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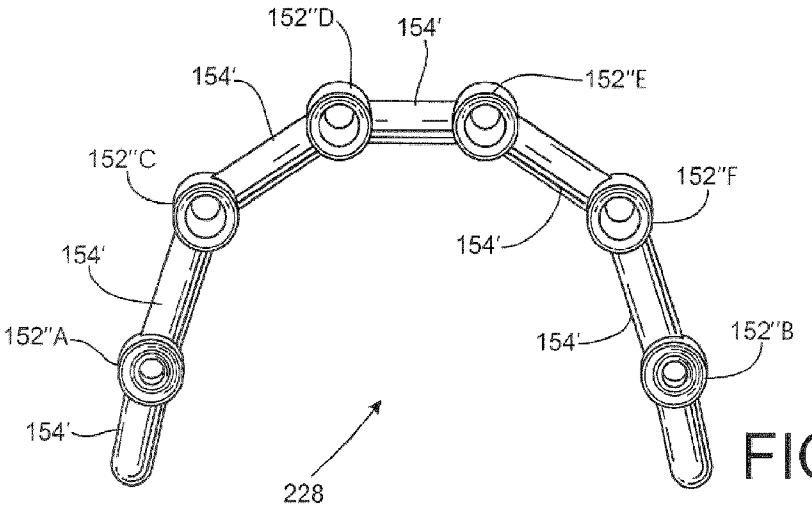

FIG. 25

(57) Abstract: A method of preparing a dental framework or mathematical model thereof comprises creating a replica of a patient's mouth or a framework to be inserted into the patient's mouth, electronically scanning the replica or framework, electronically determining a surface model of a dental framework and manufacturing the framework.

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TITLE OF THE INVENTION: Dental Framework

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FIELD OF THE INVENTION

[0001] The invention relates generally to the creation of dental frameworks, and typically dental frameworks for dentures. More particularly it relates to computer implemented methods of manufacturing dental frameworks.

BACKGROUND OF THE INVENTION

[0002] Many different processes have been devised to make a dental framework. In the most common of these a dentist makes an impression of a patient's mouth in which copings are embedded that are attached to anchors in the patient's mouth to which the dental framework of the denture will be later attached.

[0003] The dentist then attaches analogs to the copings and casts a stone cast replica of the patient's mouth.

[0004] The dentist then forms a replica or model dental framework on top of the stone cast in the exact size and shape he wishes the actual dental framework. The dentist then lost wax casts the actual dental framework from the model dental framework.

[0005] Unfortunately these models are warped and distorted by the casting process and must be cut apart and soldered together until they fit properly.

[0006] What is needed is a method of manufacturing a dental framework that is more precise than these cast frameworks. It is an object of at least one aspect of this invention to provide such a dental framework. It is also an object of at least one aspect of this invention to provide a method for registering dental surfaces that have been digitally scanned in order to define a volume or space in which a computer-generated framework can be disposed.

[0007] These and other objects of the invention will become clear upon examination of the various embodiments and methods described below.

SUMMARY OF THE INVENTION

[0008] In accordance with a first aspect of the invention, a method of preparing a dental framework for a dental prosthesis for a patient is provided, the patient having a plurality of anchors embedded in the patient's mandible or maxilla, comprising the steps of coupling a plurality of fittings to a plurality of analogs in a positive replica of a patient's mandible or maxilla; fixing the fittings together with a bridging structure to form a model dental framework; fixing a surface extension to each of the fittings; sequentially scanning a plurality of points on the surface of the model dental framework and the surface extensions to create a point cloud dataset; for each of the fittings represented in the point cloud dataset, deriving from the points scanned from the surface extension coupled to that fitting a desired location and orientation of a corresponding mount to engage the analog on which that fitting was mounted; generating a surface model of an actual dental framework from the derived desired locations and orientations of the mounts; and manufacturing the actual dental framework from the surface model.

[0009] The mounts may be configured to be fixed directly to anchors in a patient's mouth. The mounts may be configured to be fixed to intermediate structures that are in turn fixed to the anchors. Each of the surface extensions may have a longitudinal axis that is coaxial with a corresponding longitudinal axis of the fitting on which it is fixed.

[0010] In accordance with a second aspect of the invention, a method of preparing an actual dental framework for a dental prosthesis for a patient from a model framework is provided, wherein the model framework comprises a plurality of fittings configured to engage a plurality of corresponding anchors in the patient's mouth, and a bridging structure coupling the fittings together, the method comprising the steps of fixing surface extensions to each of the plurality of fittings; sequentially scanning a plurality of points on the surface of the model dental framework and the surface extensions to generate a point cloud dataset; for each of the fittings, deriving from the points scanned from the surface extension coupled to that fitting a desired location and orientation of a corresponding mount to engage the analog on which that fitting was mounted; and generating a surface model of an actual dental framework from the derived desired locations and orientations of the corresponding mounts.

[0011] The mounts may be configured to be fixed directly to anchors in a patient's mouth. The mounts may be configured to be fixed to intermediate structures that are in turn fixed to the anchors. Each of the surface extensions has a longitudinal axis that is coaxial with a corresponding longitudinal axis of the fitting on which it is fixed.

[0012] In accordance with a third aspect of the invention, a method of preparing a dental prosthesis for a patient is provided, comprising the steps of coupling a plurality of copings to a plurality of anchors or surmounted abutments embedded in a patient's mandible or maxilla; impressing a negative replica of the patient's mandible or maxilla; removing the negative replica and embedded copings; fixing surface extensions to each of the copings; scanning a plurality of points on the surface extensions; deriving from the plurality of points a desired location and orientation of mounts to engage the anchors or surmounted abutments on which the copings were mounted; generating a surface model of the dental prosthesis from the derived desired locations and orientations of the mounts; and manufacturing the dental prosthesis from the surface model.

[0013] The step of generating a surface model may include the step of generating a surface model of at least a portion of the mounts. The surface model of the at least a portion of the mounts may include a surface model of surfaces configured to engage the plurality of anchors or surmounted abutments. The step of generating a surface model may include the step of generating a surface model of a bridging structure that extends between and couples the mounts. The dental prosthesis may comprise a dental framework and further wherein the dental framework may comprise the mounts. The method of claim 9, wherein the dental prosthesis is a denture.

[0014] In accordance with a fourth aspect of the invention, a method of preparing a dental prosthesis for a patient from a negative replica of the patient's maxilla or mandible is provided, the negative replica including a plurality of copings configured to engage a corresponding plurality of anchors or surmounted abutments in the patient's maxilla or mandible, the method comprising the steps of fixing surface extensions to each of the copings; scanning a plurality of points on the surface extensions; deriving from the plurality of points a desired location and orientation of mounts configured to engage the anchors or surmounted abutments; and generating a surface model of the dental prosthesis from the derived desired locations and orientations of the mounts.

[0015] The step of generating a surface model may include the step of generating a surface model of at least a portion of the mounts. The surface model of the at least a portion of the mounts may include a surface model of surfaces configured to engage the plurality of anchors or surmounted abutments. The step of generating a surface model may include the step of generating a surface model of a bridging structure that extends between and couples the mounts. The dental prosthesis may comprise a dental framework and the dental framework may comprise the mounts. The dental prosthesis may be a denture.

[0016] In accordance with a fifth aspect of the invention, a method of preparing a dental prosthesis for a patient from a negative replica of the patient's maxilla or mandible is provided, the negative replica including a plurality of copings configured to engage a corresponding plurality of anchors or surmounted abutments in the patient's maxilla or mandible, the method comprising the steps of scanning a surface of the negative replica to provide a first point cloud dataset representing a surface of the negative replica; and generating a surface model of the dental prosthesis from the first point cloud dataset.

[0017] The surface of the negative replica may include surfaces of copings. The method may further include the steps of fixing surface extensions to the negative replica and scanning the surface extensions to provide a second point cloud dataset. The dental prosthesis may comprise a dental framework and the dental framework may comprise the mounts. The dental prosthesis may comprise a denture.

[0018] In accordance to a sixth aspect of the invention, a method of computer generating a digital model of a dental prosthesis for a patient is provided, the method comprising the steps of coupling a plurality of surface extensions to analogs or surmounted abutments embedded in a positive replica of the patient's mouth, the positive replica of the patient's mouth including a positive replica of the patient's mucosal tissues; sequentially scanning surfaces of the surface extensions and deriving therefrom a location of the analogs or surmounted abutments; sequentially scanning the replica of the patient's mucosal tissues to create a point cloud dataset indicating a surface of the patient's mucosal tissues with respect to the anchors or surmounted abutments; and computer-generating a digital model of a dental prosthesis, the digital model comprising model mounts configured to engage analogs or surmounted abutments in the patient's mandible or maxilla, the digital model also comprising model bridging structures extending between and coupling the model mounts, wherein the model bridging structures are computer-generated such that they do not intersect the surface of the patient's mucosal tissue as indicated by the point cloud dataset.

[0019] The bridging structure may comprise a dental framework. The bridging structure may comprise a component of a denture. The model bridging structure may comprise computer-generated to be spaced a predetermined distance away from the surface of the patient's mucosal tissue as indicated by the point cloud dataset.

[0020] In accordance with a seventh aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient is provided, the method comprising making an impression of the patient's mouth; making a stone cast of the impression; forming a diagnostic wax-up on the stone cast; digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the impression to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

[0021] The step of digitally registering may comprise the steps of registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the surface of the diagnostic wax-up, from which the portion of the first point cloud dataset was scanned, was formed by a portion of a common surface of the stone cast; and further wherein the portion of the second point cloud dataset was formed by a portion of a surface of the impression that formed the common surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the step of digitally scanning both a first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast to create the first point cloud dataset, which comprises at least a common point cloud dataset including points defined by the diagnostic wax-up and points defined by the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points defined by the surface of the stone cast in the common point cloud dataset, and points defined by the impression in the second point cloud dataset. A first impression surface may be formed the points defined by the impression in the second point cloud dataset, and the first impression surface may form the stone cast surface from which the points defined by the surface of the stone cast in the common point cloud dataset were scanned.

[0022] In accordance with an eighth aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient from an impression taken of the patient's mouth, a stone cast made from the impression, and a diagnostic wax-up made on the stone cast is provided, the method comprising the steps of digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the impression to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

[0023] The step of digitally registering may comprise the steps of registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the surface of the diagnostic wax-up from which the portion of the first point cloud dataset was scanned was formed by a portion of a surface of the stone cast that was formed by a common surface of the stone cast; and further wherein the portion of the second point cloud dataset was formed by a portion of a surface of the impression that formed the common surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the step of digitally scanning both a first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast to create the first point cloud dataset, which comprises at least a common point cloud dataset including points defined by the diagnostic wax-up and points defined by the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points defined by the surface of the stone cast in the common point cloud dataset, and points defined by the impression in the second point cloud dataset. A first impression surface may form the points defined by the impression in the second point cloud dataset, and further wherein said first impression surface may form the stone cast surface from which the points defined by the surface of the stone cast in the common point cloud dataset were scanned.

[0024] In accordance with a ninth aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient is provided, comprising the steps of making an impression of the patient’s mouth; making a stone cast of the impression;

making a diagnostic wax-up on the stone cast; digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the stone cast to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

[0025] The step of digitally registering may comprise the steps of digitally registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the portion of the first point cloud dataset was scanned from a portion of the diagnostic wax-up formed by a forming surface of the stone cast; and wherein the portion of the second point cloud dataset was scanned from the forming surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the steps of digitally scanning both the first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast; and creating a common point cloud dataset including points scanned from the first surface of diagnostic wax-up and points scanned from the first portion of the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points scanned from the first portion of the surface of the stone cast in the common point cloud dataset, and points scanned from the stone cast in the second point cloud dataset. A common portion of the stone cast surface may define both the points scanned from the surface of the stone cast in the common point cloud dataset and the points scanned from the stone cast in the second point cloud dataset. The step of digitally registering the first and second point cloud datasets may comprise the step of registering points in both the first and second point cloud datasets taken from the common portion of the stone cast surface.

[0026] In accordance with a tenth aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient from an impression of the patient's mouth, a stone cast of the impression, and a diagnostic wax-up formed on the stone cast is provided, the method comprising the steps of digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the stone cast to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

[0027] The step of digitally registering may comprise the steps of digitally registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the portion of the first point cloud dataset was scanned from a portion of the diagnostic wax-up formed by a forming surface of the stone cast; and wherein the portion of the second point cloud dataset was scanned from the forming surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the steps of digitally scanning both the first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast; and creating a common point cloud dataset including points scanned from the diagnostic wax-up and points scanned from the first portion of the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points scanned from the first portion of the surface of the stone cast in the common point cloud dataset, and points scanned from the stone cast in the second point cloud dataset. A common portion of the stone cast surface may define both the points scanned from the surface of the stone cast in the common point cloud dataset and the points scanned from the stone cast in the second point cloud dataset. The step of digitally registering the first and second point cloud datasets may comprise the step of registering points in both the first and second point cloud datasets taken from the common portion of the stone cast surface.

[0028] In accordance with an eleventh aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient from an impression of the patient's mouth, a stone cast of the impression, a diagnostic wax-up formed on the stone cast, and a putty index formed on the diagnostic wax-up and the stone cast is provided, the method comprising the steps of digitally scanning at least a first surface of the putty index to form a first point cloud dataset; digitally scanning at least a second surface of the stone cast to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

[0029] The step of digitally registering may comprise the steps of digitally registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the portion of the first point cloud dataset was scanned from a portion of the putty index formed by a forming surface of the stone cast; and wherein the portion of the second point cloud dataset was scanned from the forming surface of the stone cast. The step of digitally scanning at least a first surface of the putty index may comprise the steps of digitally scanning both the first surface of the putty index and a first portion of the surface of the stone cast while said putty index is mounted on the stone cast; and creating a common point cloud dataset including points scanned from the putty index and points scanned from the first portion of the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points scanned from the first portion of the surface of the stone cast in the common point cloud dataset, and points scanned from the stone cast in the second point cloud dataset. A common portion of the stone cast surface may define both the points scanned from the surface of the stone cast in the common point cloud dataset and the points scanned from the stone cast in the second point cloud dataset. The step of digitally registering the first and second point cloud datasets may comprise the step of registering points in both the first and second point cloud datasets taken from the common portion of the stone cast surface. The impression may comprise a plurality of copings. The method may further comprise the step of fixing a plurality of surface extensions to the plurality of copings. The step of digitally scanning at least the second surface may comprise the step of digitally scanning surfaces of the plurality of surface extensions. The stone cast may comprise a plurality of analogs. The method may further comprise the step of fixing a plurality of surface extensions to the plurality of analogs. The step of digitally scanning at least the second surface may comprise the step of digitally scanning surfaces of the plurality of surface extensions.

[0030] In accordance with a twelfth aspect of the invention, a method of preparing a denture for a patient is provided, the method comprising the steps of coupling a plurality of fittings to a plurality of analogs embedded in a stone cast of the patient's maxilla or mandible; forming a diagnostic wax-up on the stone cast in which the plurality of fittings are embedded; removing the diagnostic wax-up with embedded fittings from the stone cast; fixing surface extensions to each of the plurality of fittings; sequentially scanning a plurality of points on the surface of the diagnostic wax-up and on the surface extensions to generate a point cloud dataset; and, for each of the fittings represented in the point cloud dataset, deriving from the points scanned from the surface extension of that fitting a desired location and orientation of a corresponding mount configured to engage the analog on which that fitting was mounted.

[0031] In accordance with a thirteenth aspect of the invention, a method of creating a dental framework having a plurality of mating surfaces that are configured to engage corresponding plurality of anchors in a patient's mouth, is provided the method comprising the steps of: attaching a plurality of copings to the anchors; forming an impression in which the copings are embedded; attaching an analog to each of the plurality of copings; forming a stone cast in which the plurality of copings are embedded; attaching alignment posts having surface extensions to each of the analogs; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and making the framework in accordance with the toolpath.

[0032] The alignment posts may be attached to surfaces of the analogs that correspond to the plurality of mating surfaces on the anchors. The framework may further comprise a bridging structure that extends between and couples the plurality of mating surfaces together, and the step of generating a toolpath may further comprise the step of generating a toolpath configured to generate the bridging structure. The step of digitally scanning the surface extensions may further comprise the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising the three dimensional datapoints. The step of deriving the relative positions and orientations may further comprise the step of electronically fitting datapoints scanned from the surface extensions to a predetermined three dimensional geometry of the surface extensions stored in a computer memory.

[0033] In accordance with a fourteenth aspect of the invention, a method of generating a toolpath for manufacturing a dental framework for a patient's mouth is provided, the patient's mouth comprising a plurality of anchors embedded in the patient's mandible or maxilla, the framework being made from a stone cast with embedded analogs, the stone cast being made from an impression having embedded copings, the impression being taken directly from the patient's mouth, wherein the framework further comprises a plurality of mating surfaces that are configured to engage the plurality of anchors, the method comprising the steps of: attaching alignment posts having surface extensions to each of the analogs embedded in the stone cast of the patient's mouth; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; and generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations.

[0034] In accordance with a fifteenth aspect of the invention a method of creating a dental framework having a plurality of mating surfaces that are configured to engage a corresponding plurality of anchors in the patient's mouth is provided, the method comprising the steps of: attaching a plurality of copings to the anchors; forming a stone cast in which the copings are embedded; attaching an analog to each of the plurality of copings; forming a stone cast in which the plurality of analogs are embedded; attaching a fitting to each of the plurality of analogs; coupling the fittings together with a bridging structure to hold them in their relative positions thereby forming a model framework; removing the fittings and bridging structure from the copings; attaching alignment posts having surface extensions to each of the fittings; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and making the framework in accordance with the toolpath.

[0035] The alignment posts may be attached to surfaces of the fittings that correspond to the plurality of mating surfaces on the anchors. The step of digitally scanning further may comprise the step of digitally scanning the surface of the bridging structure to generate the point cloud dataset, and the step of generating a toolpath may comprise the step of generating a toolpath configured to generate the bridging structure from datapoints scanned from the surface of the bridging structure. The step of digitally scanning the surface extensions may comprise the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, the point cloud dataset comprising the three dimensional datapoints. The step of deriving the relative positions and orientations may comprise the step of electronically fitting datapoints scanned from the surface extensions to a predetermined geometry of the surface extensions stored in a computer memory.

[0036] In accordance with a sixteenth aspect of the invention, a method of creating a dental framework having a plurality of mating surfaces that are configured to engage a corresponding plurality of anchors in the patient's mouth, the method comprising the steps of: attaching a plurality of copings to the anchors; forming a stone cast in which the copings are embedded; attaching an analog to each of the plurality of copings; forming a stone cast in which the plurality of analogs are embedded; attaching a fitting to each of the plurality of analogs; coupling the fittings together with a bridging structure to hold them in their relative positions thereby forming a model framework; removing the fittings and bridging structure from the copings; attaching alignment posts having surface extensions to each of the fittings; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and making the framework in accordance with the toolpath.

[0037] In accordance with the 17th aspect of the invention, a method of locating a dental appliance with respect to dental surfaces is provided, the method comprising the steps of: scanning a first dental surface to create a first point cloud dataset; scanning a second dental surface to create a second point cloud dataset; registering the first and second point cloud datasets by aligning points in each dataset taken from the overlapping surface portions; and using non-overlapping portions of both point cloud datasets to define the location of the dental appliance.

[0038] The first dental surface and the second dental surface may be selected from the group comprising an impression, a stone cast, a diagnostic wax-up, a facial index and a dental framework. Not second dental surface is selected from the group comprising an impression, a stone cast, a diagnostic wax-up, a facial index, and a dental framework. The first point cloud dataset may comprise both points scanned from a surface of a diagnostic wax-up disposed on a stone cast and points scanned from a surface of the stone cast while the diagnostic wax-up is disposed on it, and the second point cloud dataset may comprise points scanned from the surface of the stone cast and points scanned from a surface of the stone cast that was covered by the diagnostic wax-up when the diagnostic wax-up was scanned to create the first point cloud dataset, and the portions of the stone cast common scanned to both point cloud datasets may constitute the overlapping portions of both point cloud datasets. A facial index may have a first surface formed in abutment to a diagnostic wax-up and a second surface formed in abutment to a third surface of a stone cast, the first point cloud dataset may comprise points scanned both from the first surface and the second surface, and the second point cloud dataset may comprise points scanned from the third surface and points scanned from a fourth surface of the stone cast adjacent to the third surface, and the overlapping portions of both point cloud datasets may comprise points scanned from the second surface in the first point cloud dataset and points scanned from the third surface in the second point cloud dataset.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039] **FIGURE 1** is a fragmentary cross sectional view of an anchor embedded in a mandible.

[0040] **FIGURES 2A** and **2B** are perspective views of a two piece coping to be attached to the anchor of **FIGURE 1**.

[0041] **FIGURE 3** is a perspective view of anchor with coping attached.

[0042] **FIGURE 4** is a fragmentary perspective view of a patient’s open mouth with the anchors embedded in the patient’s mandible.

[0043] **FIGURE 5** is a fragmentary perspective view of the patient’s open mouth with several copings attached to the anchors and an impression tray with impression material surrounding the patient’s mucosal tissue and submerging the copings.

[0044] **FIGURE 6** is a perspective view of the impression of **FIGURE 5** inverted and removed from the patient’s mouth with two analogs attached to two of the copings.

[0045] **FIGURE 7** is the same perspective view of **FIGURE 6,** but with all the analogs attached to all the copings, and the impression filled with dental stone material and all the analogs submerged in the dental stone material.

[0046] **FIGURE 8** is a perspective view of the stone cast formed by the dental stone material poured in the impression of **FIGURE 7** in its hardened state, inverted, and with the impression removed showing the analogs with the analog surfaces that mated with the copings (in **FIGURE 7** now exposed .

[0047] **FIGURE 9** is a perspective view of the stone cast of **FIGURE 8** with the dentist’s manufactured diagnostic wax-up that was previously built up on the top of the mandible now disposed on the stone cast and abutting the analogs.

[0048] **FIGURE 10** is a cross-sectional view of the stone cast of **FIGURE 9**

taken at section line 10-10 in **FIGURE 9**.

[0049] **FIGURE 11** is a perspective view of the stone cast of **FIGURES 8-10**, with a putty index molded to the facial aspect of the diagnostic wax-up.

[0050] **FIGURE 12** is a cross sectional view of the stone cast of **FIGURES 8-11** taken at section line 12-12 in **FIGURE 11**.

[0051] **FIGURE 12B** is a cross sectional view of the stone cast of **FIGURES 8-12** with the diagnostic wax-up removed to show the inner surface of the putty index and the impression of the facial aspect of the diagnostic wax-up formed on the inner surface of the putty index.

[0052] **FIGURE 13A** is a perspective view of the stone cast of **FIGURES 8-12B** with six fittings, one fitting attached to each of the six analogs.

[0053] **FIGURE 13B** is a perspective view of the stone cast of **FIGURES 8-13A** with bridging structures fixed to and between each of the six fittings to form a wax-up framework mounted on the six analogs.

[0054] **FIGURE 13C** is a bottom view of the wax-up framework of **FIGURES 13A-13B** as it would appear when removed from the stone cast and inverted.

[0055] **FIGURE 14** is a perspective view of the removed wax-up framework of **FIGURE 13C** with an alignment post attached to each of the six fittings.

[0056] **FIGURE 15** is a cross sectional view of the wax-up framework of **FIGURE 14** with alignment posts attached taken along the longitudinal axis of either one of the two end alignment posts and its associated fitting.

[0057] **FIGURE 16** is a cross sectional view of the wax-up framework of **FIGURE 14** with alignment posts attached taken along the longitudinal axis of any one of the four central alignment posts and its associated fitting.

