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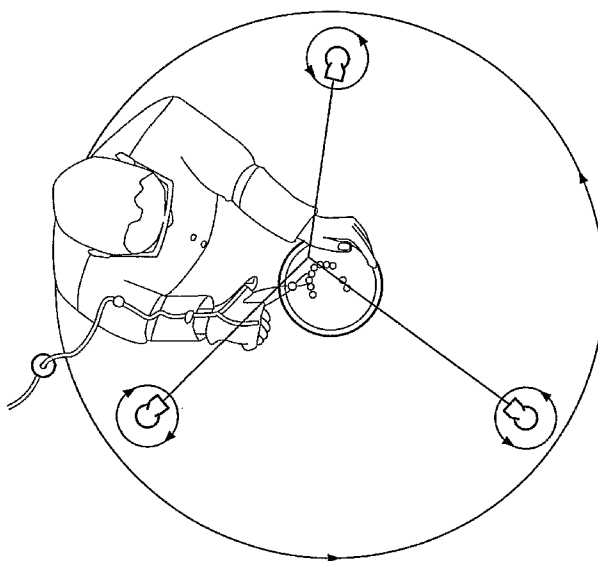
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(54) Title: METHOD AND APPARATUS FOR MANUFACTURING ORTHODONTIC APPLIANCES



(57) Abstract: The application discloses a method of manufacturing a series of tooth positioners for incrementally repositioning one or more teeth of a patient from an initial configuration to a final configuration via one or more intermediate configurations. A composite model of the patient's teeth in the initial configuration and a model of the teeth in the final configuration are provided, and these models scanned to obtain a computer simulation of the teeth in their initial and final configurations. One or more computer simulations of intermediate configurations of the teeth based on the computer simulations of the teeth in their initial and final configurations are generated, and the composite model is manipulated based on the computer simulations of the intermediate configurations of the teeth to form one or more intermediate models of the patient's teeth.

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METHOD AND APPARATUS FOR MANUFACTURING ORTHODONTIC APPLIANCES

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The present invention relates generally to the field of orthodontics and more specifically to methods and apparatus for the manufacture of orthodontic appliances that can be used to reposition teeth.

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In the applicant's own earlier International patent application published under publication number WO2007/077429, a method and apparatus for manufacturing orthodontic appliances is disclosed. The description from this earlier application is incorporated herein by reference.

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This earlier application and the present application discuss the use of positioners of generally U-shape form that fit over the teeth of the upper or lower arch. A realignment of the teeth is achieved by using a series of positioners, each positioner typically to be worn for a period of several weeks, to incrementally reposition the teeth. The positioners can be removed by the patient themselves to allow their teeth to be cleaned avoiding the dental hygiene problems associated with the fixings of metal braces.

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As discussed in the earlier application, Align Technology describe in their US Patent No. 5,975,893 a process by which a series of moulded polymeric tooth positioners can be produced. In this process, a digital model of the patient's initial (malformed) tooth arrangement is obtained by laser scanning a plaster cast of the patient's teeth obtained in a conventional manner. The digital model is manipulated to produce a final tooth arrangement (i.e. with the teeth correctly positioned with respect to one another) and, through a number of complex computations, the system creates a series of intermediate tooth arrangements representing the incremental steps in the tooth repositioning process. Rapid prototyping methods are then used to create a corresponding series of 'positive' tooth moulds, one for each intermediate tooth arrangement and one for the final tooth arrangement, on which the positioners themselves can be formed. This approach requires a trade off between the level of detail in the digital models and the computational overheads when creating the digital models of the final and intermediate teeth arrangements. Any discrepancies in the model compared with the patient's teeth will likely be compounded as the model is digitally manipulated.

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Although the earlier application suggests that the use of computer techniques such as the technique described above can be complex and have high processing overheads, in contrast, the present invention may provide a method of manufacturing positioners, using computer techniques, that is straightforward and reliable.

At its most general, the method of present invention uses the same or similar techniques described in the earlier application for manufacturing positioners; however, rather than relying on a technician's own skill and knowledge to reposition appropriately one or more of the model teeth to reconfigure the composite model to an intermediate or a final configuration, a computer is used to determine appropriate repositioning of the model teeth based on both a model of the patient's actual teeth configuration and a model of the patient's desired / final teeth configuration.

According to the present invention, there is provided a

a method of manufacturing a series of tooth positioners for incrementally repositioning one or more teeth of a patient from an initial configuration to a final configuration via one or more intermediate configurations, the method comprising:

providing a composite model of the patient's teeth in the initial configuration,

providing a model of the patient's teeth in the final configuration;

scanning the two models to obtain a computer simulation of the teeth in their initial and final configurations;

producing one or more computer simulations of intermediate configurations of the teeth based on the computer simulations of the teeth in their initial and final configurations; and

manipulating the composite model based on the computer simulations of the intermediate configurations of the teeth to form one or more intermediate models of the patient's teeth.

Preferably, the computer program determines appropriate intermediate configurations for the teeth based on treatment and planning procedures. For example, the computer program may be programmed such that one or more teeth are moved by approximately 0.2 mm, which may be the maximum limit of movement that will not cause damage to the teeth or surrounding gum. Other limitations may be provided for e.g. the maximum degree of tooth rotation or movement in and out of the gum.

Preferably, the composite model comprises a base and one or more discrete model teeth, the or each model tooth including a crown portion and a root portion and being mounted on the base in a tooth mounting portion of the base formed from a mounting material in which the root portion can be imbedded and retained in position but which can allow movement of the root portion through the tooth mounting portion upon application of a force to the crown portion of the model tooth.

Preferably, each intermediate model is formed by changing the position of one or more of the model teeth in the mounting portion of the base to reconfigure the composite model or a previous intermediate model.

To form the positioner, a negative impression of the intermediate model may be obtained.

The model of the patient's teeth in their final configuration may be a perfect kessling model.

- 5 Preferably, one or more lasers are used to scan the models to obtain computer simulations of the teeth.

10 Preferably, the position of one or more of the model teeth in the mounting portion of the base is adjusted using a laser guidance system, the laser guidance system guiding the model teeth in accordance with the computer simulations of the intermediate configuration.

15 Preferably, to guide a model tooth to a new position, three lasers are used. Each laser may focussed on a single point beyond a reference point (preferably a centre point) of the model tooth in its position prior to movement, and the reference point is guided toward this point. This helps to control the period of movement (the distance moved), if not the orientation of the tooth. Alternatively, the lasers may focus at separate points corresponding to separate reference points of the tooth. Thus, the orientation of the tooth can be controlled, e.g. by controlling the positioning of the tooth's zenith, azimuth and vertical dimensions.

20 Another preferred method for guiding a model tooth to a new position uses a tracking system including one or more image capture devices, images captured by the image capture device(s) being used to determine the relative movement between the model tooth and a reference point (e.g. its starting position or another fixed point on the composite model).

25 The relative movement may, for example, be determined based on captured images of an arrangement of three or more light sources that are fixed in position relative to one another and that have a known positional relationship to either the model tooth or the reference point, the images being captured by an image capture device that has a known positional relationship to the other of the model tooth and the reference point. The reference point may be a fixed point
30 on the composite model.

This preferred approach may use a target fixed in position relative to the model tooth (e.g. mounted on the tooth), the target comprising three or more light sources having a known geometric relationship with one another. An image capture at a known position relative to a
35 fixed point on the composite model can capture images of the three or more light sources of the target. The changing images as the model tooth is moved can be used to determine relative movements between the tooth and the fixed point on the composite model and can therefore be used to guide movement of the model tooth to a desired new position. Advantageously, this can be achieved using only a single image capture device. In some cases it may be preferable

to use multiple image capture devices, especially where the movements of two or more teeth are being tracked.

The light sources on the target are preferably held at a fixed distance from one another that is sufficiently great that they can be readily distinguished from one another in images captured by the image capture device, whilst being sufficiently close to one another that they all remain in the field of view of the image capture device throughout the expected movement of the model tooth.

The use of three light sources, which define a plane, makes it possible to measure movement in any dimension. More preferably, however, the target includes four distinct light sources, or more than four, such that there is some redundancy in the pattern of light sources detected by the image capture device. This allows, for instance, the one or more redundant light sources in an image to be used to provide a measure of the reliability of the detected movement of the model tooth.

In some embodiments of the invention the light sources on the target may all lie in a single plane, which at the beginning of a procedure will typically be aligned to be generally orthogonal to the focal axis of the image capture device.

More preferably, however, in a target having four or more light sources, the light sources are arranged in a three-dimensional configuration so that they are not all in the same plane. This gives the captured image of the light source some depth, meaning that for some rotational movements of the target relative to the image capture device (i.e. those movements have a rotational element about an axis orthogonal to the focal axis of the image capture device) the perceived change in the pattern of spots in the image will be greater than for light sources in a single plane, giving the system greater sensitivity to these rotational movements.

In one preferred embodiment, the target comprises four light sources arranged in a tetrahedral configuration. The light sources may be arranged, for example, with two light sources in a first plane and another two light sources in a second plane, parallel to the first. In use, the target is preferably oriented such that these two planes are offset from one another along the focal axis of the image capture device. Conveniently, the four light sources may be configured as a cross when viewed in a direction orthogonal to the planes containing the light sources, with the light sources in one plane forming one arm of the cross and those in the other plane forming the other arm for instance. This allows a simple construction for the structure of the target in which the light sources are housed.

