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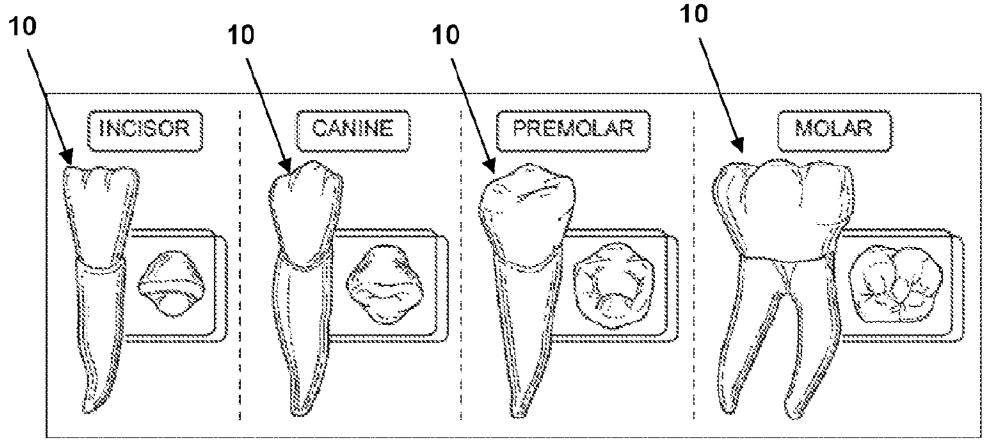
(71) Demandeur/Applicant:
CLEARCORRECT OPERATING, LLC, US
(72) Inventeur/Inventor:
MAH, JAMES, US
(74) Agent: SMART & BIGGAR LLP

(54) Titre : SYSTEMES ET PROCEDES DE CONCEPTION ET D'AMELIORATION DE LA RETENUE DE GOUTTIERES ORTHODONTIQUES
(54) Title: SYSTEMS AND METHODS FOR DESIGNING, AND IMPROVING RETENTION OF, ORTHODONTIC ALIGNERS



(57) Abrégé/Abstract:
A computer implemented method for designing a removable orthodontic aligner includes operating a digital scanner to obtain a digital image of a patient's dentition and operating a computing environment, to: (a) receive a copy of the digital image; (b) create a reference plane relative to teeth featured within the digital image; (c) position a line that runs perpendicular from the reference plane and runs tangential to a height of maximum convexity of each of the teeth; (d) measure an area of undercut; (e) repeat steps (a) - (d) at a plurality of points; (f) construct a three-dimensional model that represents a compilation of each area of undercut; and (g) translating the three-dimensional model into a removable orthodontic aligner. The removable orthodontic aligner has anti-relapse features and is configured to cause the removable orthodontic aligner to mate with areas of undercut for each of the teeth.

Abstract

A computer implemented method for designing a removable orthodontic aligner includes operating a digital scanner to obtain a digital image of a patient's dentition and operating a computing environment, to: (a) receive a copy of the digital image; (b) create a reference plane relative to teeth featured within the digital image; (c) position a line that runs perpendicular from the reference plane and runs tangential to a height of maximum convexity of each of the teeth; (d) measure an area of undercut; (e) repeat steps (a) - (d) at a plurality of points; (f) construct a three-dimensional model that represents a compilation of each area of undercut; and (g) translating the three-dimensional model into a removable orthodontic aligner. The removable orthodontic aligner has anti-relapse features and is configured to cause the removable orthodontic aligner to mate with areas of undercut for each of the teeth.

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SYSTEMS AND METHODS FOR DESIGNING, AND IMPROVING RETENTION OF, ORTHODONTIC ALIGNERS

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] This application is a divisional of Canadian Patent Application No. 3,068,654 and claims priority from therein.

[001a] This application claims priority to U.S. patent application serial number 15/640,941, filed on July 3, 2017.

FIELD OF THE INVENTION

[002] The field of the present invention relates to systems and methods for designing thermoformed removable orthodontic aligners and improving the retention of such aligners to patient teeth (and, furthermore, for improving the efficacy of such treatments).