[0058] **FIGURE 17** is a side view of either one of the two end alignment posts (two-piece) of **FIGURES 14-15** showing the fitting in which it is fitted in phantom lines.

[0059] **FIGURE 18** is a side view of any one of the four central one-piece alignment posts of **FIGURES 14, 16**.

[0060] **FIGURE 19** is a schematic diagram of the scanner and the wax-up framework and alignment posts of **FIGURE 14** that it is scanning.

[0061] **FIGURE 20** is a flow chart of the process of scanning and manufacturing the framework of **FIGS 13A-14** with alignment posts attached as shown in **FIGS 14-16**.

[0062] **FIGURE 21** is a graphical representation of the surface model scanned from the wax-up framework plus alignment post assembly of **FIGURES 14 and 19** with the alignment posts subsequently digitally removed.

[0063] **FIGURE 22** is a graphical representation of the surface model of **FIGURE 21** with pads.

[0064] **FIGURE 23** is a graphical representation of the surface model of **FIGURE 22** with parameterized fitting sunk into the pads configured to be mounted to the anchors.

[0065] **FIGURE 24** is a flow chart of the process of manufacturing a denture framework from a scan of the stone cast shown in **FIGURES 8-13B** but with alignment posts attached to it -- and optionally a scan of the diagnostic wax-up and/or the putty index of **FIGURES 9-12B**.

[0066] **FIGURES 25-27** are three different perspective views of a mathematical surface model of a denture framework generated by the scanner of **FIGURE 19**.

[0067] **FIGURE 28** is a perspective view of a diagnostic wax up formed on the surface of a stone cast with embedded fittings.

[0068] **FIGURE 29** is a perspective view of the wax-up of **FIGURE 28** removed from the stone cast with the fittings embedded in the diagnostic wax-up and alignment posts fixed to the now-free surfaces of the fittings.

[0069] **FIGURE 30** is a perspective view of an impression with coping extending therefrom to which alignment posts have been attached.

[0070] **FIGURES 31-36** are side and end views of alternative alignment posts.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0071] In **FIGURE 1**, the patient's jaw or mandible **100** can be seen overlaid with soft mucosal tissue **102** (known commonly as “gum tissue”). An anchor **104**, also known as an "implant" or "fixture" is shown embedded into the patient's mandible **100**. This anchor is retained within the mandible by a screw thread **106**. It is driven into the mandible **100** by coupling a wrench or similar device to the top of the anchor **104** and rotating the wrench to drive the anchor into the jaw bone just as one would drive a screw into a piece of wood. In an alternative embodiment, the anchor **104** is press fitted into a hole formed with a drill, reamer, broach, osteotome, or similar device.

[0072] **FIGURE 1** illustrates the first step in the process, that of forming an opening in the mandible of the patient and fixing an anchor therein, while leaving a top surface of the anchor exposed above mucosal tissue **102** for mating (coupling) to and supporting a dental prosthesis or restorative component such as a denture, bridge, crown, framework, abutment, healing cap, or coping (hereinafter referred to as “denture”). Note that while the process illustrated herein describes and illustrates a mandible for illustration purposes, the same process is performed to embed anchors **104** into the patient's maxilla and create dental prostheses for the maxilla.

[0073] To attach anchors **104**, the dentist first makes an incision in the mucosal tissue **102** where a missing tooth or teeth would normally extend from the mandible where it is embedded, through the gum, and into the oral cavity. Once the incision is made, the dentist makes a hole (which may include such processes as drilling, broaching or reaming) in the mandible **100** in the same general direction and location as the missing tooth. The dentist then fixes an anchor **104** into the hole thus created and sutures the incision, typically leaving mating surface **108** of anchor **104** exposed while the bone osseointegrates to the outer surface of anchor **104**. Alternatively, the dentist may attach a healing cap to the anchor **104** and suture the gum around or over the top of the anchor **104** and the healing cap, permitting the gum to heal around or over the top of the anchor **104** as it osseointegrates. In this alternative process, once the anchor has osseointegrated, the dentist incises the mucosal tissue **102** extending over the top of the now-integrated anchor **104** and retracts the mucosal tissue to each side, exposing the mating surface **108** of anchor **104** and permitting the mucosal tissue to heal.

[0074] The anchor **104** has a central longitudinal aperture **107** in the top which is configured to receive an impression coping **110 (FIGURE 2)** (or a fastener configured to mount the impression coping **110)** that is affixed to the anchor **104**. This coping transfers the size, shape, location or orientation of the mating surface **108** of the anchor (and preferably all four) to the stone cast (see below). It is the mating surface **108** that is oriented to the finished denture, and hence the mating surface **108** from which the structures of the denture that mount to the anchors are derived. For convenience of illustration in **FIGURE 1** only a single anchor **104** is shown. In practice, anywhere from one to twelve of these anchors are embedded in the maxilla and are provided as mounting points for the denture. In an alternative configuration, anchor **104** may have a variety of configurations on its mating surface **108** including threaded or unthreaded protrusions or recesses that are configured to engage a denture. The use of an anchor **104** having a central aperture and internal threads for engaging a coping is a matter of convenience herein and should not suggest that the process is limited to an anchor having this configuration.

[0075] **FIGURES 2A**, **2B and 3** illustrate an impression coping **110** that is configured to be fixed on to the mating surface **108** of anchor **104**. In the second step of the process, the dentist fits anchor **104** with a coping **110** that is aligned to surface **108** (**FIGURE 1**). Mating surface **108** is typically the surface on which the denture will be mounted or a surface having a predetermined position with respect to that surface on which the denture will ultimately be mounted. The coping **110** is configured to engage surface **108** and surrounding structures of anchor **104** (if any) such as holes that extend into (or protrusions that extend above) the surface **108**.

[0076] These interengaging surfaces of coping **110** and anchor **104** serve to align the coping and the anchor in predetermined positions with respect to each other when fixed together, such that if one knows the position and orientation of surfaces on the coping one can know the position and orientation of corresponding structures on the anchor **104** and more preferably when a scanner (see below) determines the position and orientation of structures on copings **110** it can mathematically determine the position and orientation of corresponding structures on anchors **104**. Anchor **104** is preferably cylindrical and has a longitudinal axis **111**, as does coping **110**. In a typical arrangement, when the coping **110** is fixed in its predetermined position with respect to anchor **104**, a longitudinal axis **111** of the coping is coaxial with the longitudinal axis of the anchor **104**. The coping **110** and the anchor **104** are preferably threadedly engaged to permit surfaces on the coping to be drawn down tightly against mating surface **108** for precise alignment of their interengaging surfaces. Alternatively, the coping **110** and anchor **104** to which it is coupled may be equipped with interengaging snap fastening connecting surfaces that hold the coping in the proper orientation with respect to anchor **104**.

[0077] **FIGURE 2A** shows a tubular central portion **116** of coping **110** that is configures to be received in an outer sleeve portion **112** of the coping having a central longitudinal hole **114** shown in **FIGURE 2B**.

[0078] Sleeve portion **112**, as shown in **FIGURE 3**, abuts the soft mucosal tissue surrounding the mating surface **108** of anchor **104**, preventing the tissue from covering mating surface **108**. Tubular central portion **116** extends through outer sleeve portion **112** and is engaged to the central longitudinal aperture **107** formed in the end of anchor **104** (see **FIGURE 1**). This is the preferred form of the coping **110**, and the preferred means for attaching the coping to anchor **104**. It is not the only means, however.

[0079] **FIGURE 4** illustrates the mandible **100** of **FIGURES 1**, **2A**, **2B**, **and 3**, with all the anchors **104** implanted in the mandible, and ready for the next step in the process. In this **FIGURE**, the edentulous mandible **100** has six anchors **104** affixed therein in a spaced-apart relation extending from the front of mandible **100** around each side. The anchors **104** are disposed in a generally upright and parallel relation extending into the top surface of mandible **100**. The dentist attaches corresponding copings **110** to the top of each anchor **104** and extends upward in a generally upright and parallel relation to the other copings **110**. The application illustrated herein shows the use of six anchors configured to support a denture. Other applications with more or fewer anchors **104** are possible. Furthermore, the mandible need not be edentulous (shown here), but may have, and often does have, a few natural teeth remaining in the maxilla or mandible between which the anchors **104** are embedded to support one or more dentures (such as fixed or removable partial dentures) to fill the gap or gaps between the existing natural teeth. In this case, the anchors would not be spaced evenly about the mandible, as shown here, but would be spaced irregularly in the gaps created by the absence of natural teeth.

[0080] **FIGURE 5** illustrates the next step in the process of creating a denture, the step of creating an impression of the patient's mandible. This **FIGURE** shows an impression tray **120** filled with flexible impression material **122**. The tray is a semi flexible plastic structure that holds the impression material **122** in position around the patient's teeth (if any) and mucosal tissue. **FIGURE 5** shows a tray **120** for the lower teeth surrounding teeth, mucosal tissue, and mandible of the patient.

[0081] The copings **110** previously attached by the dentist to the anchors **104** are completely submerged by the dentist in impression material **122** such that the entire outer surfaces of the copings **110** extending above the surface of the mucosal tissue on the patient's mandible **100** are completely covered. The impression material is left in this position to cure. Once cured, the individual copings **110** are fixed with respect to each other in the same position and orientation that the anchors **104** are fixed with respect to each other. The curing process fixes the copings in this position and thereby permits the copings to be collectively removed together with the impression material while preserving their orientation.

[0082] In the next step of the process, the dentist flexes the tray **120** and the now-cured impression material **122** and removes them from the patient's mouth. Enough impression material **122** is placed in the tray and disposed around the patient's mandible **100** to cover any still-existing teeth of the mandible and the mucosal tissue **102** of the mandible as well as the copings **110**.

[0083] When the tray **120** and impression material **122** are removed, the copings are removed with them, embedded in the now-cured impression material **122**. The process of removal disconnects the copings **110** from the anchors **104**, permitting the copings to be removed while still embedded in the impression material **122**. If the copings include a threaded portion that holds them to the anchors, this threaded portion is unthreaded from the anchors. If the copings are fastened to the anchors with a snap fastening portion, the snap fastening portions are unsnapped from each other. The now-cured impression material **122** that couples the copings **110** to each other preserves the relative positions and orientations of the mating surfaces of all the copings **110** and hence relative positions and orientations of the mating surfaces **108** of all the anchors **104** with respect to each other. This relationship is preserved in the relative positions and orientations of the surfaces of copings **110** that were connected to the mating surfaces **108** of anchors **104**. The impression material **122** in which copings **110** are embedded also preserves the surface contours of the mucosal tissue and the remaining teeth (if any) in the mandible and their relative positions with respect to the mating surfaces of copings **110** and anchors **104**. The surface of the impression material **122**, once removed from the patient's mouth, is a negative replica of the soft tissue and teeth. The surfaces of copings **110**, now separated from anchors **104** and exposed on the inside surface of the impression material **122**, are a negative replica of surfaces **108** of anchors **104** to which they were coupled. The now-cured impression material **122** is therefore a negative replica of all the free surfaces, including teeth, mucosal tissue, and the surfaces of the copings embedded in the impression material are a negative replica of the mating surfaces **108** of anchors **104**. The cured impression material with embedded copings is commonly called an "impression" and identified in the **FIGURES** herein as item **123**.

[0084] **FIGURE 6** shows the impression **123** inverted and removed from the patient's mouth. In this embodiment, there are six copings **110** embedded in the impression **123**. The bulk of the copings **110** are embedded in the impression **123**. Only the very ends of the copings **110** extends upward and out of the impression **123** (in this inverted orientation).

[0085] In **FIGURE 6** the dentist has begun the next step of the process, that of attaching analogs **124** to the exposed surfaces of all of the copings **110**. Analogs **124** are structures that replicate the anchors **104**. As in the case of the copings themselves, each analog **124** preferably comprises a generally cylindrical body with a longitudinal axis **127** that is coaxial with the longitudinal axis **111** when attached to coping **110**.

[0086] The end surfaces of analogs **124** are configured to abut and mate with the free surfaces of the copings **110** that were previously coupled to anchors **104**. The surfaces of analogs **124** replicate the position and orientation of mating surfaces **108** of anchors **104**. In effect, the spacing and orientation of anchors **104** was transferred to the copings **110**, and transferred back again to analogs **124**, which have the same spacing and orientation as the anchors **104**. Thus, each analog **124** is coaxial with and is disposed in the same position as anchor **104**.

[0087] In the next step of the process, illustrated in **FIGURE 7**, the dentist pours a mixed dental stone material **126** into the cavity in impression **123** that was formed by the patient's mandible, submerging all of the analogs **124**. Stone material **126** covers the exposed portion of the analogs **124** as well as the surfaces of impression **123** formed by the patient's mucosal tissues and teeth. Once filled into impression **123**, the stone material **126** is then permitted to harden to a rock-like consistency, creating a structure that is called a "stone cast" **125**.

[0088] **FIGURE 8** represents the next step of the process which the dentist performs once the stone material **126** has hardened. The dentist removes impression **123** from the stone cast **125**, leaving the stone cast **125** with the analogs embedded therein. The stone cast **125** positively replicates the position and orientation of mating surfaces **108** of anchors **104**, which are represented in the stone cast **125** by the mating surfaces **128** of the analogs **124** that were fixed to the free ends of copings **110** (**FIGURE 6**). The portions of the stone cast **125** surrounding analogs **124** positively replicates the surface of the mucosal tissues of the mouth, which were transferred from the mucosal tissues of the mouth to the impression as a negative replica and then back to the stone cast as a positive replica of those tissues. The stone cast **125** also replicates the surface of the patient's existing teeth (not shown). When the patient has existing teeth, the position and orientation of the surfaces of the teeth are transferred first to the impression as a negative replica and then to the stone cast as a positive replica. In the present embodiment, the mandible **100** is edentulous and therefore there are no existing teeth.

[0089] As will be explained later, teeth that are replicated in impression **123** and stone cast **125** provide a precise reference to indicate the location of the jawbone. The soft tissues that are replicated in the impression **123** and stone cast **125** can change their position due to swelling, edema, injury, irritation, or damage to the mouth. Teeth, since they are much harder and are embedded in the jawbone, provide a more stable reference, over time, of the position of the jawbone and thus indirectly, of the position and orientation of anchors **104**.

[0090] The impression molding and stone casting processes described above provide accurate replicas of the position and orientation of the mating surfaces **108** of anchors **104**, the mucosal tissues, and the teeth.

[0091] In the preferred embodiment, the mating surfaces **108** of anchors **104** are exactly duplicated by the mating surfaces **128** of the analogs **124**: they are in exactly the same position and at exactly the same orientation. In an alternative embodiment, the mating surfaces **128** on the analogs may be offset slightly or configured slightly differently than the mating surfaces **108** of anchors **104**. In some cases, manufacturers choose to make analogs or other connecting components that have mating surfaces slightly different from the mating surfaces **108** of the anchors **104** for example to permit the copings **110** to be more easily attached to anchors **104** or to permit analogs **124** to be more easily attached to copings **110**. Any slight difference in position such as this is intentional, however, and is eliminated later in the process when the denture is created so that the mating surfaces of the denture are precisely oriented to mate properly with surfaces **108** of anchors **104** in the patient's mouth.

[0092] Further, the anchors **104** in the patient's mouth may not be connected directly to the dental framework. Abutments may be mounted on the anchors **104** (i.e. the anchors have surmounted abutments). The dental framework may be mounted to these abutments, and thus indirectly mounted to anchors **104**. When the dental framework being designed is intended to be mounted on abutments mounted on anchors **104**, the analogs **124** may be provided with surmounted abutments, i.e. the analogs may include the abutment design incorporated into it, to replicate the mating structure of the abutment to the framework.

[0093] While the mating surfaces **128** of the analogs **124** and the mating surfaces **108** of anchors **104** may be slightly differently configured, the longitudinal axes of each of the anchors **104** and the analogs **124** are preferably identically oriented and spaced apart, each pair of corresponding analog and anchor sharing a common longitudinal axis (i.e. they are coaxial). Considered differently, if the surface of the stone cast representing the soft tissues and teeth of the patient's mouth could be superimposed on top of the patient's mucosal tissues **108** that formed the stone cast **125**, all the longitudinal axes defined by the analogs would be superimposed on (i.e. simultaneously coaxial with) all the corresponding axes defined by the anchors. The longitudinal axes **127** of the analogs **124** and the surfaces of the stone cast **125** defined by the mucosal tissues **108** the patient are positive replicas of the longitudinal axes **111** of anchors **104** and the surfaces of mucosal tissues **108**.

[0094] The replica of any teeth formed in the surface of the stone cast are formed with respect to one another and with respect to the analogs such that they duplicate the position of any existing real teeth in the patient's mouth with respect to one another and with respect to mating surfaces **108** and longitudinal axes of the anchors **104** in the patient's mandible. The replica of the mucosal tissues formed in the surface of the stone cast are in generally the same position on the stone cast as they are in the patient's mouth including the replication in the stone cast **125** of the junction between the mucosal tissue and any existing teeth and anchors **104**, as well as a replication in the stone cast of all the mucosal tissue that will be covered by the denture.

[0095] Once the dentist has created the stone cast **125**, which is a positive replica of the patient's jaw, including replication of existing teeth, mucosal tissue, and anchors, the dentist then proceeds to the next step in the process: designing and creating the denture that will be fitted to the patient's mouth (in this case, the patient's jaw).

[0096] The dentist manually creates a diagnostic wax-up **130** of the desired denture teeth position and occlusal orientation, using flexible molding materials such as wax, acrylic, and other polymers.

[0097] The diagnostic wax-up **130** is created to verify the proper location of the denture mucosal tissue and denture teeth with respect to the patient's actual mouth to ensure proper tooth orientation, and to ensure that the location and placement of the denture within the patient's mouth restores form, fit and function. In short, the diagnostic wax-up **130** is a model of and looks like the denture that is ultimately produced, but is made of softer materials to permit it to be adjusted and adapted until the patient and dentist are pleased with its form, fit and function.

[0098] The dentist creates the wax-up **130** on the stone cast, building it up on the patient's replica mucosal tissue. When the dentist is finished making the wax-up **130**, he removes the wax-up **130** from the stone cast **125**, and places it into the patient's mouth so the patient can see, firsthand, what the denture will look like when it is finished. If the wax-up **130** fits, the patient can bite properly, and the patient is pleased with the appearance of the wax-up **130**, the dentist then proceeds to manufacture the denture.

[0099] **Figures 9-10** illustrate the process of creating a wax-up, showing the stone cast **125** as it would appear with a wax-up **130** modeled on its outer surface. In **FIGURE 9**, the stone cast **125** is shown covered with the wax-up **130** which comprises the denture teeth **132** embedded in wax **134** which the dentist has molded directly to the surface of the stone cast **125**. **FIGURE 10** is a cross-sectional view through the stone cast **125** plus wax-up **130** assembly shown in **FIGURE 9**. This cross-section is taken at section line 10-10 in **FIGURE 9**.

[00100] Once the dentist has created the wax-up **130** and has verified the fitting of the wax-up **130** in the patient's mouth, he then proceeds to the next step in the process, which is illustrated in **FIGURES 11-12**. In this step, he removes the wax-up **130** from the patient's mouth, and places it back on stone cast **125**. He then creates a negative replica **142** of the facial form of wax-up **130** called a "putty index" (or as it is alternatively and equivalently called: a “facial index”).

[00101] To create the putty index **142**, the dentist molds silicone putty **144** directly to the facial surface of wax-up **130** including the teeth **132** and the wax **134** that represents the artificial mucosal tissue portion of the denture. This silicone putty **144** extends beyond the edges of wax-up **130** to the adjacent surfaces of stone cast **125**.

[00102] **FIGURE 11** shows the silicon putty, already solidified, surrounding the wax-up **130** on stone cast **125**. **FIGURE 12** is a cross-section through the stone cast/wax-up/silicon putty of **FIGURE 11**, taken at section line 12-12 in **FIGURE 11**. Referring now to **FIGURE 12**, we can see that silicon putty **144** has been manually molded on to the surface of the stone cast **125** adjacent to wax-up **130**, at junction **145**, for example.

[00103] In the next step, the dentist removes the now-solidified silicon putty **144** (i.e. putty index **142**) from the stone cast **125** and wax-up **130**, removes the wax-up **130** from the stone cast **125** and replaces the putty index **142** on the stone cast **125** in its original position, as shown in **FIGURE 12B**.

[00104] This removal creates an outline form **147** formed on the inner surface of the putty index **142** that is the exact size and shape of the facial aspect of the wax-up **130**. Outline form **147** is a negative replica of the teeth **132** of wax-up **130**, the mucosal tissue formed in wax **134** that surrounds and supports the teeth **132**.

[00105] When forming the putty index **142**, the dentist extends the silicone putty **144** beyond the edge of the wax-up at junction **145** and abuts the stone cast **125** to form a direct junction between the putty index **142** and the stone cast **125**. This abutting relationship molds the two surfaces together and permits the dentist to orient the putty index **142** in its as-formed position with respect to stone cast **125**. The dentist does this by aligning surfaces **146** of the putty index **142** that were molded in abutment to surfaces **148** of the stone cast **125**. Surface **148** is a negative replica of surface **146**.

[00106] As in the case of many irregular surfaces, such as the mating broken edges of two pieces of pottery, a surface portion of stone cast **125** mates with the surface on putty index **142** on which it was formed to define a very precise assembled orientation that is easy to recreate once wax-up **130** is removed.

[00107] With the putty index **142** created, the dentist can proceed to the next step in the process, illustrated in **FIGURES 13A**, **13B**, in which the dentist molds a wax-up framework **150**. Wax-up framework **150** is later duplicated in metal and embedded in the plastic body of the denture to support the denture on anchors **104** in the patient's mouth.

[00108] With the putty index **142** removed, the dentist fixes precision copings or fittings **152** that are typically provided by the manufacturer of analogs **124** and are configured to mate with the analogs. These are shown in the **FIGURES** as items **152A-152F** and are attached to the mating surfaces **128** of analogs **124** extending from stone cast **125** (**FIGURE 13A**). The analogs **124** embedded in stone cast **125**

orient fittings **152** precisely with respect to one another to replicate the position and orientation of anchors **104**. In short, the stone cast holds fittings **152** in the same position with respect to each other in which they would be held by anchors **104** if they were inserted into the patient's mouth instead of being fastened to the analogs **124**.

[00109] Referring now to **FIGURE 13B**, once the dentist has attached fittings **152** to analogs **124**, he then proceeds to create a bridging structure **154** of the framework **150**. Bridging structure **154** is typically formed from a moldable wax/acrylic material. The dentist manipulates this material and extends it as a narrow band adjacent to the surface of stone cast **125** until each of the fittings **152** are coupled together with bridging structure **154** (**FIGURE 13B**) to form a single structure.

[00110] The dentist must verify the wax-up framework **150** before he can cast it in metal, however. In order to verify the wax-up framework **150**, the dentist must fit the putty index **142** (whose outline form **147** negatively replicates the position and orientation of the facial surface of diagnostic wax-up **130** and thus the facial surface of the denture) to ensure that wax-up framework **150** is enclosed within the putty index where desired, and therefore will be embedded within the denture material when the denture is finally created. Portions of the wax-up framework **150** may be deliberately designed to extend outside of the denture and reach remote anchors **104** to provide additional stability. Typically, however, the framework is completely embedded within the denture material that replicates the mucosal tissue. By testing the shape of the framework (typically by repeatedly placing and removing the putty index from the stone cast **125** in front of the wax-up framework **150**) as the dentist builds the framework, the dentist can build and adjust the bridging structure **154** of the framework until it is disposed well back from the outline form **147** of the putty index in a position where it will provide the most support for the denture teeth and the denture gum material that supports the denture teeth.