The light sources themselves are preferably of a uniform shape (e.g. circular) and intensity.

Any of a number of suitable light sources may be used. One example of an appropriate light

source is a light emitting diode (LED). The discrete light source visible on the detector may share a common source of generated light.

5 Preferably the target comprises a body in which the light sources are mounted, a surface of the body on which the sources are visible preferably having a colour that contrasts with the colour of the light sources to help the clarity of the image of the spot pattern. For example, the surface may be a dark colour tone, e.g. black, and preferably has a matt finish. The light sources are preferably mounted in the surface of the target body in such a way that they have a generally uniform intensity irrespective of the viewing angle within several degrees, e.g. 1, 2, 3, 4 or 5
10 degrees of an axis through the light source, parallel to the focal axis of the image capture device. With an arrangement of four light sources in two planes it has been possible to reliably track rotations of +/- 25 degrees or more.

15 The colour of the LEDs, or other light sources, may be chosen to also maximise the clarity of the captured image. Red LEDs have been shown to work well.

In an alternative arrangement, the target may include a pattern (e.g. of three or more spots) on the surface of the model tooth that is discernible in images captured by the image capture device. The change in the position and/or orientation of this pattern (in the captured images) as
20 the tooth is moved can be used to track the movement.

Preferably the pattern is applied in a colour that contrasts with the colour of the surface of the model tooth. For instance, the surface of the tooth may be black (or another dark colour) and the pattern may be red (or another light / bright colour). It may be desirable for the pattern to be
25 applied using a fluorescent material to give greater contrast.

Another alternative is for the pattern to comprise one or more fibre optic elements.

30 In another alternative arrangement, rather than using a pattern applied to the model tooth to track its movement, the plain image of the model tooth itself is used. Each tooth will have specific features (shapes, contours, etc) on its surface that can be used, in the same way as a pattern applied to the tooth, to track changes in position and/or orientation of the tooth.

35 The image capture device may be a digital camera, for example a camera comprising a charge coupled device (CCD) as the image capture element. Cameras sold as 'webcams' can be used. Images captured by the image capture device are preferably transmitted to a processing means. They may be transmitted by a wired or a wireless connection.

The image capture device preferably has a short effective shutter speed; that is a short exposure or integration time for the capture of any one image/frame. This gives a sharper image. A shutter speed of no more than 2 msec is preferred, preferably 1 msec or less.

- 5 The resolution of the image capture device should also be chosen to ensure that a clear image of the pattern of spots created by the light sources can be obtained. For example, in the case of a CCD device, the resolution of the CCD is preferably such that the image of any one of the spots spans more than one pixel of the CCD as this will allow the location of the spot in the captured image to be more accurately determined.

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Another variable in relation to image capture is the frame rate; that is the frequency at which subsequent images are captured. Higher frame rates will improve the accuracy of tracking a path of movement of the target but, with most webcams, if the frame rate is too high the image quality may suffer. Frame rates from 2 to 10 frames per second are preferred, with a frame rate of about 5 frames per second represents a good compromise between accuracy of tracking movement and quality of image.

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In static conditions, for example at the beginning of a procedure before any movement has started or at the end of a movement, data from multiple captured images can be averaged to provide a greater accuracy.

The system preferably also includes processing means that calculates a change in position of the facial skeleton portions with respect to one another based on a series of two or more images of the target captured by the image capture means.

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Preferably, the processing means determines that position and orientation of the target relative to the image capture device, as seen in any particular captured image, by comparing the pattern (e.g. of spots, LED lights, features on the tooth surface, etc) in the image with a virtual model of the target that models the geometry of the light sources or other pattern on the tooth surface.

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The virtual model is manipulated to find a best fit with the pattern (e.g. of spots) observed in the captured image, the position and orientation of the model once a best fit is found being taken as the position and orientation of the target/model tooth at the time the image was captured. The change in position and orientation of the model when it is matched against successive captured images then provides a measure of the movement of the target/tooth relative to the image capture device and hence a measure of the relative movement between the model tooth and the fixed part of the composite model to which these components are mounted.

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The processing means may be implemented in software running on a computer or computer network.

5 Preferably, movement of the model tooth is performed using a mechanical device, e.g. a three digit pincer.

10 Preferably the mounting material of the mounting portion of the base is a thermoplastic material to allow the desired movement of the root portion in a controlled manner. The material may be chosen so that it can be softened to allow the desired movements of the teeth, whilst still retaining them, and subsequently hardened (preferably at room temperature) to more securely hold the teeth in place between successive incremental movements. For instance, the mounting material may be wax that can, for example, be softened by gentle heating and subsequently harden as it cools.

15 Preferably, the mechanical device can heat the model tooth it is to move, such that local heating of the surrounding mounting material can be achieved. Thus, only the material local to the model tooth may be softened, reducing the possibility that other model teeth could be moved undesirably during movement of the model tooth. To heat the model tooth, the mechanical device may be supplied with an electrical current and the model tooth may act as a heating element. So that it can act as a heating element, the model tooth may be impregnated with a material such as carbon.

25 An embodiment of the present invention will now be described by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a composite model for use with an embodiment of the present invention;

Figs. 2a to 2i illustrate the steps in the manufacture of the composite model of fig. 1;

30 Fig. 3a to 3f illustrate the steps in the manufacture of a positioner using the composite model of fig. 2;

Fig. 4 is a process flow diagram illustrating the overall process of manufacturing the composite model and using it to manufacture a series of positioners;

35 Fig. 5 shows a composite model in initial and final configurations, and possible points about which the teeth may be moved/rotated for repositioning;

40 Fig. 6 shows model teeth with reference points, to enable movement of the model teeth using a laser guidance system;

Fig. 7 illustrates an alternative method for determining the initial configuration of the teeth, using a scan of the patient's jaw;

- 5 Fig. 8 illustrates the manner in which a tooth may be moved incrementally using a laser guidance system;

Fig. 9 shows an apparatus for moving one or more model teeth of a composite model;

- 10 Fig. 10 illustrates how the positions of the lasers may be adjusted; and

Fig. 11 shows a technician using a 3-digit pincer connected to a power supply to move model teeth.

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Figure 1 shows a composite model 1 for use with an embodiment of the present invention. In this example the model is for a patient's lower complete set of teeth (mandibular arch). A similar model can be produced for the upper set of teeth (maxial arch) or for selected portions of one or other of the arches only.

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The model comprises a base 10 that can be a gypsum derivative or a polymeric material for instance. In this example the rear three teeth 12 on each side of the arch are retained as an integral part of the base 10 as the planned treatment does not include any movement of these teeth. Depending on the planned movement, more or fewer (or even no) teeth 12 may be
25 formed integrally with the base 10.

At the forward part of the base 10 there is a recessed portion 14 into which a mounting material, in this example wax 16, is moulded to model the gum and underlying bone of the mandible in which the teeth that are to be moved are supported.

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The teeth that are to be moved during the planned treatment are represented in the model by discrete model teeth 18, each of which has a crown portion 20 and a root portion 22. The root portion 22 is imbedded in and retained by the wax mounting material 16.

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In use, tooth movements within the model are achieved by warming the wax 16 (e.g. by immersing the composite model in a bath of hot water) to soften it. Once the wax 16 is sufficiently softened to allow some movement of the root portions of the teeth within it, whilst still retaining the model tooth 18, one or more of the model teeth 18 can be manipulated to modify their position in accordance with the planned treatment. The wax 16 provides resistance

to movement of the root 22. The presence of the root 22 as part of the tooth model serves to constrain the possible movements to more realistically represent what is possible in the patient.

Figure 4 illustrates the process by which the composite model 1 of figure 1 is manufactured and then used to manufacture a series of polymeric positioners 2. The process for manufacturing the model will be described first, with reference also to figures 2a to 2h.

The starting point is an impression 24 of the patient's teeth 3 (in this case the lower arch) made in an impression block 26 (see Figs 2a and 2b). As shown in Figs. 2c and 2d, the impression block 26 is placed in a container 28, and an initial cast 30 is formed by pouring e.g., a gypsum derivative or polymeric material into the container 28, as indicated by arrow 32. The model teeth 18 that it is planned to move are separated from the initial cast 30 and their root portions 22 shaped, as shown in Fig 2e. Accordingly, a recess portion 34 is left in the initial cast 30, as shown in Fig. 2f. By forming discrete tooth models 18 for each tooth in this way the movements possible in the model 1 closely reflect those possible in the patient.

The composite model 1 is then assembled. As shown in Fig. 2g, first the model teeth 18 are located in their respective cavities 36 in a negative mould 38 created by taking an impression from the initial cast 30 (alternatively, the original impression 24 may be used). With reference to Fig. 2h, the negative mould 38 is placed in a container 40, the model base 10 (formed by re-using the remainder of the initial cast 30 from which the teeth 18 have been cut) is inserted into the mould and the mounting material, in this example wax 16, is melted and poured over into the mould to cover the root portions, as indicated by arrow 42. In combination the model teeth 18, wax mounting part 16 and gypsum derivative/polymeric material base 10 are a complete replica of the initial cast 30. The composite model 1, as shown in Fig. 2i, is then ready for use.