BACKGROUND OF THE INVENTION

[003] Removable orthodontic aligners are increasingly being used to impart orthodontic tooth movement (in connection with orthodontic treatment protocols). Such orthodontic aligners are often preferred over more conventional orthodontic appliances for a variety of reasons, namely, removable orthodontic aligners have been found to be more visually desirable, comfortable, and easier to use (compared to conventional orthodontic appliances, e.g., metallic braces). Although removable orthodontic aligners have been shown to be effective in imparting desired tooth movements, challenges persist relating to the retention of such aligners on a patient's teeth. It has been shown that orthodontic aligner retention can be negatively influenced by multiple factors. In particular, it has been shown that variations in tooth morphology within a patient are often responsible for insufficient aligner retention.

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[004] Accordingly, a continuing demand exists for systems and methods that can be used for designing and manufacturing orthodontic aligners in a manner that accommodates patient-specific variations in tooth morphologies and positions. In addition, a continuing demand exists for systems and methods for designing and positioning custom attachments (engagers) for teeth, when such attachments are needed or desired to encourage enhanced retention of an orthodontic aligner to a patient's teeth. Such custom-formed attachments may further encourage desired tooth movements (i.e., improve the efficiency of an orthodontic treatment plan).

[005] As the following will demonstrate, the inventions described herein address such continuing demands (as well as others).

SUMMARY OF THE INVENTION

[006] According to certain aspects of the invention, systems for designing thermoformed removable orthodontic aligners and improving the retention of such aligners to patient teeth are disclosed. In certain embodiments, the systems include a digital scanner that is configured to obtain a digital image of a patient's dentition and a computing environment (with a graphical user interface) that is configured to receive a copy of (and analyze) the digital image. More particularly, within the computing environment and its associated graphical user interface, the system is further configured to create a reference plane relative to one or more teeth featured within the digital image (and position a line that runs perpendicular from the reference plane, which also runs tangential to a height of maximum convexity of each of one or more teeth being analyzed by the system).

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In addition, within the computing environment (and graphical user interface), the system is configured to then measure an area of undercut between such perpendicular line and an exterior surface of each of the one or more teeth being analyzed. The system is preferably configured to repeat the foregoing steps at a plurality of points along a perimeter of each of the one or more teeth - - and then construct a three-dimensional model of the undercut area for each of the one or more teeth being analyzed. The three-dimensional model of the undercut area can then be used to design the interior regions of removable orthodontic aligners, such that the interior dimensions of the removable orthodontic aligners are configured to mate with and retentively sit adjacent to the undercut areas for each of the one or more teeth.

[007] According to further aspects of the invention, methods of using the systems described herein (for designing thermoformed removable orthodontic aligners and improving the retention of such aligners to patient teeth) are encompassed by the present invention, along with removable orthodontic aligners that are designed and produced using the systems and methods described herein.

[008] According to additional aspects of the invention, systems and methods are provided for designing and producing dental restorations (e.g., dental crowns), either temporary or permanent, which are customized to provide a desired restoration undercut for enhanced aligner retention and treatment.

[009] According to yet further embodiments of the invention, systems and methods are provided for designing and producing aligners and restorations that

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are customized to exhibit integrated anti-relapse features, such as dimples, ridges, depressions, and others.

[009a] According to further embodiments of the invention, there is provided a computer implemented method for designing a removable orthodontic aligner, which comprises operating a digital scanner to obtain a digital image of a patient's dentition and operating a computing environment, which comprises a central processor, memory, imaging software, and graphical user interface, to: (a) receive a copy of the digital image; (b) create a reference plane relative to one or more teeth featured within the digital image; (c) position a line that runs perpendicular from the reference plane and runs tangential to a height of maximum convexity of each of the one or more teeth; (d) measure an area of undercut between such perpendicular line and an exterior surface of each of the one or more teeth; (e) repeat steps (a) - (d) at a plurality of points along a perimeter of each of the one or more teeth; (f) construct a three-dimensional model that represents a compilation of each area of undercut calculated by the system for each of the one or more teeth; and (g) translating the three-dimensional model into a set of dimensions that are correlated to preferred interior dimensions of a removable orthodontic aligner, wherein the preferred interior dimensions of the removable orthodontic aligner are configured to cause the removable orthodontic aligner to mate with and retentively sit adjacent to areas of undercut for each of the one or more teeth, and the removable orthodontic aligner further comprises one or more anti-relapse features, wherein the anti-relapse features are configured to discourage or prevent relapse movement of an underlying tooth.