[00111] **FIGURE 13B** illustrates stone cast **125** with wax-up framework **150** including bridging structure **154** extending across the surface of the stone cast **125** and coupling together all of the fittings **152** coupled to the mating surfaces **128** of analogs **124** that extend outward from the stone cast **125**. In the next step, the dentist detaches the wax-up framework **150** from stone cast **125**.

[00112] **FIGURE 13C** illustrates wax-up framework **150** as it would appear detached from stone cast **125** and inverted, exposing surfaces of fittings **152** that mate with analogs **124**. Fittings **152** include two fittings **152A**, **152B** that have cylindrical or frusto-conical recesses **159** with apertures **158** extending completely through fittings **152** and wax-up framework **150**. Apertures **158** are configured to receive screws that are attached to anchors **104** in the patient's jaw. The other four fittings **152C**, **152D**, **152E**, **152F** do not have apertures **158** but do have cylindrical or frusto-conical recesses **159** common to all the fittings **152**. They are configured to be supported on mating cylindrical or frusto-conical posts (not shown) that will be an integral part of anchors **104** or that will be attached to the anchors **104**. In the illustrated embodiment the two rear fittings **152A**, **152B** are configured to be fixed to anchors with screws passing though apertures **158**. In an alternative embodiment, any of the other fittings **152** (or none, or all) may be provided with apertures or other means for attaching the fittings **152** to anchors **104**.

[00113] It should be remembered that wax-up framework **150**, fittings **152** and bridging structure **154** are never intended to be mounted to anchors **104** in the patient's mouth. Instead, a duplicate is made of wax-up framework **150** out of much stronger materials that is inserted in the patient's mouth. It is the duplicates of fittings **152** in the final framework that actually mount to anchors **104**.

[00114] For that reason, in order for the duplicates of fittings **152** formed in the final framework to mount properly to anchors **104** in the patient's mouth, fittings **152** themselves must be configured to mount to anchors **104**. If they are not configured to mount to anchors **104**, then their duplicates in the final framework will not mount to anchors **104**.

[00115] To configure the fittings **152** for mounting to the patient's jaw, each of fittings **152** illustrated in the **FIGURES** has at least one surface portion configured to mate with anchors **104**. Thus, the final framework can be fixed to analogs **124**. Since analogs **124** are mounted to and axially oriented to copings **110** (**FIGURE 13A**), and since copings **110** were initially fixed to and coaxial with anchors **104**, fittings **152** are configured to be fixed to and coaxial with anchors **104**

[00116] Each mating surface on fittings **152** is symmetric about a longitudinal axis that extends through that fitting and are coaxial with the analogs **124** on which they are mounted. In this case, the surfaces are those interior to frusto-conical recesses **159**. This should not suggest that the mating surfaces must have any particular shape or orientation. Generally speaking, the mating surfaces may be concave or convex, they may be conical, cylindrical, circular, or parabolic. Regardless of their shape, each fitting **152** has at least one mating surface that preferably defines a longitudinal axis, and more preferably each of the mating surfaces is a surface that is symmetric about that longitudinal axis. It is these surfaces when duplicated to create the metal framework that orient the metal framework with respect to anchors **104**. Hence the longitudinal axes defined by the mating surfaces of fittings **152** replicate the longitudinal axes of anchors **104**.

[00117] Once the dentist has created the wax-up framework **150**, he sends the wax-up framework **150** to a laboratory for further processing.

[00118] In the next step of the process, and referring to **FIGURE 14**, a technician inserts alignment posts **156** (shown in the **FIGURES** as items **156A**, **156B**, **156C**, **156D**, **156E**, **156F**) into fittings **152**. Alignment posts **156** engage the surfaces of fittings **152** that are configured to engage surfaces **108** of anchors **104**. Alternatively, they are inserted such that they abut other surfaces of fittings **152** that are not configured to engage anchors **104** but are in a known pre-determined position and orientation with respect to surfaces **108** of anchors **104**. Alignment posts **156** have a longitudinal axis that is preferably coaxial with fittings **152** when they are mounted to fittings **152**. Since they are coaxial with fittings **152**, they are also coaxial with anchors **104**. As described in the process above, anchors **104** transfer their position and orientation to copings **110**, which transfer their position and orientation to analogs **124**, which transfer their position and orientation to fittings **152**, which transfer their position and orientation to posts **156**. Thus posts **156** are coaxial with fittings **152**, analogs **124**, copings **110** and anchors **104**.

[00119] In the next step of the process, the surfaces of wax-up framework **150** and the alignment posts **156** are electronically scanned, preferably by a laser scanner or alternative devices such as an optical, light, touch probe, or CT scanner.

[00120] The scanner is configured to generate a plurality of three-dimensional position data or points that represent the three-dimensional coordinates of each scanned point on the surface of wax-up framework **150** and alignment posts **156**. The scanning process need not scan all points on the surface of wax-up framework **150**, nor does it need to determine each point on the surface with the same accuracy. The particular location of points on the surface of bridging structure **154** may not be as critical as points on the surfaces of the fittings **152**. Points on the surfaces of fittings **152** represent points on the surfaces of the metal framework made from the wax-up framework **150**, including points that will mate with mating surfaces **108** of anchors **104**. The relative position of the mating surfaces of fittings **152** ultimately determine the quality of the denture fit and the loads placed on anchors **104**. In contrast to this, some error in determining the surface of bridging structure **154** can be tolerated more easily, since any errors in determining the surface of bridging structures **154** will be accommodated when the denture material is processed around the outside of the metal framework.

[00121] The alignment posts **156** are used to provide a more accurate determination of the position and orientation of the surfaces of fittings **152** that, when duplicated in metal will engage mating surfaces **108** of anchors **104**. The alignment posts provide several extension surfaces that have a predetermined orientation and location with respect to the mating surfaces of fittings **152** (and hence with respect to mating surfaces **108** of anchors **104**). The surface extensions provided on posts **156** preferably have a larger surface area than the mating surfaces of fittings **152** to which they are coupled. The surface extensions provided on posts **156** preferably have a well-defined geometry that, when scanned, provide scanner position data bearing a known spatial relationship to the mating surfaces on posts **156** that can be easily processed by a digital computer to generate a much more accurate estimation of the position of the mating surfaces of fittings **152** (and hence mating surfaces **108** of anchors **104** on which the denture will be mounted) than can be provided by directly scanning those surfaces of posts **156** directly with the scanner.

[00122] Each of anchors **104**, and its corresponding copings **110**, analogs **124**, and fittings **152** preferably share a common longitudinal axis about which their respective mating surfaces, whatever their shape, are revolved. To determine the orientation and position of the surfaces, and particularly to determine the orientation of the surfaces on fittings **152** that are configured to mate with mating surfaces **108** of anchors **104**, the scanner, or the computer processing the data provided by the scanner, determines (1) the orientation of that longitudinal axis in three dimensions, and the particular point along that longitudinal axis where the mating surfaces are located. The mating surfaces may have slightly different profiles, they may have slightly different surface contours, they may be disposed at different positions along the longitudinal axis. Nonetheless, they all bear a distinct, repeatable, and predetermined position and orientation with respect to each other.

[00123] In **FIGURE 15**, alignment post **156A** is preferably made of two separate structures (shown as post portions **1000**, **1002)** that are inserted into opposite sides of aperture **158**. Post portions **1000**, **1002** of alignment post **156A**, abut surfaces on opposite sides of wax-up framework **150**. In the preferred embodiment, post portion **1000** of alignment post **156A** extends into aperture **158** in fittings **152A**, and is threadedly engaged to post portion **1002** of alignment post **156A** extending into aperture **158** from the other side of the wax-up framework **150**. Pin portion **1000** has external threads that are coupled to and engage mating internal threads of pin portion **1002**.

[00124] Fitting **152A (FIGURE 15)**, has several surfaces that engage alignment post **156A**. These include frusto-conical sections **160**, **162**, **164** as well as cylindrical sections **166**, **168**. Frusto-conical sections **160**, **162** engage matching frusto-conical portions **161**, **163** of the shank of post portion **1002**. Frusto-conical section **164** engages a matching frusto-conical section **165** of the shank of post portion **1000**. Tightening post portions **1000**, **1002** by threading one into the other through aperture **158** causes the compressive forces exerted on the frusto-conical and cylindrical sections **160**, **162**, **164**, **166 and 168** to align the longitudinal axes of post portions **1000**, **1002** coaxial with each other and coaxial with the longitudinal axis of fitting **152A** to which they are attached.

[00125] When tightened, the relative position of alignment post **156A** indicates the location in three dimensions of the mating surfaces of fitting **152A** and the angular alignment of those mating surfaces in three dimensions. They indicate the position and longitudinal axis of fittings **152A**. Post **156A** self-aligns with respect to fitting **152A** in a predetermined relative orientation when post **156A** is tightened on fitting **152A**.

[00126] For convenience and economy of illustration, only fitting **152A** and alignment post **156A** are illustrated herein. Since fittings **152A** and **152B** are identical to each other, and since alignment posts **156A** and **156B** are identical to each other, the description above of fitting **152A** and its alignment post **156A** applies equally to fitting **152B** and its alignment post **156B**.

[00127] There are four other fittings **152** comprising wax-up framework **150**. They are identified as fittings **152C**, **152D**, **152E**, and **152F**. These fittings are identical as are their corresponding alignment posts **156C**, **156D**, **156E**, and **156F**.

[00128] For convenience and economy of illustration, only fitting **152C** is shown in axial cross section in **FIGURE 16**, coupled to its associated alignment post **156C**.

It should be understood that the other fittings and their corresponding alignment posts are identically configured and arranged and that the description below of fitting **152C** and alignment post **156C** applies equally to fittings **152D**, **152E**, **152F** and alignment posts **156D**, **156E**, **156F**.

[00129] Fitting **152C** differs from fitting **152A** in that it has no aperture **158** extending through the fitting. Instead, fitting **152C** is generally cylindrical having a cylindrical or frusto-conical recess **159** with a generally flat bottom.

[00130] Recess **159** has two frusto-conical surface portions **172**, **174** that engage mating frusto-conical surface portions **173**, **175**, respectively, on alignment post **156C**. Surface portions **172**, **174** are the surfaces that, when duplicated in the metal framework, mate with mating surfaces **108** of anchors **104** (or an intermediary component attached to anchor **104**). These mating pairs of frusto-conical surface portions on the alignment post and on the fitting orient the alignment post with respect to the fitting such that the longitudinal axis of the fitting and the alignment post are the same. The position and orientation of alignment post **156C** therefore indicates the position and longitudinal axis of fitting **152C**. Since post **156C** is fixed directly to fitting **152C**, it represents the position and orientation of fitting **152C**, and not the position and orientation of the bridging structure **154** that is fixed to and surrounds fitting **152C**. Alignment post **156C** is held in place in fitting **152C** by frictional or snap engagement of an inwardly facing and flexible lip **170** that captures a flange extending outward from the periphery of alignment post **156C**. This mechanical inter-engagement prevents post **156C** from being withdrawn from fitting **152C** without significant mechanical force being applied, however this mechanical engagement could be replaced by a screw retainment mechanism. It also holds post **156C** in its proper and predefined (preferably coaxial) orientation with respect to fitting **152C**. Post **156C** is configured to self-aligns with fitting **152C** in a predetermined relative orientation when it is attached. Fitting **152C** is configured to hold post **156C** in a specific alignment with respect to the fitting when assembled.

[00131] **FIGURE 17** illustrates alignment post **156A** in greater detail as it is aligned when tightened with fitting **152A** (shown in phantom lines). As shown in **FIGURE 17**, both of post portions **1000**, **1002** of alignment post **156A** are threaded together in a coaxial relationship as are when engaged and aligned to fitting **152A**. Each of post portions **1000**, **1002** is in the form of an elongated body having a predefined surface geometry (here shown as spherical outer surface portions **176**) at one end of the post portion **1000**, **1002** and the frusto-conical surfaces **161**, **163**, **165** disposed at the other end.

[00132] The spherical outer surface portions **176** on each of the alignment post portions **1000**, **1002** of alignment post **156A (FIGURE 17)** are configured to have centers disposed on the longitudinal axes of each of the alignment post portions **1000**, **1002** and are also concentric with the longitudinal axis of fitting **152A**. The threads on alignment post portions **1000**, **1002** are concentric as well. Furthermore, the cylindrical and frusto-conical surfaces on each alignment post portion are symmetric surfaces of revolution about the common longitudinal axis. Alternatively, other alignment posts with concentric geometrical shapes or even known irregular shapes can be used to identify the position and orientation of the fittings **152A**.

[00133] As a result of this arrangement, when alignment post portions **1000**, **1002** are threadedly attached to each other through aperture **158** in fitting **152A**, the center points of each of the spherical outer surface portions **176** are disposed on the longitudinal axis of fitting **152A** in which they are mounted. Furthermore, portions **176** are located at a predetermined distance apart from each other, and at a predetermined distance from the mating surfaces of the fitting **152A**.

[00134] **FIGURE 18** illustrates alignment post **156C**. This alignment post includes two spherical surface portions **178**, **180**. Spherical portion **178** is disposed at one end of the elongate alignment post **156C**, and the two frusto-conical portions **173**, **175** are disposed at the other end. Second spherical portion **180** is spaced apart from spherical portion **178**, disposed partway between the two ends of post **156C**. Both spherical surface portions **178**, **180** have centers that are disposed on the longitudinal axis of post **156C**. Frusto-conical surfaces **173**, **175** are both symmetric surfaces of revolution about the longitudinal axis of post **156C**. Alternatively, other alignment posts with concentric geometrical shapes or even known irregular shapes can be used to identify the position and orientation of the fittings **152C**.

[00135] Referring now to **FIGURE 19**, a scanner **182** including a scanning unit **184** having a chassis **185** and a laser probe **187**, a digital microprocessor-based computer **186**, a display screen **188**, a keyboard **190**, and a digitizer **192** are illustrated, together with wax-up framework/alignment post assembly **196** (see also **FIGURE 14**) which is coupled to and supported on scanning unit **184** by a jig **194** mounted on chassis **185**. Preferably a NEXTEC WizProbe.

[00136] Computer **186** is configured to control the scanning process and to interact with each of the other components, including the scanning unit, display screen, keyboard, and digitizer. Computer **186** includes a program that is configured to scan the surface of the framework/alignment post assembly **196** (comprising wax-up framework **150** and alignment posts **156**) and to store coordinates of each point it scans on the surface of assembly **196** in its internal memory. The coordinates stored for each point are three-dimensional coordinates, sufficient to represent the position of each point in three dimensions. These positions may be absolute, or they may be relative with respect to a known position.

[00137] Scanning unit **184** is configured to scan assembly **196** under the control of computer **186** to which it is coupled. Scanning unit **184** preferably includes programmable mechanical positioning stages configured to change the relative position of the laser probe **187** with respect to the assembly **196** thus permitting scanner **182** to gather position data from the surface of assembly **196** from all sides. In addition, jig **194** may include mechanical positioning stages from which it can change the relative position of assembly **196** in relation to the laser probe **187**.

[00138] The operator interacts with scanner **182** using display screen **188**, keyboard **190**, and digitizer **192** which are coupled to computer **186**. Using keyboard **190** and digitizer **192** (preferably a mouse or digitizer pad), the operator enters commands that direct scanner **182** to perform the operations described herein. Display screen **188** is coupled to computer **186** to permit the operator to view the collected scanned surface point coordinates (point clouds) in three dimensions, to select various points of the point clouds for mathematical manipulation, to remove particular points from the point cloud, and to instruct the scanner **182** how to scan assembly **196**.

[00139] The process of manufacturing a dental framework from the wax-up framework **150**, is shown in **FIGURE 20**. The first steps of this process, described below, are the steps performed by the scanner **182** under the control of the scanner operator and computer **186**. The computer instructions that configure the computer to perform these steps are stored in a digital memory of the computer **186**.

[00140] In general, and as described below in greater detail, the process includes scanning the surface of the assembly **196** to determine the general overall shape of the wax-up framework **150**. This shape, represented as a point cloud dataset, is a surface model of the wax-up framework in a preliminary form. This

surface model is then further modified and refined by removing the points in the point cloud dataset representing the alignment pins and adding surface structures (typically in parameterized form and not as individual points) representing the surface of fittings **152** that will attach to anchors **104**. This complete surface model is then used in subsequent manufacturing processes such as computer numeric controlled multi-axis machining, to create the framework for the denture.

[00141] In the first step of the framework manufacturing process, step **200**, the computer **186** signals scanning unit **184** to scan the surface of assembly **196**. Scanning unit **184** responsively scans the surface and transmits the coordinates of each point on the surface of the assembly **196** to computer **186**. As necessary, computer **186** directs the scanning unit to reposition laser probe **187** with respect to assembly **196** in order to scan substantially the entire surface of assembly **196**.

[00142] In the next step in the process, step **202,** computer **186** derives the location of fitting surfaces from the predetermined geometry of the fittings **152** and the alignment posts **156** In the preferred embodiment, in order to determine the position of the mating surfaces of fittings **152** (and hence their position with respect to anchors **104** to which the final framework will be coupled), computer **186** is configured to use the geometry of the alignment posts **156** and the fittings **152** together with the coordinates of the point scanned on the surface of the alignment posts **156** to determine the precise location of the fitting **152** surfaces with greater accuracy than computer **186** could do if it scanned the fitting surfaces **152** surfaces directly.

[00143] Computer **186** is programmed to derive the center of each of the spherical surface portions **176, 178, 180** on each of the alignment posts from the coordinates of each point on spherical surface portions **176, 178, 180** that it previously stored. Each of the datum points in the point cloud dataset that were scanned from the surface of the alignment posts (including spherical surface portions **176, 178, 180**) have an associated position error. Due to this error, directly scanning the cylindrical and frusto-conical surfaces of fittings **152** may not be sufficiently accurate to determine the orientation and position of the mating surfaces of the fittings **152** to which anchors **104** are coupled (in the metal duplicate of wax-up framework **150**). To reduce this error, alignment posts **156** are provided with the spherical surface portions **176, 178, 180** which have larger surface areas than the mating surfaces of fittings **152** to which they are coupled. These spherical surface portions **176, 178,180** have known predetermined geometrical shapes and orientations with respect to the fittings **152.** These shapes and orientations are programmed into computer **186**, which employs algorithms incorporating this predetermined geometry to derive a more accurate position and orientation for the mating surfaces of fittings **152**.

[00144] In particular, computer **186** is programmed with the diameter (or radius) of each of the spherical surfaces **176, 178, 180** as well as the distances between the centers of the spherical surfaces **176, 178, 180** and the fittings **152**, as well as the particular shape and orientation of the frusto-conical and cylindrical surfaces of the fittings **152** themselves. Computer **186** is configured to fit the set of data points for each spherical surface **176**, **178**, **180** of alignment posts **156** to an ideal sphere having the same diameter (or radius). It is therefore configured with the geometric parameters (in this case the diameter) of geometric surfaces (spherical surface portions **176, 178, 180**) on alignment posts **156** and applies these parameters to points gathered from a scan of the geometric surfaces to derive other geometric parameters (in this case the center of spherical surface portions **176, 178, 180**). In the preferred embodiment, the technician uses the digitizer to select data points by selecting regions on the screen that show portions of the point cloud dataset having the predetermined geometry. Once selected, the technician signals the computer to calculate the parameters of a predetermined geometry that best fits the selected data points of the point cloud dataset. The computer **186**, in turn sequentially fits a surface of the predetermined geometry to the selected data points until it determines the parameter of a geometry having a best fit to the data points. In the preferred example, the computer **186** fits the data points to a sequence of spheres having different diameters and center locations until it finds a diameter and center point of a sphere that fits the data points best. The computer **186** then saves the center point of this sphere for later use in determining the location of the surfaces of the fittings in the manner described below.

[00145] In a preferred embodiment, computer **186** is configured to find the center of the spherical surface portions by using an algorithm incorporating error minimizing mathematical methods. In the example given here, computer **186** is configured to calculate the root mean square (RMS) error of all the data points scanned from the spherical surface portions **176, 178, 180** (and selected by the technician) with respect to the closest data points on the surface of the ideal sphere and vary the diameter and center of the ideal sphere to minimize this error until computer **186** determines a center having the smallest RMS error. The results of this calculation are coordinates for the center of the sphere that is closest to the centers of the spherical surface portion.

[00146] Computer **186** is configured to repeat this process of fitting data points of a spherical surface portion to an ideal sphere having the same diameter for data points scanned from each spherical surface portion. In this manner, computer **186** derives the coordinates of the centers of each of the spherical surface portion **176**, **178**, **180** for all of the alignment posts **156**.

[00147] In its digital memory, computer **186** stores the geometry of each of the alignment posts **156** and the position and orientation of alignment posts **156** with respect to fittings **152** when they are coupled together. In particular, computer **186** stores the distance between the spherical surface portions **176, 178, 180** of the alignment posts **156** and the distances between these centers and the mating surfaces of fittings **152**. Once computer **186** calculates the centers of spherical surface portions **176,178,180** using the method above, and since spherical surface portions **176, 178, 180** are aligned on the longitudinal axis of the alignment posts **156**, computer **186** can easily calculate the location and orientation of fittings **152** linearly interpolating between the previously calculated centers of spherical surface portions **176, 178, 180**. By combining this geometric distance information with the previously determined centers of each of the spherical surface portions, computer **186** can determine the precise location and angular orientation of fittings **152**, particularly, the cylindrical and frusto-conical surfaces on the fitting **152** to which the posts **156** having those centers are fixed. It is these surfaces on fittings **152** (in the metal duplicate of wax/acrylic framework **150**) to which mating surfaces **108** of anchors **104** are mounted.

[00148] In this manner, even though the mating surfaces of fittings **152** are hidden by the alignment posts **156** during scanning, computer **186** is able to determine their precise location and orientation using stored data indicating parameters of the predetermined geometric shapes (diameter/radius of the spherical surface portions **176**, **178**, **180**, distance from the centers to the fittings **152**, and shape of the mounting surfaces on the fittings, etc.) comprising alignment posts **156** and their predetermined relationship to fittings **152** when properly attached to the fittings. In this manner, a scanner can determine with much greater accuracy the shape, position, and orientation of surfaces that it could not determine directly by scanning those surfaces.

[00149] One reason this method is an improvement is due to the difference in surface area between the mating surfaces on fittings **152** as compared to the spherical surface portions **176, 178, 180** of alignment pins **156**. The mating surfaces **160, 162, 164** on fittings **152** are relatively small and difficult to scan.

[00150] While it is possible to scan the mating surfaces of fittings **152** (e.g. the surfaces to which anchors **104** will be fixed), nonetheless due to their small size any position measurements taken using current technology would not give the accuracy of position and orientation required to insure a precise fit between the denture and the anchors. The supplemental or extension surfaces on the alignment posts **156** (e.g. spherical surface portions **176, 178, 180**) are much larger and thus can be scanned to generate many more data points (i.e. data scanned on the spherical surface portions **176, 178,180**) that, combined with knowledge of supplemental surfaces geometry, provides more data points and permits a more accurate determination of the location of fittings **152** thereby effectively increasing the accuracy of the derived datum point, in particular the radius (or diameter) and the center point of the spherical surface portion.

[00151] At this step in the process, computer **186** has determined the longitudinal axes of each of the alignment pins **156** and hence the longitudinal axes of each of fittings **152**. Computer **186** has also determined the location along each of the longitudinal axes where the fitting **152** associated with the axis is located. This calculated axial orientation and position information comprise a vector that defines the location and angular orientation of the mating surfaces of each fitting **152**.