To form the desired series of positioners, as illustrated in Figs. 3a to 3f and Fig. 4, the composite model 1 is heated (e.g. in a bath of hot water (not shown)) to soften the wax 16. One or more of the model teeth 18 can then be repositioned, as indicated by arrows 44 in Fig. 3a, and the wax 16 allowed to harden to retain the model teeth 18 in their new configuration. In general, each tooth 18 that is moved will not be moved by more than 0.25 to 0.5 mm at most in any one increment of the model.

With reference to Figs. 3b and 3c, once the wax 16 is set, an impression of the composite model with the teeth in the new configuration is taken in an impression block 46 to create a negative mould 48 of the first intermediate tooth configuration. The negative mould 48 is then placed in a container 50, as shown in Fig. 3d, and a positive mould 52 is formed by pouring e.g., gypsum derivative or polymeric material into the container 50, as indicated by arrow 54. This positive mould 52 (see fig 3e) is for the first intermediate tooth configuration, and the first positioner 2 (illustrated in Fig. 3f) in the planned series is formed over this positive mould 52, for

example by vacuum forming. The positioners 2 are preferably formed from a transparent polymeric material.

Meanwhile, the model 1 can be heated once more and a second movement of teeth carried out.

5 The second movement may involve moving the same teeth as the first movement and/or one or more of the other model teeth. Another impression can then be taken to create a negative mould for the second intermediate tooth configuration, which is used in the same manner as the first one to create a positive mould and then a second positioner in the series.

10 This process is repeated until a complete series of positioners for the planned treatment has been manufactured. Generally, there will be eight positioners in the series. The series of positioners can then be provided to the patient to be used in sequence to incrementally move the patient's teeth from the initial configuration to a final configuration (for the particular course of treatment – further courses may follow) via several intermediate configurations.

15 Fig. 5 shows, in accordance with an embodiment of present invention, a composite model of the patient's teeth in the initial configuration, a model of the patient's teeth in their final configuration, and possible points of model teeth about which the teeth may be moved/rotated for repositioning. The models are poured. The model of the patient's teeth in their final
20 configuration is a perfect kissing. Both models are scanned and software plots movements of the teeth from given points.

Fig. 6 shows, in accordance with the embodiment of the present invention, model teeth with reference points, to enable movement of the model teeth using a laser guidance system.

25 Individual teeth are fabricated incorporating the roots structure by a 3D printer in a carbon thermo conductive composite and the individual teeth are assembled as they would relate to each other within the dental arcade. In an alternative embodiment using a light spot-based tracking system (as described above), a target comprising three or more light sources (e.g. LEDs) could be mounted on the model teeth that are to be moved. In other alternative
30 embodiments a pattern (e.g. of three or more spots) may be applied to the surface of each model tooth that is to be moved or natural features on the surface of the model tooth itself could be used to track the movement (as noted above).

Fig. 7 shows, in accordance with the embodiment of the present invention, an alternative
35 method to determine the initial configuration of the teeth, which uses a scanner to scan the patient's jaw.

Fig. 8 shows, in accordance with the embodiment of the present invention, the manner in which
40 a tooth may be moved incrementally, using a laser guidance system. Preferably, each model tooth is moved no more than 0.2 mm between each intermediate model configuration, to

prevent tooth or gum damage. Each tooth is represented by a dot (100microns sq) placed on the buccal surface and at the mid point on the long axis; this point being referred to as the CENTRE POINT. A similar approach can be taken using the light spot-based tracking system described above to guide incremental movements of each tooth. Likewise, a similar approach
5 could be taken using a pattern-based (pattern applied to each tooth or a pattern comprising natural features on the surface of the tooth) image tracking system as described above.

As the majority of malocclusion treated by OPT requires some degree arch development, it has been decided that all three lasers are preferably focused on one point some 0.2mm beyond the
10 CENTRE POINT of the tooth/teeth selected for movement. In this way control of the period of movement if not (completely) the direction can be made. Other such minute refinements could be addressed on an individual basis i.e. tooth by tooth using all three lasers directed upon predestinated and separate points of the tooth thus controlling zenith, azimuth and vertical dimensions (i.e. controlling orientation of the tooth).

15 Fig. 9 shows, in accordance with the embodiment of the present invention, an apparatus for moving one or more model teeth of a composite model. A 3-digit pincer with bipolar DC current is used, which may be controlled by a foot peddle. This current produces localized heat in resistant carbon impregnated in the tooth, thus melting temporarily the polymorphic base and
20 allowing tiny movements toward the laser/lasers guidance points. The resulting movement then being duplicated and a secondary model fabricated for the production of a positioner.

A series of positioners would be produced from start to finish and an analogous tally would correlate with e.g. a 3D pictorial representation on a computer.

25 Fig. 10 shows, in accordance with the embodiment of the present invention, how the positions of the lasers may be adjusted.

Fig. 11 shows, in accordance with the embodiment of the present invention, a technician using
30 a 3-digit pincer connected to a power supply to move model teeth.

Claims:

1. A method of manufacturing a series of tooth positioners for incrementally repositioning one or more teeth of a patient from an initial configuration to a final configuration via one or more intermediate configurations, the method comprising:
- 5 providing a composite model of the patient's teeth in the initial configuration,
providing a model of the patient's teeth in the final configuration;
scanning the two models to obtain a computer simulation of the teeth in their initial and final configurations;
- 10 producing one or more computer simulations of intermediate configurations of the teeth based on the computer simulations of the teeth in their initial and final configurations; and
manipulating the composite model based on the computer simulations of the intermediate configurations of the teeth to form one or more intermediate models of the patient's teeth.
- 15 2. A method according to claim 1, wherein a computer program determines appropriate intermediate configurations for the teeth based on treatment and planning procedures.
3. A method according to claim 2, wherein the treatment and planning procedures define a maximum limit of movement for a tooth between one configuration and the next.
- 20 4. A method according to claim 2, wherein the treatment and planning procedures define a maximum degree of rotation for a tooth between one configuration and the next.
- 25 5. A method according to any one of the preceding claims, wherein the composite model comprises a base and one or more discrete model teeth, the or each model tooth including a crown portion and a root portion and being mounted on the base in a tooth mounting portion of the base formed from a mounting material in which the root portion can be imbedded and retained in position but which can allow movement of the root portion through the tooth mounting portion upon application of a force to the crown portion of the model tooth.
- 30 6. A method according to any one of the preceding claims, wherein one or more lasers are used to scan the models to obtain computer simulations of the teeth.
- 35 7. A method according to any one of the preceding claims, wherein the position of one or more of the model teeth in the mounting portion of the base is adjusted using a laser guidance system, the laser guidance system guiding the model teeth in accordance with the computer simulations of the intermediate configuration.
- 40 8. A method according to claim 7, wherein the laser guide system includes three lasers.

9. A method according to claim 8, wherein the lasers are each focussed on a single point beyond a reference point of a model tooth in its initial position, and the reference point is guided towards this single point.

10. A method according to claim 8, wherein each of the lasers are focussed on separate points corresponding to separate reference points of a model tooth.

11. A method according to any one of claims 1 to 6, wherein the position of one or more of the model teeth in the mounting portion of the base is tracked by a tracking system including one or more image capture devices, images captured by the or each image capture device being used to determine a relative movement between the model tooth and a reference point.

12. A method according to claim 11, wherein the reference point is a fixed point on the composite model.

13. A method according to claim 11 or claim 12, wherein the relative movement is determined based on captured images of a pattern having a known positional relationship to either the model tooth or the reference point, the images being captured by an image capture device that has a known positional relationship to the other of the model tooth and the reference point.

14. A method according to claim 13, wherein the pattern comprises an arrangement of three or more light sources that are fixed in position relative to one another.

15. A method according to claim 14, wherein the pattern comprises an arrangement of four or more light sources.

16. A method according to claim 15, wherein the light sources are arranged in a three-dimensional configuration.

17. A method according to claim 16, wherein the light sources are arranged in a tetrahedral configuration.

18. A method according to claim 13, wherein the pattern comprises three or more spots.

19. A method according to claim 13, wherein the pattern comprises one or more fibre optic elements.

20. A method according to any one of claims 13 to 19, wherein the pattern is applied in a colour that contrasts with the colour of the surface of a model tooth.

21. A method according to claim 13, wherein the pattern is based on features derived from captured images of an image of a model tooth.

5 22. A method according to any one of claims 11 to 21, wherein the or each image capture device is a digital camera.

23. A method according to claim 22, wherein the camera comprises a charge coupled device (CCD) as the image capture element.

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24. A method according to any one of claims 11 to 23, wherein the tracking system includes processing means that calculates a change in position of the facial skeleton portions with respect to one another based on a series of two or more images of the target captured by the or each image capture device.

15

25. A method according to claim 24, wherein the processing means determines the position and orientation of the target relative to the or each image capture device by comparing the pattern in the image with a virtual model of the target that models the geometry of the pattern.

20

26. A method according to claim 25, wherein the virtual model is manipulated to achieve a best fit with the pattern observed in the captured image.

27. A method according to any one of claims 24 to 26, wherein the processing means is implemented in software running on a computer or computer network.

25

28. A method according to any one of the preceding claims, wherein movement of the model tooth is performed using a mechanical device, e.g. a three digit pincer.