[009b] According to further embodiments of the invention, there is provided a removable orthodontic aligner that is configured to mate with and retentively sit

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adjacent to an undercut area of each of one or more teeth of a patient, wherein the removable orthodontic aligner is produced by: (a) operating a digital scanner to obtain a digital image of the patient's dentition; (b) operating a computing environment, which comprises a central processor, memory, imaging software, and a graphical user interface, to: (i) receive a copy of the digital image; (ii) create a reference plane relative to one or more teeth featured within the digital image; (iii) position a line that runs perpendicular from the reference plane and runs tangential to a height of maximum convexity of each of the one or more teeth; (iv) measure an area of undercut between such perpendicular line and an exterior surface of each of the one or more teeth; (v) repeat steps (i) - (iv) at a plurality of points along a perimeter of each of the one or more teeth; and (vi) construct a three-dimensional model that represents a compilation of each area of undercut calculated by the system for each of the one or more teeth; and (c) producing the removable orthodontic aligner to exhibit interior dimensions that are configured to mate with and retentively sit adjacent to the undercut area for each of the one or more teeth, whereby the removable orthodontic aligner further comprises one or more anti-relapse features, wherein the anti-relapse features are configured to discourage or prevent relapse movement of an underlying tooth.

[0010] The above-mentioned and additional features of the present invention are further illustrated in the Detailed Description contained herein.

BRIEF DESCRIPTION OF THE FIGURES

[0011] **FIGURE 1** is a drawing that illustrates the variations in tooth morphology that are common among various types of teeth, such as incisors, canines, premolars, and molars.

[0012] **FIGURE 2** is a drawing that shows the variations in tooth morphology

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that are common within a single type of tooth, such as the variations that commonly exist among central incisors.

[0013] **FIGURE 3** is a drawing that shows the use of a dental surveyor to impart a temporary (carbon) mark or line around the height of contour (or point of first contact) of a tooth.

[0014] **FIGURE 4** is a diagram that illustrates the system of the present invention being used to (1) create a reference plane; (2) locate a line perpendicular to the reference plane which also contacts (or runs tangential to) the height of maximum convexity of a tooth; and (3) measure the area of undercut between such perpendicular line and the surface of the tooth.

[0015] **FIGURE 5** is a flow diagram that summarizes certain methods of the present invention.

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[0016] **FIGURE 6** is a drawing that shows an attachment (engager) affixed to a tooth, which can be used to further encourage retention between an orthodontic aligner and the underlying tooth.

[0017] **FIGURE 7** is a drawing that shows a tooth crown preparation that has minimal undercut.

[0018] **FIGURE 8** is a drawing that shows another crown that is specifically designed to exhibit adequate undercut (compared to the undercut of Figure 7), to enhance aligner retention to the tooth.

[0019] **FIGURE 9** is a drawing that illustrates a malpositioned tooth (rotationally malpositioned); the malpositioned tooth in a counter-rotated / corrected position; the direction of rotational relapse forces; and the location of an anti-relapse elevated ridge.

[0020] **FIGURE 10** is a drawing that illustrates another malpositioned tooth (a retrocline malposition); the malpositioned tooth in a corrected position; the direction of relapse forces exerted on the corrected tooth; and the location of an anti-relapse elevated ridge.

