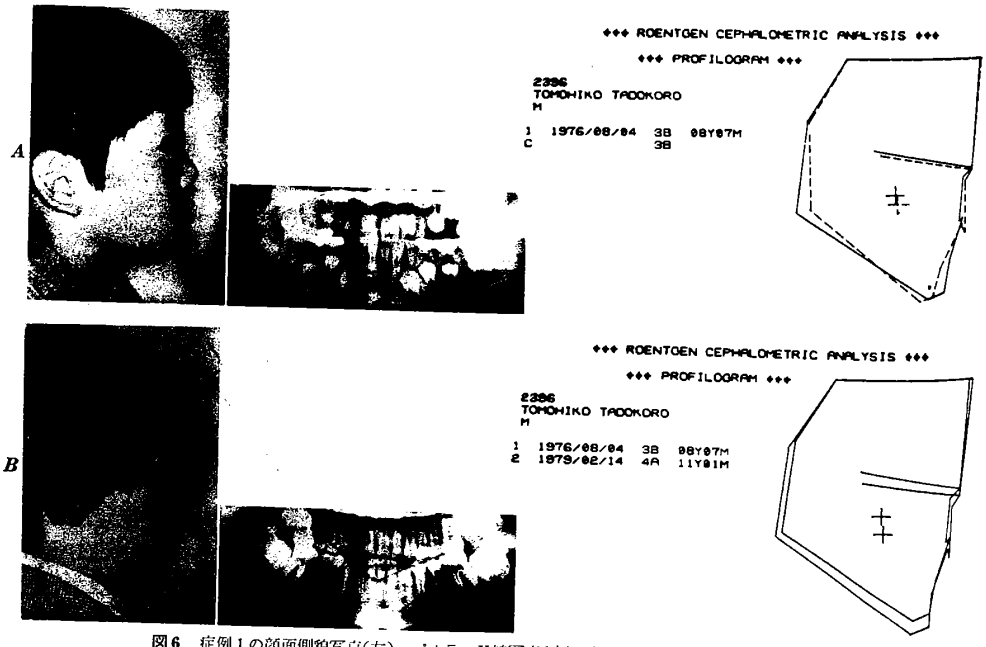


図6　症例1の顔面側貌写真(左)，パノラマX線写真(中)，側貌頭部X線規格写真より求めたプロフィログラム（NEA C 3200コンピューター画像解析システムによる S-N 重ね合わせ）
A：術前　B：術後