30

29. A method according to claim 28, wherein the model tooth is mounted in a thermoplastic material and the mechanical device heats the model tooth it is to move, such that local heating of the surrounding mounting material is achieved.

30. A method according to claim 29, wherein to heat the model tooth, the mechanical device is supplied with an electrical current and is adapted to act as an electrical heating element.

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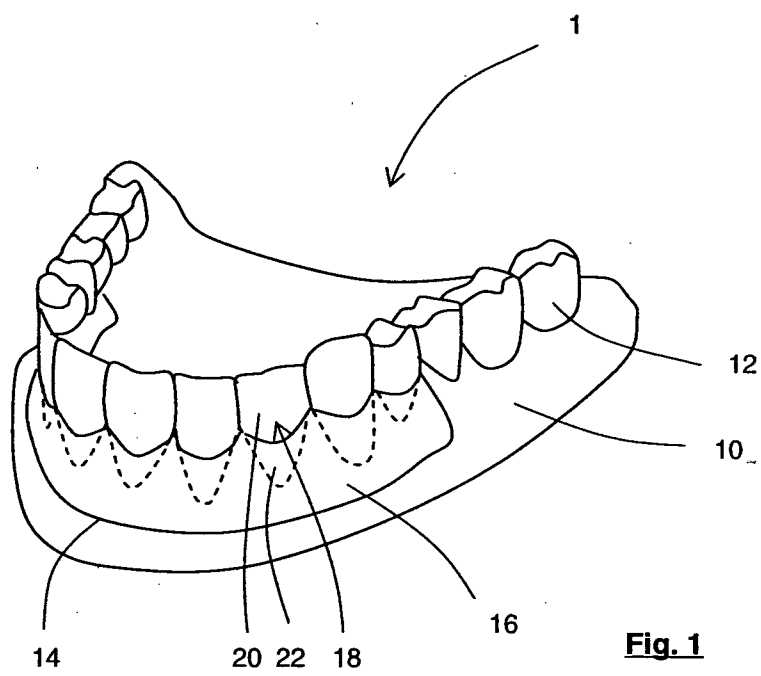


Fig. 1

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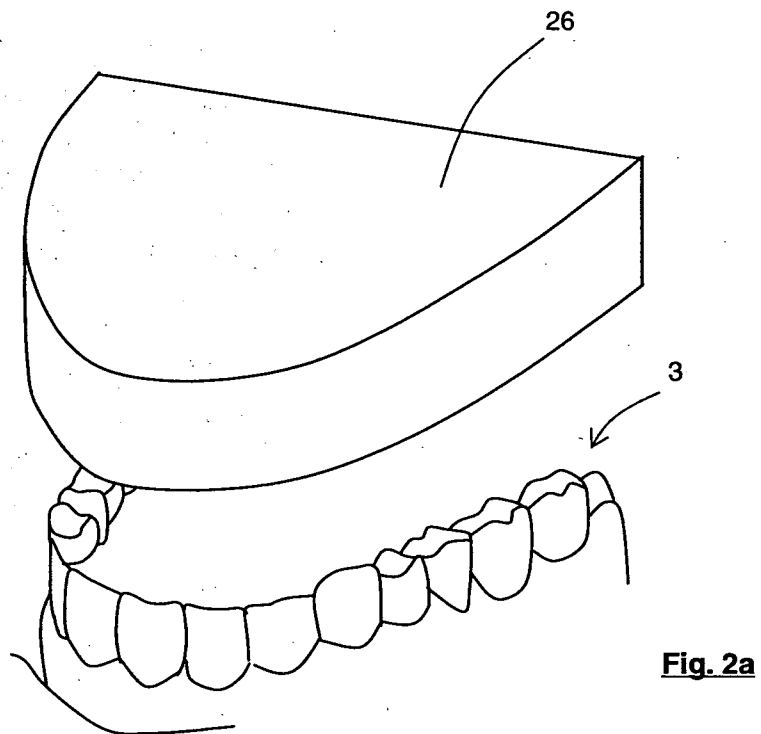


Fig. 2a

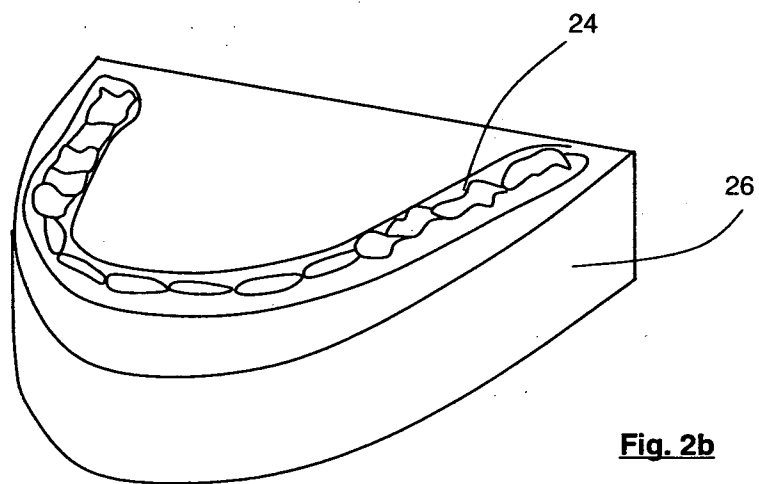
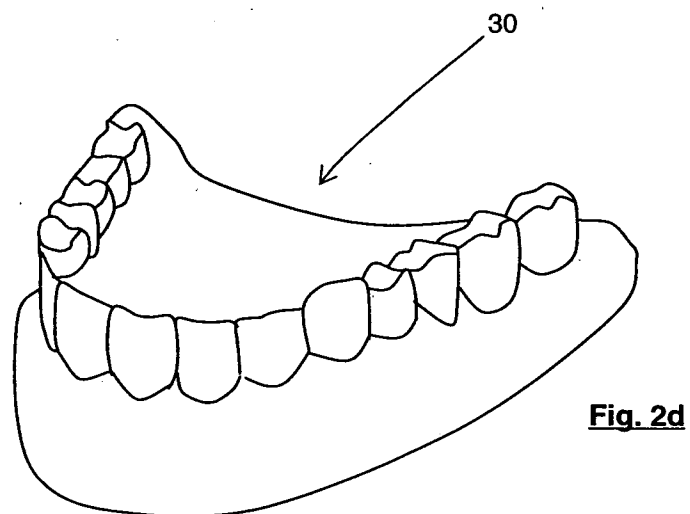
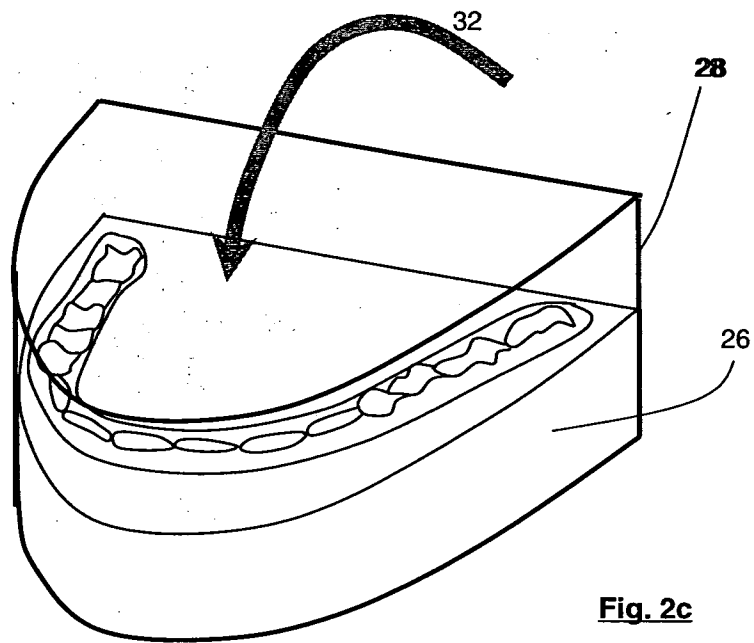
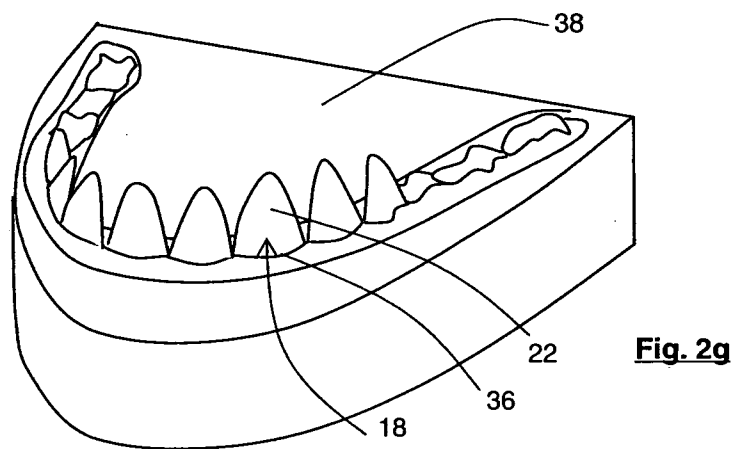
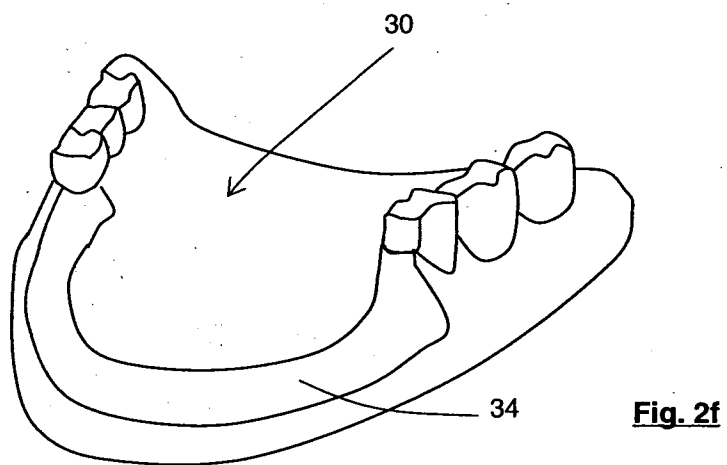
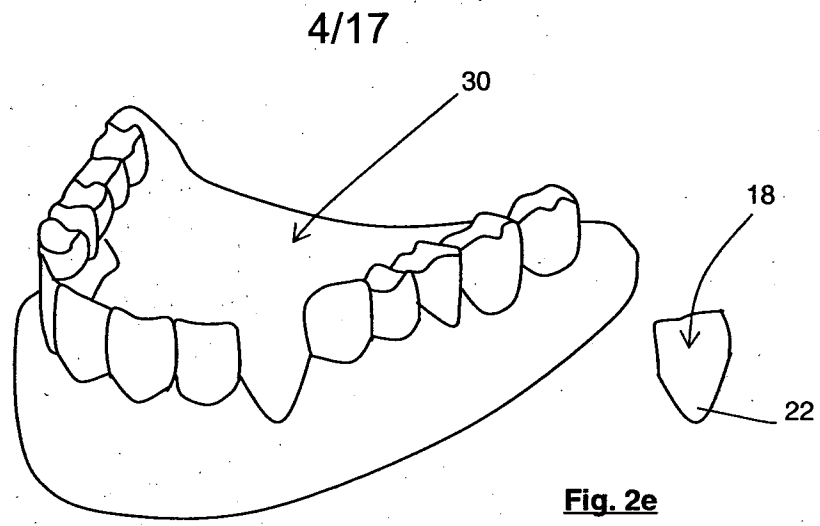


