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COMPUTER IMPLEMENTED MODELLING OF A PATIENT-SPECIFIC DENTAL RESTORATION

The invention comprises a computer-implemented method for modelling an individual patient denture part, a computer program product and a computer system and processing system to implement the method.

Denture parts are usually made by machine or completely by hand. Because in addition to precise measurement of the denture part, the aesthetic appearance of which in particular plays an important role in interaction with the conditions of the patient's teeth, in which the relevant denture part is to be used, even in the case of machine production, there is usually finishing by hand. Because in general no two patient sets of teeth are identical, there are high demands for modelling an individual patient denture part which should precisely fit both with regard to dimensions as well as appearance. Therefore, even in the case of a machine-made denture part, normally there is modelling of the relevant denture part using computer models. In this, the known modelling methods prove to be time consuming and unwieldy. Thus each change to the model must be done by hand. There may be repeated changes to the model leading to the previously adjusted partial area of the model not fitting any more as the result of the subsequent change and which must then be compensated for.

DE 10 2011 005899 A1 describes a method for processing of a denture part using virtual three-dimensional tooth model created in planning of a set of dentures using a virtual tool. The first virtual tooth model will be processed using the virtual tool, wherein during the processing using the virtual tool, the first virtual tooth model is automatically adjusted using a computer, so that certain basic conditions remain fulfilled during the planning of the dentures.

US 2018/085203 A1 describes a computer-implemented method to design a tooth restoration on a display, wherein the method comprises the provision of a virtual three-dimensional representation of at least on part of the patient's tooth situation. The method comprises the display of a virtual three-dimensional tooth restoration model in an execution with the virtual three-dimensional representation. The method also comprises the provision of a draft tool that can be selected to shape at least one part of the three-

dimensional tooth restoration model. When this design tool is selected, a line can be drawn on one surface of the three-dimensional tooth restoration model.

US 2013/282351 A1 describes a method to determine virtual tooth restorations based on scan data of oral structures, wherein a model database is used that comprises a number of parameterized tooth models for each of multiple tooth types, wherein the parameterization is performed based on model parameters, which comprises position parameters and/or shape parameters, and wherein each tooth model is linked to a number of tooth types equal to the tooth model, and wherein for each desired tooth type an optimal tooth model is determined in the model database using an iterative method, for which initially at least one starting tooth model of the desired tooth type is selected from the model database and then starting from this tooth model, it is checked in each step of iteration that a tooth model has a quality value, wherein for the purpose of an individualization the currently tested model is adjusted to the scan data by variation of model parameters and wherein a quality value is calculated for this individualization.

EP 2 134 290 A1 describes a method for automatic or semi-automatic planning of a dental treatment for a patient which comprises: (a) Collecting data about an area to be treated and data about a patient's face; (b) Implementation of a computer-aided analysis of the data to determine the characteristics of at least the face of the patient; (c) Creation of a modified tooth configuration using a set of saved rules, which use the collected facial characteristics. A three-dimensional representation simulates the appearance of the modified tooth configuration and the face of the patient that surrounds the treatment area.

The invention is based on the object of enabling an improved method for modelling denture parts.

The object on which the invention is based is solved using the characteristics of the independent patient needs. Embodiments of the invention are indicated in the dependent claims.

The invention comprises a computer-implemented method for modelling an

individual patient dental part, wherein the method comprises:

- providing a digital three-dimensional patient situation model, wherein the patient situation model defines patient-specific delimiting surfaces of one or more objects of a set of the patient's teeth which define a patient situation geometry to which the denture part is to be adapted during the course of the modelling,
- providing a first digital three-dimensional denture part model in a starting state, wherein the first denture part model defines denture part-specific delimiting surfaces of the denture part which define a denture part geometry,

wherein the first denture part model, in the starting state, has a denture part geometry in the form of a starting geometry,

- providing one or more geometric adaptation criteria defined using the patient-specific delimiting surfaces, which criteria must be satisfied by the denture part-specific delimiting surfaces during the course of a patient-individualised adaptation of the denture part geometry to the patient situation geometry,
- patient-individualized adaptation process comprises arranging the first denture part model in a starting position provided by the patient situation model,

wherein the patient-individualized adaptation process also comprises an arrangement of the first denture part model in a patient situation model for the starting position provided for the denture part,

wherein the patient-individualized adaptation also comprises a repeated implementation of user-defined changes to the arranged first denture part model, wherein the first denture part model dynamically passes through a sequence of intermediate states during the course of each of the user-defined changes until a change state resulting from each user-defined change is reached, wherein for each of the corresponding intermediate states and also the resulting change state, a state-specific state geometry of the first denture part model is automatically calculated from the starting geometry of the first denture part model whilst satisfying the geometric adaptation criteria,

wherein each of the user-defined changes is displayed by means of a graphical user surface on a display device, wherein each display of a user-defined change comprises a display of the first denture part model dynamically passing through the relevant sequence of intermediate states until the corresponding change state has been reached through the first denture part partial model with the relevant state-specific state geometries calculated for this,

- using a change geometry resulting from the patient-individualised adaptation of the first denture part model to provide a patient-individualised denture part geometry for the production of the patient-individualised denture part.

Embodiment models may have the advantage that they enable a user to adapt a digital three-dimensional denture part model starting from a starting state to the individual conditions of the patient situational geometry. A patient situational geometry is defined by one or multiple objects arranged in a patient mouth, to which the denture part model is adapted. The proscribed geometric adaptation criteria ensure that each user-defined change is done while adhering to the relevant adaptation criteria. In other words, one can prevent that a state is set by a user-defined change of the denture part model that violates a geometric adaptation criterion. Embodiments have the advantage that one can hinder that rectifications need to be made on the denture part model as a result of user-defined changes, in order to fulfil the relevant adaptation criteria. Thus the problem of a user-defined changes leading to rectifications being necessary to re-fulfil a previous adaptation criteria previously fulfilled by previous changes which violated a state can be avoided. Such rectification may lead to the previous user-defined change at least being made retroactive, so that this must be partially repeated, which may then lead to problems with the fulfilment of the relevant adaptation criterion. Through a fixed simulation of the relevant geometric adaptation criteria, one can ensure that an extensive iterative approximation of the simultaneous fulfilment of the relevant adaptation criteria on the one hand and user-defined changes to the individual patient adaptation of the denture part model on the other can be avoided.

In addition, a display of a dynamic run of a sequence of interim states allows the user to have a better understanding of the outside influences of the user-defined changes

they perform. In particular, the user can recognize whether one of the dynamic run interim states represents the advantageous change status of the denture part model they desire. If this is the case, the user can return one part of the user-defined changes to the relevant interim state. This can significantly increase the manageability of the method and significantly reduce the processing time.

There is an advantage in particular in this that both for the interim states and for the resulting change state, the state-specific state geometry is automatically calculated from the initial geometry. In other words, a calculation of the state geometry of the interim states and/or the change state is made from the initial geometry. Calculation of the individual state geometries from the initial geometry can ensure that all of the user-defined changes made by a user can be reversed without problem. This can in particular make an adaptation of the denture part model to a previous interim state easier. In particular, a situation can be avoided in which the user feels obliged to start the modelling from the beginning, because a combination of user-defined changes made by them cannot be reversed. This situation may arise in particular if from state to state an adaptation of the denture part model is calculated using numerical approximation methods. Thus, for example, as a result of numeric effects, such as rounding errors, it may be that without a fixed reference state for the denture part model, changes cannot fundamentally be totally reversed. In this case, a fixed reference state in the form of the initial geometry is provided. Embodiments can thus enable a significantly easier to use and more rapid modelling of individual patient denture parts.

Embodiments can also have the advantage, because the change state is made individually based on the starting geometry, that for every change state, a set of change data can be created that define the changes in the starting geometry for the changes made relevant to the change status. Such a set of changes enables changes to the first denture part model in a simple form to be transferred to a second denture part model. For example, the changes defined in the set of change data are used for the second denture part. Because these are changes directly calculated from the starting geometry, numeric and/or denture part model-specific inaccuracies can be reduced in the transfer.

The previously described advantages are particularly important when a plurality of

denture parts, in particular parts that are dependent on each other are to be modelled.

A denture part is understood as any form of object to be inserted in or on a patient's set of teeth, which replaces and/or supplements one or more lacking or present natural teeth and/or one or more parts of them. Denture parts may be, for example, bridges, inlays, overlays, crowns or the like. Denture parts are made of a denture material, such as of ceramics, such as zinc oxide ceramic, aluminium ceramic, of metal or metal alloys. For example, CrCo alloys, gold or gold alloys. In addition, denture material may also comprise plastic.

A denture part geometry means a geometric form formed by denture part-specific delimiting surfaces and/or forms of a denture part model. These forms can be quantitatively described by geometric dimensions or proportions of geometric dimensions, such as distances, lengths, widths, height, angle, points, surfaces or volumes. A denture part model can be created from a collection of predefined denture part models, meaning a library, or be created for a concrete use case. In this, physical objects of a patient's set of teeth are used as a template for a digital three-dimensional model or even existing patient-specific digital three-dimensional digital models can be used as a template and/or starting model.

A patient situation geometry means a geometric form formed by patient-specific delimiting surfaces of one or more geometric forms formed by the present objects of a patient's set of teeth and/or those to be supplemented and/or forms of a patient situation model or the relevant models of the patient's teeth comprised in the patient situation model. These forms can be quantitatively described by geometric dimensions or proportions of geometric dimensions, such as distance, lengths, widths, height, angle, points, surfaces or volumes. A patient situation model represents teeth status and/or a state of one or more parts of a patient's teeth, into which the denture is to be fitted or to which it will be adapted. The patient situation model is dependent on, for example, a measurement of a patient's teeth and/or one or more parts of a patient's teeth.

According to embodiments, there is a display of the user-defined changes simultaneous to their entry. Embodiments may have the advantages that the user can

immediately receive a visualisation of the adaptations made by him. The calculation of intermediate states and the resulting change state is done on-the-fly in real time.

According to embodiments, the adaptation of the denture part geometry is defined while maintaining the morphological features defined by the starting geometry and which are characteristic for the denture. Embodiments may have the advantage that the relevant denture part always retains it functional and/or aesthetic basic character.

According to embodiments, the provision of the resulting change geometry comprises the use of the resulting change geometry as a patient-individualised denture part geometry. Embodiments may have the advantage that the resulting change geometry may be used indirectly as the patient-individualised tooth geometry, such as for creating the denture using a suitable processing method, such as a CAM method or a Rapid Prototyping method. In this there may be a chip removing method, such as CNC milling or an additive process method such as 3D printing.

According to embodiments, the provision of the resulting change geometry comprises a transfer of the resulting change geometry to a second digital three-dimensional denture part model, wherein the second denture part model has a higher resolution than the first denture part model. Embodiments may have the advantage that they enable a multi-level modelling of patient-individualised denture parts. In this, the accuracy of the modelled denture part increases level by level. So, for example, on a first modelling level, a first digital three-dimensional denture part model can be used with a first resolution. This resolution may be a comparatively rough resolution, which enables a rapid adaptation of fundamental measurements of the denture part model to the conditions of a patient situation geometry with low calculation effort. The resulting change geometry can then be transferred to a second denture part model with a higher resolution than the first denture part model. In other words, the user can use the changes previously made. On the second denture part model, a fine adjustment can be made for the relevant conditions of the patient situation geometry.

According to embodiments, the geometric adaptation criteria set forth one or more permitted maximum and/or minimum values for positive and/or negative distances or

offsets between patient-specific delimiting surfaces of the patient situation model and denture part-specific delimiting surfaces of the denture part model. Embodiments may have the advantage that through the geometric adaptation criteria it can be ensured that each of the calculated state-specific state geometries of the denture part model fulfils one or more of the fundamental geometric relationships with regard to patient-specific delimiting surfaces. A negative distance is a distance between a patient specific delimiting surface and a denture part-specific delimiting surface, wherein the denture part-specific delimiting surface extends within the patient situation model. A positive distance is a distance between a patient-specific delimiting surface and a denture part-specific delimiting surface, wherein the denture part-specific delimiting surface extends outside of the patient situation model.

According to embodiments, the patient-specific delimiting surfaces are delimiting surfaces of one or more antagonists in the patient situation model, one or more approximal teeth comprised in the patient situation model and/or one or more of the denture parts of the patient situation model. According to embodiments, one or more of the permitted maximum and/or minimum values are zero. Embodiments may have the advantage that a penetration of delimiting surfaces of the denture part model and the patient situation model can fundamentally be ruled out.

According to embodiments, the geometric adaptation criteria set forth one or more permitted minimum values for positive distances between the dental part-specific delimiting surfaces of the denture part model. In other words, the geometric adaptation criteria set forth a minimum material strength for the dental part model.

According to embodiments, the geometric adaptation criteria defined using the patient-specific delimiting surfaces must meet at least one of the following state-specific state geometries calculated during the patient-individualised adaptation of the denture part geometry: the material strengths of the dental part model limited by the delimiting surfaces may not fall under a pre-defined minimum value, maximum penetration depths of delimiting surfaces of the denture part model and delimiting surfaces of the patient situation models do not exceed a pre-defined maximum value, minimum distances between delimiting surfaces of the denture part model and delimiting surfaces of the

patient situation module do not fall below a pre-defined second minimum value.