[0021] **FIGURE 11** is a drawing that illustrates yet another malpositioned tooth (an intruded tooth); the malpositioned tooth in a corrected position; the direction of relapse forces exerted on the corrected tooth; and the location of an anti-relapse (anti-extrusive) feature / bump on a crown and aligner.

DETAILED DESCRIPTION OF THE INVENTION

[0022] The following will describe, in detail, several preferred embodiments of the present invention. These embodiments are provided by way of explanation

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only, and thus, should not unduly restrict the scope of the invention. In fact, those of ordinary skill in the art will appreciate upon reading the present specification and viewing the present drawings that the invention teaches many variations and modifications, and that numerous variations of the invention may be employed, used and made without departing from the scope and spirit of the invention.

[0023] Referring now to Figures 1 and 2, it is well known that a patient's teeth exhibit significantly different morphologies (i.e., when comparing the morphology of one tooth to another). For example, differences in morphologies exist between the crown regions **10** of teeth, as illustrated Figure 1. In addition, significant variations also exist within a single type of tooth, such as variations that often exist among central incisors **12**, as illustrated in Figure 2. Such variations in tooth morphologies will often compromise the retentive capability of orthodontic aligners. Accordingly, as mentioned above, an object of the present invention is to provide a system and method that can be used to quantify such variations in tooth morphology (and undercuts associated with each tooth within a set of teeth), such that the internal dimensions of an orthodontic aligner may be designed and manufactured to more accurately accommodate such differences in morphology among a patient's teeth (which enhances orthodontic aligner fit, retention, and efficacy).

[0024] Referring now to Figure 3, such differences in tooth morphology have traditionally been measured using so-called dental surveyors **14**. More particularly, dental surveyors **14** have been used to mark, identify, and determine the amount of undercut of individual teeth. Notably, conventional dental

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surveyors **14** have been used in such capacity to assist in the design of partial dentures, but have not been used in the design of orthodontic appliances, such as removable orthodontic aligners. Referring to Figure 3, for example, such dental surveyors **14**, e.g., a Jelenko carbon marker, can be used to mark (with a temporary carbon line **16**) one or more teeth and subsequently measure the height of contour (or point of first contact) between different teeth. As shown in Figure 3, a dental surveyor **14** can be used by moving the dental surveyor **14** around the perimeter of a tooth within a single plane, such that the dental surveyor **14** is configured to impart a temporary (carbon) mark or line **16** around the height of contour (or point of first contact). Such marking procedures have been used by clinicians to then identify the amount of undercut (tooth morphology) for a particular tooth (again, which have traditionally been used in the design of partial dentures).

[0025] The systems and methods of the present invention preferably employ the use of certain digital technologies to more accurately and efficiently identify and measure the amount of undercut (tooth morphology) for one or more teeth (instead of using more rudimentary dental surveyors **14**). More particularly, the invention utilizes a computer / digital system for quantifying the undercut and retentive morphology of one or more teeth. Referring now to Figure 4, the system of the present invention is configured to create and utilize at least one reference plane **18**. The invention provides that such reference plane **18** may, for example, represent a horizontal reference plane **18**. However, the reference

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plane **18** does not necessarily need to exhibit a horizontal orientation (a vertical or other orientation may also be employed).

[0026] The invention provides that the system is configured to then position at least one line **20** that runs perpendicular from the reference plane **18**, while the perpendicular line **20** is simultaneously positioned to contact (and run tangential to) each tooth at its most protruded location **22** (the most protruded location of a tooth is also known as the "height of maximum convexity"). The perpendicular line **20** is then used by the system to identify and quantify an area **24** that exists between the perpendicular line **20** and the variable / exterior tooth surface. The invention provides that the reference plane **18** – and at least one line **20** that runs perpendicular from the reference plane **18** – are visualized by a user of the system within a graphical user interface of the system.