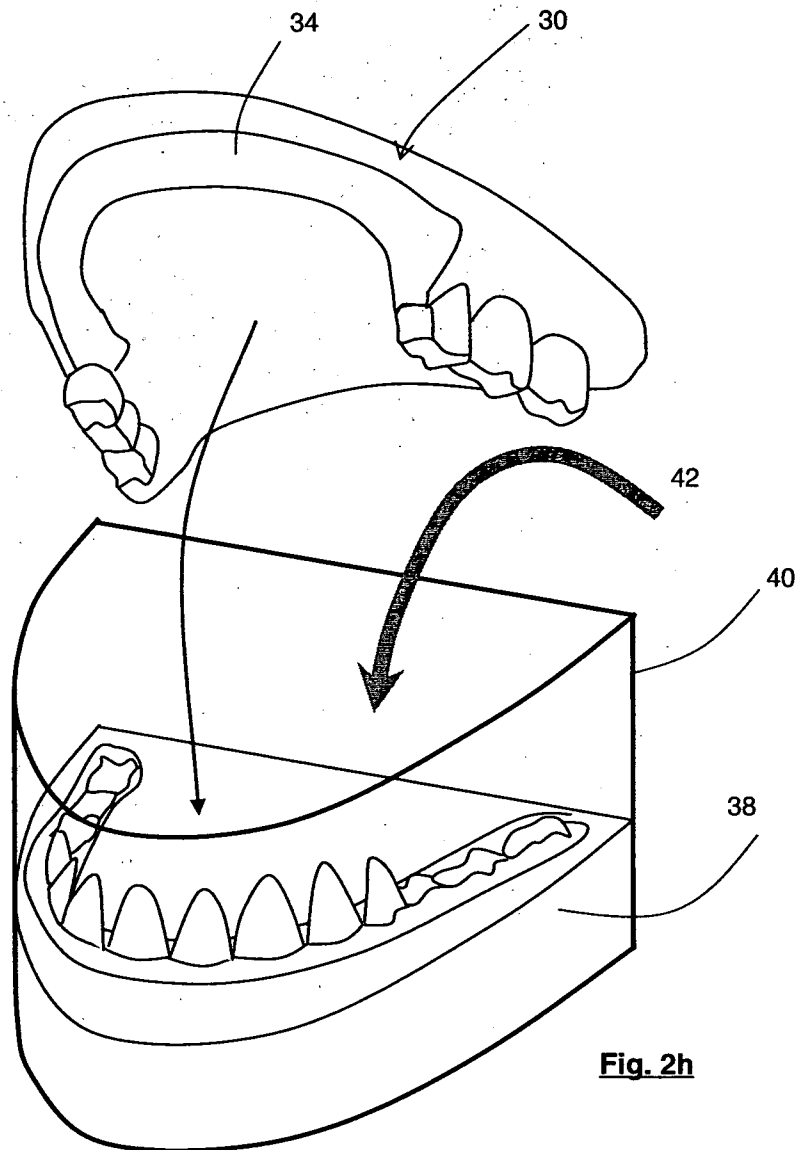
Fig. 2b

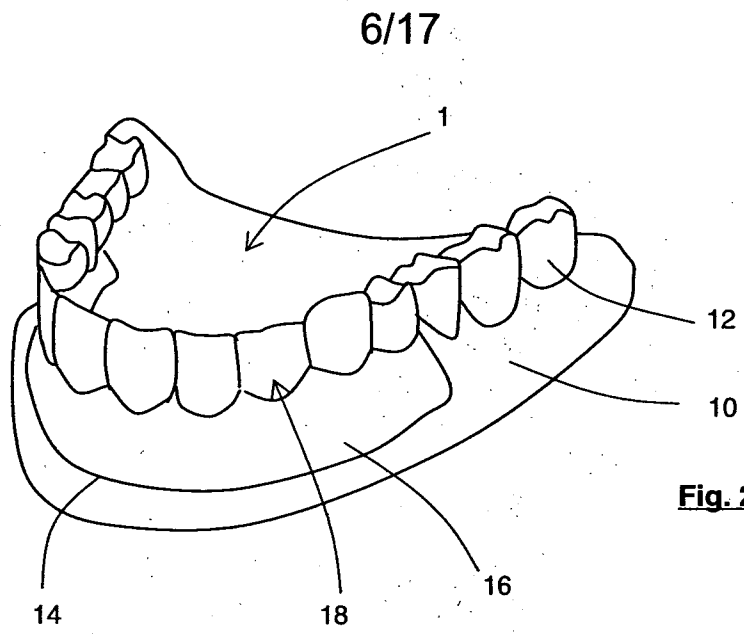
3/17



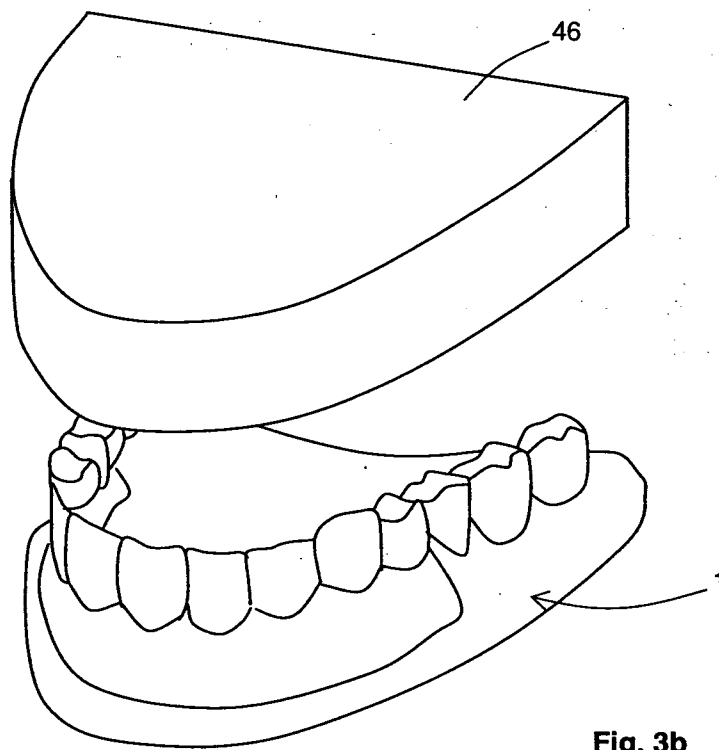
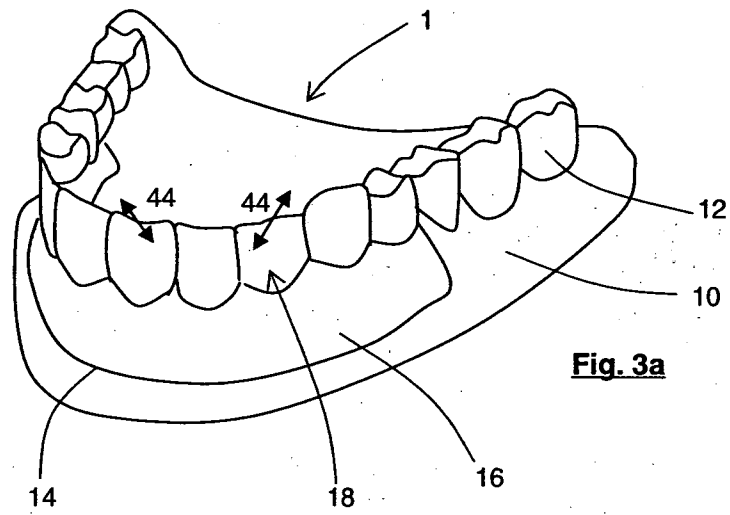