For example, it is set forth that a material strength of the denture part model may not fall below a pre-defined minimum value. Embodiments may have the advantage that long life and high stability of the denture part can be ensured. In particular, it can be ensured that parts of an object of the patient's teeth, such as a tooth stump, do not penetrate the denture part model completely as a result of a shift of the denture part model and partially protrude from it. If a distance between two delimiting surfaces are reduced so far as a result of user-defined changes so that this meets the pre-defined first minimum value, a further approximation of the relevant delimiting surfaces can be prevented. Much more, the distance can be kept constant at the relevant minimum value and additional changes made through a geometric deformation of the denture part model. If a user, for example, shifts the denture part model within the patient situation geometry, there may be a situation in which the crown of the denture part model is pushed further forward, but a lower section of the denture part model but remains in place or partial areas of delimiting areas of the lower section stay in place.

According to embodiments, for the delimiting surfaces of the patient situation model for which the maximum penetration depths or minimum distances are limited by delimiting surfaces of one or more of the antagonists comprised in the patient situation model, one or more of the approximal teach comprised in the patient situation model and/or one or more of the dentures comprised in the patient situation model.

For example, it can be determined that the maximum penetration depths of delimiting surfaces of the denture part model and delimiting surfaces of the patient situation model do not exceed a pre-defined maximum value. In this, for example, it can be determined that no penetration is permitted or, if a relevant penetration is permitted, this can be limited to a permitted maximum value. A limited penetration between denture part model and patient situation model can, for example, be permitted between the denture part model and an antagonist. For this, a minimum penetration may be sensible to ensure a contact feeling between the patient when biting and effective chewing. In addition, an unlimited penetration during modelling may be sensible, to initially adjust the denture part model as a whole to a patient situation geometry and to locally alleviate

remaining minimal penetration during fine adaptation at the end of the modelling method. This may happen, for example, through a local deformation of the surface geometry of the denture part model or through local removal of material of the denture part model.

For example, it can be determined that maximum distances between delimiting surfaces of the denture part model and delimiting surfaces of the patient situation model do not exceed a pre-defined maximum value. Embodiments may have the advantage that it can be ensured that distances between denture part model and patient situation model do not become too great.

For example, it can be determined that maximum distances between delimiting surfaces of the denture part model and delimiting surfaces of the patient situation model do not fall below a pre-defined maximum value. Embodiments may have the advantage that a distance between the denture part model and the patient situation model cannot be made too small.

If a set limit value is achieved through one of the adaptation criteria, it can be defined, for example, that additional user-individualised changes to the denture part model are enabled through a deformation of the same under the maximum, so that the adaptation criteria are met.

Embodiments may have the advantage that a penetration of delimiting surfaces of the denture part model and the patient situation model can fundamentally be ruled out.

According to embodiments, the geometric adaptation criteria are structured hierarchically. In the case of geometric adaptation criteria not compatible with one another, individual geometric adaptation criteria receive precedence in the hierarchical structure over one or multiple other geometric adaptation criteria. Embodiments may have the advantage that conflicts between geometric adaptation criteria can be solved using the hierarchical structure. For example, the selection criterion of maintaining a minimum value for the material strength may be weighted higher than the adaptation criterion for limiting the penetration depth. For example, if there is a contradiction

between two adaptation criteria, the hierarchically lower adaptation criterion can be softened, so for example, in the case of a contradiction between minimum material strength and the maximum permitted penetration depth, the maximum permitted penetration depth can be increased. A violated adaptation criterion as a result of such a conflict may be alleviated for example during a fine adaptation of the denture part model at the end of the modelling process. So, for example, a desired penetration through a local deforming or material removal from a denture part model can be solved.

According to embodiments, the display of the user defined change occurs in real time. Embodiments may have the advantage that a user sees immediately which effects user-defined changes have and can quickly and effectively make adjustments.

According to embodiments, the user-defined changes comprise at least one of the following changes defined by interactive user entry: a scaling of a stretch of the denture part model along a pre-defined direction of the denture part model, a shift of the denture part model relative to the patient situation model and a rotating of the denture part model relative to the patient situation model.

According to embodiments, the entry of the user-defined changes comprises a selecting and interactive processing of at least a partial area of a delimiting surface of the denture part model visually displayed on the graphic user interface using one of the interactive digital processing tools provided by the graphic user interface.

According to embodiments, the interactive processing comprises deforming an area and/or trimming a volume portion of the denture part geometry delimited by the area.

A deforming can have the advantage that a general form of the denture part is mostly retained. Embodiments may have the advantage that local adaptations can be made while the general shape of the tooth can remain unchanged. In particular, smooth transitions between various areas of the delimiting surfaces can be ensured.

Trimming a delimiting surface, possibly with offset, may have the advantage that

the denture is changed very little or not at all outside of the trimmed area. Thus, for example, so-called facet surfaces or ground surfaces on teeth can be retained. Embodiments may have the advantage that local adaptations of the dental part model are enabled, while the rest of the geometry remains unchanged to the greatest extent possible.

Through local trimming and/or deforming, for example, touch contacts, such as approximal and/or occlusal, can be optimized. Thus, for example, a bite contact of an occlusal delimiting surface of the denture part model with occlusal delimiting surface of antagonists of the denture part in the patient situation model can be optimized.

According to embodiments, the entry of the user-specific changes is done using an input device. The input device comprises for example a mouse, a keyboard, a touch pad, a touch screen, an entry pen or stylus, a three-dimensional haptic input device and/or a device for gesture recognition. According to embodiments, the input device uses the interactive processing tool on the graphic user interface for control. According to embodiments, the interactive digital processing tool comprises a pointer to select a partial area of a surface and moves the selected area on the graphic user interface. Moving can be done for example as a drag-and-drop function. The pointer can have any type of form, in particular it can be designed as a tool that symbolised processing options provided by the pointer or interactive digital processing tool. According to embodiments, the processing comprises a local application of material, removal or material, smoothing of fissures and/or deepening of fissures. According to embodiments, a point on the surface is selected. According to embodiments, the partial area is selected using the paintbrush function.

According to embodiments, in the digital three-dimensional denture part model, one or more areas are defined specific to function. Partial areas comprise, for example, cusps, cusp tips, fissures, chewing surfaces etc. According to embodiments, its pre-defined for one or more of the function-specific defined partial areas for whether these can be changed, such as mobile, or are unchangeable, such as to be retained in their original shape and/or position. According to embodiments, the user may be able to determine using user input or hot keys whether the function-specific defined areas can

be changed and/or in which scope the relevant areas can be changed or whether the relevant areas cannot be changed.

According to embodiments, input is made of the user-defined change indirectly using hot keys, numerical values or other 2D control elements, wherein an intermediate algorithm performs a change to the digital three-dimensional denture part model depending on the entry. A change may be a change to an articulator state, shrinking, expanding and/or tooth ageing or flattening.

According to embodiments, the entry of the user-defined changes comprises setting a settable material application value, to add or remove material on the selected area of the first denture part model, such as a crown or part of the crown. According to embodiments, the material application value may be positive, in the case of material addition, or negative, in the case of material removal.

Embodiments may have the advantage that a removal and/or addition of material can be done in real time and assessed by the user. Thus, for example, a necessary layer thickness can be quickly estimated for a ceramic veneer on the denture part to be created.

Material removal or shrinking and material application or expansion are not technically scaling. This is about a movement of an area or surface of the denture part model by a constant distance value relative to the centre of the denture part model, meaning for each point on the area. In this, the constant distance value is independent from the distance to the centre.

According to embodiments, pre-defined areas of the denture part model are changed by removing and/or applying material. For example, if these areas are aesthetically relevant areas which, for example, are to be faced. Aesthetically relevant areas are areas of a denture part model representing the areas of the denture part to be repaired, which are regularly visible in an arrangement of the denture part in the patient's set of teeth during normal mouth movements.

According to embodiments, the arrangement of the denture part model in the

starting position comprises an automatic adaptation of the denture part model to a preparation limit for the denture part defined in the patient situation model. Embodiments may have the advantage that, preparation limits are always met as defined by the patient situation model. Thus, in particular one can prevent that, as a result of a user-defined change to the denture part model, rectification must be made to adhere to the preparation limit. An appropriate preparation limit could be determined by the user at the start of the method and adapted to patient-individualised conditions of the patient situation model.

According to embodiments, the method also comprises:

- selection of a change state for the first denture part model,
- simulation of a chewing motion for the selected change state of the first denture part, wherein the simulation of the chewing motion comprises a calculation of a dynamically run sequence of relative positions of the denture part model to an antagonist of the denture part model determined by the patient situation model, wherein for each of the relative positions, using the graphic user interface on the display device, on which at least one occlusal delimiting surface of the denture part model and an occlusal delimiting surface of the antagonists are displayed.

Embodiments may have the advantage that a virtual articulator is provided, using which the effects of adaptations of the denture part model can be simulated on the dynamic chewing movement of the patient. Thus one can ensure that an adaptation of the denture part not only is suitable not only for a single relative positioning compared to the antagonist, but also for relative positioning during a chewing movement.

According to embodiments, for the individual relative positions the dynamic sequence of the areas of the occlusal delimiting surfaces of the denture part model is displayed, which penetrate the occlusal delimiting surface of the antagonist. According to embodiments, the chewing movement is a generic chewing movement. According to embodiments, the chewing movement is a patient-individualised chewing movement.

During the simulation of the chewing movement, for example, the antagonist is influenced in its relative position to the denture part or expanded and/or modified. For

example, during the simulation of one or more pre-determined positions which are not superimposed, are initiated with trajectories and adapted to the relevant pre-determined positions as positions of the antagonist. This is the case, for example, when a user selects a jaw movement potion previous calculated by the virtual articulator using the slider and then immediately receives a result for the relevant position on the display.

For example, during a simulation of a new virtual antagonist as a superimposition of the many antagonist positions summarised by the trajectories is created and then displayed as individual movements of the counter bite as a virtual imprint. In this case, a new artificial delimiting surface is crated from an enveloping surface of all jaw movement trajectories.

A virtual articulator designates a simplified digital simulation of a real articulator, which represents a dental device for the simulation of a chewing movement with normal movement trajectories, e.g. laterotrusion left/right, retrusion, etc. Alternatively, trajectories of the jaw can be loaded from the patient measurement systems and used for the movement of the antagonist.

Embodiments may have the advantage that a dynamic interaction of the denture part model with antagonists in the patient situation geometry can be considered during chewing. In particular, an adaptation of the denture can be made for various interaction situations.

According to embodiments, the provided denture part model in the starting position is a generic model for the denture part. Embodiments may have the advantage that generic models can be used, which determine fundamental geometric conditions, such as distance ratios between points of the dental part model. During modelling, a relevant generic model can be adapted to the conditions of a patient-individualised patient situation model. In this, the generic conditions of the underlying generic model can be adhered to, for example. Relevant generic denture part models are, for example, provided in the form of libraries from which these can be loaded.

According to embodiments, the provision of the denture part model in the starting

state comprises selecting and copying a tooth and/or part of the tooth comprised in the patient situation model. According to embodiments, the provision also comprises a mirroring. Embodiments may have the advantages that when modelling a denture part, one can assume a denture part model that is at least partially adapted to the patient-individualised conditions of the patient situation model. This type of previously adapted denture part model may have the advantage that through this the adaptation process is shortened. Embodiments may have the advantage that one can use patient-individualised objects that are already present.

According to embodiments, the provision of the denture part model in the starting position comprises selecting and copying a patient-individualised denture part already adapted to the patient situation model. According to embodiments, the provision also comprises a mirroring. Embodiments may have the advantage that one can use patient-individualised objects that are already present.

According to embodiments, the objects of a patient's set of teeth may comprise one or more of the following objects: a tooth, a tooth stump, gum tissue, a denture, an implant, a tooth retention apparatus, a locator, an occlusal guard, a bridge, a prosthesis or a partial prosthesis, a cast model prosthesis, a temporary denture, filling or inlay. A tooth retention apparatus is a functional anchoring system for a tooth, which is also known as an attachment. A locator is an assembled connection element to connect a removable denture to an implant. An occlusal guard is an overlay similar to a prosthesis adapted to the dental arch, in particular made of plastic, which is used, for example, for the treatment of myoarthropathies. A bridge is used, for example, to secure a bridge prosthesis. The bridge has a retention and/or supportive function to hold and/or support the bridge prosthesis. This type of bridge can have a round or rectangular cross section. A bridge serves to interlock at least two teeth or implants, wherein the bridge can be secured to root caps, anchor crowns or suprastructures. For example, multiple bridges can be connected to each other.

According to embodiments, the method also comprises repair of the patient-individualised denture using the change geometry determined by the patient-individualised denture part geometry.

According to embodiments, the patient specific and denture part specific delimiting surfaces are implemented using one of the following methods: a polygonal mesh structure, wherein vertices of the relevant mesh structure and/or points within the polygons of the mesh structure define the corresponding delimiting surfaces, a point cloud, wherein the points of the point cloud define the corresponding delimiting surfaces, a 3D volume data structure which comprises a voxel grid, or a 3D signed distance field.

According to embodiments, the number and increments of the dynamic sequence will depend on a desired target frame rate for the displayed animation or depend on a change expected visually. Thus one can avoid unnecessarily overloading the computer and simultaneously ensure the best possible interactivity. For example, to accelerate a movement, fewer intermediate steps can be calculated. Conversely, to accelerate a movement for a fine adjustment, more intermediate steps can be calculated.