[00152] In the next step of the process, step **204 (FIGURE 20)**, computer **186** is configured to remove the alignment posts **156** from the set of surface data points of the assembly **196** -- i.e. the point cloud dataset created from the coordinate data scanned from the surface of assembly **196** by scanner **182**. The reduced dataset produced by the operation is shown schematically in **FIGURE 21.**

[00153] In **FIGURE 21** the point cloud dataset **205** (i.e. the preliminary surface model of the wax-up framework **150**) is shown with alignment posts **156** removed and replaced symbolically with vectors **198** and circle center points **199**. The eight vectors **198** represent the longitudinal axes of alignment pins **156** and fittings **152**. The circle centers **199** represent the centers of the spherical surface portions

176,178,180 of alignment pins **156** derived as described above. The data points scanned from the surface of the alignment pins **156** are not shown in **FIGURE 21**, but have been removed by computer **186**.

[00154] In the next step of the process, step **206**, computer **186** further modifies the surface model **205** of the framework by combining the remaining portion of the point cloud dataset (i.e. with the alignment pins removed) with a surface model of flat surfaces or pads **207** defining an exposed surface of each fitting **152**. These parameterized flat surfaces or pads are stored in a digital electronic memory of the computer **186**. This process is preferably done by Boolean union.

[00155] These flat surfaces or pads represent the surface of the fittings that face the patient's mucosal tissue. Computer **186** previously determined the orientation and location of each of the fittings **152** (and thus pads **207**) based upon the computer's calculation of the center points of the spherical surface portions of posts **156**. Computer **186** also stores a parametric representation of the shape, location and orientation of the surfaces of each fitting **152**. In the preferred embodiment, computer **186** stores numerical models of fittings that the user selects and inserts into the surface model of wax-up framework **150**. **FIGURE 22** shows the surface model **205** of **FIGURE 21** after computer **186** has modified it with the addition of pads **207**.

[00156] In the next step in the process, step **208 (FIGURE 20)**, computer **186** is configured to insert fitting surfaces --particularly the surfaces of the fittings that mate with mating surfaces **108** of anchors **104**. The computer **186** has determined the orientation and location of each fitting **152** (step **202**) to determine the location of the fitting. Digital parameterized fittings **152'** are digital models of the mating surfaces of actual fittings **152** that are configured to engage anchors **104** or surmounted abutments. These digital parameterized fittings are stored in a digital electronic memory of the computer **186**. In the preferred embodiment, the computer **186** performs a Boolean subtraction thereby combining the appropriate selected digital parameterized fittings **152'** with the surface model **205** to insert the mating surfaces of the fitting into the surface model. In the illustrated embodiment this removes portions of the surface model **205** underneath the surface of pads **207** to the appropriate depth, leaving the sunken mounting surfaces surrounded by a surrounding portion of pads **207**. The surface model **205** as it exists before the Boolean subtraction is shown in **FIGURE 22**. The surface model **205** after the

Boolean subtraction and insertion of the mounting surfaces of fittings **152'** is shown in **FIGURE 23**

[00157] In the next step of the process, step **210**, computer **186** calculates the tool paths for manufacturing the actual dental framework from the surface model **205**. There are a variety of processes by which the actual denture framework can be manufactured and hence a variety of tool paths that can be generated. For example, the calculated tool paths can describe the path of a single or multiaxis CNC cutting tool such as a multi-axis milling machine, the path of an EDM electrode, or the path of a material deposition device such as stereolithography, rapid prototyping, 3D printing, or laser sintering machines. Even further, the tool path may comprise several tool paths for different machines and processes that are performed in succession to manufacture the denture framework from surface model **205**. Even further, the tool path can define the path of a tool used to manufacture a mold in which the denture framework (or a precursor thereto) is cast.

[00158] In the final step in the process, step **212**, the tool path is used to manufacture the denture framework. Typically the tool path is loaded in digital form into a computer numeric controlled (CNC) machine that drives a tool such as a material removal tool to remove excess material or a material deposition tool to build up material. The framework may be machined in a single process or in a series of processes on several machines. In the preferred embodiment, the denture framework is preferably manufactured by a multiaxis computer numeric controlled (CNC) milling machine. In an alternative process, the bridging structures **154** of the framework **150** are manufactured from the surface model **205** using one process, such as a milling machine, and recessed portions, such as the mounting (mating) surfaces of the fittings **152**, are manufactured using another process, such as wire electrodischarge machining (EDM) or plunge EDM. In another alternative process, the milling machine, stereolithography, rapid prototyping, 3D printing, or laser sintering machines or EDM can be used to manufacture the mold in which the denture framework (or a precursor thereto) is cast .

[00159] The framework is preferably manufactured from titanium, zirconia, alumina, or other ceramic material having mechanical strength characteristics similar to titanium. If it is a ceramic material, the material can be machined in its fully sintered state or in a partially green or fully green state in which the ceramic material is only partially sintered, or has not been sintered at all. A ceramic (e.g. zirconia) may be cast in a mold that has been machined using the surface model and then sintered to form the final part. Alternatively, the ceramic may be cast in a mold that only approximates the shape of the final framework indicated by the surface model and then subsequently machined to the final dimensions using machining tools employing tool paths generated from the surface model.

[00160] Once the final framework has been made, it is returned to the dentist together with the stone cast **125** and the wax-up framework **150**. The dentist then verifies the accurate manufacture of the final framework and then follows his traditional procedures in manufacturing a denture from the final framework.

[00161] One of the reasons this process above is recommended is because of the unfamiliarity of dentists with the technology and the need to, at least initially, permit them to have the greatest degree of control in the denture manufacturing process. As they become more comfortable with the process, however, the dentist can dispense with additional dentist-performed steps, such as the creation of the stone cast, the putty index, and the wax-up framework can be dispensed with by scanning the dentist's handiwork earlier in the process. This is beneficial because it reduces the possibility of error and inaccuracies by eliminating several of the replication steps. In the process proposed above, the dentist would first make a negative replica of the mandible (or the maxilla) with an impression. The dentist would then use the impression to make a positive replica of the mandible (or the maxilla) with a stone cast. The dentist then uses the stone cast to define the mating surface locations of the framework, and then the wax-up framework itself is scanned. Each of these transfer steps generates a small amount of error, which can be eliminated once dentists are comfortable with the accuracy of the final framework that is manufactured using the scanning technology.

[00162] In a first alternative process for manufacturing the final framework, the dentist will manufacture the stone cast **125** as described above, but will not manufacture the framework, leaving the design and manufacture of the framework to the laboratory. This first alternative process is shown in **FIGURE 24**.

[00163] The first steps of this alternative process are performed exactly as they are in the process described above: the dentist places anchors in the patient's mouth, waits for them to heal, takes an impression of the patient's mouth, and makes a stone cast from that impression. Once the stone cast has been created, however, the dentist does not manufacture the wax-up framework. Instead, the dentist sends the stone cast directly to the laboratory and the laboratory scans the stone cast, then designs and manufactures the final framework from the stone cast. In the discussion of this process below, the stone cast is referred to as stone cast **125** since it is made in exactly the same manner as the stone cast **125** in the example above: it is configured to receive a framework having six fittings that include two fittings **152A, 152B** with through holes and four fittings **152C, 152D, 152E, 152F** without through holes.

[00164] This first alternative process is shown in **FIGURE 24**. In step **214** of the first alternative process, the dentist sends the stone cast **125** to the laboratory. The dentist may also send a diagnostic wax-up **130** or putty index **142** of the denture.

[00165] In step **216**, the laboratory inserts six alignment posts **156** into the analogs **124** embedded in the stone cast **125**. These alignment posts **156** are the same as the alignment posts shown in **FIGURES 14-18** with one difference: their mating surfaces are configured to engage the mating surfaces of analogs **124** and hold the alignment posts coaxial with the longitudinal axis of analogs **124**. They may have differently shaped flat, frusto-conical and cylindrical surfaces configured to engage with the mating surfaces of analogs **124** instead of the fittings **152**. As in the case of alignment posts **156** described above in the first process, the alignment posts **156** used in this first alternative process have two spherical surfaces comprising centers coaxial with coping **110**. Since they are mounted to analogs **124** on the stone cast, all six of the alignment posts **156** mounted on stone cast **125** are of the style identified above as **156C-F**, comprising a single post portion having two spherical surface portions. As in the first process described above, these fittings need not have a spherical surface portions, but may have any predetermined geometric shape. Further, and as described above, the alignment posts **156** can be dispensed with in this step of the first alternative process and the analog surfaces can be scanned directly by scanner **182** if scanner **182** is of sufficient accuracy that it can scan and determine the position and orientation of the mounting surfaces of analogs **124** without the need of attaching a supplemental surface to those mounting surfaces, such as the alignment posts **156**.

[00166] The shape and orientation of the mounting surfaces on the alignment posts **156** in this alternative process are not configured to engage mating surfaces on fittings **152** in the wax-up framework **150**, but are configured to engage with exposed mating surfaces on the analogs **124** in the stone cast **125**. As in the case of the alignment posts **156** attached to fittings **152**, the mating surfaces on the alignment posts and the mating surfaces on the analogs **124** interengage to cause the alignment posts **156** to be aligned coaxial with analogs **124**. The alignment posts **156** cover the free ends of the analogs **124**.

[00167] In step **218**, once the alignment posts **156** have been attached to the analogs **124**, the scanner **182** is configured to scan the alignment posts and the soft tissue replica of the patient's mouth formed in the surface of the stone cast **125**, and the alignment posts **156**. This scanning is done in the same manner as described above in conjunction with **FIGURE 20**. The surfaces of stone cast **125** that are scanned by scanner **182** include the surfaces of the stone cast that replicate the mucosal tissue in the patient's mouth. Scanner **182** stores in the memory of computer **186** a first point cloud dataset of the stone cast **125** with alignment posts **156** attached. In step **218**, scanner **182** also scans the surface of diagnostic wax-up **130** and the surface of stone cast **125** (preferably when they are assembled) and saves a second point cloud dataset collectively representing the scanned surface of the diagnostic wax-up **130** and stone cast **125**. Alternatively, the operator can scan the diagnostic wax-up **130** separately from the stone cast and later register the point cloud dataset of the stone cast **125** and the diagnostic wax-up **130**. As a further alternative, instead of scanning the diagnostic wax-up **130** scanner **182** can scan the putty index **142**.

[00168] When the diagnostic wax-up **130** is scanned, it can be scanned either in its proper position on the stone cast **125**, or it can be scanned separately.

[00169] If it is scanned on the stone cast **125**, the scan preferably includes data points taken from all the exposed external surfaces of the diagnostic wax-up **130** (i.e. the outwardly facing surfaces that model the gum and the teeth) as well as surfaces of the stone cast **125** adjacent to the diagnostic wax-up **130**. The surfaces of the stone cast **125** adjacent to the diagnostic wax-up that are scanned in the second point cloud dataset are also preferably scanned in the first point cloud dataset and thus there is some overlap in surface contours in both the first and the second point cloud datasets -- both datasets include data points scanned from the same surfaces of stone cast **125**. This permits later registration of the first and second point cloud datasets.

[00170] If the diagnostic wax-up **130** is scanned when it is separate from the stone cast **125**, it is preferably scanned so that the second point cloud dataset includes data points taken from all the exposed external surfaces of the diagnostic wax-up **130** (i.e. the outwardly facing surfaces that model the gum and the teeth) as well as surfaces of the diagnostic wax-up **130** that would abut stone cast **125** if the diagnostic wax-up **130** was mounted on the stone cast. Since the diagnostic wax-up **130** was formed by molding a plastic material to the surface of the stone cast **125**, the scanned surface contour of the diagnostic wax-up **130** that abut the stone cast are a mirror image of surface contours of the stone cast **125**.

[00171] In the preferred embodiment these abutting stone cast **125** surfaces were scanned previously and are a part of the first point cloud dataset. Thus, the first and second point cloud datasets include a subset of data points taken from mirror image surface contours -- surface contours common to both the first and second point cloud datasets -- common to the diagnostic wax-up **130** and to the stone cast **125**. This permits later registration of the first and second point cloud datasets.

[00172] In a further alternative, the putty index **142** may be scanned instead of the diagnostic wax-up **130**. When the putty index **142** is scanned, it can be scanned either in its proper position on the stone cast **125**, or it can be scanned separately.

[00173] If the putty index **142** is scanned while on the stone cast **125**, the scan preferably includes data points taken from all the exposed external surfaces of the putty index **142** (i.e. the inwardly facing surfaces of the putty index that were molded to the outwardly facing surfaces of the diagnostic wax-up **130** (i.e. the facial aspect, including the outwardly facing teeth **132** and gum **134** of the diagnostic wax-up **130**) as well as surfaces of the stone cast **125** adjacent to the putty index **142** when it is fitted on the stone cast **125**. The surfaces of the stone cast **125** adjacent to the putty index **142** that are scanned in the second point cloud dataset are also preferably scanned in the first point cloud dataset and thus there is some overlap in surface contours in both the first and the second point cloud datasets -- both datasets include data points scanned from the same surfaces of stone cast **125**. This permits later registration of the first and second point cloud datasets.

[00174] If the putty index **142** is scanned when it is separate from the stone cast **125**, it is preferably scanned so that the second point cloud dataset includes data points taken from all the exposed external surfaces of the diagnostic wax-up **130** (i.e. the outwardly facing surfaces that model the gum and the teeth) as well as surfaces of the putty index **142** that abut stone cast **125** when the putty index **142** is mounted on the stone cast. Since the putty index **142** was formed by molding a plastic material to the surface of the stone cast **125** and to the facial aspect of the diagnostic wax-up **130**, the scanned surface contour of the putty index **142** that abut the stone cast are a mirror image of surface contours of the stone cast **125**.

[00175] In the preferred embodiment, these abutting stone cast **125** surfaces were scanned previously and are a part of the first point cloud dataset. Thus, the first and second point cloud datasets include a subset of data points taken from mirror image surface contours -- surface contours common to both the first and second point cloud datasets -- common to the putty index **142** and to the stone cast **125**. This permits later registration of the first and second point cloud datasets.

[00176] In step **220**, computer **186** is configured to derive the location and orientation of the mating surfaces of the analogs from the predetermined geometry of the alignment posts **156**, in the same manner as it determined the location and orientation of the mating surfaces of the fittings in step **202** (**FIGURE 20**).

[00177] In step **222**, computer **186** is configured to remove the data points corresponding to the alignment posts from the first point cloud dataset in the same manner as it removed the alignment posts in step **204**.

[00178] In step **224**, computer **186** is configured to generate a first surface model of the stone cast **125** from the first point cloud dataset. This surface model includes the analogs as they would appear uncovered, with alignment posts **156** removed, and the surface of stone cast **125** that replicates the patient's mucosal tissue. The first surface model includes the mating surfaces of the analogs **110**, which represent the anchors **104** in the patient's mouth. Further in step **224**, computer **186** generates a second surface model of diagnostic wax-up **130** (or alternatively putty index **142**) from the second point cloud dataset.

[00179] The first surface model and the second surface model include surface contours that are common to both the first and second point cloud datasets: they include data points in each model that were scanned from a common surface, preferably a portion of stone cast **125** that was scanned into both the first and the second point cloud datasets, or they include data points of abutting surfaces in the first and second point cloud datasets.

[00180] In step **226**, computer **186** is configured to generate a surface model of a dental framework **228** (**FIGURES 25-27**) from the first surface model of the stone cast **125** that was generated in step **224**. Computer **186** is first configured to generate the fittings of the dental framework, in particular the surfaces of the fittings in the final framework that mate with mating surfaces **108** of anchors **104**. The computer **186** refers to an internal library of digital parameterized fittings **152"** which define in parametric form the location and orientation of the mounting surfaces of the actual fittings. The digital parameterized fittings **152"** are digital models of the surfaces of the actual fittings that are configured to engage anchors **104**. These digital parameterized fittings can be pre-designed, modified by the user, derived from existing alignment post CAD geometries, or free form designed. These digital parameterized fittings **152"** are stored in a digital electronic memory of the computer **186**.

[00181] Computer **186** electronically stored at least one and preferably a plurality of different digital parameterized fittings **152"** (shown in **FIGURES 25, 26, 27** as items **152"A, 152"B, 152"C, 152"D, 152"E, and 152"F**) in its internal library between which it can select. These digital parameterized fitting **152"** have surfaces that are configured to mate with the analog **124** surfaces in the first surface model of the stone cast **125** that were derived in step **220**.

[00182] In step **220**, above, computer **186** determined the location and orientation of the six analogs **124** in the stone cast **125** in the first point cloud dataset of the first alternative process. Computer **186** sequentially selects a digital parameterized fitting **152"** from its internal library for each of the analogs and aligns the mating surface (or surfaces) and axis of the selected digital parameterized fitting **152"** with the surface (or surfaces) and axis of one of the analogs whose location and orientation it determined in step **220**. Computer **186** repeats this process for each of the six analogs **124** whose location and orientation were determined in step **220**, until it has built up a surface model of dental framework **228** comprising the six digital parameterized fittings **152"** (shown in **FIGURES 25-27** as items **152"A, 152"B, 152"C, 152"D, 152"E and 152"F**).

[00183] As in the case of the digital parameterized fittings **152'** in **FIGURE 20**, these fittings are configured to engage mating surfaces **108** of anchors **104**. The digital parameterized fittings **152"** mathematically represent the structures that will be coupled to the anchors **104** in the final denture framework that is mounted in the patient's mouth.

[00184] Further in step **226**, the computer **186** is configured to generate a surface model of bridging structure **154’** (**FIGURES 25-27**) that will join the six digital parameterized fittings **152**”. This includes the computer **186** determining the cross-sectional shape, length and location of the bridging structures as described below. This surface model of this bridging structure **154’** extends between and joins the six digital parameterized fittings **152”** and thereby completes the surface model of the dental framework **228**. Bridging structure **154'** also comprises the portions **155** that extend away from the end digital parameterized fittings **152"A** and **152"B** and are supported only at one end. One form of the bridging structure is shown in FIGURES 25-27 as a simple elongated member having a predetermined cross section. Other forms that computer 186 is configured to calculate include

[00185] To generate bridging structure **154’**, computer **186** determines the shape, length, and location of the individual portions of the bridging structure between each of adjacent digital parameterized fittings **152”**. It is further configured to determine the shape length and location such that the individual portions will not intersect the first surface model (i.e. the surface model of the stone cast **125** provided in step **222**). Since the surface of the stone cast represents the exposed surfaces (including mucosal tissue) in the patient's mouth, this reduces the likelihood that the physical framework created from the surface model will contact and damage the patient's mucosal tissue. Computer 186 is configured to provide a separation distance between the surface model of the stone cast and the bridging structures. In one arrangement the computer 186 is configured to place the bridging structures a predetermined minimum distance from the surface model of the stone cast. In another arrangement the computer is configured to permit the operator to select a desired minimum distance between the bridging structure and the surface model of the stone cast. In another arrangement, the computer is configured to offer to and/or accept from the operator only a certain range or number of minimum separation distances, such minimum separation distances preferably ranging between 1 mm and 5 mm.

[00186] Computer **186** is configured to create the bridging structure extending from or between each of the digital parameterized fittings by providing a pre-designed list of bridging structure forms (e.g., pontic form, abutment/tooth form, bar form wherein the bar form is e.g. a cylinder, circle, ellipse, square, polygon or other geometric shape) that have been previously stored in the electronic memory of the computer. In one configuration, the computer is configured to automatically select the cross sectional dimensions of each form (diameter, radius, major and minor diameter, height, width, etc.). In another configuration the computer is configured to present the user with a list of pre-set values or defined by the user among which the user can select preferred dimensions. In yet another configuration, the computer is configured to prompt the user to enter specific numeric values for these dimensions. The form of the bridging structures can also be defined by the user.

[00187] Computer 186 is configured to determine the proper location of the bridging structure **154'** extending from each of the digital parameterized fittings **152"** by locating the beginning and end of each structure according to position information for the fitting that is derived from the scanned point cloud dataset.

In another arrangement, the computer **186** is configured to determine the location of the bridging structure **154'** extending from each of the digital parameterized fittings **152"** by locating the beginning and end of each structure according to reference points and axes assigned to the digital parameterized fittings **152"** by the computer program from a list of pre-set values or defined by the user. For example, each digital parameterized fitting which is placed in the model may have only certain types of bridging structures to which it can be connected, and may only connect to those bridging structures at certain locations one the digital parameterized fitting. This information. Is stored in the electronic memory of computer **186** in association with each digital parameterized fitting. When a particular fitting is inserted into the model, computer **186** is configured to the type and location information associated with the inserted fitting and locate (or permit the operator to locate) bridging structures of the type and at the locations compatible with those digital parameterized fittings. In another arrangement computer **186** is configured to locate the bridging structure **154'** (e.g., pontic form, abutment/tooth form, bar form) between each of the digital parameterized fittings **152"** by locating the beginning and end of each structure according to free form features selected by the user between each of the digital parameterized fittings**152"**.

[00188] In the case of distal extensions **155**, computer **186** is configured to cantilever them off the digital parameterized fittings **152"** and extend them distally along the arch of the patient's mouth. These distal extensions **155** are preferably 20mm in overall length or less. They are also selected as described above.

[00189] Computer 186 is configured to conduct a mechanical design analysis of the distal extensions **155** that validates shear and bending strength limits for those geometries relative to their chosen material and shapes. Computer **186** is configured to apply the appropriate shear, tensile and compressive stress analysis techniques to the chosen geometries automatically or from a pre-determined list of tests chosen by the user. Upon successful analysis of the distal extension designs, the extensions are verified or accepted by the user.

[00190] As part of the step of generating the bridging structure **154'** computer **186** is configured to determine a location for the bridging structure **154'** that will not intersect the second surface model (i.e. the surface model of diagnostic wax-up **130**). This insures that the bridging structure **154'** of the final denture framework will not stick through, but will be disposed within, the body of the denture. Computer **186** first aligns or registers the first point cloud dataset (representing the stone cast **125** surfaces) with respect to the second point cloud dataset (representing the diagnostic wax-up **130** surfaces), thereby mathematically determining the three-dimensional volume defined by the diagnostic wax-up **130**. This volume defined by the intersection of these two datasets is the volume of the denture as the dentist has designed it.

[00191] To align or register these two volumes, computer **186** is configured to identify the overlapping portions common to both the first and second point cloud datasets, i.e. the portions of both datasets that have the same (i.e. matching) surface contours. A preferred program for performing these functions is Raindrop Geomagic Studio Suite (by Geomagic of Research Triangle Park, North Carolina, USA).

[00192] In the first instance, the stone cast **125** is scanned to generate the first point cloud dataset, and the diagnostic wax-up **130** is mounted on the stone cast **125** and both are scanned to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the data points of the stone cast **125** for surfaces of the stone cast **125** that were scanned in both the first point cloud dataset and the second point cloud dataset.

[00193] In the second instance, the stone cast **125** is scanned to generate the first point cloud dataset and the diagnostic wax-up **130** is not mounted on the stone cast **125** but is scanned separately to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the surface of the stone cast **125** that abuts the diagnostic wax-up **130** in the first point cloud dataset, and the surface of the diagnostic wax-up **130** that abuts stone cast **125** when it is mounted on the stone cast **125** in the second point cloud dataset. Since the two abutting portions were formed by pressing the diagnostic wax-up **130** material against the stone cast when soft, the two abutting surfaces have identical surface contours that can be matched one to the other, and in that sense overlap.

[00194] In the third instance, the stone cast **125** is scanned to generate the first point cloud dataset, and the putty index **142** is mounted on the stone cast **125** and both are scanned to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the data points of the stone cast **125** for surfaces of the stone cast **125** that were scanned in both the first point cloud dataset and the second point cloud dataset.