[0027] Importantly, in certain embodiments, the system of the present invention is preferably configured to execute such procedures and analyses around the entire perimeter **26** of a particular tooth (e.g., at a plurality of points around the perimeter **26** of a particular tooth). That is, the system of the present invention is preferably configured to position the perpendicular line **20**, at various points around the perimeter **26** of a tooth, and subsequently quantify the area **24** between the perpendicular line **20** and the variable / exterior tooth surface. The invention provides that the plurality of area **24** values are then used by the system to compute and build a three-dimensional model of the undercut / retentive features of each tooth, which can then be used to design and manufacture an orthodontic aligner (with the internal dimensions of the aligner

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preferably being configured to mate fittingly with and to accommodate the precise three-dimensional undercut morphology of each tooth). The invention provides that the system is preferably configured to execute the above-described measurements and analysis for each tooth within a patient's dental arch (or copy of a dental arch, e.g., a dental stone model or digital image of a patient's dental arch).

[0028] As mentioned above, the systems and methods of the present invention preferably employ the use of certain digital technologies to more accurately and efficiently identify and measure the amount of undercut (tooth morphology) for one or more teeth. The invention provides that various types of digital technologies may be employed in such capacity. In certain preferred embodiments, for example, a three-dimensional digital image may be obtained of a patient's dentition, e.g., using digital scanning (camera) technology. The invention provides that the three-dimensional digital image may then be imported into a computing environment, e.g., a computer system that includes a central processor, memory, imaging software, and a graphical user interface. Within the computing environment, the system can be operated to then use the three-dimensional digital image to conduct the above-described measurements and analysis for each tooth within a patient's dental arch (or for those teeth that will be covered by the orthodontic aligner).

[0029] More particularly, within the computing environment, imaging software can be used that is configured to (1) create and position at least one digital reference plane **18** for each tooth to be analyzed; (2) position at least one digital

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line **20** that runs perpendicular from the reference plane **18** which is further oriented to contact (and run tangential to) the tooth at its most protruded location **22** (i.e., at its "height of maximum convexity"); (3) quantify the area **24** between the perpendicular line **20** and the variable / exterior tooth surface; and (4) repeat steps (1) – (3) for a plurality of locations around the perimeter **26** of the particular tooth being analyzed.

[0030] The invention provides that such measurements and the system can then be used to produce a three-dimensional model of the undercut areas **24** for each of one or more teeth (i.e., a three-dimensional model that represents a compilation of each area of undercut **24** calculated by the system for each of the one or more teeth). The invention provides that the system is preferably configured to translate the three-dimensional model of the undercut area **24** for each of one or more teeth into a set of dimensions that are correlated to preferred interior dimensions of a removable orthodontic aligner. In such embodiments, the preferred interior dimensions of the removable orthodontic aligner are configured to mate with and retentively sit adjacent to the undercut area of each of the one or more teeth. The invention provides that such steps and methods of using the system described herein are further encompassed by the present invention, as summarized in Figure 5.

[0031] Referring now to Figure 6, when the system of the present invention is used for treatment planning and design of orthodontic aligners, a clinician may choose to supplement the undercut area (as identified and quantified by the system) by affixing dental restorative material, an attachment / bracket **28**, or

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other material to the tooth to facilitate sufficient retention for efficient tooth movement. More particularly, the invention provides that the three-dimensional model of the undercut area **24** for each of one or more teeth may be used identify a desirable location (and size and configuration) of an attachment **28** (also known as an engager) that can be affixed to such teeth to provide even more retention between an orthodontic aligner and the patient's teeth. In such embodiments, the attachment **28** will provide additional tooth morphology, such that the orthodontic aligner can better grasp the underlying tooth. The invention provides that such attachments **28** can further be used to facilitate a variety of tooth movements, such as rotation, intrusion, extrusion, translation, tipping, and torqueing.

[0032] Referring now to Figures 7 – 8, according to yet further embodiments, the systems and methods of the present invention are further configured to produce (and/or utilize) dental restorations **30**, e.g., dental crowns, either temporary or permanent, which are customized to provide a desired restoration undercut **32** for enhanced aligner retention and treatment. The invention provides that the desired restoration undercut **32** may be built into the restoration **30**, regardless of whether an aligner will be used or not (e.g., the desired restoration undercut **32** may be built into the restoration **30** for the mere possibility that a patient may, at some time in the future, elect for aligner treatment).