Embodiments have the advantage that on the one hand, a high degree of interactivity can be guaranteed, while on the other, the computing time can be reduced. In addition, through a reduction in the number of intermediate steps, running through the dynamic sequence can be increased, through which a more rapid adaptation of the denture part model is possible.

According to embodiments, pre-defined areas of the denture part model can be kept outside of an interface. The relevant interfaces are, for example, pre-defined or can be set by the user. Embodiments may have the advantage that only a size-related limited transition area outside of the pre-defined area is elastically deformed. To be able to pull a dental cusp tip until it is arranged in a suitable position in the opposing jaw chewing surface, the dental cusp itself cannot be deformed too much if this is a relevant pre-defined area.

According to embodiments, neighbouring dental part models arranged in the same jaw or in the opposing jaw mutually influence each other, in order to retain the optimal dental shape. In this, for example, the upper jaw may receive priority over the lower jaw and denture parts to be arranged in front of the set of teeth can have priority for aesthetic

reasons over dentures to be placed further back. For example, there may be mixed forms, for which the priority is defined by percentage. In this one can determine which of the influencing denture parts receive more or and which less. Embodiments may have the advantage that through a determination of priorities, conflicts between mutually influencing adaptations of denture part models can be solved.

According to embodiments, one or more of the denture parts selected by the user can be fixed on the delimiting surface of the patient model, possibly with offset or nestled against it. Thus, for example, a contact surface between a denture part and an antagonist can be compelled at certain positions. At the same time, optionally other denture parts can have no contact to the same delimiting surface, possibly with an offset, e.g. in order to leave enough distance for the dental cusps or fissures of the corresponding denture part from the antagonist. Embodiments may have the advantage that different adaptation requirements are fulfilled in different areas of a denture part model and/or different denture part model.

According to embodiments, the interfaces for patient-specific and/or denture part-specific delimiting surfaces can be defined by the user for geometrically created objects. For example, a digital interface in the form of one level can be loaded and put in place, perhaps in the form of Spee-Wilson curve. In additional, a digital interface, e.g. from a library can be loaded. For example, a calotte from a library is loaded and put in place. A calotte serves as a levelling aid for jaws with no teeth or for pre-fabricated tooth arrangements for the opposing jaw, which may be advantageous in the overall prosthesis. Embodiments may have the advantage that, through this the modelling can be done more efficiently and more effectively. In particular, supplementing with additional elements may be simplified.

According to embodiments, one of the patient-specific delimiting surfaces is defined as the minimum thickness surface for a patient-specific delimiting surface, such as a tooth stump, dental implant part, and/or dental abutment part. In this, for example, an offset surface can be defined for a tooth stump, a minimum thickness can be loaded or optionally, a material-specific generated offset surface can be determined.

According to embodiments, a physical form is absolutely taken into consideration and modelling adapted on-the-fly if exceeded. The adaptation is created, for example, by trimming and/or in consideration of a pre-defined morphology, such as a tooth morphology, in an available existing space within the physical proscribed form. This may be advantageous for fully prosthetic teeth. According to embodiments, this can be used by loading an additional surface per denture part, always being moved with the denture part or relative to the denture part and serves as a delimitation of the currently modelled denture part geometry. A corresponding surface can be loaded, for example, from a pre-form library, meaning for example a library of forms for the use of blanks with pre-fabricated implant connection or a full prosthetic tooth library.

Embodiments may have the advantage that pre-forms can be used effectively and efficiently in interaction with the denture part model. Embodiments may have the advantage that changes to the library can be implemented effectively and efficiently. In particular, embodiments can ensure that an adaptation already made can be adopted and one does not have to start from the beginning.

According to embodiments, the library can be changed, wherein a first denture part model from a first library can be exchanged for a second denture part model from a second library. According to embodiments, a current change geometry of the first denture part model can be transferred to the second denture part model. This may be, for example, a positioning or shape, e.g. location of dental cusps, fissures or other contact points of the first denture part model. Embodiments may have the advantage that if there is a library change, not all of the adaptations have to be done again.

According to embodiments, multiple denture part models from various libraries for the same denture part are shown using the graphic user interface. Embodiments may have the advantage that for the same denture part, denture part models can be simultaneously displayed from more than one and moved or changed on-the-fly. And adaptation and display can occur either by split screen display or simultaneously in the form of a superimposition, e.g. transparent and/or with various colours.

Embodiments may have the advantage that various libraries can be used

simultaneously. This makes it possible to make one and the same change simultaneously for multiple libraries, so that at the end, identical adaptation results can be created for various libraries and a selection can be made from these. In particular, such an adaptation can be done, which is optimised simultaneously not for one, but for multiple and/or all libraries.

According to embodiments, the denture part may be a bridge, which may be loaded from a bridge library. Embodiments may have the advantage that a relatively low and/or greater individual or multiple teeth for a bridge is set. This may be advantageous for a total prosthesis of molars. According to embodiments, these molars are loaded together and set together according to size and location. According to embodiments, entire bridges can be deposited together as one surface.

Embodiments may have the advantage that in the case of bridges and/or parts of bridges, an adaptation is simplified and can be accelerated because this is provided as an object or denture part model and adapted.

According to embodiments, the denture part model that is loaded from a library has a gingiva section. Embodiments may have the advantage that a gingiva section is directly comprised in the denture part model and can be adapted and/or moved with a change of a tooth shape of the denture part model. According to embodiments, the denture part model with a gingiva section is a bridge model, which is loaded from a bridge library.

According to embodiments, a digital gingiva section can be created automatically, such as on-the-fly for a certain denture part model. For example, a gingiva section is created where there is too much distance between approximal delimiting surfaces or where there is too much distance to the patient's jaw. Embodiments may have the advantage that gingiva gaps are prevented or automatically filled in. Embodiments may have the advantage that a gingiva section are effectively and efficiently considered in the adaptation of denture part models.

According to embodiments, transformations and deformations of front teeth are

done symmetrically. For example, transformations and deformations are reflected symmetrically. Embodiments may have the advantage that a symmetrical adaptation can be implemented for front teeth.

According to embodiments, the method comprises a simulation of tooth ageing or quasi-abrasion. With increasing degree of ageing, fissures are increasingly raised, cusps increasingly reduced and/or chewing surfaces increasingly flattened. An input of the degree of ageing can be done as a user-defined change via a settable value. Through this, a heuristically simulated tooth ageing process can be controlled on-the-fly. Embodiments may have the advantage that ageing processes can be done effectively and efficiently during modelling.

The invention also comprises a computer program product for modelling a patient-individualised denture part which comprises a non-volatile computer-readable storage medium with computer-readable program instructions for modelling the patient-individualised denture part, wherein execution of the program instructions by a processor of a computer system that prompts the computer system to execute a method for modelling the patient-individualised denture part, which comprises:

- providing a digital three-dimensional patient situation model, wherein the patient situation model defines patient-specific delimiting surfaces of one or more objects of a set of the patient's teeth which define a patient situation geometry to which the denture part is to be adapted during the course of the modelling,
- providing a digital three-dimensional denture part model in a starting state, wherein the denture part model defines denture part-specific delimiting surfaces of the denture part which define a denture part geometry,

wherein the denture part model, in the starting state, has a denture part geometry in the form of a starting geometry,

- providing one or more geometric adaptation criteria defined using the patient-specific delimiting surfaces, which criteria must be satisfied by the denture part-specific delimiting surfaces during the course of a patient-individualised adaptation of the denture part geometry to the patient situation geometry,
- patient-individualised adaptation of the denture part geometry of the denture part model to the patient situation geometry of the patient situation model,

wherein the patient-individualised adaptation comprises an arrangement of the denture part model in a starting position provided by the patient situation model for the denture part,

wherein the patient-individualized adaptation also comprises a repeated interactive implementation of user-defined changes to the arranged denture part model, wherein the denture part model dynamically runs through a sequence of intermediate states during the user-defined changes until a resulting change state is reached from the corresponding user-defined change, wherein for each of the corresponding intermediate states and the resulting change state, a state-specific state geometry of the denture part model is calculated automatically from the starting geometry of the denture part model adhering to the geometric adaptation criteria, wherein each of the user-defined changes are displayed using a graphic user interface on a display device,

wherein the display of the corresponding user-defined change comprises the display of the dynamic run-through of the relevant sequence of intermediate states until the relevant change state is achieved by the denture part model with the state-specific state geometries calculated for this,

- determination of a change geometry resulting from the patient-individualised adaptation of the denture part model and the creation of the patient-individualised dental part geometry to be used for the creation of the patient-individualised dental part.

According to embodiments, the computer program product is configured to execute one or multiple of the aforementioned embodiments of the method for modelling a patient-individualised denture part.

The invention also comprises a computer system for modelling a patient-individualised denture part, wherein the computer system has a storage medium, a processor, an input device and a display device, wherein, on the storage medium there are computer-readable program instructions saved for the modelling of the patient-individualised denture part, wherein an execution of the program instructions by the processor of the computer system prompts the computer system to model the patient-specific denture part, which comprises:

- providing a digital three-dimensional patient situation model, wherein the

patient situation model defines patient-specific delimiting surfaces of one or more objects in a patient's set of teeth, which define a patient situation geometry, to which the denture part is fitted during modelling,

- providing a digital three-dimensional denture part model in a starting state, wherein the denture part model defines denture part-specific delimiting surfaces of the denture part, which defines a denture part geometry,

wherein the denture part model, in the starting state, has a denture part geometry in the form of a starting geometry,

- providing one or more geometric adaptation criteria defined using the patient-specific delimiting surfaces, are to be adhered to through the denture part-specific delimiting surfaces during a patient-individualised adaptation of the denture part geometry to the patient situation geometry,
- patient-individualised adaptation of the denture part geometry of the denture part model to the patient situation geometry of the patient situation model,

wherein the patient-individualised adaptation comprises an arrangement of the denture part model in a starting position provided by the patient situation model for the denture part, wherein the patient-individualized adaptation also comprises a repeated interactive implementation of user-defined changes to the arranged denture part model, wherein the denture part model undergoes a dynamic sequence of intermediate states during each of the user-defined changes until a change state resulting from the relevant user-defined change is achieved,

wherein for each of the relevant intermediate states and the resulting change state a state-specific state geometry of the denture part model is automatically calculated from the starting geometry of the denture part model while adhering to the geometric adaptation criteria, wherein each of the user-defined changes is displayed using a graphic user interface on a display device, wherein the display of the relevant user-defined change comprises a display of the dynamic run-through the relevant sequence of intermediate states until reaching the relevant change state through the denture part model with the relevant state-specific state geometries calculated for this,

- determination of a change geometry resulting from the patient-individualised adaptation of the denture part model and the creation of the patient-

individualised dental part geometry to be used for the creation of the patient-individualised dental part.

According to embodiments, the computer system is configured to execute one or more of the aforementioned embodiments of the method for modelling a patient-individualised denture part.

The invention also comprises a processing system to produce a patient-individualised denture part, wherein the processing system comprises a computer system according to one of the aforementioned embodiments and a processing device to create a patient-individualised denture part of denture material using the patient-individualised denture part geometry.

Embodiments of the invention regarding the figures are explained in more detail below. They show:

Figure 1: a schematic block diagram of an example computer system for modelling a patient-individualised denture part,

Figure 2: a schematic flow diagram of an example method for modelling a patient-individualised denture part,

Figure 3: a schematic block diagram of an example processing system for modelling a patient-individualised denture part,

Figure 4: a schematic block diagram of an example processing system for modelling a patient-individualised denture part,

Figures 5 A-C: example denture part models and patient situation models,

Figures 6 A-C: example adaptation of a denture part model,

Figures 7 A-E: example adaptation of a denture part model,

Figures 8 A-E: example adaptation of a denture part model,

Figures 9A-D: example adaptation of a denture part model,

Figures 10A-D: example adaptation of a denture part model,

Figures 11 A-C: example adaptation of a denture part model and patient situation model

Figure 12: an example penetration situation of denture part model and patient

situation model,

Figures 13 A-C: an example quasi-abrasion of denture part models,

Figures 14 A-C: an example quasi-abrasion of denture part models,

Figures 15 A-C: an example quasi-abrasion of a denture part model,

Figures 16 A-C: an example quasi-abrasion of a denture part model

Figures 17A-C: an example quasi-abrasion of denture part models

And

Figures 18A-C: an example quasi-abrasion of denture part models.

Elements of the following embodiments that correlate are labelled with the same reference number.