[00195] In the fourth instance, the stone cast **125** is scanned to generate the first point cloud dataset and the putty index **142** is not mounted on the stone cast **125** but is scanned separately to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the surface of the stone cast **125** that abuts the putty index **142** in the first point cloud dataset, and the surface of the putty index **142** that abuts stone cast **125** when it is mounted on the stone cast **125** in the second point cloud dataset. Since the two abutting portions of the stone cast **125** and the putty index **142** were formed by pressing the putty index **142** material against the stone cast **125** when soft, the two abutting surfaces have identical surface contours that can be matched one to the other, and in that sense overlap.

[00196] In the third and fourth instances (that use the putty index **142**), the computer **186** locates the bridging structure **154**' by locating the bridging structure behind the portion of the second point cloud dataset that was scanned from the inner surface of the putty index **142** that was formed by pressing it against the facial aspect of the diagnostic wax-up **130**. This portion of the second point cloud dataset in the third and fourth instance has the same surface contours as the facial aspect of the diagnostic wax-up **130**, which is a replica of the front of the body of the denture when made.

[00197] By locating the bridging structure **154'** behind the inner surface of the putty index **142** in the second point cloud dataset, the computer insures that the surface model of the denture framework thus created will not protrude through the front of the denture body.

[00198] By locating the bridging structure **154'** above the surface of the first point cloud dataset (i.e. stone cast **125**) that represents the surface of the mucosal tissue the computer **186** insures that the surface model of the denture framework **228** thus created will not extend through the lower surface of the denture body and abut the mucosal tissues of the patient.

[00199] Computer **186** digitally assembles each of the short bridging sections of the bridging structure **154'** and the digital parameterized fittings **152"** into the surface model of denture framework **228**. Computer **186** thereby generates the locations of the digital parameterized fittings **152"**, and the location of the bridging structures **154**' coupling the digital parameterized fittings **152"**.

[00200] A graphic example of the surface model of the denture framework **228** generated by the computer in this manner can be seen in **FIGURES 25-27**, which illustrate a bottom view, front perspective view, and top view, respectively, of the surface model of the denture framework **228** and showing the digital parameterized fittings **152"** and bridging structure **154'**.

[00201] In the illustrated embodiment, each section of bridging structure **154'** has a constant cross-sectional area (in this case a circular cross section) designed to **minimize** manufacturing time of the final framework. In an alternative embodiment, computer **186**, when placing the bridging structure **154'**, is configured to customize the joints between the digital parameterized fittings **152"** and the sections of bridging structure **154'** by providing stress reduction factors such as radiused intersections between the digital parameterized fittings **152"** and bridging structure **154'**.

[00202] In the final step of this alternative process, step **230**, the framework is manufactured in the same manner as described above in accordance with step **212**.

[00203] Above were described two processes for manufacturing a dental framework. In the first process an impression **123**, then a stone cast **125**, then a wax-up framework **150** was made before anything was scanned. In the first alternative process an impression **123** and then a stone cast **125** was made before anything was scanned. This second process eliminated the need for creating a wax-up framework **150** and used a computer to generate the framework from an internal stored library of digital parameterized fittings **152"**. By eliminating additional replication steps, the possibility for error as well as the cost and time of manufacture is further reduced.

[00204] In a second alternative process for manufacturing a denture framework, the step of creating a stone cast **125** is eliminated and the impression

123 is used as the stone cast **125** was used in the first alternative process of **FIGURES 24-27**. The dentist may, of course, make a stone cast **125** on which to create his diagnostic wax-up **130**, but the stone cast **125** in this second alternative process is not required for making a denture framework.

[00205] In the second alternative process, the dentist makes impression **123** as described in the first process and first alternative process (above) and sends it to the laboratory. The laboratory then mounts alignment posts **156** to the copings **110** located in the impression **123.**

[00206] Scanner **182** is configured to scan the interior surface of the impression **123**, which is a negative replica of the patient's mucosal tissues. This scan produces a first point cloud dataset that indicates the surface contours of the patient’s mandibular mucosal tissues. The alignment posts **156** are coupled to the mating surfaces of the copings **110** embedded in the impression material.

[00207] The surfaces to which the alignment posts **156** are coupled are the surfaces that previously mated to the surfaces **108** of anchors **104**. This second alternative process is substantially the same as the first alternative process. The dentist can optionally send a diagnostic wax-up **130** of the desired denture as well.

[00208] In the second alternative process, alignment posts **156** are attached to copings **110** embedded in impression **123**. The impression **123** is a negative replica of the patient's mandible. The impression-plus-alignment-posts assembly is then fixed to jig **194**.

[00209] Scanner **182** then scans the inside surface of impression **123** formed by the patient's mandible, which includes the patient’s mucosal tissue and any existing dentition and edentulous areas. Scanner **182** also scans the surface of the alignment posts **156**, which in this case are attached to the copings **110**. The alignment posts are preferably as shown in **FIGURE 18**, however the frusto-conical portions **173** and **175** may be configured differently to be fixed to the coping in a coaxial relationship in the same manner described above for the first process and the first alternative process.

[00210] Computer **186** is configured to save the three-dimensional data points of the interior surface of the impression formed by the patient's mandible and the alignment posts **156** as a point cloud dataset, to derive the location of the surfaces of copings **110** from the predetermine geometry, to remove the alignment posts **156** from the point cloud dataset of the impression-plus-alignment-posts assembly, to generate a surface model of the patient's mucosal tissue and the copings **110**, and to generate a surface model of a dental framework **228** in the same manner described above in conjunction with the first alternative process.

[00211] In the final step of the second alternative process, the surface model of the framework **228** is manufactured as in step **212**.

[00212] In a third alternative process, the surface model of a dental framework **228** can be generated from the diagnostic wax-up **130** itself.

[00213] In this process, shown in **FIGURES 28-29**, the dentist first mounts fittings **152** on the analogs **124** embedded in the stone cast **125** in the same manner as described in the above processes.

[00214] In the next step, the dentist forms the diagnostic wax-up **130** on the stone cast **125**. The dentist molds the wax-up material to the surface of the stone cast **125** to capture the contours of the mucosal tissue as described above. The dentist also molds the wax-up material to the fittings **152**, embedding the fittings **152** in the wax-up material.

[00215] The competed diagnostic wax-up **130** supported on the stone cast **125** with the fittings **152** embedded in the diagnostic wax-up **130** are shown in **FIGURE 28**.

[00216] The dentist then removes the diagnostic wax-up **130** from the stone cast **125** and sends it to the laboratory.

[00217] Once at the laboratory, a technician fixes alignment posts **156** (preferably alignment posts **156C, D, E** or **F**, since they extend from only one side of the fitting **152** to which they are coupled) to the now-exposed mating surfaces of the fittings **152**. This arrangement is shown in **FIGURE 29**.

[00218] The technician then mounts the assembly of diagnostic wax-up **130** with alignment posts **156** to scanner **182** and directs the scanner to scan the assembly in the same manner as described above for scanning wax-up framework **150** with alignment posts **156**.

[00219] This scan produces a point cloud dataset representing the contours of the diagnostic wax-up **130** and the alignment posts **156**.

[00220] As in the previous examples, the technician directs computer **186** to determine the location of the centers of the spherical surface portions of the point cloud dataset, and ultimately the location and orientation of the mating surfaces of the fittings **152**.

[00221] Computer **186** then generates a surface model of a framework **228** that will be enclosed within the diagnostic wax-up **130**. Computer **186** inserts digital parameterized fittings **152"** into the surface model of a denture framework **228** that correspond to fittings **152**. Computer **186** then inserts the bridging structure **154'** and distal extensions **155** into the surface model of a denture framework **228**.

[00222] To generate bridging structure **154'**, computer **186** determines the shortest distance between each of the adjacent digital parameterized fittings **152"** that will not intersect the surface model of the diagnostic wax-up **130**, but will be contained completely within the contours of the diagnostic wax-up **130**. Computer **186** already has the surface contours of the diagnostic wax-up **130** because it already scanned the surface of the diagnostic wax-up **130** in the point cloud dataset. This insures that the actual bridging structure of the denture framework (created from the model of the bridging structure **154'**) will not protrude through, but will be disposed within, the body of the denture.

[00223] In a fourth alternative process, illustrated in **FIGURE 30**, the dentist fixes the alignment posts **156** directly to the copings **110**. The alignments posts are suitably modified to mate with the copings **110** in a predetermined position, preferably coaxial with the copings, such that the surface extensions of the alignment posts can, as in the previous examples, be scanned and the location and orientation of the copings determined with some accuracy just as in the previous processes the surface of the fittings to which the alignment posts were attached was determined accurately using the surface extensions on the alignment posts.

[00224] In the discussion above, scans of surface extensions on the surface of alignment posts are used to provide a more accurate determination of the location of the objects to which they were attached. The position and orientation of these objects are determined by the position and orientation of the mounting surfaces of anchors embedded in the patient's maxilla or mandible. The scans therefore indicate, incorporate or encode the position and orientation of the anchors.

[00225] The alignment posts above are elongate members having spherical surface portions (e.g. the surface extensions) at various positions along their length. These are merely exemplary, however. **FIGURES 31-36** illustrate alternative alignment posts **250, 252, 254** that provide scannable surface extensions that can be coupled to any of the structures indicate above to which the alignments posts of the foregoing **FIGURES** were attached to serve the same function: to provide scannable surface extensions that are in predetermined locations with respect to the mounting surfaces to which the base of the alignment posts are coupled. **FIGURES 31-32** show an alignment post that is configured to be attached to any one of fittings **152C-152F**. Referring to **FIGS. 31 and 32**, alignment post **250** is shown. It has three spherical surface extensions **256, 258, 260** that are in a predetermined position with respect to the base **262** of the alignment post **250**. In this embodiment, the centers **264** define a plane that extends perpendicular to the longitudinal axis **266** of the alignment post **250**. This axis **266** intersects the plane at a point equidistant to all of centers **264**. The point equidistant is a predetermined distance along axis **266** from base **262**. Computer **186** is programmed with this parametric information and is configured to scan the surface extensions, determine the plane, determine the longitudinal axis and the position along the longitudinal axis where base **266** is located, a well as the location and orientation of the mounting surfaces of the structure to which the base is connected.

[00226] **FIGURES 33-34** show another alignment post arrangement having a first spherical surface extension **268** lying on the longitudinal axis **272** of base **270**. A second surface extension **274**, shown here as a flat plane, is also disposed along and perpendicular to longitudinal axis **272** and a predetermined distance away from base **270**. As in the previous examples, computer **186** is configured to scan the surface extensions, determine the center of spherical surface extension **268**, determine the plane of surface extension **274**, and determine the longitudinal axis **272** and the position along the axis where base **272** is located, as well as the location and orientation of the mounting surfaces of the structure on which the base **272** is connected.

[00227] **FIGURES 35-36** show another alignment post arrangement having a first surface extension **280** forming a plane that is normal to the longitudinal axis **282** of base **284**. A second surface extension **286**, shown here as a flat plane, is disposed parallel to longitudinal axis **284** a first distance away from the axis. A third surface extension **288** shown here as a flat plane is also disposed parallel to longitudinal axis **284** the first distance away from the axis. A fourth surface extension **290** shown here as a flat plane is also disposed parallel to longitudinal axis **284** the first distance away from the axis. Each of the three surface extensions parallel to the longitudinal axis **284** are spaced equiangularly with respect to each other about the longitudinal axis to define an equilateral triangle in an end view (**FIG.**

36). As in the previous examples, computer **186** is configured to scan the surface extensions, determine the planes of the surface extensions center of spherical surface extension **268**, determine the planes of the surface extensions determine the longitudinal axis **282** and the position along the axis where base **284** is located, as well as the location and orientation of the mounting surfaces of the structure on which the base **284** is connected.

CLAIMS

We claim:

1. A method of creating a dental framework having a plurality of mating surfaces that are configured to engage corresponding plurality of anchors in a patient's mouth, the method comprising the steps of:

attaching a plurality of copings to the anchors;

forming an impression in which the copings are embedded;

attaching an analog to each of the plurality of copings;

forming a stone cast in which the plurality of copings are embedded;

attaching alignment posts having surface extensions to each of the analogs;

digitally scanning the surface extensions to generate a point cloud dataset;

deriving the relative positions and orientations of the mating surfaces from the point cloud dataset;

generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and

making the framework in accordance with the toolpath.

2. The method of claim 1, wherein the alignment posts are attached to surfaces of the analogs that correspond to the plurality of mating surfaces on the anchors.

3. The method of claim 1, wherein the framework further comprises a bridging structure that extends between and couples the plurality of mating surfaces together, and wherein the step of generating a toolpath further comprises the step of generating a toolpath configured to generate the bridging structure.

4. The method of claim 1, wherein the step of digitally scanning the surface extensions further comprises the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising the three dimensional datapoints.

5. The method of claim 1, wherein the step of deriving the relative positions and orientations further comprises the step of electronically fitting datapoints scanned from the surface extensions to a predetermined three dimensional geometry of the surface extensions stored in a computer memory.

6. A method of generating a toolpath for manufacturing a dental framework for a patient's mouth, the patient's mouth comprising a plurality of anchors embedded in the patient's mandible or maxilla, the framework being made from a stone cast with embedded analogs, the stone cast being made from an impression having embedded copings, the impression being taken directly from the patient's mouth, wherein the framework further comprises a plurality of mating surfaces that are configured to engage the plurality of anchors, the method comprising the steps of:

attaching alignment posts having surface extensions to each of the analogs embedded in the stone cast of the patient's mouth;

digitally scanning the surface extensions to generate a point cloud dataset;

deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; and

generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations.

7. The method of claim 6, wherein the alignment posts are attached to surfaces of the analogs that correspond to the plurality of mating surfaces on the anchors.

8. The method of claim 6, wherein the framework further comprises a bridging structure that extends between and couples the plurality of mating surfaces together, and wherein the step of generating a toolpath further comprises the step of generating a toolpath configured to generate the bridging structure.

9. The method of claim 6, wherein the step of digitally scanning the surface extensions further comprises the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising the

three dimensional datapoints.

10. The method of claim 6, wherein the step of deriving the relative positions and orientations further comprises the step of electronically fitting datapoints scanned from the surface extensions to a predetermined three-dimensional geometry of the surface extensions stored in a computer memory.

11. A method of creating a dental framework having a plurality of mating surfaces that are configured to engage a corresponding plurality of anchors in the patient's mouth, the method comprising the steps of:

attaching a plurality of copings to the anchors;

forming a stone cast in which the copings are embedded;

attaching an analog to each of the plurality of copings;

forming a stone cast in which the plurality of analogs are embedded;

attaching a fitting to each of the plurality of analogs;

coupling the fittings together with a bridging structure to hold them in their relative positions thereby forming a model framework;

removing the fittings and bridging structure from the copings;

attaching alignment posts having surface extensions to each of the fittings;

digitally scanning the surface extensions to generate a point cloud dataset;

deriving the relative positions and orientations of the mating surfaces from the point cloud dataset;

generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and

making the framework in accordance with the toolpath.

12. The method of claim 11, wherein the alignment posts are attached to surfaces of the fittings that correspond to the plurality of mating surfaces on the anchors.

13. The method of claim 11, wherein the step of digitally scanning further comprises the step of digitally scanning the surface of the bridging structure to generate the point cloud dataset, and further wherein the step of generating a toolpath further comprises the step of generating a toolpath configured to generate

the bridging structure from datapoints scanned from the surface of the bridging structure.

14. The method of claim 11, wherein the step of digitally scanning the surface extensions further comprises the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising the three dimensional datapoints.

15. The method of claim 11, wherein the step of deriving the relative positions and orientations further comprises the step of electronically fitting datapoints scanned from the surface extensions to a predetermined geometry of the surface extensions stored in a computer memory.

16. A method of creating a dental framework having a plurality of mating surfaces that are configured to engage a corresponding plurality of anchors in the patient's mouth, the method comprising the steps of:

attaching a plurality of copings to the anchors;

forming a stone cast in which the copings are embedded;

attaching an analog to each of the plurality of copings;

forming a stone cast in which the plurality of analogs are embedded;

attaching a fitting to each of the plurality of analogs;

coupling the fittings together with a bridging structure to hold them in their relative positions thereby forming a model framework;

removing the fittings and bridging structure from the copings;

attaching alignment posts having surface extensions to each of the fittings;

digitally scanning the surface extensions to generate a point cloud dataset;

deriving the relative positions and orientations of the mating surfaces from the point cloud dataset;

generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and

making the framework in accordance with the toolpath.

17. The method of claim 16, wherein the alignment posts are attached to

surfaces of the fittings that correspond to the plurality of mating surfaces on the anchors.

18. The method of claim 16, wherein the step of digitally scanning further comprises the step of digitally scanning the surface of the bridging structure to generate the point cloud dataset, and further wherein the step of generating a toolpath further comprises the step of generating a toolpath configured to generate the bridging structure from datapoints scanned from the surface of the bridging structure.

19. The method of claim 16, wherein the step of digitally scanning the surface extensions further comprises the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising the three dimensional datapoints.

20. The method of claim 16, wherein the step of deriving the relative positions and orientations further comprises the step of electronically fitting datapoints scanned from the surface extensions to a predetermined geometry of the surface extensions stored in a computer memory.

21. A method of locating a dental appliance with respect to dental surfaces, the method comprising the steps of:

scanning a first dental surface to create a first point cloud dataset;

scanning a second dental surface to create a second point cloud dataset;

registering the first and second point cloud datasets by aligning points in each dataset taken from the overlapping surface portions; and

using non-overlapping portions of both point cloud datasets to define the location of the dental appliance.

22. The method of claim 21 wherein the first dental surface is selected from the group comprising an impression, a stone cast, a diagnostic wax-up, a facial index and a dental framework;

23. The method of claim 22 wherein the second dental surface is selected from the group comprising an impression, a stone cast, a diagnostic wax-up, a facial index, and a dental framework.

24. The method of claim 21, wherein the first point cloud dataset comprises both points scanned from a surface of a diagnostic wax-up disposed on a stone cast and points scanned from a surface of the stone cast while the diagnostic wax-up is disposed on it, and wherein the second point cloud dataset comprises points scanned from the surface of the stone cast and points scanned from a surface of the stone cast that was covered by the diagnostic wax-up when the diagnostic wax-up was scanned to create the first point cloud dataset, wherein the portions of the stone cast common scanned to both point cloud datasets constitute the overlapping portions of both point cloud datasets.

25. The method of claim 16, wherein a facial index has a first surface formed in abutment to a diagnostic wax-up and a second surface formed in abutment to a third surface of a stone cast, wherein the first point cloud dataset comprises points scanned both from the first surface and the second surface, and wherein the second point cloud dataset comprises points scanned from the third surface and points scanned from a fourth surface of the stone cast adjacent to the third surface, and further wherein the overlapping portions of both point cloud datasets comprise points scanned from the second surface in the first point cloud dataset and points scanned from the third surface in the second point cloud dataset.

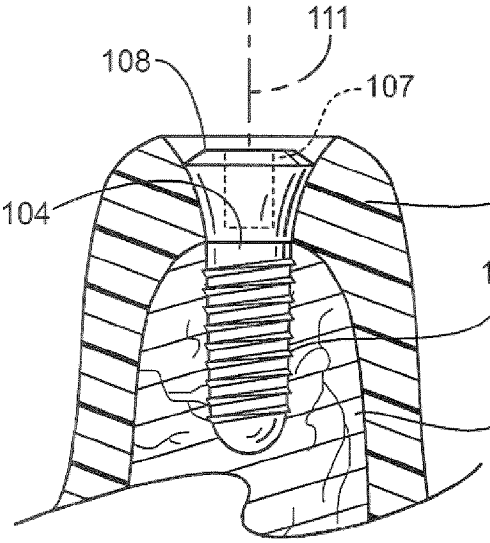

FIG. 1

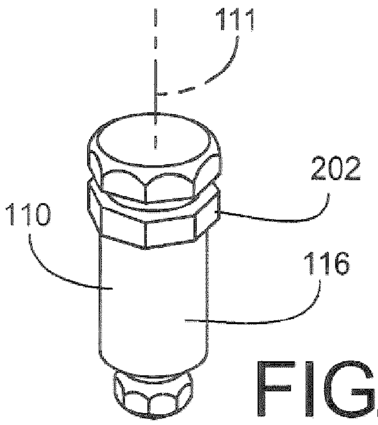

FIG. 2A

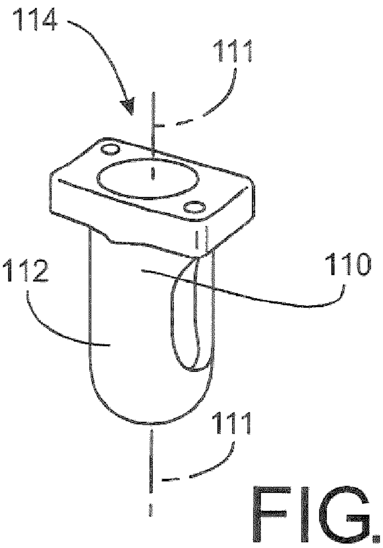

FIG. 2B

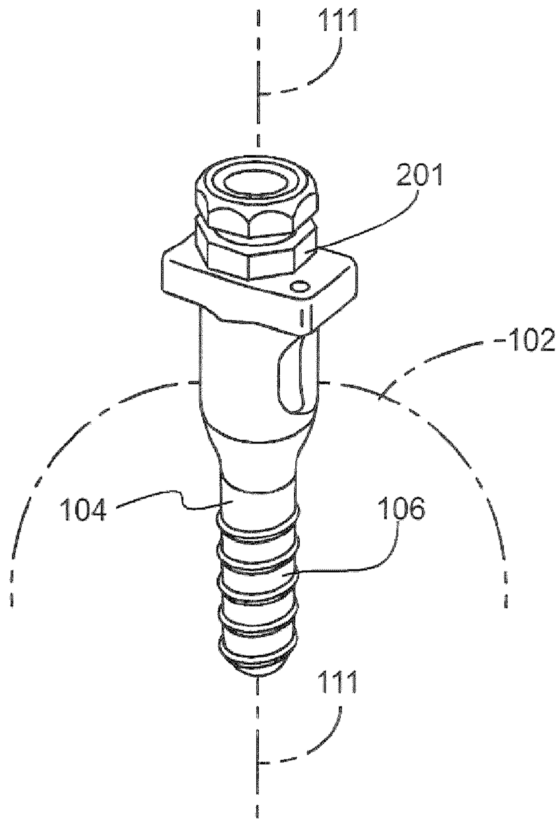

FIG. 3

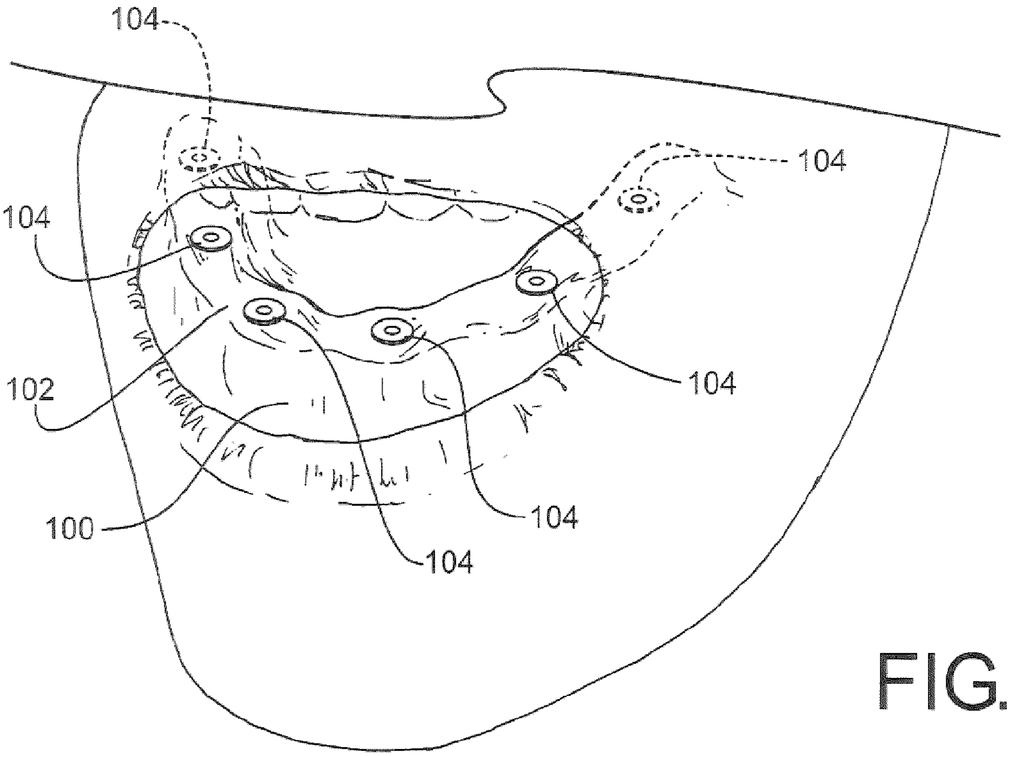
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FIG. 4