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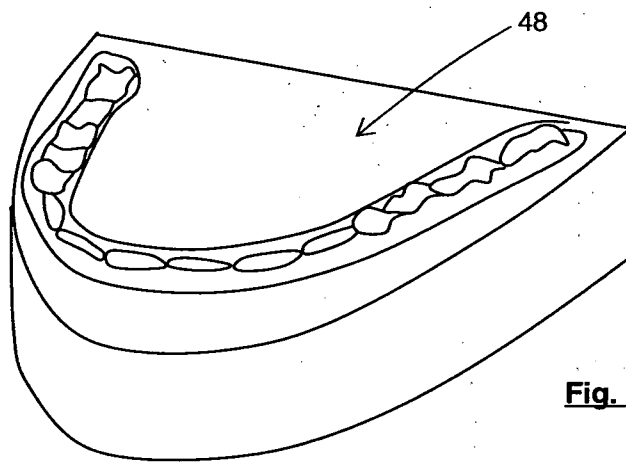


Fig. 3c

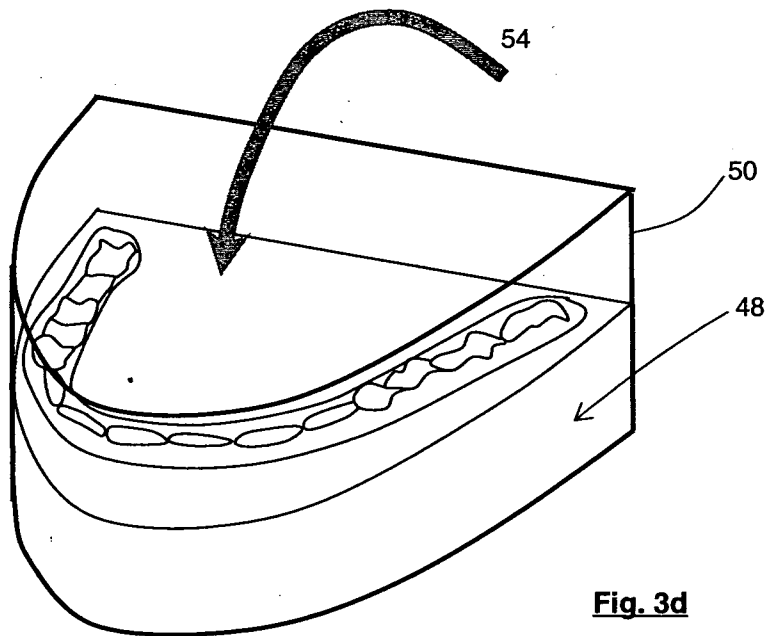


Fig. 3d

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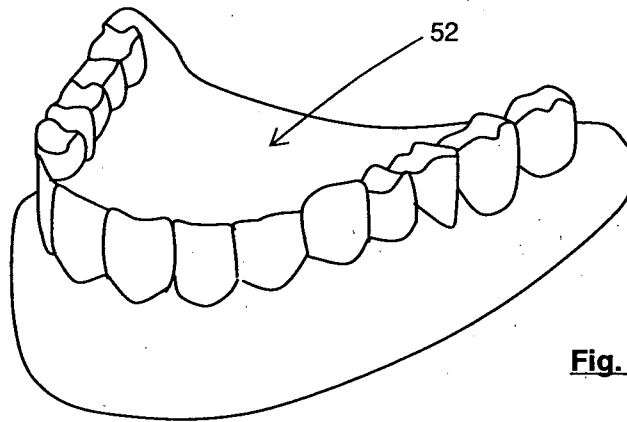


Fig. 3e

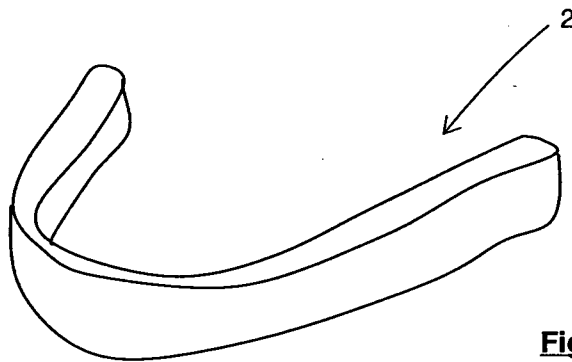


Fig. 3f

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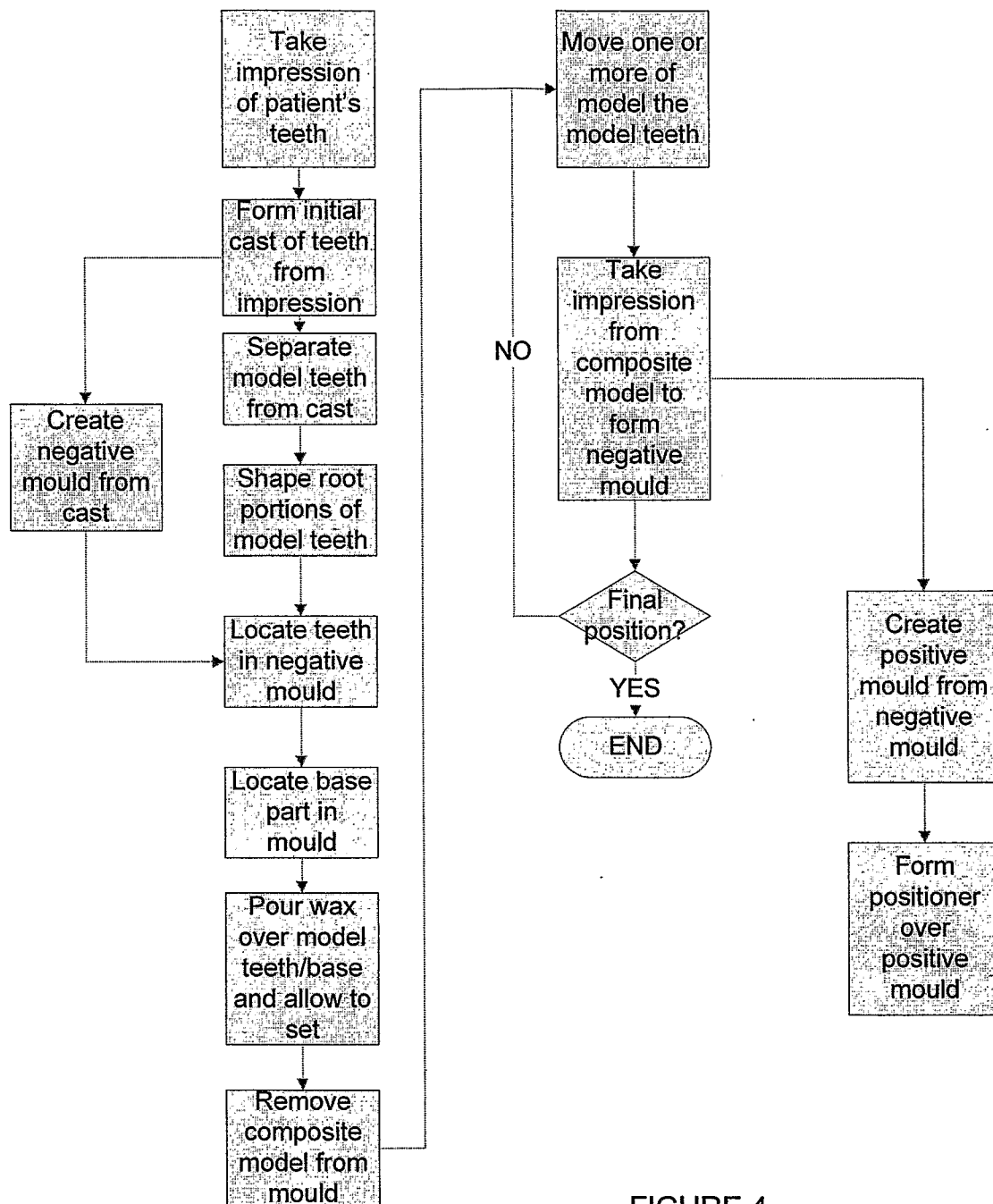
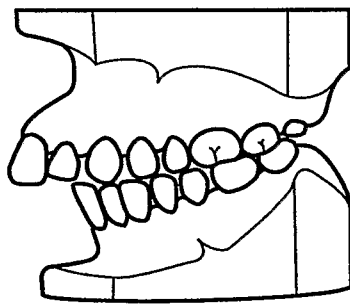
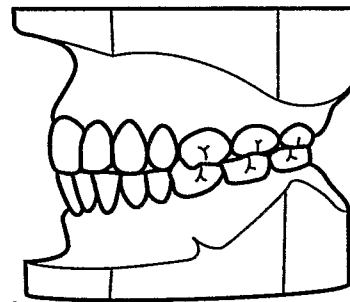