Figure 1 shows a schematic block diagram of a computer system 100 for modelling a patient-individualised denture part. The computer system 100 comprises a hardware component 102 with one or more processors and one or more storage media. Computer-readable program instructions for modelling the patient-individualised denture part are saved on one or more of the storage media. Execution of the program instructions by one or more of the processors of the hardware components 102 prompts the computer system 100 to execute a method for modelling the patient-individualised denture part. The computer system 100 further comprises a display device 108 to display a graphic user interface 110. The computer systems 100 further comprises input devices, such as a keyboard 104 and a mouse 106 to execute an interactive user input. The graphic user interface 110 comprises operating elements 112, which, using the input devices 104, 106, can be used to select settings for the modelling of a digital three-dimensional denture part model 114. On the graphic user interface 110, a digital three-dimensional denture part model 114 is also shown, which the user can adapt using the input devices 104, 106 to a provided patient situation model 118 also displayed on the graphic user interface. The denture part model 114 is defined by denture part-specific delimiting surfaces 116, which set forth a denture part geometry. The patient situation model 118, with its patient-specific delimiting surfaces 120, defines a patient situation geometry. The patient-specific delimiting surfaces 120 of the patient situation model are delimiting surfaces of one or more objects of a patient's set of teeth. The graphic user interface also comprises, for example, a digital processing tool 122, which enables the user, using the input devices

104, 106, to select and edit the patient-individualised denture part model 114 to be adapted and/or areas of the denture part model 114 or to change them in a user-defined manner. These user-defined changes comprise, for example, a shift, rotation and/or scaling of the denture part model 114. The computer-readable program instructions also lay out geometric adaptation criteria for the user-defined changing of the denture part model 114, which are to be met. In other words, only such changes are permitted which fulfil pre-defined geometric adaptation criteria. If the denture part model is changed by the user using the input devices 104, 106, or shifted relative to the patient situation model, the corresponding change is displayed on the user interface 110 as a dynamic sequence of intermediate states of the denture part model 114, which run through this until one of the entered user-defined changes has reached the relevant change state. In other words, the user can shift, rotate and/or scale the denture part model within the graphic user interface 110 relative to the patient situation model 120, wherein the corresponding changes are displayed in real time as dynamic image sequences

Figure 2 shows a schematic process diagram of an example method for modelling a patient-individualised denture part. In block 200, a digital-three dimensional patient situation model is provided. The patient situation model defines patient-specific delimiting surface of one or more objects of a patient's set of teeth. In other words, the patient situation model provides a starting situation in a patient's set of teeth, to which the denture part is to be adapted during modelling. The patient-specific delimiting surfaces define a patient situation geometry and surface structure. The patient situation models or the delimiting surfaces are, for example, described using a polygonal mesh structure, such as using triangles, using a point cloud, using a 3D volume data architecture or using a 3D signed distance field. The patient situation model is created using a measurement of the patient's teeth, such as from objects in the patient's set of teeth directly in the mouth of the patient or indirectly by measuring at least an impression or model of the patient's set of teeth or of objects of the patient's teeth, such as of plaster or plastic. For the measurement, one can use x-rays, tomosynthetic images and/or computed tomographic images. In addition, the patient situation model may comprise one or more previously modelled digital three-dimensional denture part models meaning objects, which are taken into account for a use in or on the patients set of teeth and in the adaptation of the denture part during modelling.

A digital three-dimensional denture part model in a starting state is shown in block 202. Like the patient situation model, the denture part model is defined by delimiting surfaces, meaning denture part-specific delimiting surfaces. These delimiting surfaces describe a denture part geometry. The denture part model and the delimiting surfaces are described using a polygonal mesh structure, using triangles, using a point cloud, using a 3D volume structure or using a 3D signed distance field. In the denture part model, it may be a general mode of a tooth loaded from a library, a copy of an object in the patient situation model, a copy of a previously adapted patient-individualised denture part model or a partially adapted patient-individualised denture part model. The denture part model in the starting state has a denture part geometry in the form of a starting geometry.

In block 204, one or more defined geometric adaptation criteria are set forth using the patient-specific delimiting surfaces. These adaptation criteria are to be adhered to through the denture-specific delimiting surfaces during a patient-individualised adaptation of the denture part geometry to the patient situation geometry. In other words, only adaptations of the denture part geometry are possible which fulfil the adaptation criteria or if user-defined changes for the adaptation of the denture part geometry are implemented so that they fulfil the adaptation criteria. The adaptation criteria define, for example, a permitted maximum and/or minimum positive and/or negative distance or offset between a patient-specific delimiting surface and a denture part-specific delimiting surface. In addition, the adaptation criteria define, for example, a permitted minimum material strength, meaning a permitted minimum offset between two denture part-specific delimitation surfaces. If a user makes a defined change, perhaps a shift of the denture part model relative to the patient situation model, so that an adaptation criteria was violated, possibly in that a denture part specific delimiting surface penetrates a patient-specific delimiting surface and thus a permitted maximum negative offset was exceeded, the change is only implemented in the scope as compatible with the adaptation criteria. In the case of a shift, this may lead to such denture part-specific delimiting surfaces, which have achieved a permitted maximum shift state relative to a patient-specific delimiting surface pursuant to the adaptation criteria no longer being able to be shifted further in relation to the corresponding patient-specific delimiting surface. Denture part-specific delimiting surfaces that are in no conflict with one of the adaptation

criteria, e.g. have not yet reached a permitted maximum shift state, can be further shifted, which leads to a deformation of the denture part geometry. In this the deformation is made, for example, so that the geometric mathematical relationships of the denture part geometry, meaning the characteristic properties of the form of the denture part are maintained as much as possible. Geometric mathematical relationships of the denture part geometry can, for example, be distance ratios, curvature ratios etc. The adaptation criteria can be pre-defined, for example and/or set by the user. A deformation of the denture part geometry can be calculated, for example, using a Laplace deformation method.

In block 206 there is a patient-individualised adaptation of the denture part geometry of the denture part model to the patient situation geometry of the patient situation models. For this the denture part model is arranged a starting position provided by the patient situation model for the denture part. In addition, repeated interactive user-defined changes are performed on the arranged denture part model. These changes comprise, for example, a scaling of an extension of the denture part model along a pre-defined extension direction of the denture part model; a shift of the denture part model relative to the patient situation model and/or a rotation of the denture part model relative to the patient situation model. For example, at least an area of a delimiting surface of the visually displayed denture part model on the graphic user interface is selected and interactively processed using one of the interactive digital processing tools provided by the graphic user interface.

In this, the denture part model undergoes a dynamic sequence of intermediate states during the user defined changes until a change state is achieved from the user-defined change. For each of the corresponding intermediate states as well as the resulting change state, a state-specific state geometry of the denture part mode in the relevant intermediate state or change state is automatically calculated from the starting geometry of the first denture part model, adhering to the geometric adaptation criteria. Each of the user-defined changes is displayed on a display device using a graphic user interface. In this a display of the user-defined changes occurs simultaneous to their entry. The display of the corresponding user-defined change comprises the display of the dynamic run-through of the relevant sequence of intermediate states until the relevant change state is achieved

by the denture part model with the state-specific state geometries calculated for this. In this, the number and increment of the intermediate states comprised in the dynamic sequence is pre-defined and/or set by the user. According to embodiments, it can automatically be adapted depending on the available computing power of the computer system.

In block 208, a change geometry resulting from the patient-individualised adaptation of the first denture part model is used to provide a patient-individualised denture part geometry for the production of the patient-individualised denture part. For example, the resulting change geometry is used as a patient-individualised denture part geometry for the denture part to be produced. For this, upon an output command by the user to output the constructed denture part, a digital data set is created with patient-individualised denture part geometry for the automated creation of the physical denture part, a semi-finished denture part or the prototype of the denture part of denture material, such as dental restoration material. The automated production is done, for example, using CAM or Rapid Prototyping methods, such as CNC milling or 3D printing. A semi-finished denture part is a semi-finished product that has a shape similar to a denture and from which the denture is produced through additional subsequent, e.g. manual processing steps.

According to an alternative embodiment, the provision of the resulting change geometry comprises a transfer of this resulting change geometry to a second digital three-dimensional denture part model of the same denture part. This second denture part model has a higher resolution than the first denture part model. The previously described method can be repeated for this second denture part model, wherein the starting state of the second denture part model is either defined by a generic starting state, meaning independent of the adopted change geometry or by the adopted change geometry. Independent of the adopted change geometry means here that the adopted change geometry is treated as a first user-defined change.

Figure 3 shows a block diagram of an example processing system 160 for creating a patient-individualised denture part. The processing system 160 comprises a computer system 100 for modelling of a patient-individualised denture part pursuant to figure 1.

The computer-readable program instructions of the computer system 100 are further configured so that a processing device 130 to produce the patient-individualised denture part 140 from denture material or tooth restoration material 138 from a blank 136. For the production, for example, a patient-individualised denture part geometry is used, that is the result of the modelling of the patient-individualised denture part using the computer system 100. The corresponding denture part geometry is, for example, provided as a series model and the computer system 100 controls the processing device 130, which is for example a CAM processing device according to the patient-individualised dental part geometry. In this, the processing device 130 is controlled in such a way that with a processing tool 132, using a machining method, a denture part 140 is made from a blank 136, the geometry of which is consistent with the patient-individualised denture part geometry. The processing device 130 prepares the blank 136, which is held in place by a holder 134.

Figure 4 shows a schematic block diagram of an alternative processing system 160 that in addition to a computer system 100, consistent with the computer system 100 in figure 1, allows for a 3D printer 150 as a processing device to produce the patient-individualised denture part 140 of denture material using the patient-individualised denture part geometry provided by the computer system 100. The 3D printer 150 comprises a printing element 152 with which the denture material is applied layer by layer, so that the patient-individualised denture part 140 is created layer by layer according to the patient-individualised denture part geometry.

Figures 5A to 5C show various types of patient situation models 118, which are used for modelling the patient-individualised denture part. Figure 5A shows a situation in which the patient situation model 118 is based on a scan of one or multiple objects of a patient's set of teeth. The patient situation model 118 is defined by the scanned patient-specific delimiting surfaces 120. This way, these are directly scanned delimiting surfaces 120 of the corresponded objects or a scan of a negative impression or positive impression of the actual objects of the patient's set of teeth. A digital three-dimensional denture part model 114 is adapted to this patient situation model 118, which is defined by delimiting surfaces 116. Figure 5B shows a situation in which the objects of the patient's set of teeth are previously modelled digital three-dimensional denture part models with modelled

delimited surfaces 121 which form the patient part model 118 and to which the denture part model 114 is adapted. Figure 5C ultimately shows a patient situation model 118 that is defined from a combination of scanned patient-specific delimited surfaces 120 and modelled delimited surfaces 121 of a three-dimensional denture part model modelled for the patient's set of teeth. The digital three-dimensional denture part model 114 is adapted to this patient situation model on an individual patient basis.

The figures 6A to 6C show an example of a user-defined change to a denture part model 114, that defined denture part-specific delimiting surfaces 116. The example user-defined change is a scaling, in which an opposite side denture part geometry is kept. The scaling is done, for example, along a main axis of the tooth, which can be, for example an occlusal axis, a mesial axis or a buccal axis. Figure 6B shows a starting situation of the denture part geometry, figure 6A shows a reduced scaling of the corresponding denture part geometries along the occlusal axis, while figure 6C shows an enlarged scaling of the denture part geometry along the occlusal axis.

The figures 7A to 7E show a step by step deformation of a denture part model 114 for a front tooth in consideration of an adaptation criterion in the form of a pre-set minimum thickness. The minimum thickness is presented by the interface 170 which may not exceed the denture part-specific delimiting surfaces 116, in this case the buccal delimiting surface. If the denture part model 114 is arranged on the interface 170, this may protrude from the denture part model 114 which is not comprised in the buccal delimiting surface. Thus the area 172 penetrates the interface 170 of the denture part model 114. If the front tooth or the denture part model 114 of the front tooth is shifted in the linear direction, this leads to a deformation of the front tooth, in which the diameter increases in the lingual direction, because the buccal delimiting surface of the denture part model 114 cannot exceed the proscribed interface 170. In this, the interface 170 is completely surrounded. In the figures 8A to 8E, a corresponding situation is represented for a molar, meaning a premolar or molar. Again, the minimum thickness is defined by an interface 170, which in this case is in the form of a tooth. If the denture part model 114 is shifted in the occlusal direction, the occlusal surface as a delimiting surface 116 cannot penetrate the pre-defined interface 170 according to the adaptation criterion, through which there is a flattening of the cusp and an extension of the denture part model 114 in

the occlusal direction. Initially an area 172 of the interface 170 can penetrate the denture part model 114 under the occlusal surface. If the denture part model 114 is shifted down in the occlusal direction so that the occlusal surface ends up in the area of the interface 170, the occlusal surface is shifted above the interface 170 and the penetrations 172 disappear. Figures 7B to 7E and 8B to 8E illustrate a dynamic sequence that occurs during a user-defined change to the change geometry of the denture part model 114 shown in figure 7E and 8E.

Figures 9A to 9D show an adaptation to a denture part model 114 for a front tooth in an antagonist comprised in a patient situation model 118 in consideration of an adaptation criterion, according to which no penetration between the denture part model 114 and the antagonist of the patient situation model 118 may occur. In this, as was the case in figures 7A to 7E, there is an increase in the diameter of the front tooth in the lingual direction, wherein both the buccal delimiting surface of the denture part model 114 is nearly unchanged. Figures 9A to 9B illustrate a dynamic sequence which occurs during a user-defined change of the change geometry of the denture part model 114 shown in figure 9E.

The figures 10A to 10D show an adaptation of a denture part model 114 for a molar under the same adaptation criterion as in the figures 9A to 9D, according to which a penetration of the denture part model 114 and an antagonist of a patient situation model 118 is prohibited. In this case, there is a partial extension of the occlusal surface in the occlusal direction, wherein the denture part model 114 extends around the antagonist. Figures 9A to 9B illustrate a dynamic sequence which occurs during a user-defined change of the change geometry of the denture part model 114 shown in figure 9E.