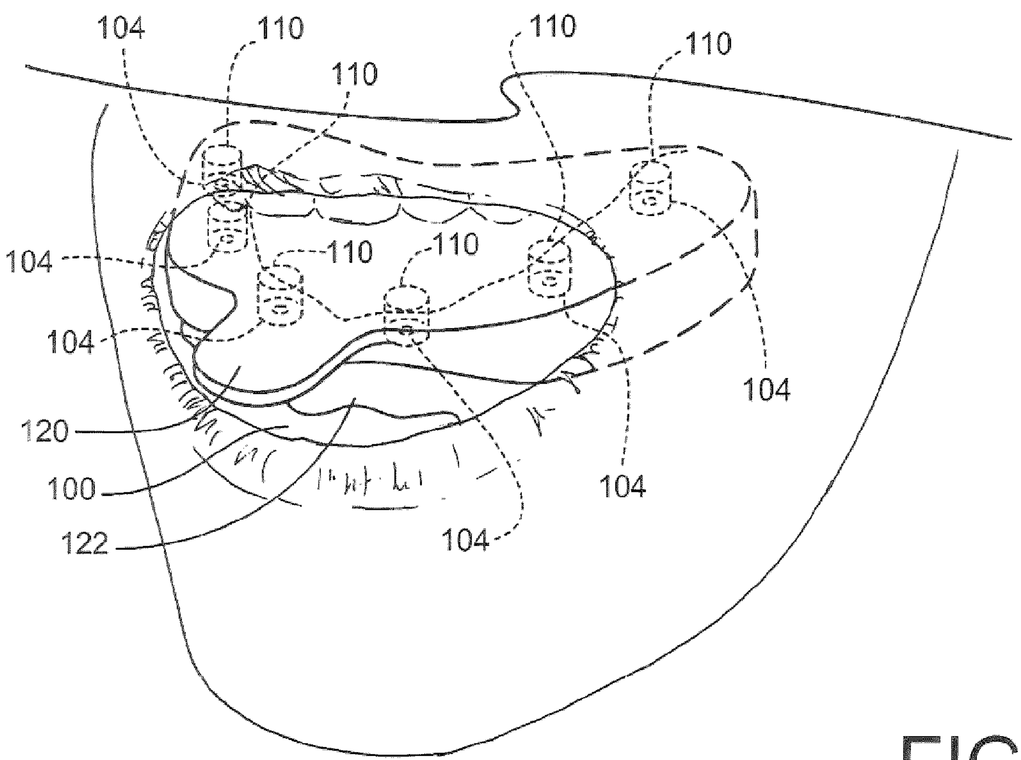
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FIG. 5

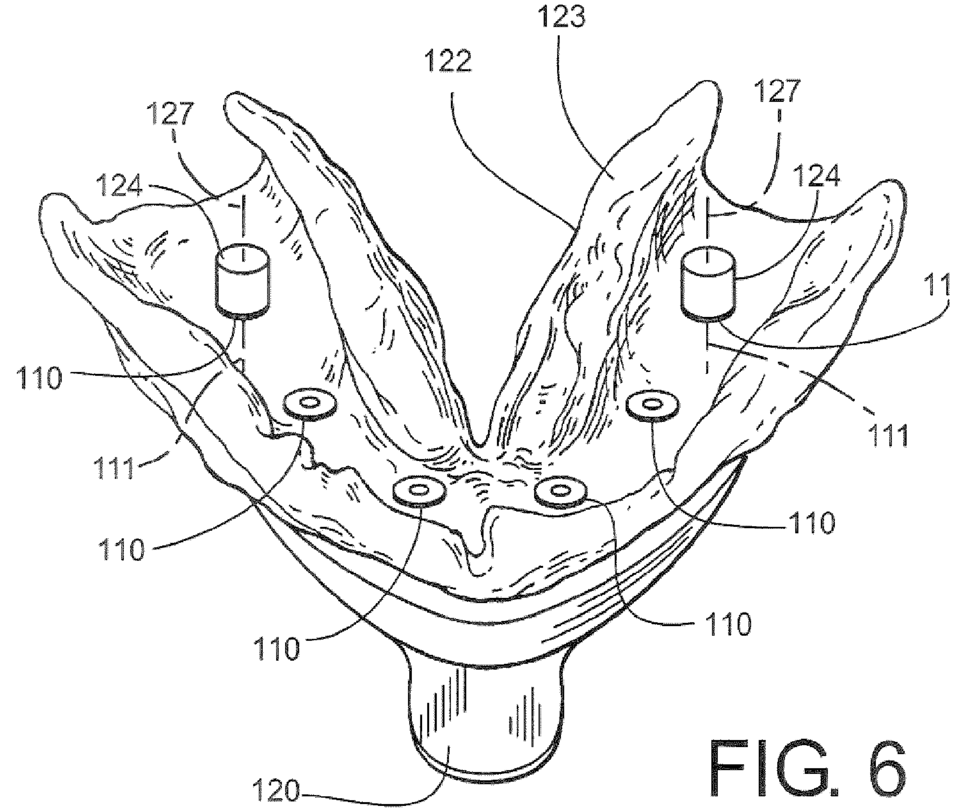
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FIG. 6

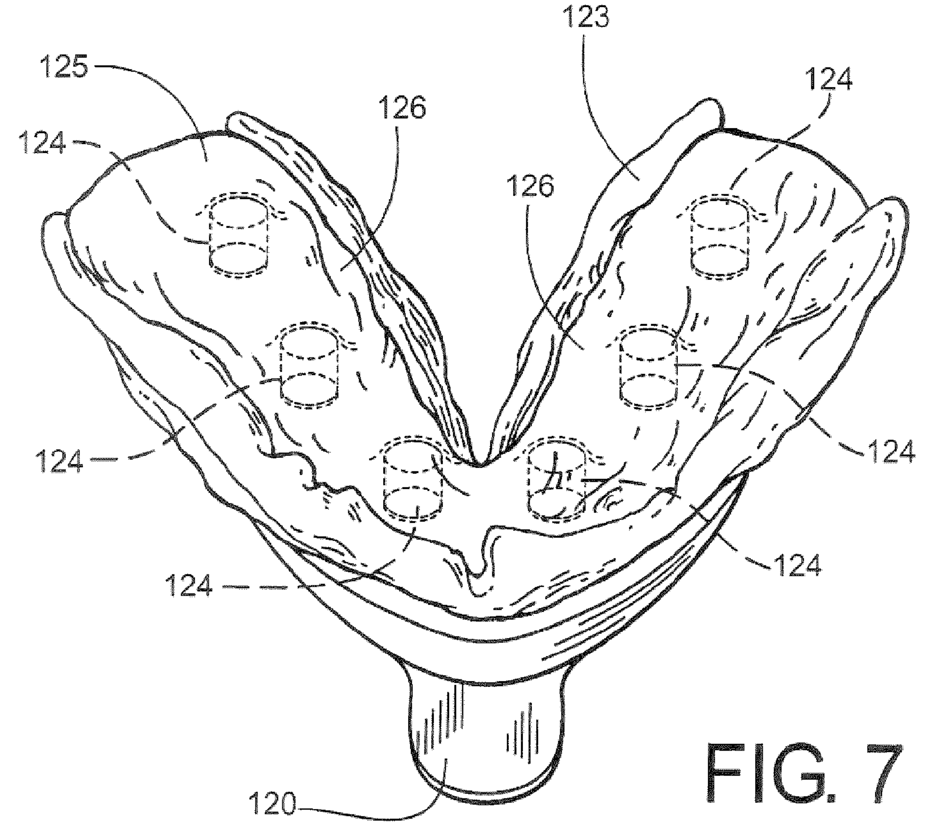
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FIG. 7

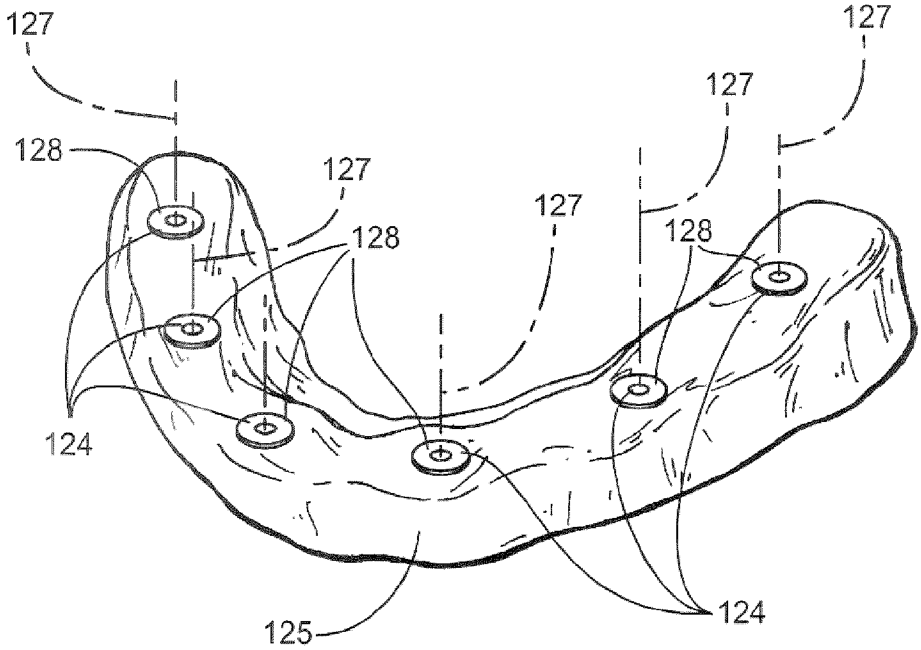
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FIG. 8

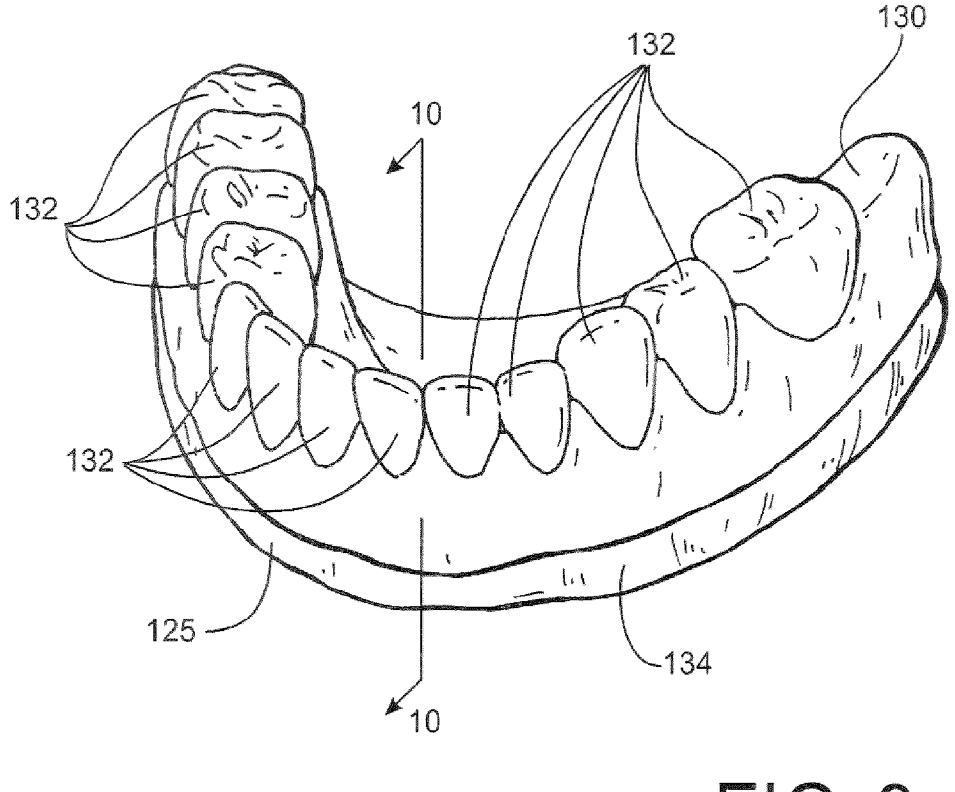
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FIG. 9