FIGURE 4

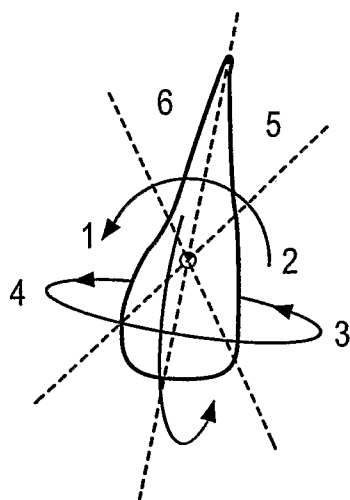
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A



B



C

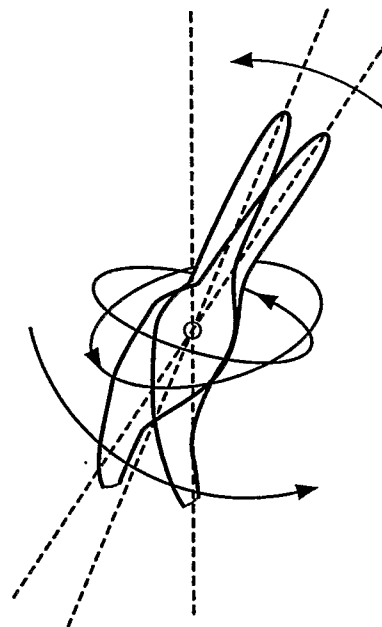


FIG. 5

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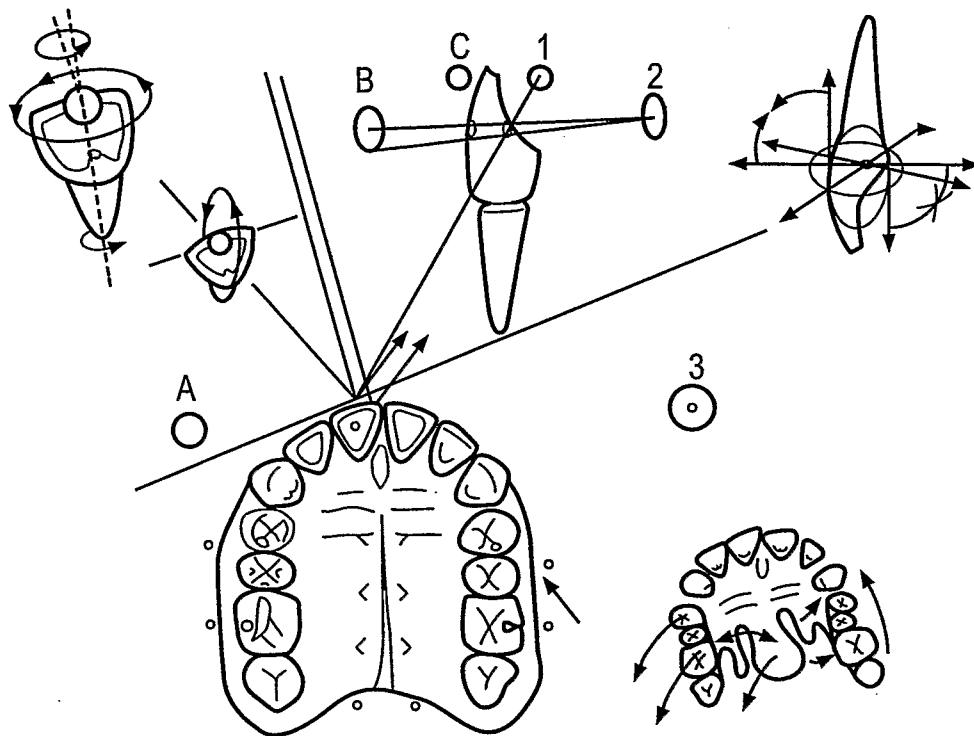


FIG. 6

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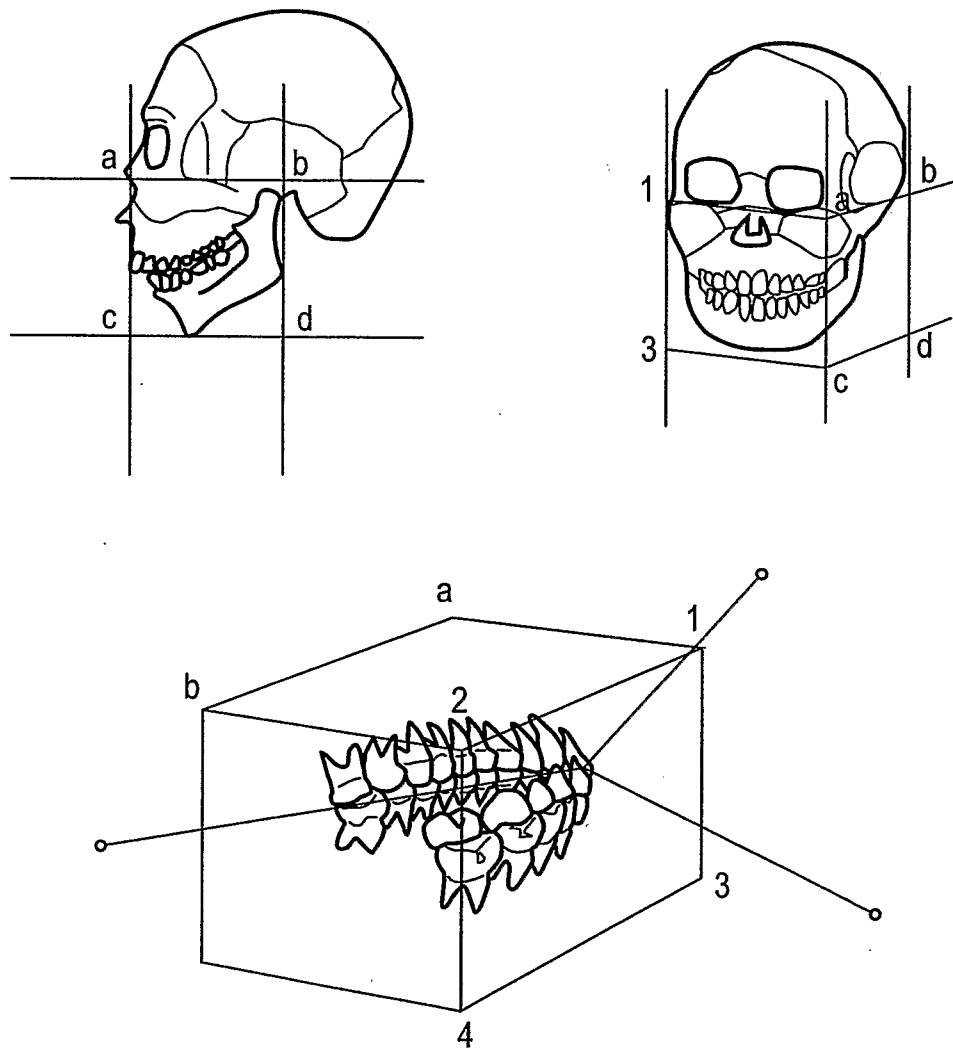


FIG. 7

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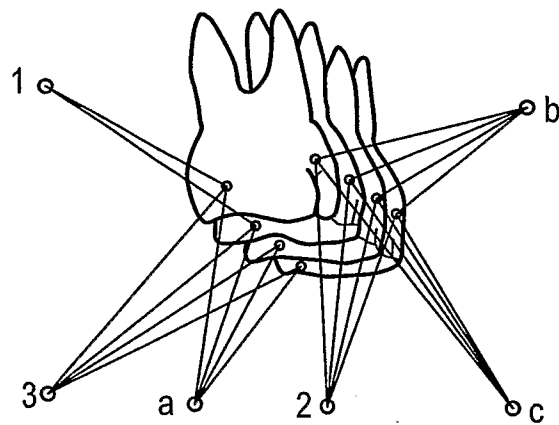
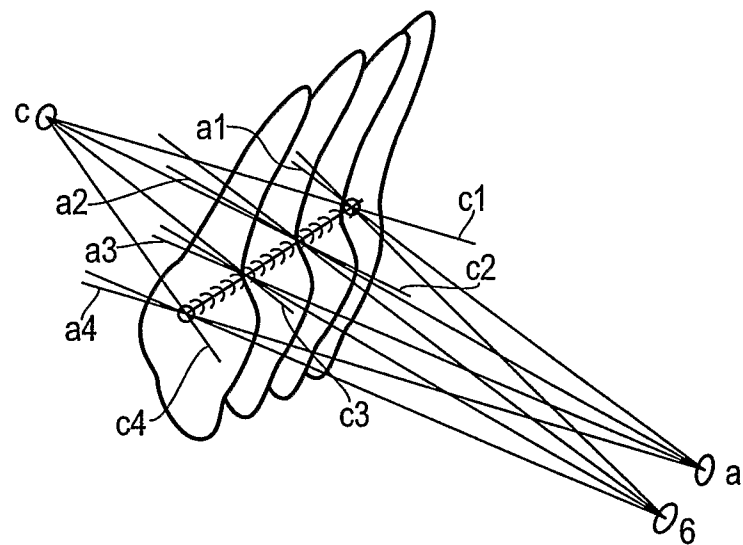
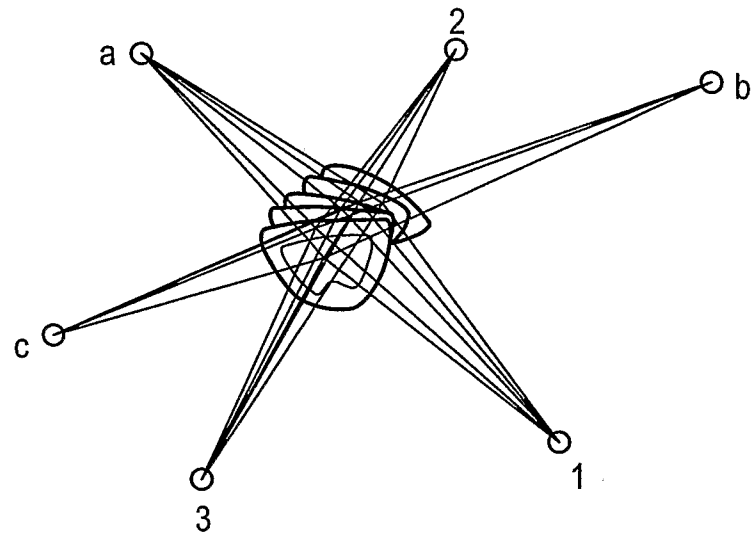