Figure 11A shows and adaptation of a denture part model 114 in which the relevant denture part model 114 remains undeformed and an adaptation criterion, such as an exclusion of a penetration with an antagonist of a patient situation model 118, taken up by the corresponding antagonist. Here the corresponding antagonist is rotated out of its original position. Figure 11B shows an example in which the adaptation criterion is fulfilled both by the denture part model 114 as well as by an antagonist of the patient situation model 118, in which both are deformed. Figure 11C shows an example in which the

adaptation criterion is exclusively fulfilled by the denture part model 114 to be adapted, while the patient situation model 118 remains unchanged.

Figure 12 shows the penetration 172 of an occlusal delimiting surface 116 of a denture part model 114 with an occlusal delimiting surface 120 of a patient situation model 118, in this case of an antagonist. The corresponding area in which there is a penetration 172, may be solved for example by trimming the relevant area 172 of the denture part model 114 or by local deformation of the occlusal delimiting surface 116 of the denture part model 114 in these areas 172. Figure 12 shoes penetrations 172 for a relative positioning of the denture part model 114 and patient situation model 118. In the case of a virtual articulator, corresponding representations for a plurality of various positionings of the denture part model 114 and the patient situation model 118 are shown together with possible penetrations 172. The various positions correspond to the various relative positions which occur during a chewing movement. The possible penetrations 172 can be displayed sequentially in the form of a dynamic sequence in which the various positions occur sequentially. Thus the user can check sequentially for each position whether adaptations are necessary due to any penetrations 172 that occur and then perform them if necessary. Alternatively, a superimposition of the penetrations 172 can be projected onto the denture part model 114 for the various positioning. Thus the user can check at a glance whether adaptations are necessary due to any penetrations 172 that occur and then perform them if necessary. In this, during adaptation all penetrations 172 for all positions can be taken into account at the same time due to the superimposition.

Figures 13A to 13C show an implementation of a quasi-abrasion, in which the cervical limits are retained and the occlusion between both of the antagonists shown for the denture model 116 are essentially retained. The left part of the figures 13A to 13C show the denture model 116 with its delimiting surfaces 118, the right part shows a cross section through the denture model 116. From figure 13A via figure 13B to figure 13C, the abrasion in the example shown reduces, meaning that the relative heights of the cusps or depths of the fissures in the occlusion surface increase.

Figures 14A to 14C show an implementation of a quasi-abrasion, in which the abrasion increased, starting from figure 14A, which is identical to figure 13A, via the figure

14B to figure 14C. In the course of the abrasion, the height of the cusps or depth of the fissures reduce in the occlusal surface. As previously in the case of figures 13A to 113C, the cervical limits are retained and the occlusion is retained nearly unchanged.

Figures 15A to 15C show, as in figures 13A to 13C, a reduction of a quasi-abrasion which represents younger teeth, while figures 16A to 16C show an increase in quasi-abrasion for a denture part model 114 with its delimiting surfaces 116, though which an ageing process of the teeth can be adjusted. Figures 16A to 16C correspond to the figures 14A and 14C. In the case of such virtual ageing of the denture part model 114, the starting geometry is deformed using an algorithm, so that it fulfils certain properties that are typical for the teeth of older patients. These properties comprise, for example, flatter fissures and/or stronger smoothing of the anatomical structures of the tooth surface.

In figures 17A to 17C, a corresponding quasi-abrasion is shown for a plurality of denture part models 114, wherein figure 17B shows a starting situation, relative to the reduction by abrasion in figure 17A, while that increases relatively in figure 17C.

Figures 18A to 18C show a corresponding quasi-abrasion for a plurality of denture part models 114 for front teeth in which is shown a corresponding ageing process, in particular through smoothing of the incisal delimiting surfaces 116 or the incisal side comprised there. Again, figure 18B shows a starting situation compared to the quasi-abrasion in figure 18A that is decreased, while it increases relatively in figure 18C.

List of Reference Numbers

100	Computer system
102	Hardware components
104	Input device
106	Input device
108	Display device
110	Graphic user interface
112	Control elements
114	Denture part model
116	Boundary surfaces
118	Patient situation model
120	Delimiting surfaces
121	Delimiting surfaces
122	Digital processing tool
130	Processing device
132	Processing tool
134	Holder
136	Blank
138	Denture material
140	Denture part
150	3D printer
152	Print element
160	Processing systems
170	Delimiting surface
172	Penetration range

Patentkrav

1. Computerimplementeret fremgangsmåde til modellering af en patientindividuel tandprotesedel (140), hvilken fremgangsmåde omfatter:

• tilvejebringelse af en digital tredimensional patientsituationsmodel (118), idet patientsituationsmodellen definerer patientspecifikke begrænsningsoverflader (120, 121) på et eller flere objekter i en patients tandsæt, som definerer en patientsituationsgeometri, til hvilken tandprotesedelen skal tilpasses under modelleringsforløbet,

• tilvejebringelse af en første digital tredimensional tandprotesedelmodel (114) i en udgangstilstand, idet den første tandprotesedelmodel definerer tandprotesedelspecifikke begrænsningsoverflader (116) på tandprotesedelen, som definerer en tandprotesedelgeometri,
idet den første tandprotesedelmodel i udgangstilstanden har en tandprotesedelgeometri i form af en udgangsgeometri,

• tilvejebringelse af et eller flere under anvendelse af de patientspecifikke begrænsningsoverflader definerede geometriske tilpasningskriterier, som skal overholdes af de tandprotesedelspecifikke begrænsningsoverflader under forløbet af en patientindividuel tilpasning af tandprotesedelgeometrien til patientsituationsgeometrien,

• patientindividuel tilpasning af den første tandprotesedelmodels tandprotesedelgeometri til patientsituationsmodellens patientsituationsgeometri,
idet den patientindividuelle tilpasning omfatter en anbringelse af den første tandprotesedelmodel i en af patientsituationsmodellen for tandprotesedelen tilvejebragt udgangsstilling,
idet den patientindividuelle tilpasning endvidere omfatter en gentagen interaktiv udførelse af brugerdefinerede forandringer på den anbragte første tandprotesedelmodel, idet den første tandprotesedelmodel under forløbet af hver af de brugerdefinerede forandringer i hvert tilfælde dynamisk gennemløber en sekvens af mellemtilstande, indtil en af den pågældende brugerdefinerede forandring resulterende ændringstilstand opnås, idet der for hver af de tilsvarende mellemtilstande samt den resulterende ændringstilstand i hvert tilfælde automatisk ud fra

udgangsgeometrien for den første tandprotesedelmodel beregnes en tilstandsspecifik tilstandsgeometri for den første tandprotesedelmodel under overholdelse af de geometriske tilpasningskriterier,
idet hver af de brugerdefinerede forandringer vises ved hjælp af en grafisk brugerflade (110) på en visningsindretning (108), idet visningen af den pågældende brugerdefinerede forandring i hvert tilfælde omfatter en visning af det dynamiske gennemløb af den pågældende sekvens af mellemtilstande, indtil den første tandprotesedelmodel har opnået den pågældende ændringstilstand med de pågældende hertil beregnede tilstandsspecifikke tilstandsgeometrier,

• anvendelse af en ud fra den patientindividuelle tilpasning af den første tandprotesedelmodel resulterende ændringsgeometri til tilvejebringelse af af en patientindividuel tandprotesedelgeometri til fremstillingen af den patientindividuelle tandprotesedel.

2. Fremgangsmåde ifølge krav 1, ved hvilken tilvejebringelsen af den resulterende ændringsgeometri omfatter en anvendelse af den resulterende ændringsgeometri som patientindividuel tandprotesedelgeometri.

3. Fremgangsmåde ifølge krav 1, ved hvilken tilvejebringelsen af den resulterende ændringsgeometri omfatter en overføring af den resulterende ændringsgeometri på en anden digital tredimensional tandprotesedelmodel, idet den anden tandprotesedelmodel har en højere opløsning end den første tandprotesedelmodel.

4. Fremgangsmåde ifølge krav 1, ved hvilken de geometriske tilpasningskriterier fastlægger en eller flere tilladelige maksimal- og/eller minimalværdier for positive og/eller negative afstande mellem patientspecifikke begrænsningsoverflader på patientsituationsmodellen og tandprotesedelspecifikke begrænsningsoverflader på tandprotesedelmodellen.

5. Fremgangsmåde ifølge krav 1, ved hvilken de geometriske tilpasningskriterier fastlægger en eller flere tilladelige minimalværdier for positive afstande mellem

tandprotesedelspecifikke begrænsningsoverflader på tandprotesedelmodellen.

6. Fremgangsmåde ifølge et af de foregående krav, ved hvilken de geometriske tilpasningskriterier er ordnet hierarkisk, og der i tilfælde af uforenelige geometrische tilpasningskriterier sikres enkelte geometriske tilpasningskriterier ifølge den hierarkiske ordning forrang frem for et eller flere andre geometriske tilpasningskriterier.

7. Fremgangsmåde ifølge et af de foregående krav, ved hvilken visningen af den brugerdefinerede forandring i hvert tilfælde foregår i realtid.

8. Fremgangsmåde ifølge et af de foregående krav, ved hvilken de brugerdefinerede forandringer i hvert tilfælde omfatter mindst en af de følgende af et interaktivt brugerinput definerede forandringer: en skalering af en udstrækning af tandprotesedelmodellen langs en forudbestemt udstrækningsretning af tandprotesedelmodellen, en forskydning af tandprotesedelmodellen i forhold til patientsituationsmodellen og en drejning af tandprotesedelmodellen i forhold til patientsituationsmodellen.

9. Fremgangsmåde ifølge et af de foregående krav, ved hvilken indlæsningen af de brugerdefinerede forandringer i hvert tilfælde omfatter en udvælgelse og interaktiv bearbejdning af mindst et delområde af en begrænsningsoverflade på den på den grafiske brugerflade visuelt gengivne tandprotesedelmodel ved hjælp af et af den grafisken brugerflade tilvejebragt interaktivt digitalt bearbejdningsværktøj (122).

10. Fremgangsmåde ifølge krav 9, ved hvilken den interaktive bearbejdning omfatter en deformation af et delområde og/eller en afskæring af et af delområdet begrænset volumenafsnit af tandprotesedelgeometrien.

11. Fremgangsmåde ifølge et af de foregående krav, ved hvilken anbringelsen af tandprotesedelmodellen i udgangsstillingen omfatter en automatisk tilpasning af tandprotesedelmodellen til en i patientsituationsmodellen defineret

fremstilliingsmargen for tandprotesedelen.

12. Fremgangsmåde ifølge et af de foregående krav, ved hvilken fremgangsmåden endvidere omfatter:

- udvælgelse af en ændringstilstand for den første tandprotesedelmodel,
- simulering af en tyggebevægelse for den valgte ændringstilstand for den første tandprotesedelmodel, idet simuleringen af tyggebevægelsen omfatter en beregning af en dynamisk gennemløben sekvens af stillinger af tandprotesedelmodellen i forhold til en af patientsituationsmodellen omfattet antagonist til tandprotesedelmodellen, idet der for hver af de relative stillinger ved hjælp af den grafiske brugerflade på visningsindretningen i hvert tilfælde vises mindst en okklusal begrænsningsflade for tandprotesedelmodellen og en okklusal begrænsningsflade for antagonisten.

13. Fremgangsmåde ifølge krav 12, ved hvilken der for de enkelte relative stillinger af den dynamiske sekvens i hvert tilfælde vises delområder af den okklusale begrænsningsflade for tandprotesedelmodellen, som gennemtrænger antagonistens okklusale begrænsningsflade.

14. Fremgangsmåde ifølge et af de foregående krav, ved den tilvejebragte tandprotesedelmodel i udgangstilstanden er en generisk model for tandprotesedelen.

15. Fremgangsmåde ifølge et af de foregående krav, ved hvilken objekterne i en patients tandsæt omfatter et eller flere af de følgende objekter: en tand, en tandstump, tandkød, en tandprotese, et implantat, et periodontalapparat, en lokator, en bideskinne, en bro, en protese eller en delprotese, en aftagelig delprotese, en midlertidig protese, en tandfyldning, et indlæg.

16. Fremgangsmåde ifølge et af de foregående krav, ved hvilken fremgangsmåden endvidere omfatter fremstilling af den patientindividuelle tandprotesedel under anvendelse af den som patientindividuel

tandprotesedelgeometri fastlagte ændringsgeometri.

17. Fremgangsmåde ifølge et af de foregående krav, ved hvilken de patientspecifikke og tandprotesedelspecifikke begrænsningsoverflader er implementeret under anvendelse en af følgende fremgangsmåder: en polygonal netstruktur, hvori toppunkter i den tilsvarende netstruktur og/eller punkter inde i netstrukturens polygoner definerer de tilsvarende begrænsningsoverflader, en punktsky, hvori punktskyens punkter definerer de tilsvarende begrænsningsoverflader, en 3D-volumendatastruktur, som omfatter et voxelgitter, eller et 3D-signed-distance-field.