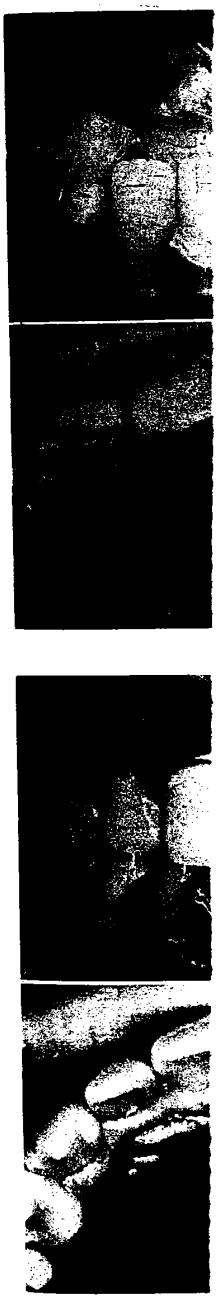


図8　D
期

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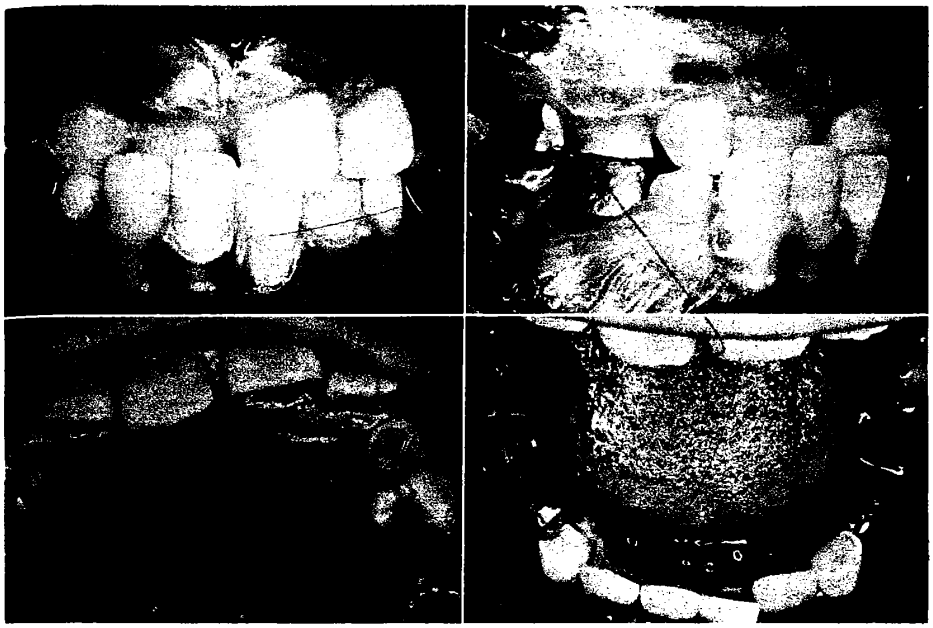


図7　治療開始時の口腔内写真（症例1）.

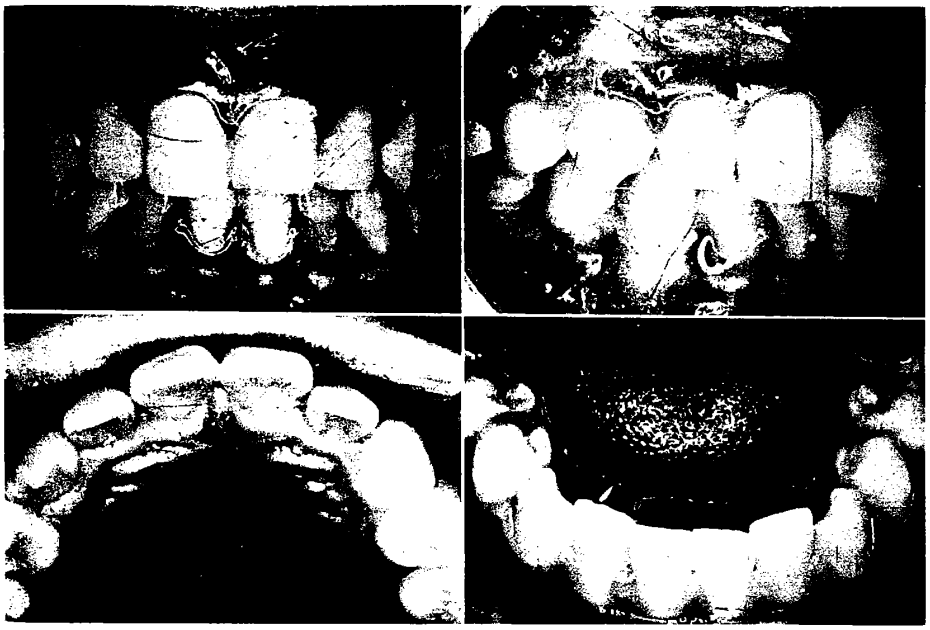


図8　D.P による治療終了時の口腔内写真（症例1）. 動的治療期間9カ月，側方歯萌出誘導期間11カ月，保定期間1年.