FIG. 8

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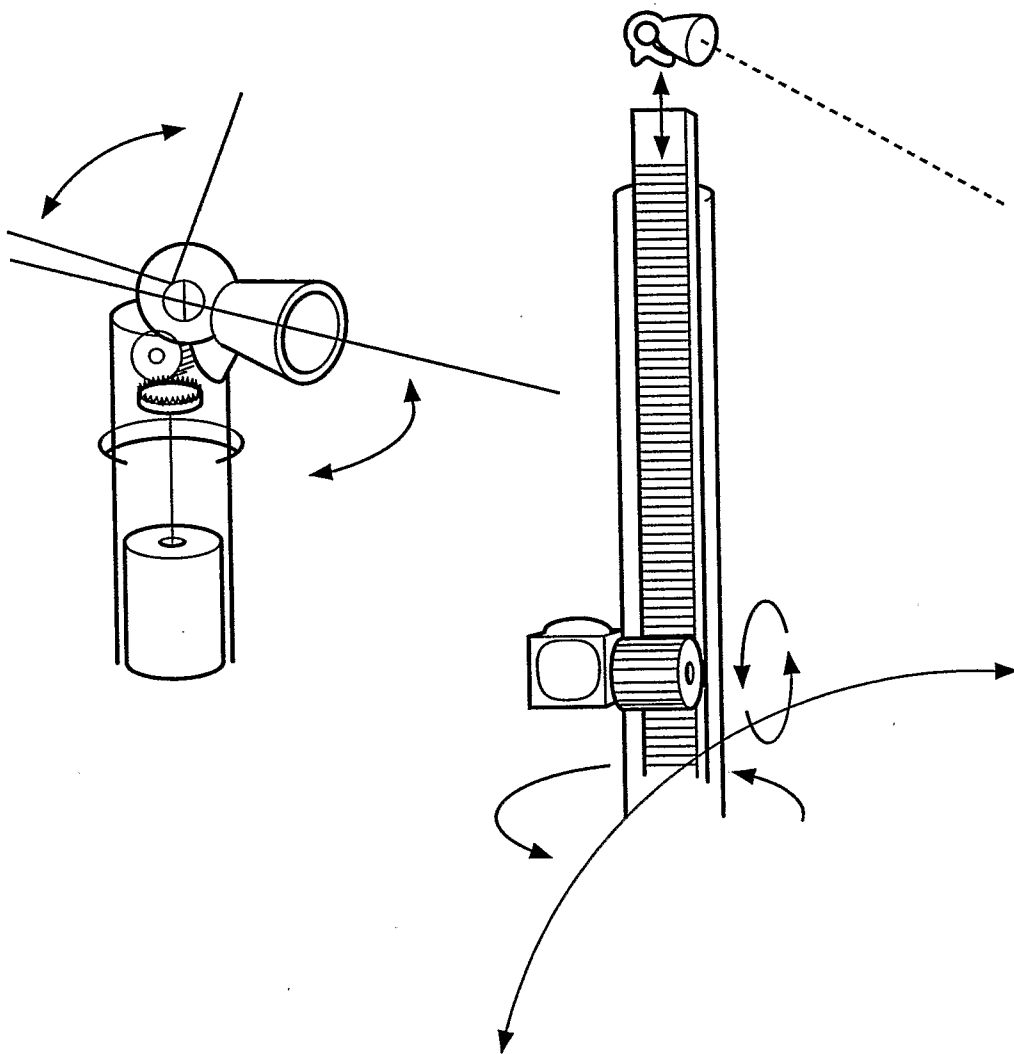


FIG. 10

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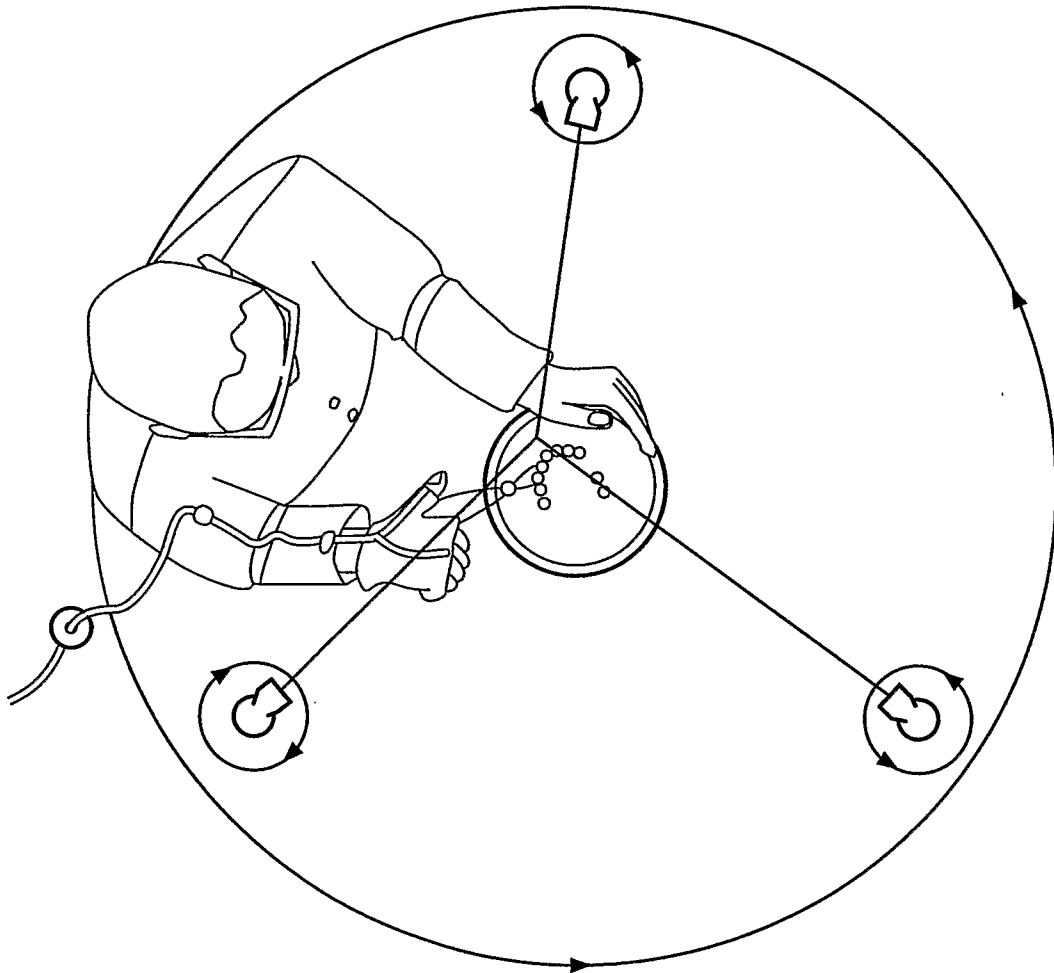


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2007/003920

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61C7/00 A61C7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2006/050452 A (ORTHOCLAR HOLDINGS INC; WEN HUAFENG [US]; LIU FRANK ZHENHUAN [US]; LI) 11 May 2006 (2006-05-11) paragraphs [0011] - [0014], [0168], [0275] - [0277], [0279], [0336] - [0341], [0400] - [0403] figures 1,15-17,29A,29B,39,50 -----	1-30
X	WO 00/33759 A (ALIGN TECHNOLOGY INC [US]) 15 June 2000 (2000-06-15) page 8, lines 12-33 page 16, line 8 - page 17, line 20 -----	1-6, 11-13, 22,23, 27,28
A	US 2005/192835 A1 (KUO ERIC E [US] ET AL) 1 September 2005 (2005-09-01) paragraph [0090] -----	1,3-5
-/--		

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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* & * document member of the same patent family

Date of the actual completion of the international search

29 January 2008

Date of mailing of the international search report

07/02/2008

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Authorized officer

Chabus, Hervé

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2007/003920

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No

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