18. Computerprogramprodukt til modellering af en patientindividuel tandprotesedel (140), som omfatter et ikke-flygtigt computerlæsbart lagermedium med computerlæsbare programinstruktioner til modellering af den patientindividuelle tandprotesedel, idet en udførelse af programinstruktionerne med en processor i et computersystem (100) bringer computersystemet til at udføre en fremgangsmåde til modellering af den patientindividuelle tandprotesedel, som omfatter:

- tilvejebringelse af en digital tredimensional patientsituationsmodel (118), idet patientsituationsmodellen definerer patientspecifikke begrænsningsoverflader (120, 121) på et eller flere objekter i en patients tandsæt, som definerer en patientsituationsgeometri, til hvilken tandprotesedelen skal tilpasses under modelleringsforløbet,
- tilvejebringelse af en digital tredimensional tandprotesedelmodel (114) i en udgangstilstand, idet tandprotesedelmodellen definerer tandprotesedelspecifikke begrænsningsoverflader (116) på tandprotesedelen, som definerer en tandprotesedelgeometri, idet tandprotesedelmodellen i udgangstilstanden har en tandprotesedelgeometri i form af en udgangsgeometri,
- tilvejebringelse af et eller flere under anvendelse af de patientspecifikke begrænsningsoverflader definerede geometriske tilpasningskriterier, som skal overholdes af de tandprotesedelspecifikke begrænsningsoverflader

under forløbet af en patientindividuel tilpasning af tandprotesedelgeometrien til patientsituationsgeometrien,

• patientindividuel tilpasning af tandprotesedelmodellens tandprotesedelgeometri patientsituationsmodellens patientsituationsgeometri, idet den patientindividuelle tilpasning omfatter en anbringelse af tandprotesedelmodellen i en af patientsituationsmodellen for tandprotesedelen tilvejebragt udgangsstilling,
idet den patientindividuelle tilpasning endvidere omfatter en gentagen interaktiv udførelse af brugerdefinerede forandringer på den anbragte tandprotesedelmodel, idet tandprotesedelmodellen under forløbet af hver af de brugerdefinerede forandringer i hvert tilfælde dynamisk gennemløber en sekvens af mellemtilstande, indtil en ud fra den pågældende brugerdefinerede forandring resulterende ændringstilstand opnås, idet der for hver af de tilsvarende mellemtilstande samt den resulterende ændringstilstand i hvert tulfælde automatisk ud fra tandprotesedelmodellens udgangsgeometri beregnes en tilstandsspecifik tilstandsgeometri for tandprotesedelmodellen under overholdelse af de geometriske tilpasningskriterier,
idet hver af de brugerdefinerede forandringer ved hjælp af en grafisk brugerflade (110) vises på en visningsindretning (108), idet visningen af den pågældende brugerdefinerede forandring i hvert tilfælde omfatter en visning af det dynamiske gennemløb af den pågældende sekvens af mellemtilstande, indtil den pågældende ændringstilstand er opnået af tandprotesedelmodellen med de pågældende hertil beregnede tilstandsspecifikke tilstandsgeometrier,

• fastlæggelse af en ud fra den patientindividuelle tilpasning af tandprotesedelmodellen resulterende ændringsgeometri som patientindividuel tandprotesedelgeometri, der skal anvendes til fremstilling af den patientindividuelle tandprotesedel.

19. Computersystem (100) til modellering af en patientindividuel tandprotesedel (140), hviket computersystem omfatter et lagermedium, en processor, en indlæsningsindretning (104, 106) og et visningsindretning (108), idet der på lagermediet er lagret computerlæsbare programinstruktioner til modellering af

den patientindividuelle tandprotesedel, idet en udførelse af programinstruktionerne med processoren i computersystemet bringer computersystemet til at udføre en fremgangsmåde til modellering af den patientindividuelle tandprotesedel, som omfatter:

- tilvejebringelse af en digital tredimensional patientsituationsmodel (118), idet patientsituationsmodellen definerer patientspecifikke begrænsningsoverflader (120, 121) på et eller flere objekter i en patients tandsæt, som definerer en patientsituationsgeometri, til hvilken tandprotesedelen skal tilpasses under modelleringsforløbet,
- tilvejebringelse af en digital tredimensional tandprotesedelmodel i en udgangstilstand, idet tandprotesedelmodellen (114) definerer tandprotesedelspecifikke begrænsningsoverflader (116) på tandprotesedelen, som definerer en tandprotesedelgeometri, idet tandprotesedelmodellen i udgangstilstanden har en tandprotesedelgeometri i form af en udgangsgeometri,
- tilvejebringelse af et eller flere under anvendelse af de patientspecifikke begrænsningsoverflader definerede geometriske tilpasningskriterier, som skal overholdes af de tandprotesedelspecifikke begrænsningsoverflader under forløbet af en patientindividuel tilpasning af tandprotesedelgeometrien til patientsituationsgeometrien,
- patientindividuel tilpasning af tandprotesedelmodellens tandprotesedelgeometri til patientsituationsmodellens patientsituationsgeometri,
  idet den patientindividuelle tilpasning omfatter en anbringelse af tandprotesedelmodellen i en af patientsituationsmodellen for tandprotesedelen tilvejebragt udgangsstilling,
  idet den patientindividuelle tilpasning endvidere omfatter en gentagen interaktiv udførelse af brugerdefinerede forandringer af den anbragte tandprotesedelmodel, idet tandprotesedelmodellen under forløbet af hver af de brugerdefinerede forandringer i hvert tilfælde dynamisk gennemløber en sekvens af mellemtilstande, indtil en ud fra den pågældende brugerdefinerede forandring resulterende ændringstilstand opnås, idet der for hver af de tilsvarende mellemtilstande samt den resulterende ændringstilstand i hvert tilfælde automatisk ud fra udgangsgeometrien af

tandprotesedelmodellen beregnes en tilstandsspecifik tilstandsgeometri af tandprotesedelmodellen under overholdelse af de geometriske tilpasningskriterier,

idet hver af de brugerdefinerede forandringer ved hjælp af en grafisk brugerflade (110) vises på visningsindretningen (108), idet visningen af den pågældende brugerdefinerede forandring i hvert tilfælde omfatter en visning af det dynamiske gennemløb af den pågældende sekvens af mellemtilstande, indtil den pågældende ændringstilstand er opnået af tandprotesedelmodellen med de pågældende hertil beregnede tilstandsspecifikke tilstandsgeometrier,

- fastlæggelse af en ud fra den patientindividuelle tilpasning af tandprotesedelmodellen resulterende ændringsgeometri som den patientindividuelle tandprotesedelgeometri, der skal anvendes til fremstillingen af den patientindividuelle tandprotesedel.

20. Bearbejdningssystem (160) til fremstilling en patientindividuel tandprotesedel, hvilket bearbejdningssystem omfatter et computersystem ifølge krav 19 samt en bearbejdningsindretning (130, 150) til fremstilling af den patientindividuelle tandprotesedel (140) ud fra tandprotesemateriale (138) under anvendelse af den patientindividuelle tandprotesedelgeometri.

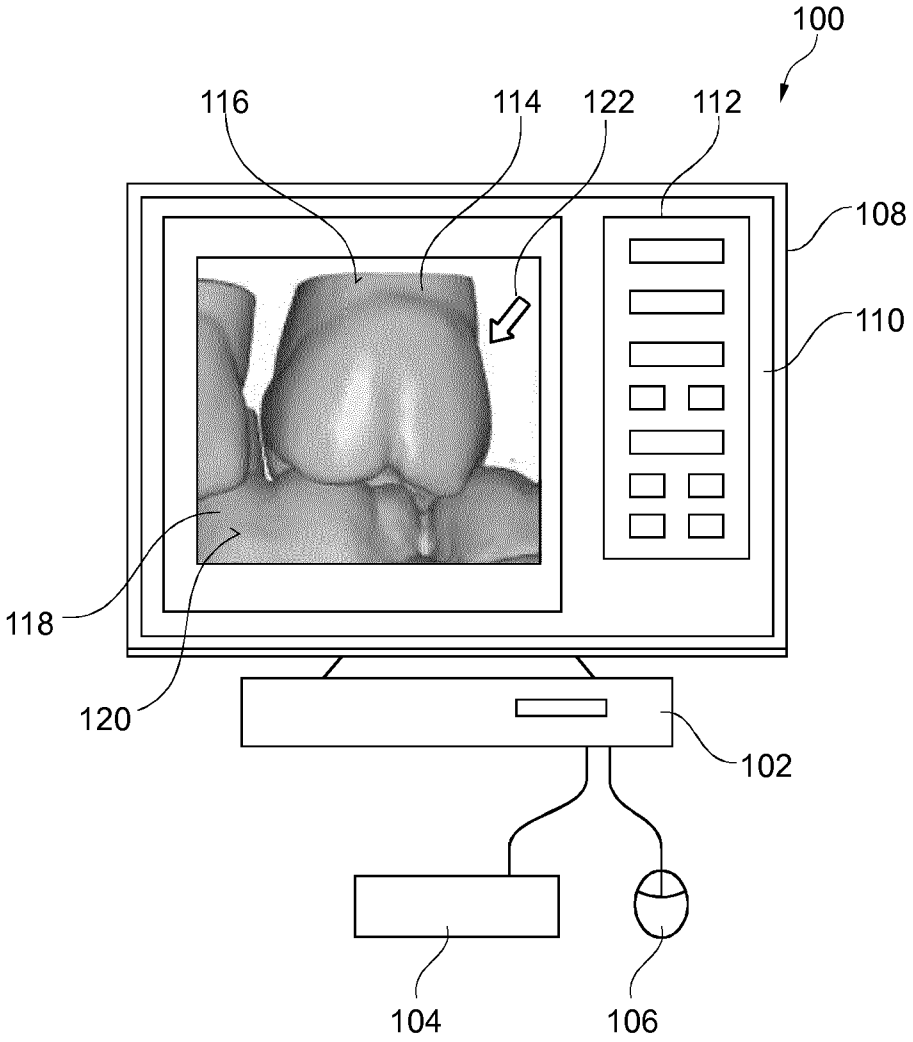


Fig. 1

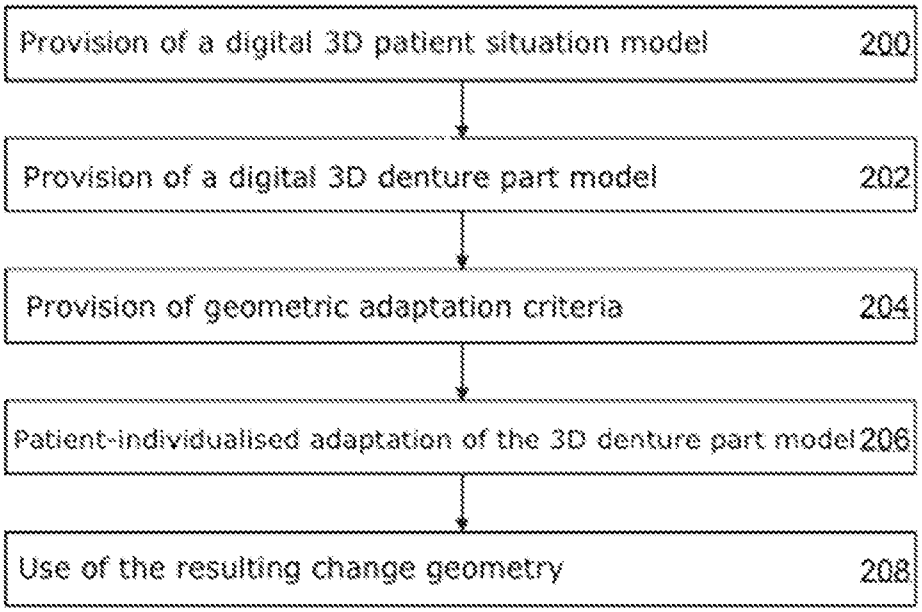

Provision of a digital 3D patient situation model
200
Provision of a digital 3D denture part model
202
Provision of geometric adaptation criteria
204
Patient-individualised adaptation of the 3D denture part model
206
Use of the resulting change geometry
208