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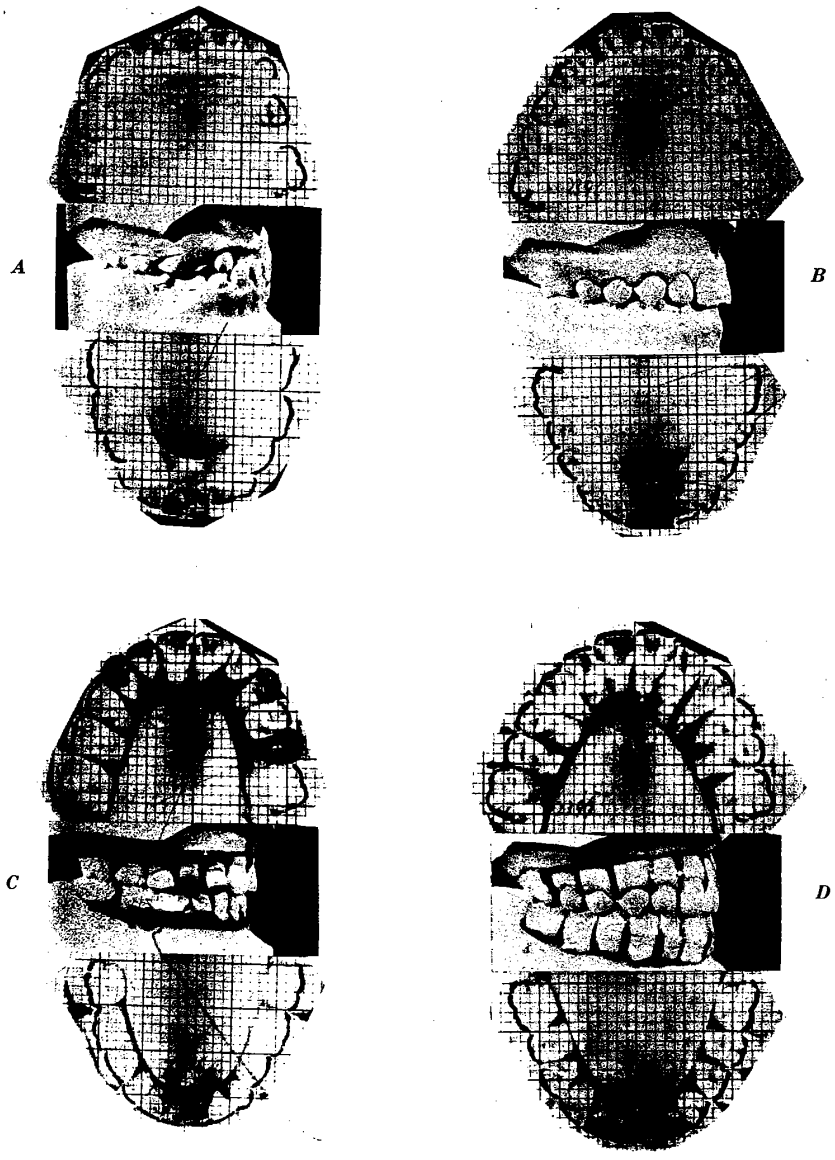


図9 症例1の石膏模型と set-up model の咬合面規格写真（1目盛りが 2mm）.
A：術前　B：術後　C：No. 1 号の set-up model
D：No. 3 号の set-up model

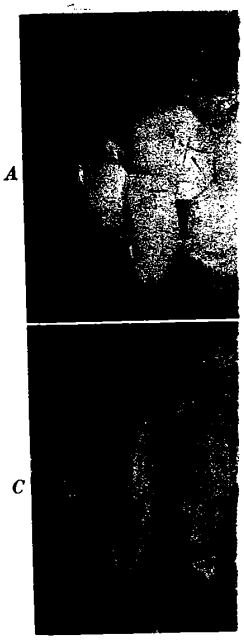
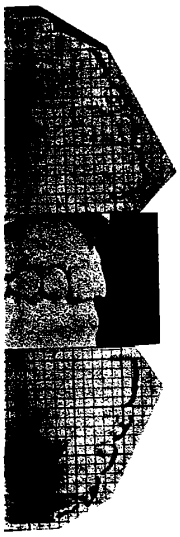


図10 症例1の



図11 側貌
トリミ
A：術

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盛りが 2mm).