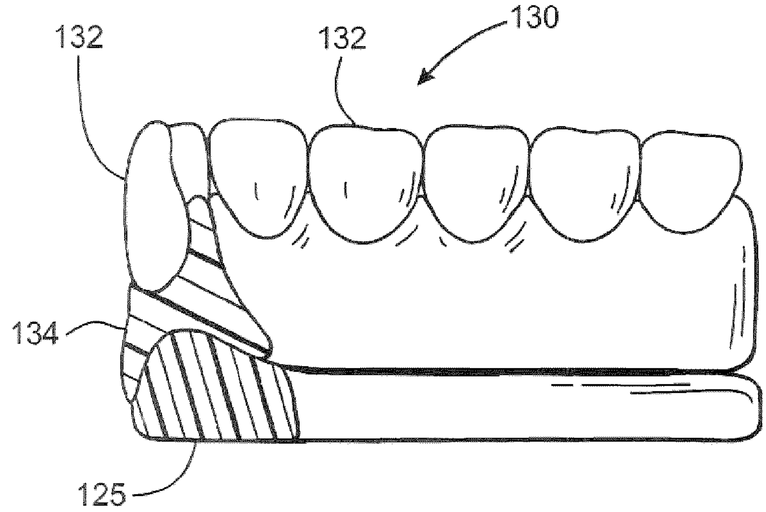


FIG. 10

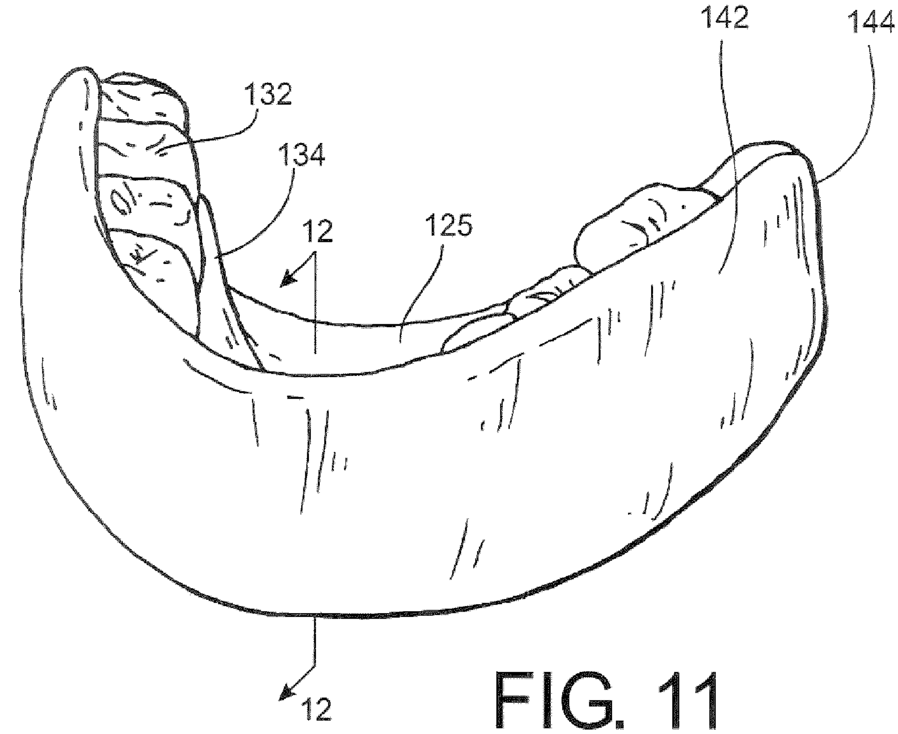


FIG. 11

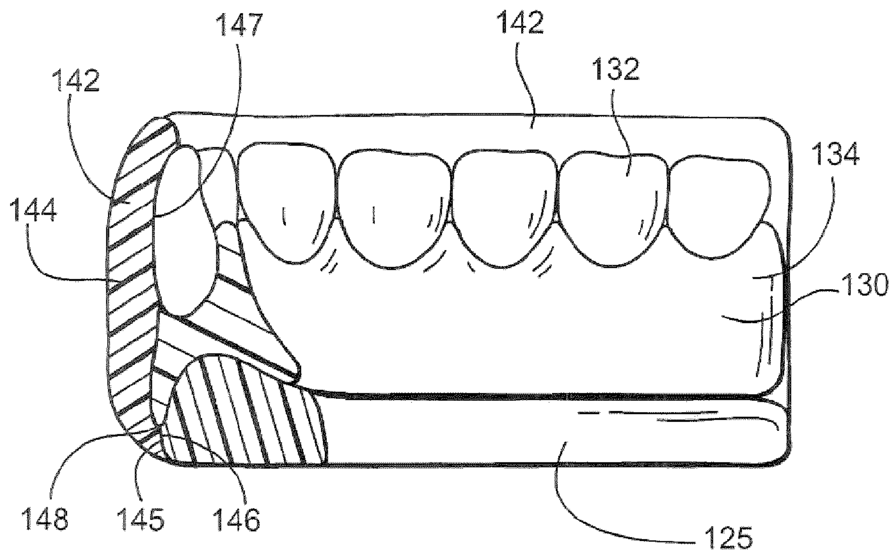


FIG. 12

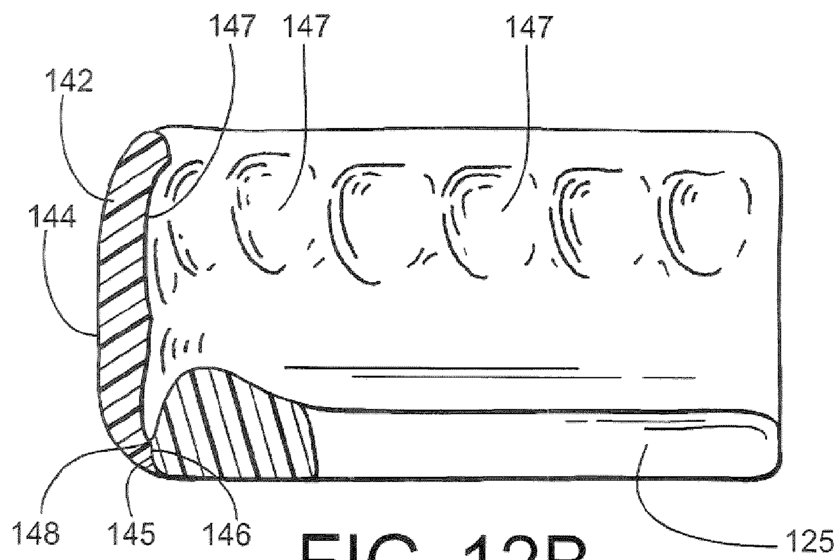


FIG. 12B

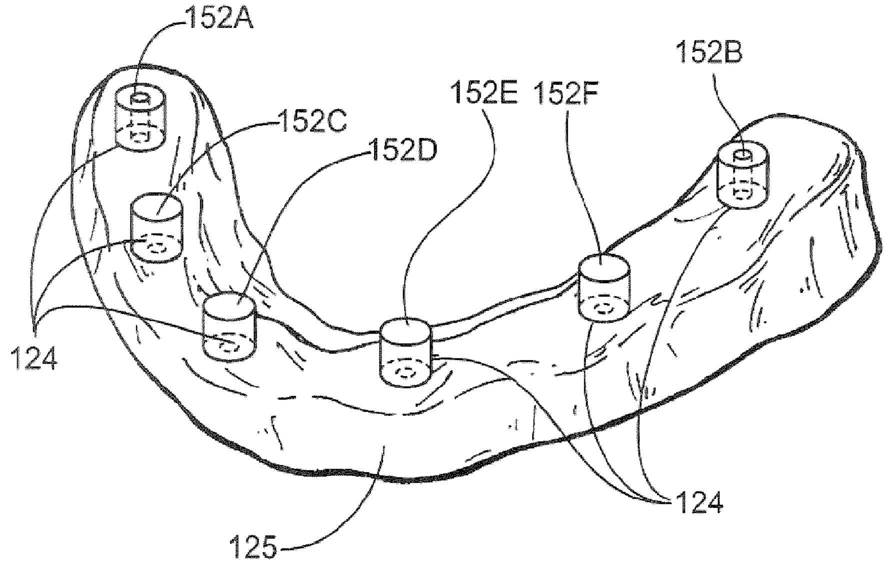


FIG. 13A

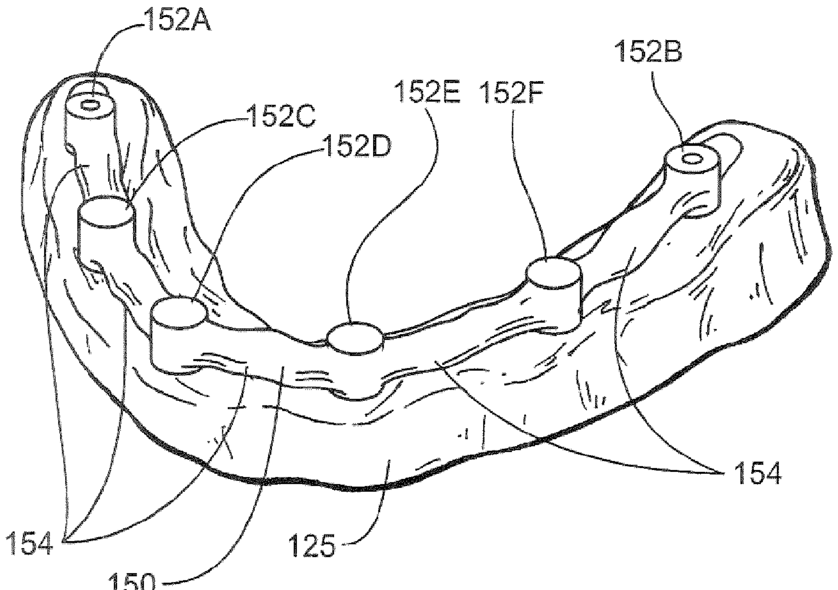


FIG. 13B

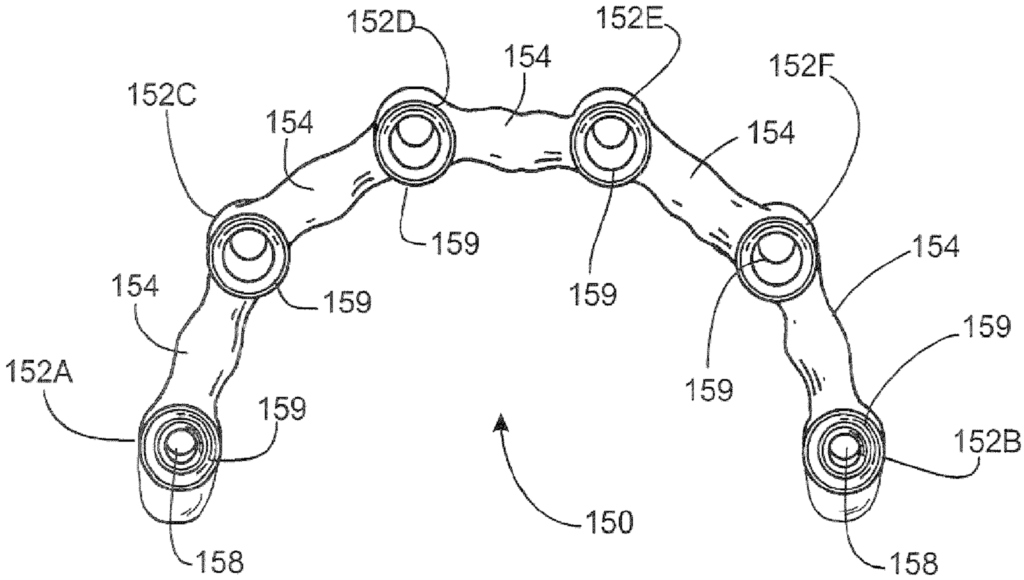


FIG. 13C

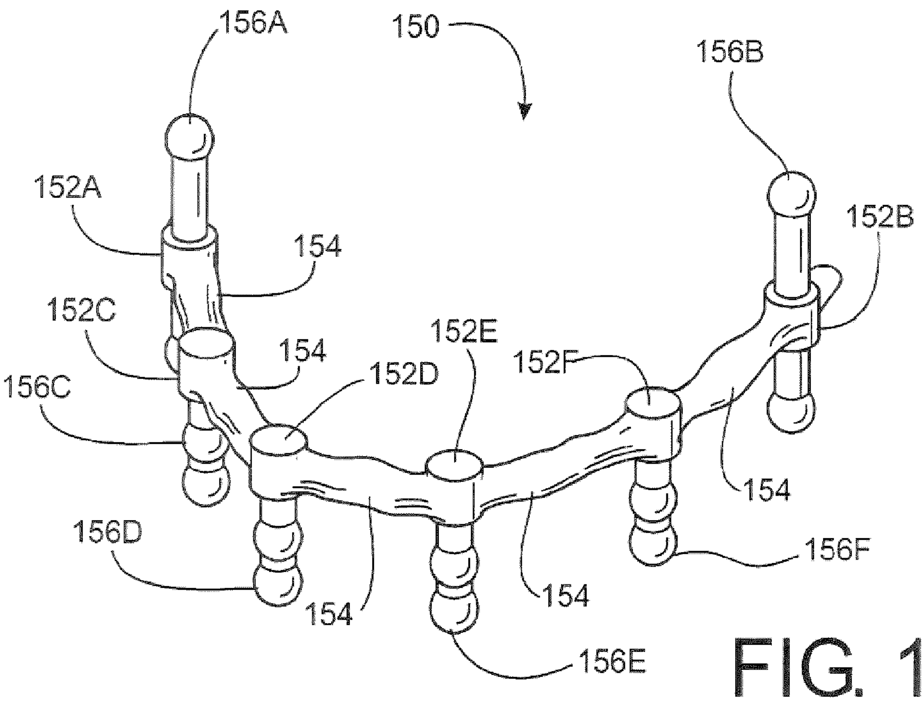
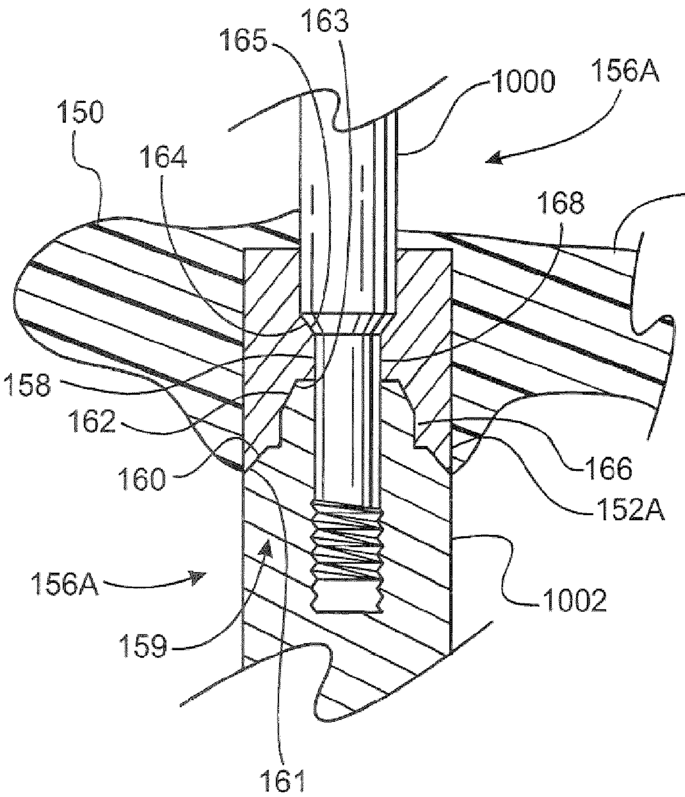


FIG. 14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156A
1002
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161

FIG. 15

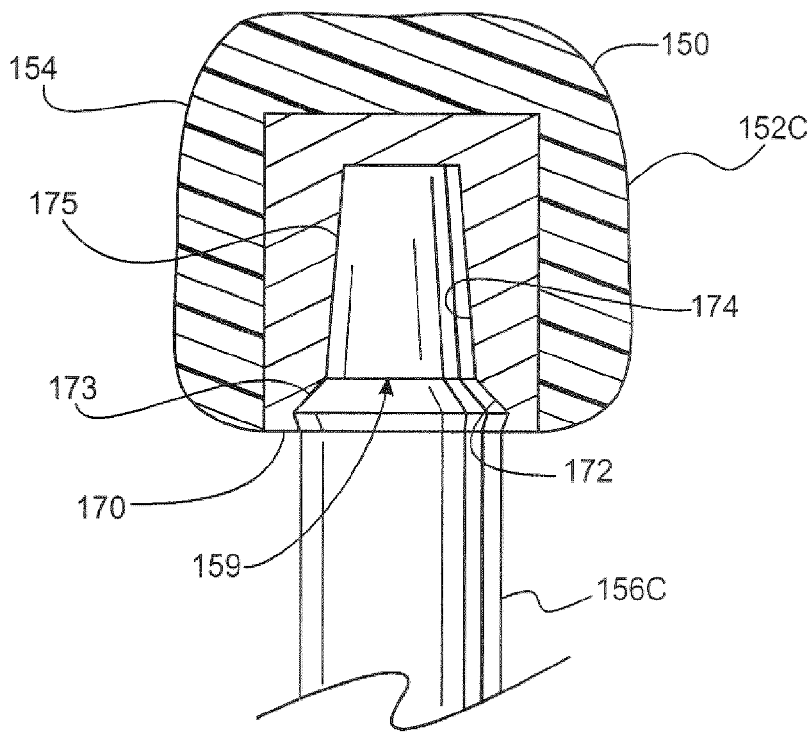
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FIG. 16

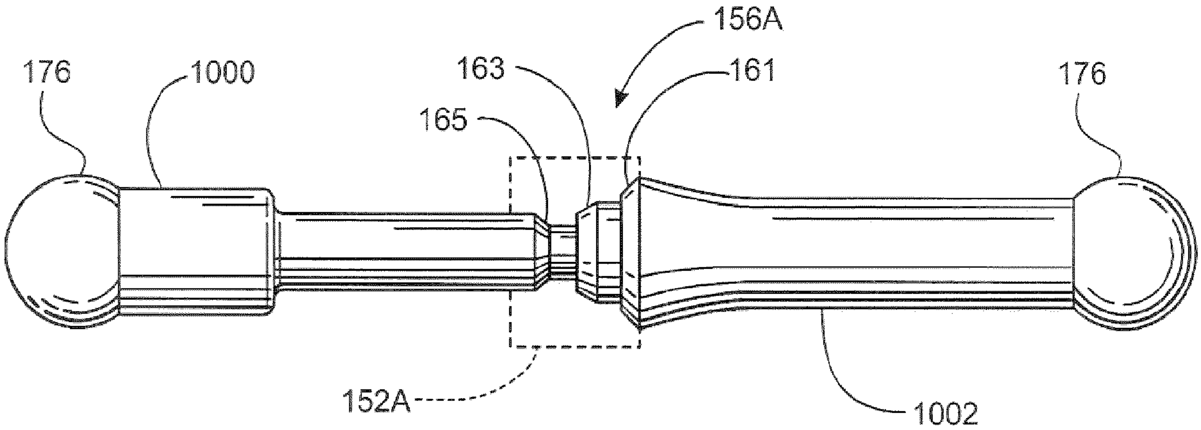


FIG. 17

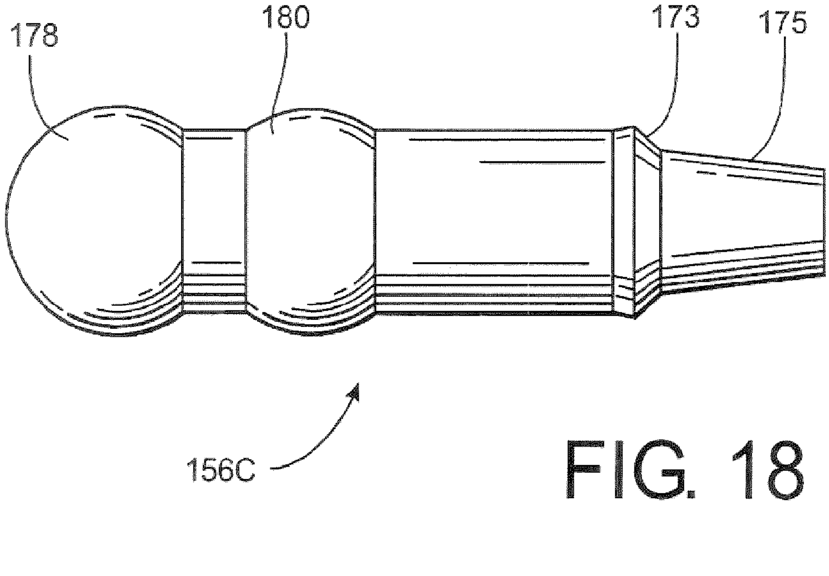


FIG. 18

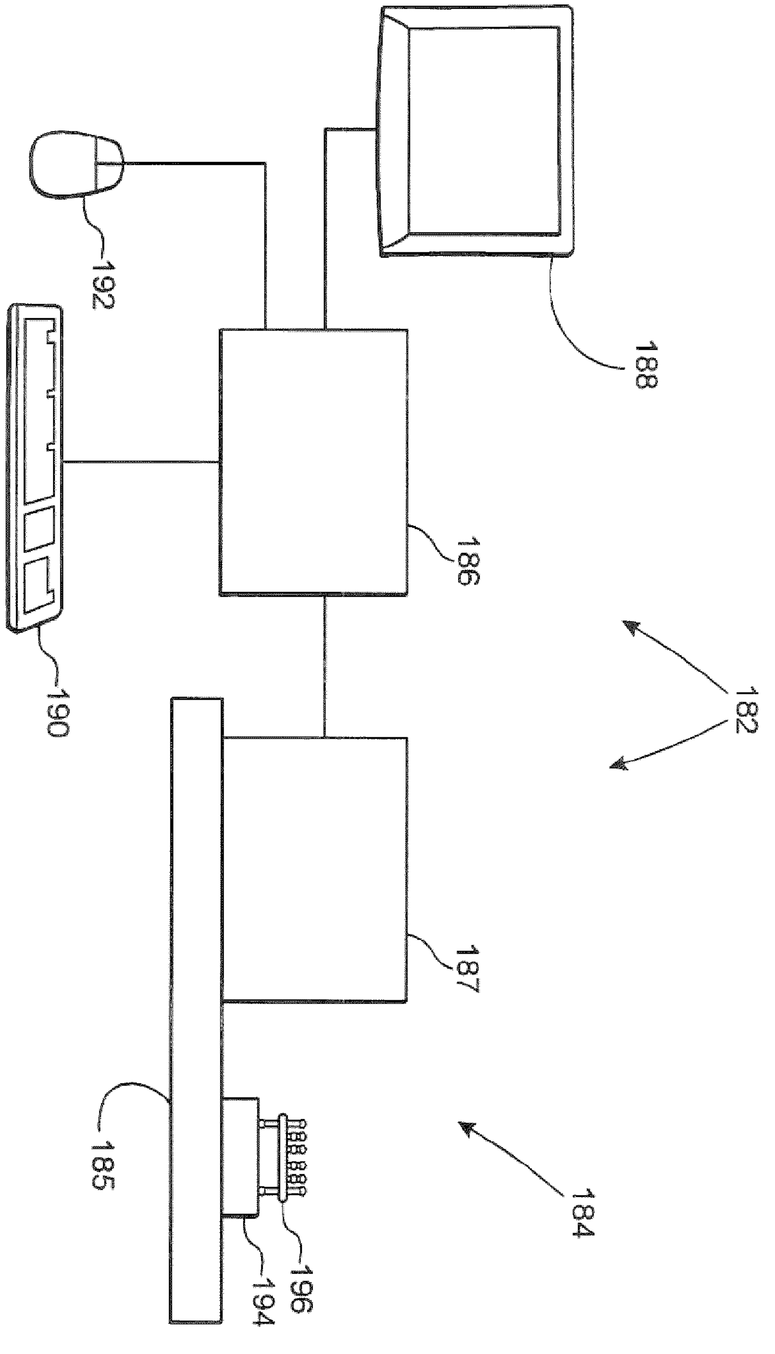


FIG. 19

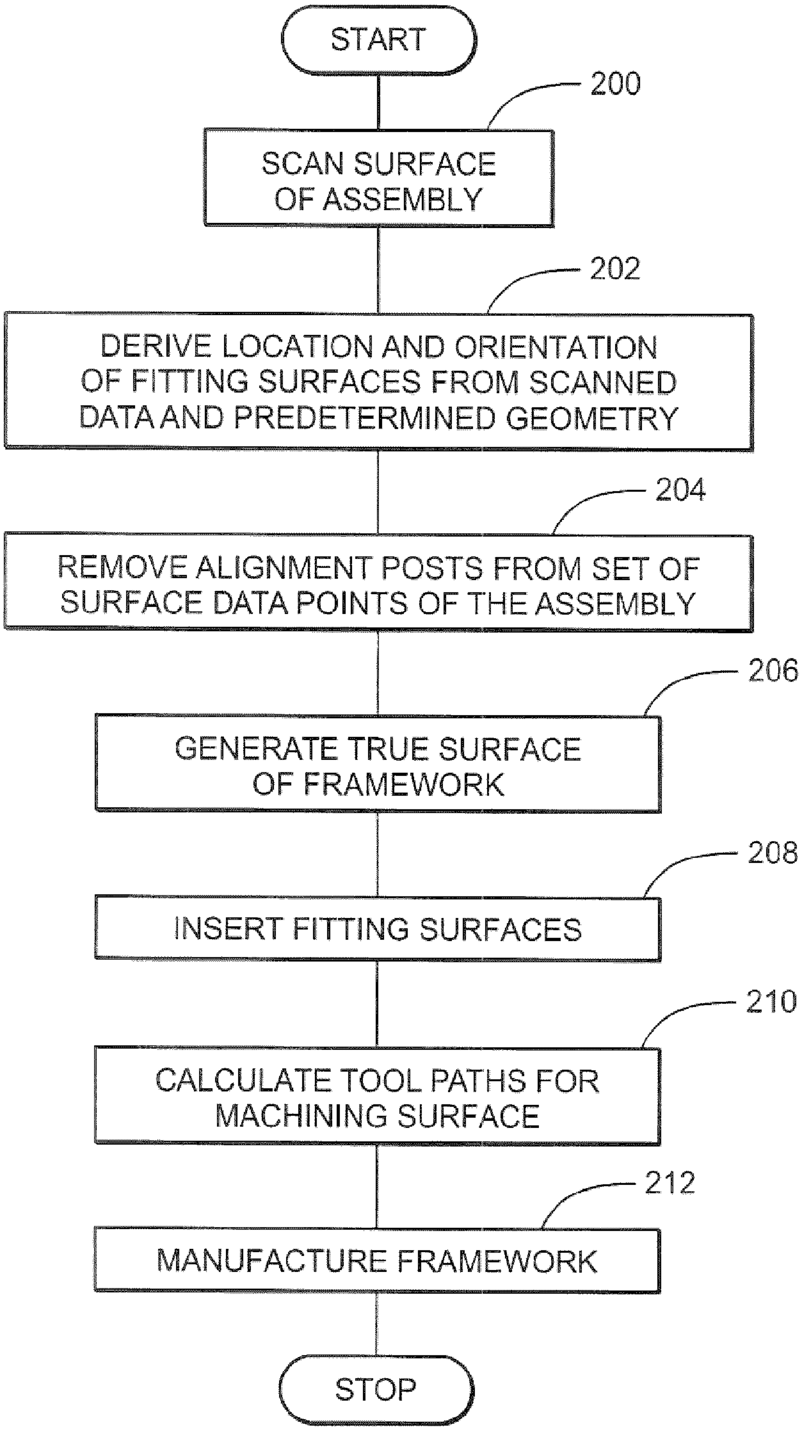

START
200
SCAN SURFACE OF ASSEMBLY
202
DERIVE LOCATION AND ORIENTATION OF FITTING SURFACES FROM SCANNED DATA AND PREDETERMINED GEOMETRY
204
REMOVE ALIGNMENT POSTS FROM SET OF SURFACE DATA POINTS OF THE ASSEMBLY
206
GENERATE TRUE SURFACE OF FRAMEWORK
208
INSERT FITTING SURFACES
210
CALCULATE TOOL PATHS FOR MACHINING SURFACE
212
MANUFACTURE FRAMEWORK
STOP