Fig. 2

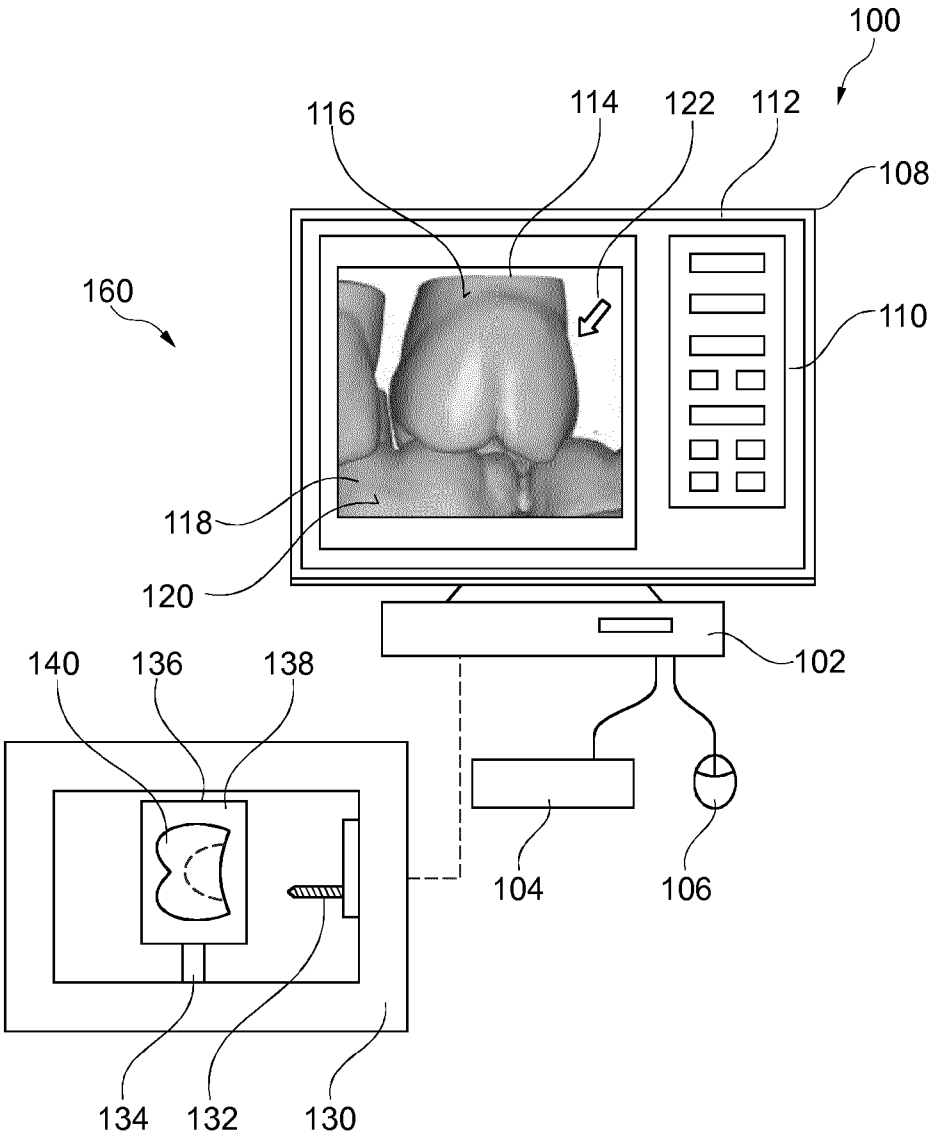

100
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Fig. 3

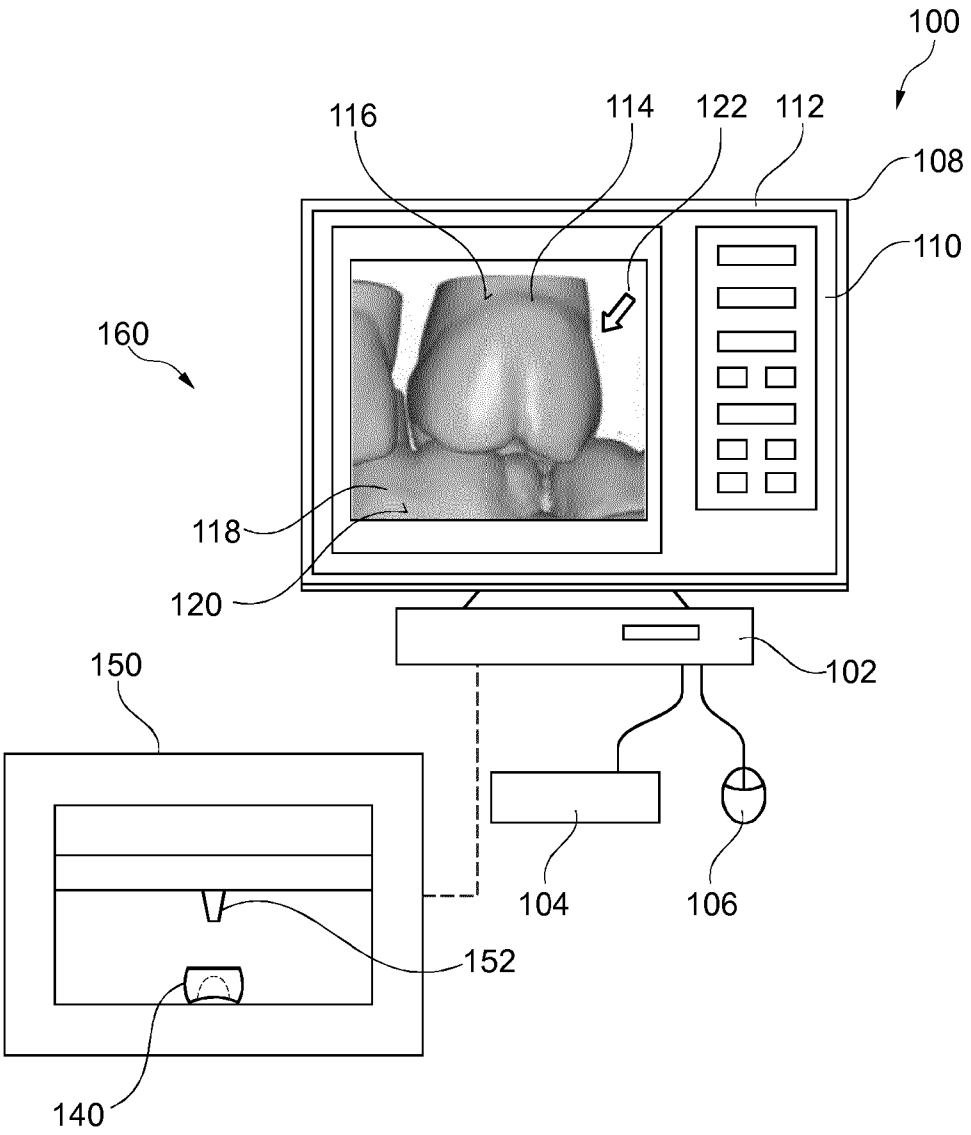


Fig. 4

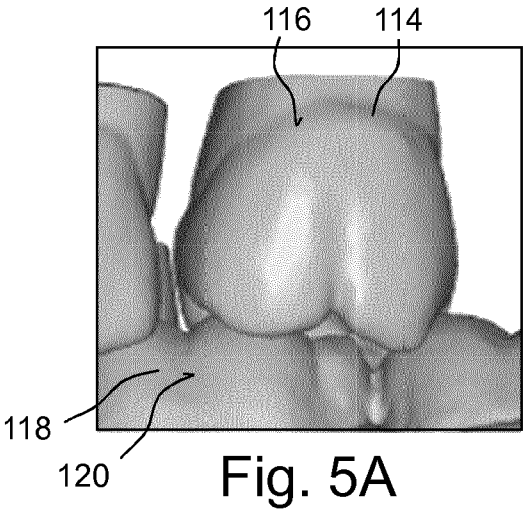


Fig. 5A

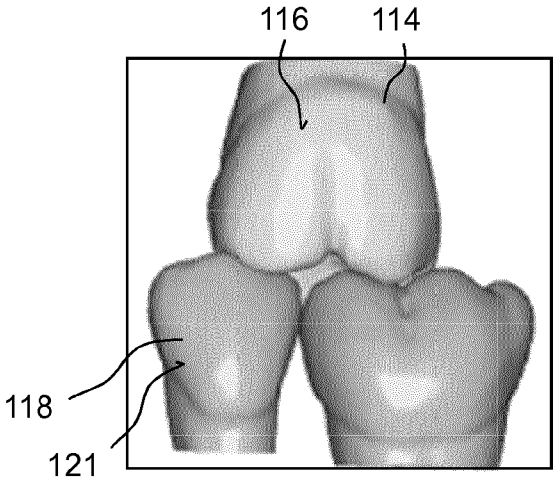


Fig. 5B

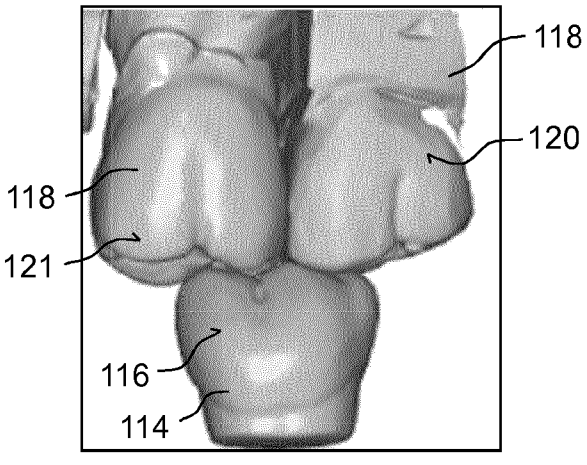


Fig. 5C

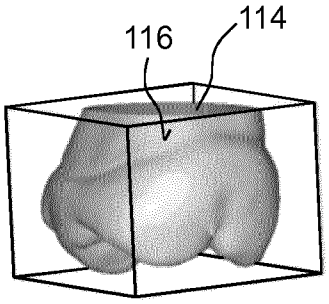


Fig. 6A

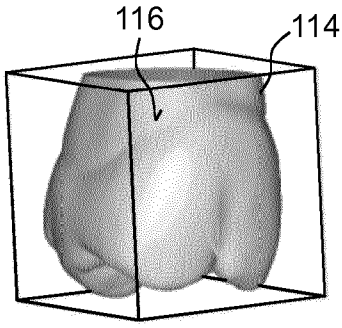


Fig. 6B

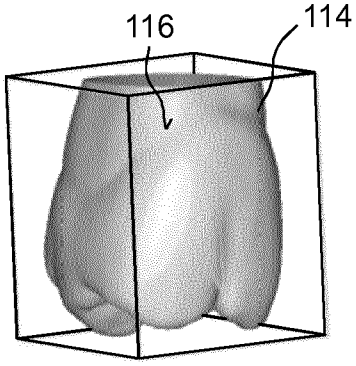


Fig. 6C

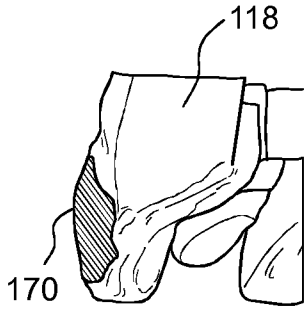


Fig. 7A

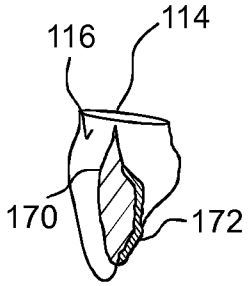


Fig. 7B

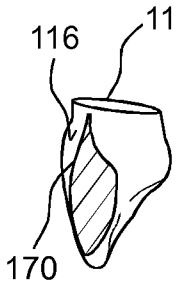


Fig. 7C

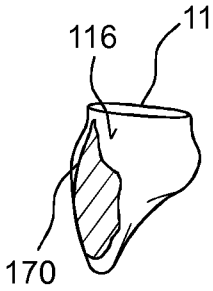


Fig. 7D

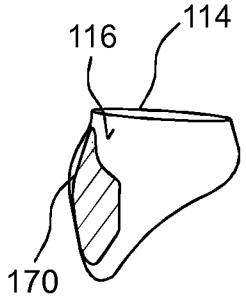


Fig. 7E

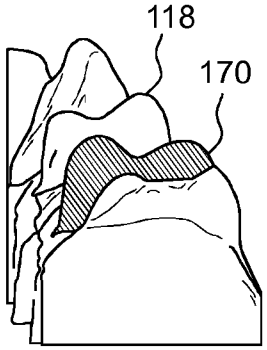


Fig. 8A

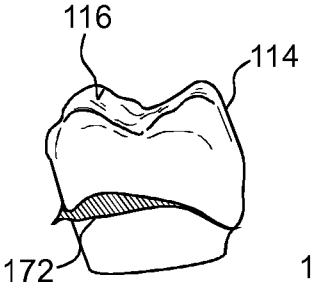


Fig. 8B

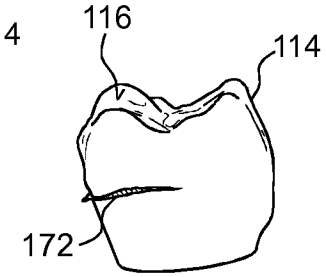


Fig. 8C



Fig. 8D

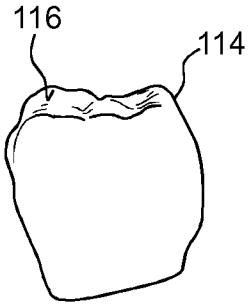


Fig. 8E

DK/EP 3705080 T3

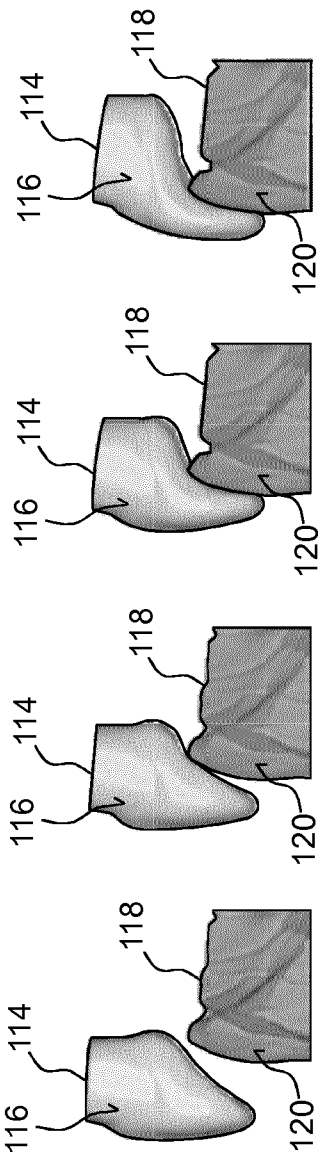


Fig. 9A

Fig. 9B

Fig. 9C

Fig. 9D

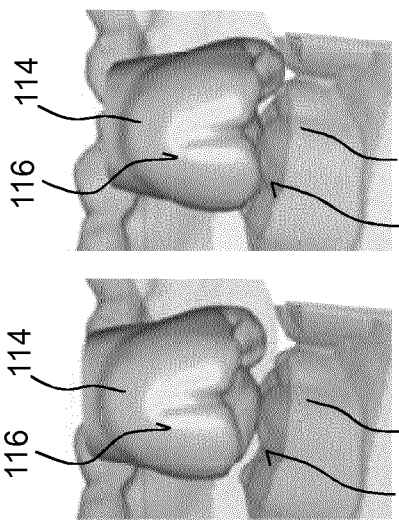


Fig. 10A

Fig. 10B

Fig. 10C

Fig. 10D