[0033] More particularly, referring to Figure 7, a tooth or restoration **30** (e.g., a crown) that is relatively flat in profile would exhibit a small amount of undercut **34**

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(which makes aligner retention more difficult); whereas, referring to Figure 8, a tooth or restoration **30** (e.g., a crown) having a bulbous profile will exhibit a more desired amount of undercut **32**. As explained above, the larger / desired restoration undercut **32** (Figure 8) is used by the system to calculate a set of dimensions that are correlated to preferred interior dimensions of a removable orthodontic aligner. In such embodiments, the preferred interior dimensions of the removable orthodontic aligner are configured to mate with and retentively sit adjacent to the desired undercut area **32** of each of one or more restorations **30**. In such embodiments, the specific amount of desired undercut area **32** for each tooth may be controlled by a clinician and operator of the system. Preferably, in such embodiments, the restorations **30** are fabricated with esthetic dental materials, such as porcelain and composite resins.

[0034] According to yet further embodiments, the systems and methods of the present invention are further configured to produce aligners and restorations that are customized to exhibit integrated anti-relapse features, such as dimples, ridges, depressions, and others. In such embodiments, the anti-relapse features are configured to exert anti-relapse forces in a specific region of a tooth (or otherwise render relapse movement more difficult). For example a small bump or ridge on the distal lingual marginal ridge of a tooth, positioned on a lower incisor (i.e., within the portion of the aligner or restoration applied to such area of the tooth), will discourage the tooth from experiencing rotational relapse movement in that direction. Figures 9 – 11 provide yet further examples of such embodiments.

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[0035] In Figure 9, for example, a rotationally malpositioned tooth **36** is shown; a counter-rotated / corrected tooth **38** is shown (such correction being achieved through traditional orthodontic procedures); the direction of rotational relapse forces **40** are shown; and the location of an anti-relapse elevated ridge **42** (located in the portion of the aligner or restoration **44** applied to the corrected tooth **38**) is shown. The invention provides that the systems described herein, when used to design and produce an aligner or restoration, may optionally include this type of anti-relapse feature (to discourage an anticipated relapse movement). In the example shown in Figure 9, the elevated ridge **42** is integrally formed into the portion of the aligner or restoration **44** – to exhibit a size, configuration, and position – that (mechanically) counteracts the anticipated rotational relapse forces **40** of the underlying corrected tooth **38**.

[0036] Similarly, Figure 10 illustrates another malpositioned tooth **46** (a retrocline malposition); a corrected tooth **48**; the direction of relapse forces **50** exerted on the corrected tooth **48**; and the location of an anti-relapse elevated ridge **52** of the aligner or restoration **44**. In this example, the anti-relapse elevated ridge **52** of the aligner **44** is configured to exhibit a size and position that counteracts the anticipated relapse forces **50** of the underlying corrected tooth **48**. Likewise, Figure 11 illustrates yet another malpositioned tooth **54** (an intruded tooth); a corrected tooth **56**; the direction of relapse forces **58** exerted on the corrected tooth **56**; and the location of an anti-relapse / anti-extrusive (a bump) feature **60** on a crown / restoration **62** (as well as a corresponding anti-relapse / anti-extrusive feature **64**) positioned on an aligner **66** that fits over the

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crown / restoration **62**. The invention provides that the foregoing examples are not exhaustive. Rather, the systems and methods described herein are useful for designing and producing aligners and/or restorations that may utilize a number of different anti-relapse features, such as bumps, dots, dimples, divots, depressions, ridges (vertical, horizontal, diagonal, and other directions), and combinations of such features, to exert the desired anti-relapse force on the underlying tooth.