FIG. 20

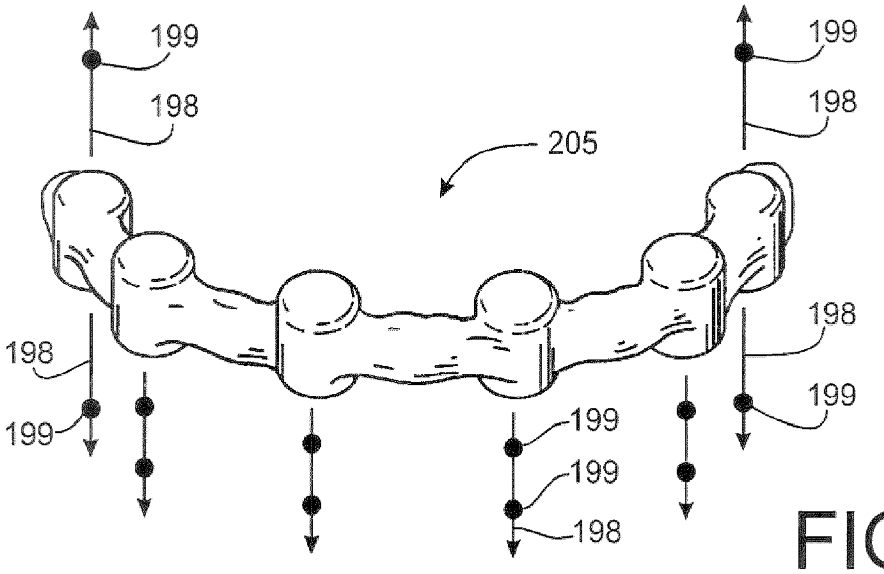


FIG. 21

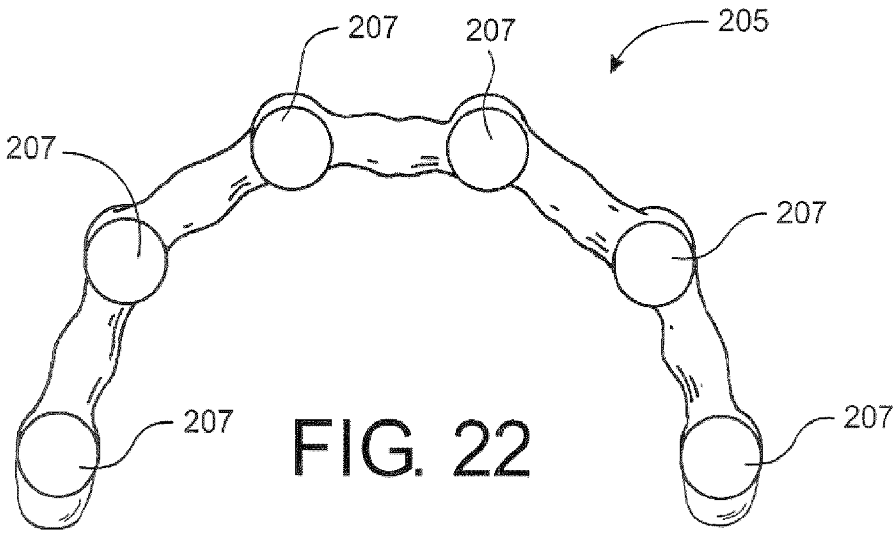


FIG. 22

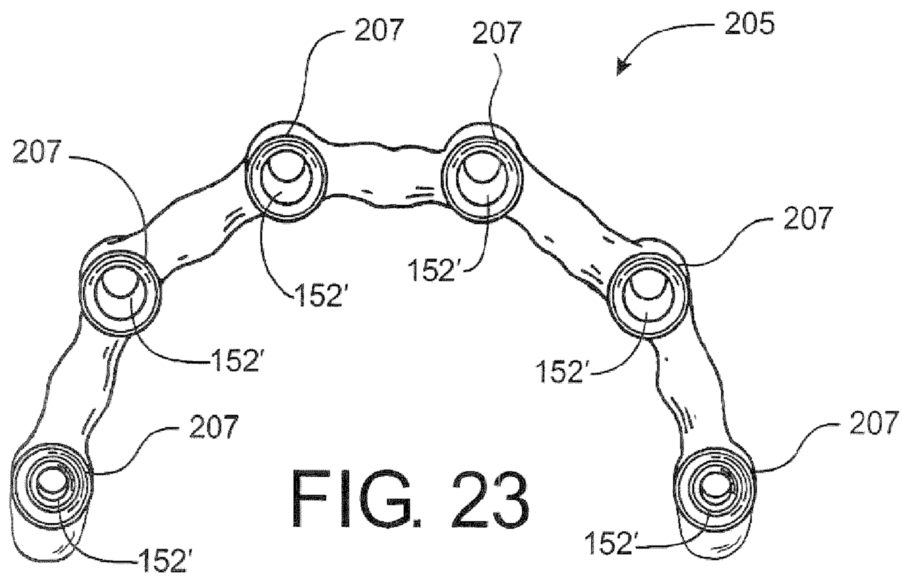


FIG. 23

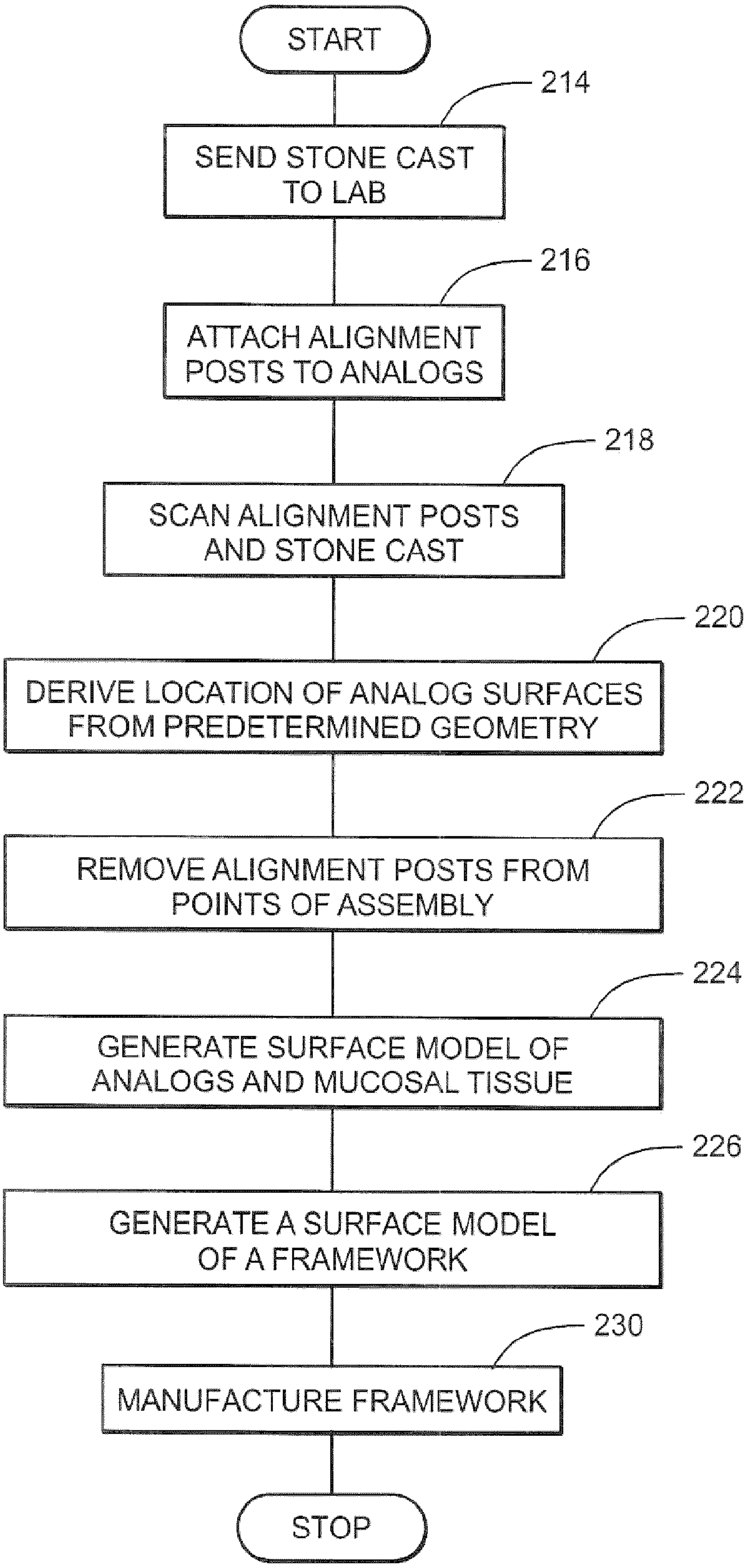

START
214
SEND STONE CAST TO LAB
216
ATTACH ALIGNMENT POSTS TO ANALOGS
218
SCAN ALIGNMENT POSTS AND STONE CAST
220
DERIVE LOCATION OF ANALOG SURFACES FROM PREDETERMINED GEOMETRY
222
REMOVE ALIGNMENT POSTS FROM POINTS OF ASSEMBLY
224
GENERATE SURFACE MODEL OF ANALOGS AND MUCOSAL TISSUE
226
GENERATE A SURFACE MODEL OF A FRAMEWORK
230
MANUFACTURE FRAMEWORK
STOP

FIG. 24

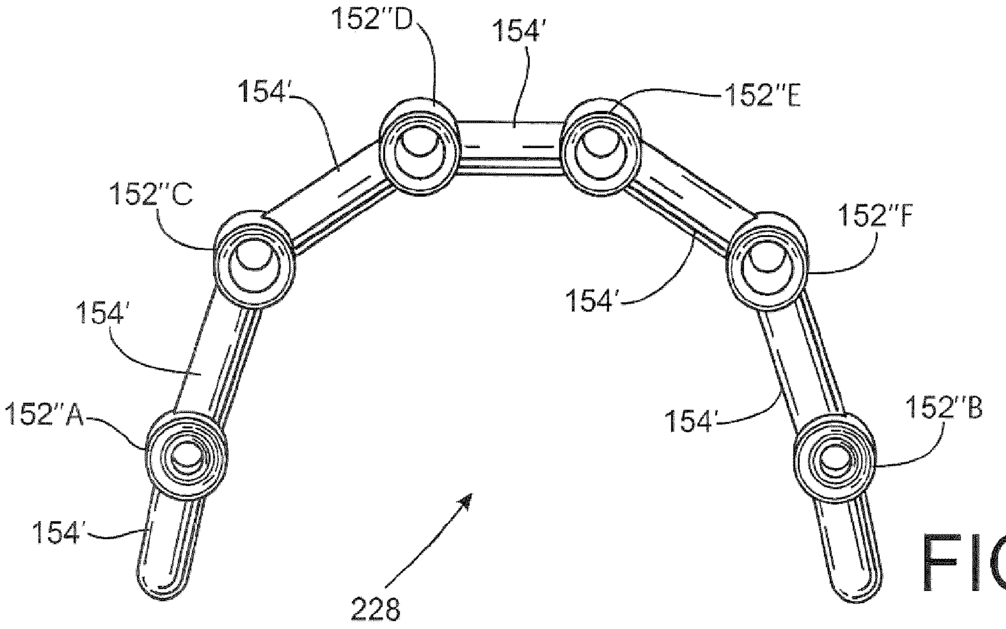
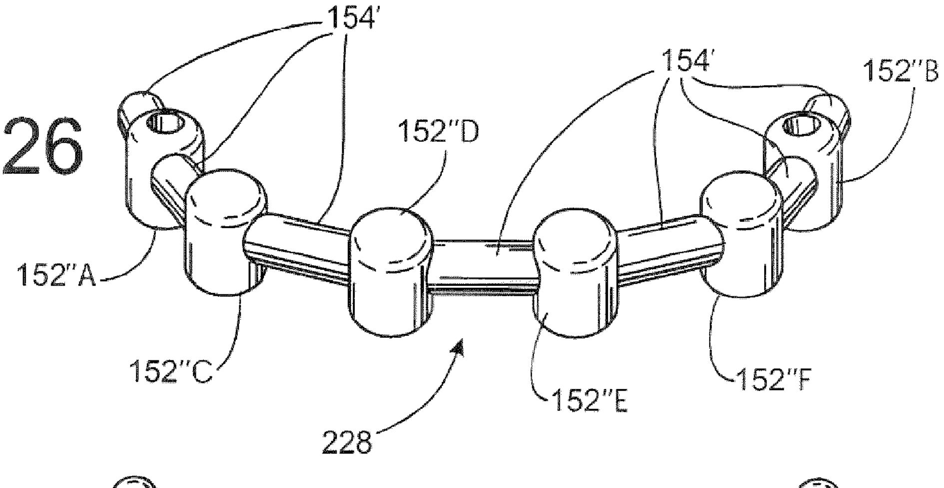


FIG. 25

FIG. 26



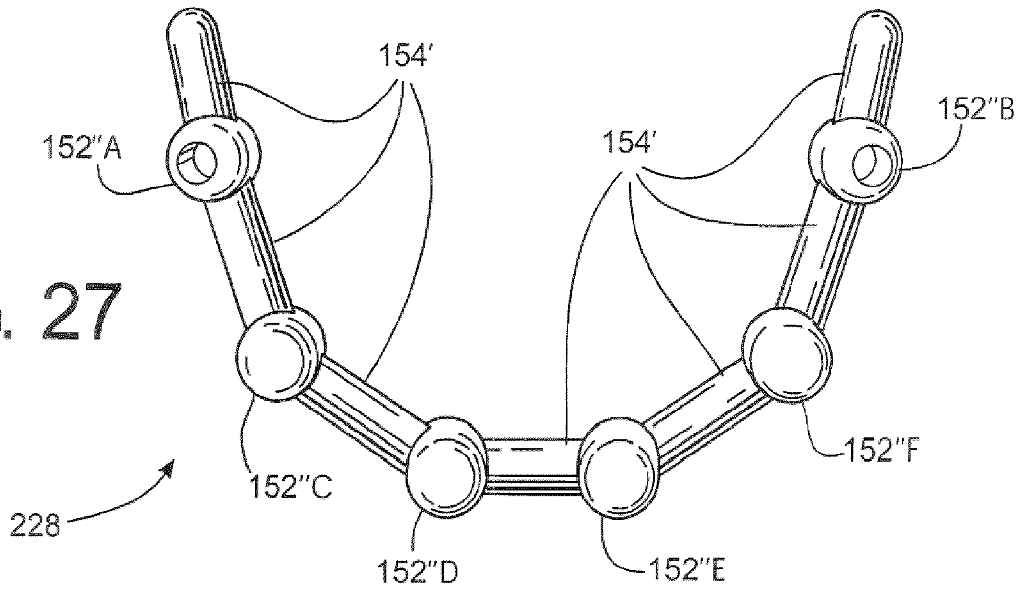


FIG. 27

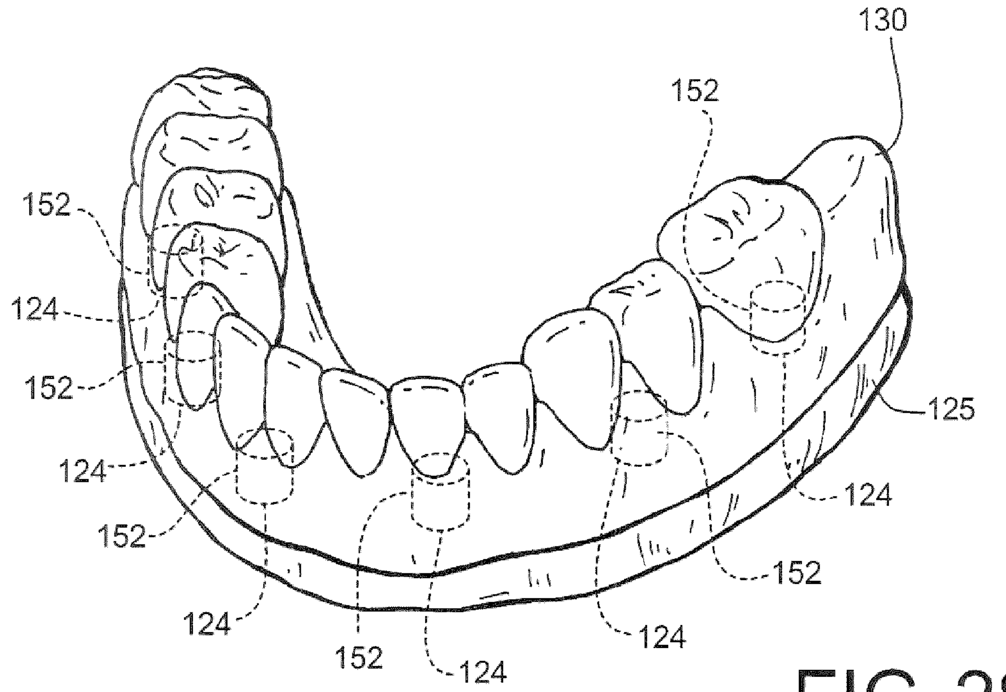

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FIG. 28

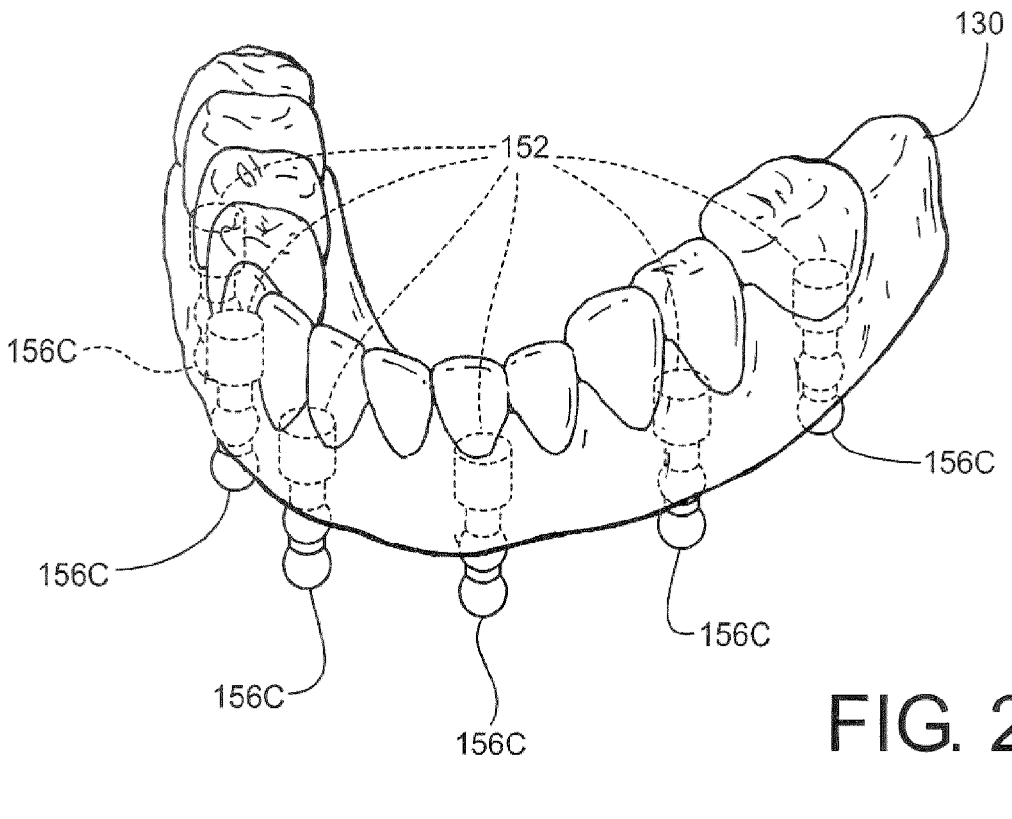
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FIG. 29

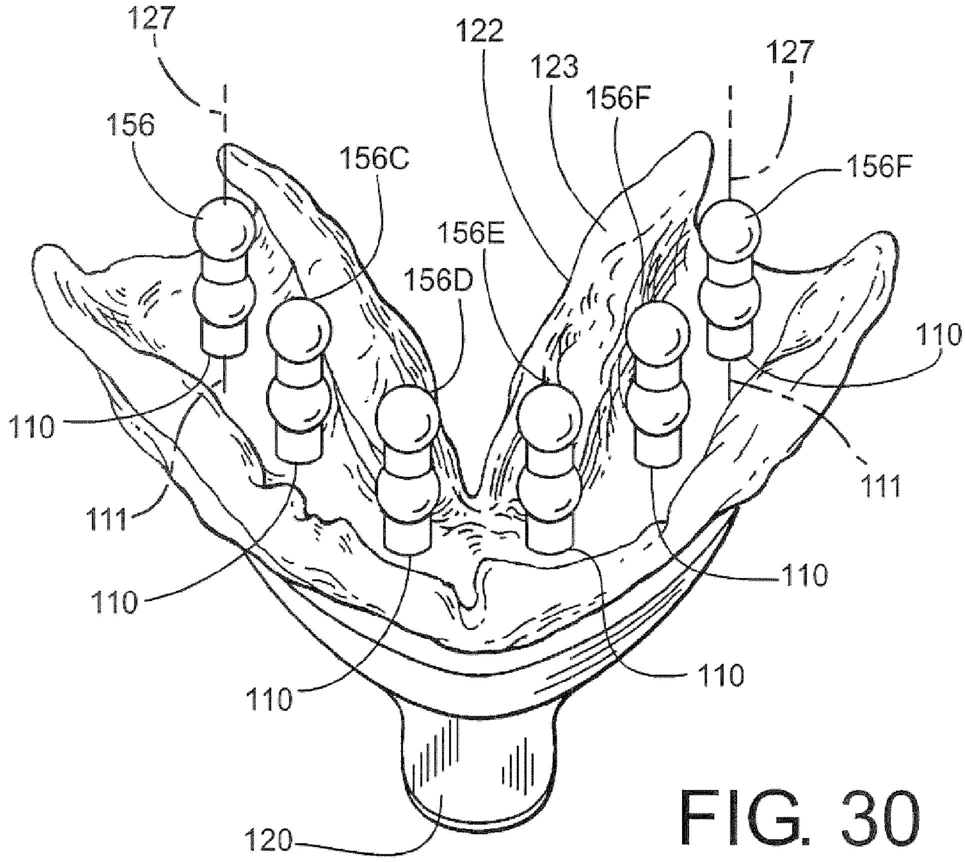
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FIG. 30

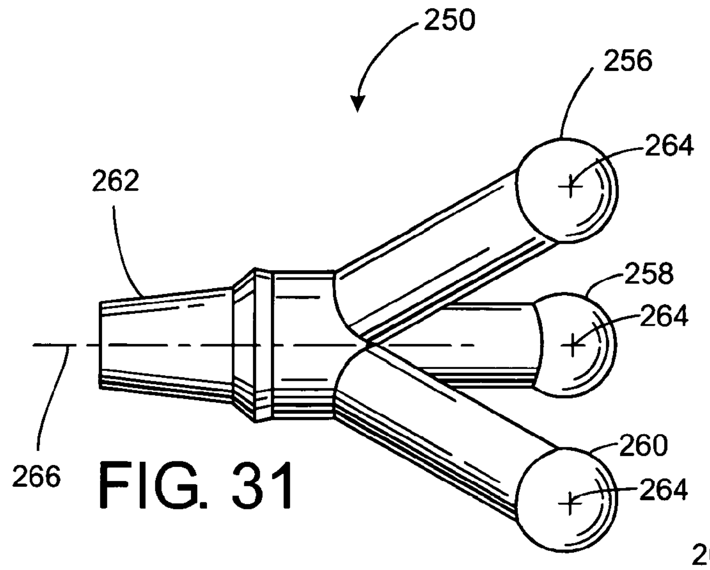

FIG. 31

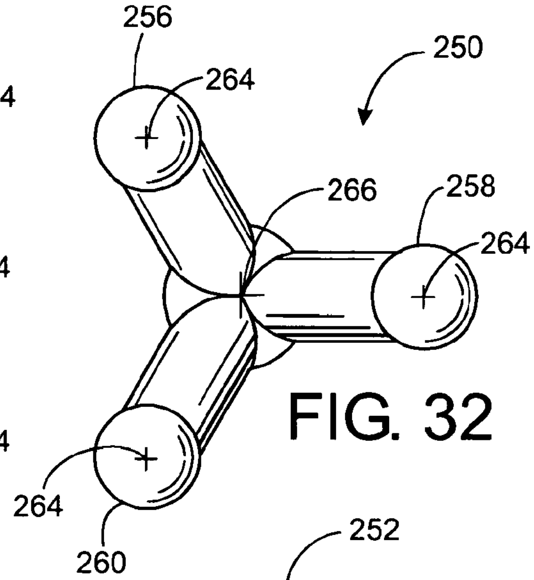

FIG. 32

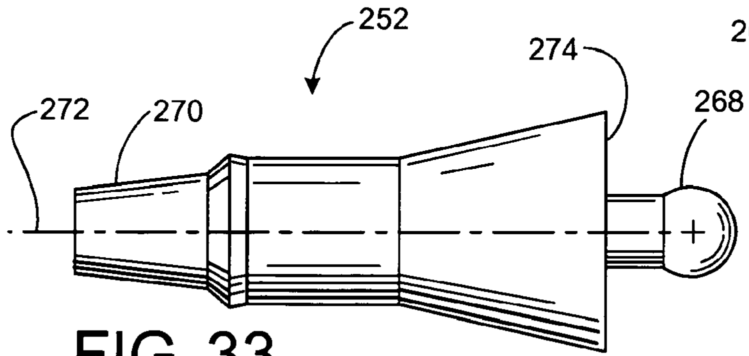

FIG. 33

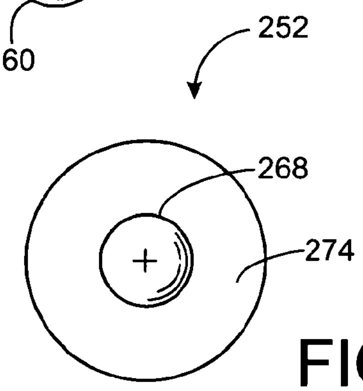

FIG. 34

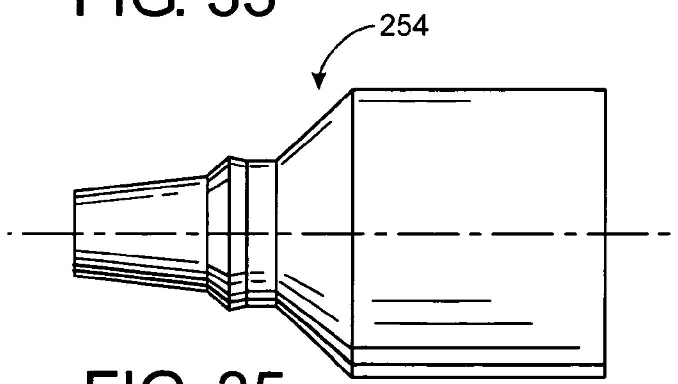

FIG. 35

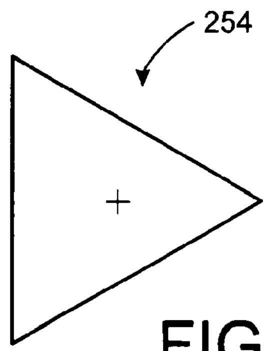

FIG. 36

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/078275

A. CLASSIFICATION OF SUBJECT MATTER

A61C 13/00(2006.01)i, A61C 8/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: A61C 13/00, A61C 8/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKIPASS(KIPO internal) & keywords : dental framework, toolpath, analog, digital scanning, stone cast

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5630717 A (MAX ZUEST and PAUL ZUEST) 20 May 1997 See Abstract; Figs. 1-14; Claims 23-35	1-25
A	US 2003/0108845 A1 (PAUL L. GIOVANNONE and ROBERT D. HICKS) 12 June 2003 See Abstract; Figs. 1-9; Claims 18-19	1-25
A	US 6322364 B1 (YOSHIKI OSHIDA and MARTIN THOMAS BARCO II) 27 November 2001 See Abstract; Figs. 1-5	1-25
A	US 5885078 A (DAVID R. CAGNA et al.) 23 March 1999 See Abstract; Figs. 1A-3D; Col.4 Lines 40 - 63	1-25
A	US 6905336 B2 (ROBERT SUMMERS) 14 June 2005 See Abstract; Figs. 1-12; Claim 1	1-25

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 MARCH 2009 (30.03.2009)	**31 MARCH 2009 (31.03.2009)**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea	OH Seung Jae
Facsimile No. 82-42-472-7140	Telephone No. 82-42-481-8469

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2008/078275

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5630717 A	20.05.1997	None	
US 2003-108845 A1	12.06.2003	None	
US 6322364 B1	27.11.2001	AU 1467300 A	29.05.2000
		AU 2000-14673 A1	29.05.2000
		US 6116070 A	12.09.2000
		WO 00-27556 A1	18.05.2000
US 5885078 A	23.03.1999	None	
US 6905336 B2	14.06.2005	US 2004-0018469 A1	29.01.2004