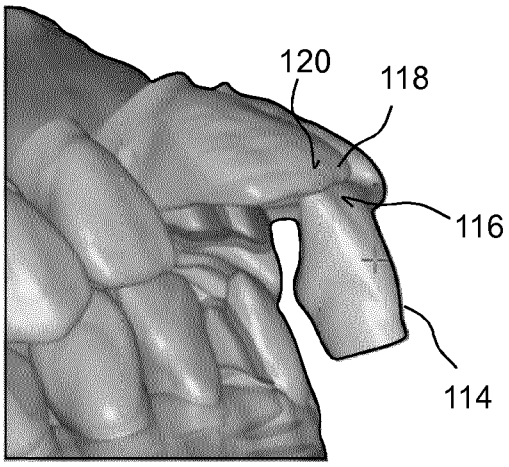


Fig. 11A

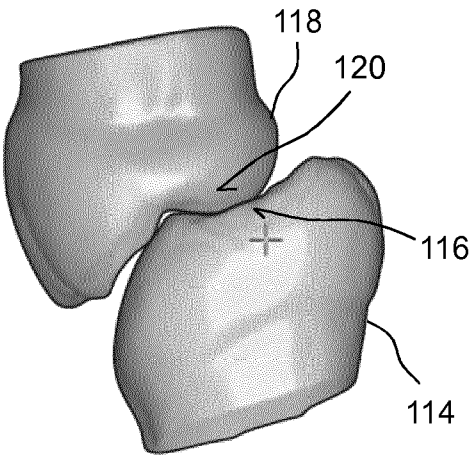


Fig. 11B

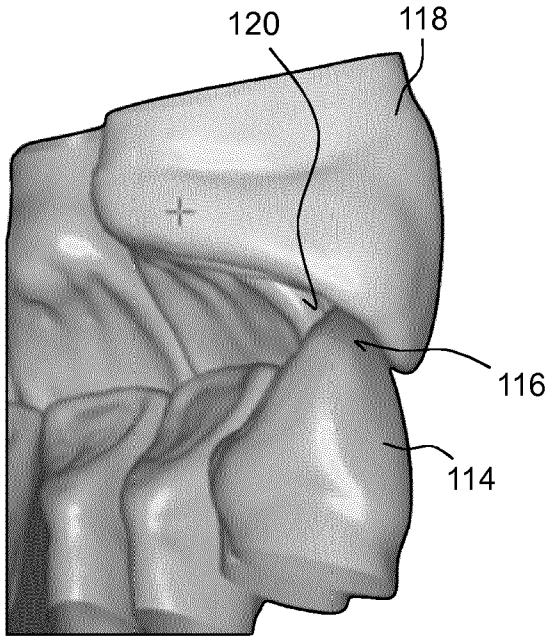


Fig. 11C

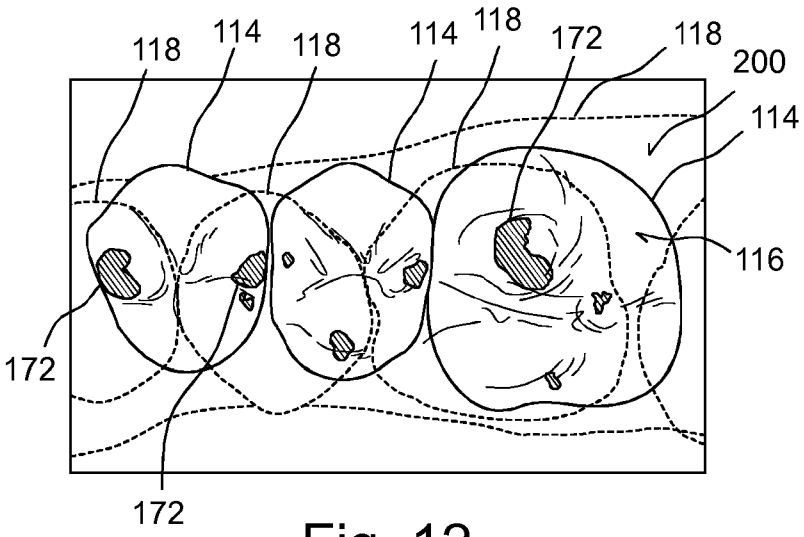


Fig. 12

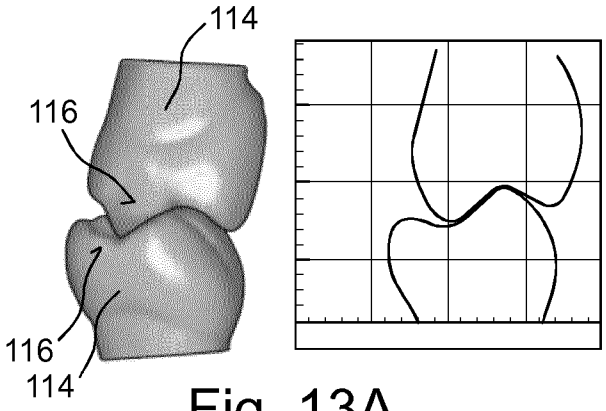


Fig. 13A

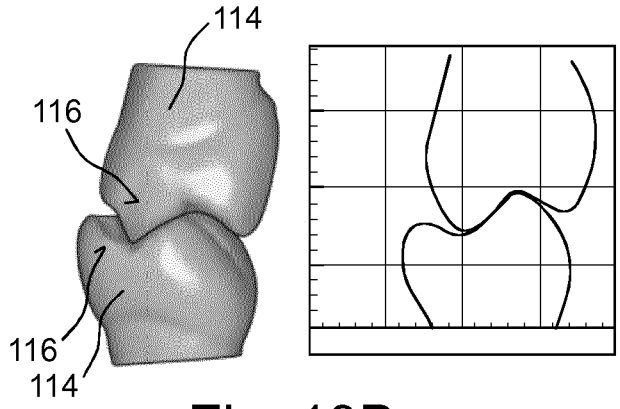


Fig. 13B

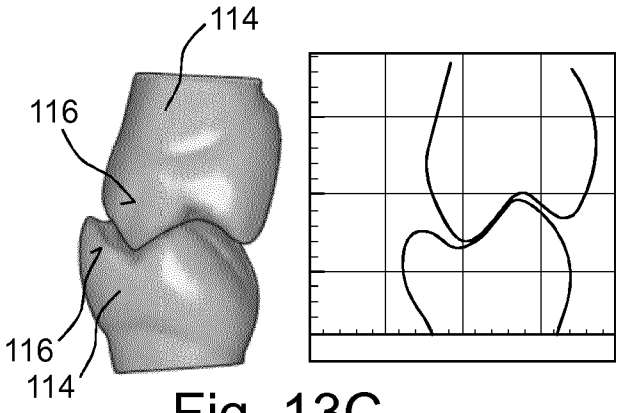


Fig. 13C

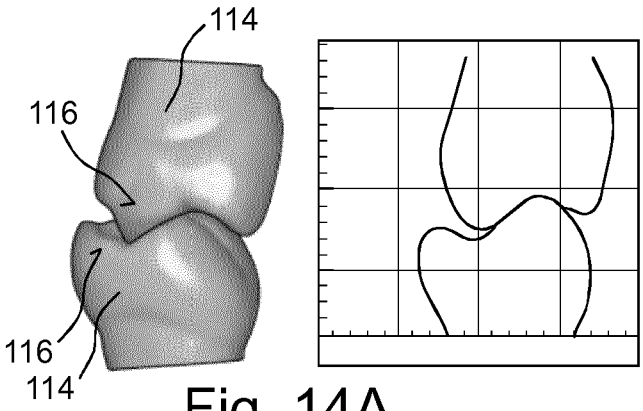


Fig. 14A

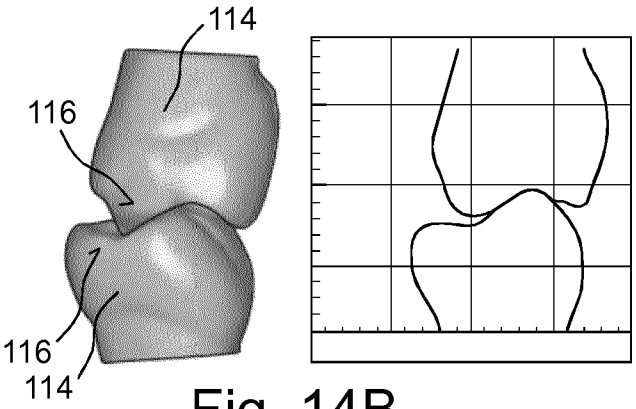


Fig. 14B

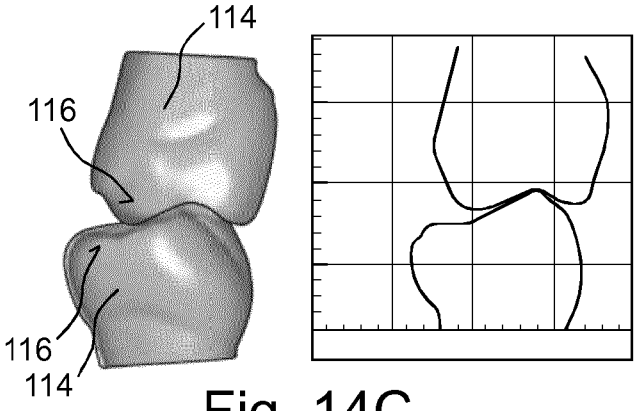


Fig. 14C

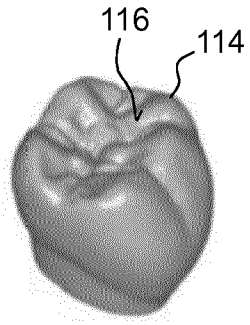


Fig. 15A

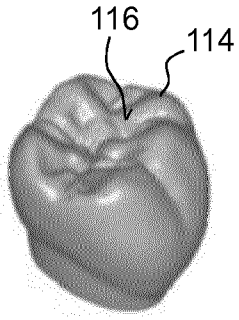


Fig. 16A

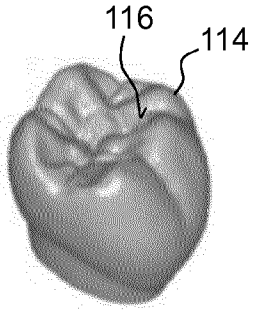


Fig. 15B

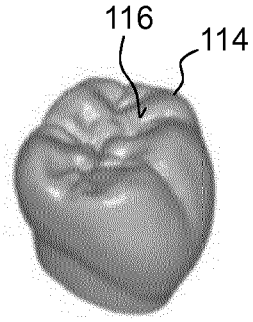


Fig. 16B

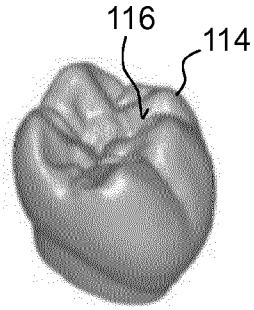


Fig. 15C

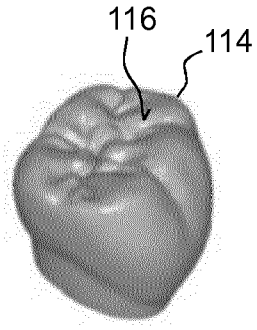


Fig. 16C

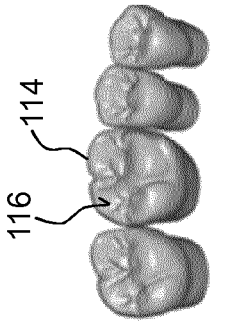


Fig. 17C

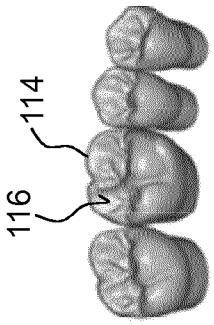


Fig. 17B

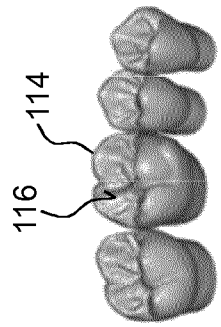


Fig. 17A

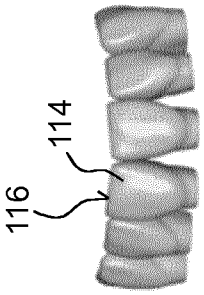


Fig. 18C

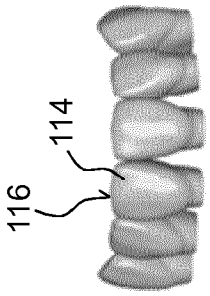


Fig. 18B

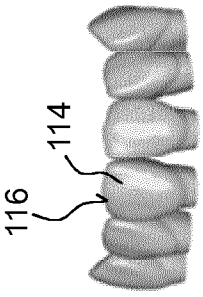


Fig. 18A