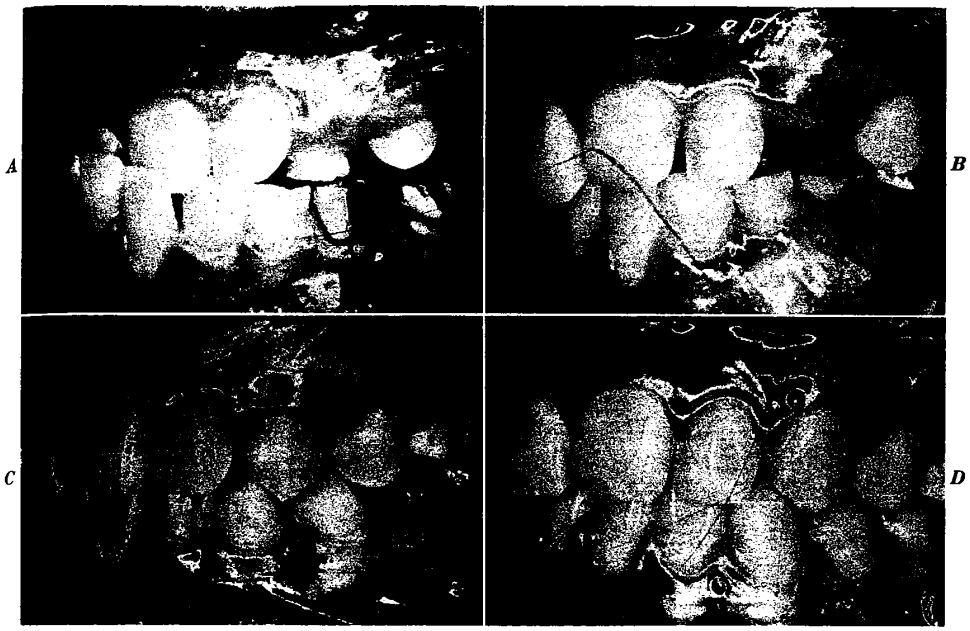


図10 症例1の治療経過. A：治療開始時 B：5カ月後 C：1年後 D：2年1カ月後



図11 側貌頭部X線規格写真よりトリミングした上下顎関係.
A：術前 B：術後

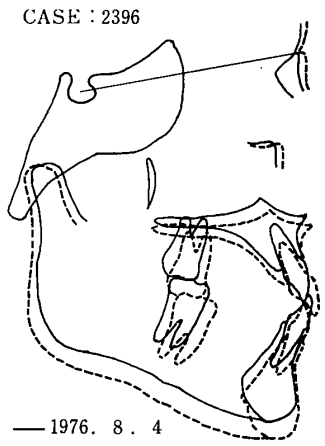


図12 側貌頭部X線規格写真の重ね合わせ(S-N)基準. 実線は術前，点線は術後を示す.

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症例2　機能的因子により下顎が前方偏位した反対咬合　8歳11カ月　女子

診断：前歯部の早期接触から下顎が前方に移動する機能性反対咬合．Angle Ⅲ級．

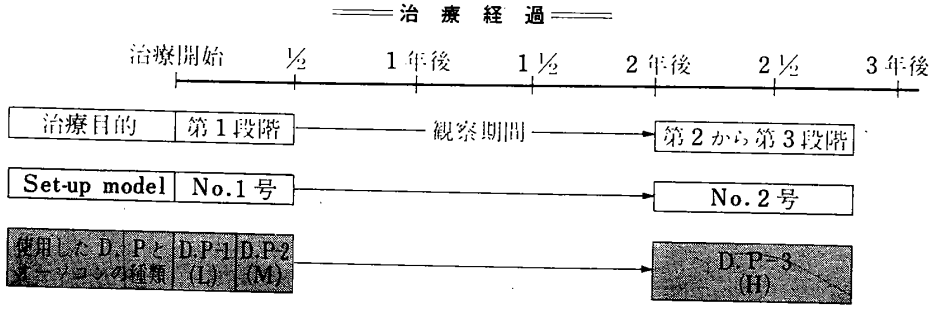
治療方針：D.P 法による非抜歯症例．

D.P の治療目的

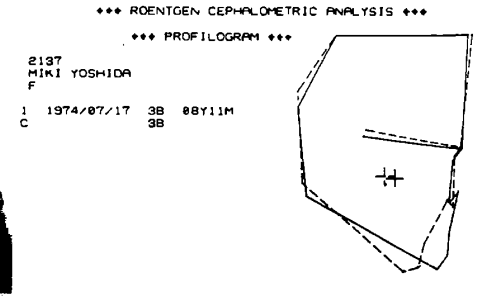
第1段階：前歯部の咬頭干渉から生じる逆被蓋関係を改善．

第2段階：上顎側方永久歯の萌出余地を側方拡大により獲得．

第3段階：保定に移る．









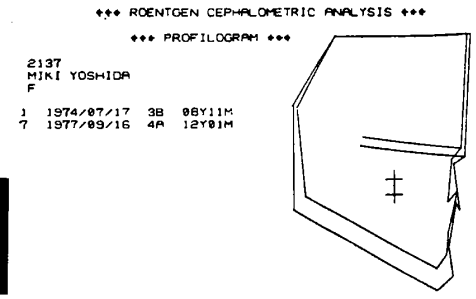


図13　症例2の顔面側貌写真（左），パノラマX線写真（中），側貌頭部X線規格写真より求めたプロフィログラム（右）．
A：術前　B：術後



図15　D.P による治療結

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