[0037] The invention provides that the systems and methods described herein are preferably operated to produce a production model of the desired aligner (and/or restoration). For example, after the three-dimensional model of the undercut areas **24** for each of the one or more teeth is produced (as described above) and translated into interior dimensions of the removable orthodontic aligner (and/or restoration) and, likewise, once the geometry of all desired anti-relapse features are defined, the system is configured to produce a production model of the desired aligner (and/or restoration). The production model will consist of a complete digital three-dimensional model of the desired aligner (and/or restoration), with all external and internal dimensions being defined, which can then be used to produce the desired aligner (and/or restoration), e.g., using various types of polymers and thermoforming procedures known in the art.

[0038] The many aspects and benefits of the invention are apparent from the detailed description, and thus, it is intended for the following claims to cover all such aspects and benefits of the invention that fall within the scope and spirit of the invention. In addition, because numerous modifications and variations will be

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obvious and readily occur to those skilled in the art, the claims should not be construed to limit the invention to the exact construction and operation illustrated and described herein. Accordingly, all suitable modifications and equivalents should be understood to fall within the scope of the invention as claimed herein.

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CLAIMS:

1. A computer implemented method for designing a removable orthodontic aligner, which comprises operating a digital scanner to obtain a digital image of a patient's dentition and operating a computing environment, which comprises a central processor, memory, imaging software, and graphical user interface, to:

(a) receive a copy of the digital image;

(b) create a reference plane relative to one or more teeth featured within the digital image;

(c) position a line that runs perpendicular from the reference plane and runs tangential to a height of maximum convexity of each of the one or more teeth;

(d) measure an area of undercut between such perpendicular line and an exterior surface of each of the one or more teeth;

(e) repeat steps (a) - (d) at a plurality of points along a perimeter of each of the one or more teeth;

(f) construct a three-dimensional model that represents a compilation of each area of undercut calculated by the system for each of the one or more teeth; and

(g) translating the three-dimensional model into a set of dimensions that are correlated to preferred interior dimensions of a removable orthodontic aligner, wherein

the preferred interior dimensions of the removable orthodontic aligner are configured to cause the removable orthodontic aligner to mate with and retentively sit adjacent to areas of undercut for each of the one or more teeth, and

the removable orthodontic aligner further comprises one or more anti-relapse features, wherein the anti-relapse features are configured to discourage or prevent relapse movement of an underlying tooth.

2. The computer implemented method of claim 1, wherein the method further comprises applying a tooth restoration to one or more of the patient's teeth, wherein the tooth restoration exhibits a desired and pre-defined undercut.

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3. The computer implemented method of claim 2, wherein the restoration is a crown.

4. The computer implemented method of claim 1, which further comprises identifying a desirable location, size, and configuration of an attachment to be affixed to the one or more teeth, wherein the attachment is configured to enhance retention of the removable orthodontic aligner to the one or more teeth.

5. A data processing system for designing a removable orthodontic aligner comprising means for carrying out the steps of the method of any one of claims 1 to 4.

6. The data processing system of claim 5, wherein the system is further configured to identify a desirable location, size, and configuration of an attachment to be affixed to the one or more teeth, wherein the attachment is configured to enhance retention of the removable orthodontic aligner to the one or more teeth.

7. The data processing system of claim 6, wherein the system is further configured to design and incorporate the preferred interior dimensions of the removable orthodontic aligner, along with the one or more anti-relapse features, into a production model of the removable orthodontic aligner, wherein the production model is configured to be used to manufacture the removable orthodontic aligner.

8. The data processing system of any one of claims 1 to 7, wherein the anti-relapse feature comprises one or more bumps, dots, dimples, divots, depressions, ridges, or combinations of the foregoing, which exhibit a configuration and are positioned within the aligner to discourage or prevent relapse movement of an underlying tooth.

9. A removable orthodontic aligner that is configured to mate with and retentively sit adjacent to an undercut area of each of one or more teeth of a patient, wherein the removable orthodontic aligner is produced by:

(a) operating a digital scanner to obtain a digital image of the patient's dentition;

(b) operating a computing environment, which comprises a central processor, memory, imaging software, and a graphical user interface, to:

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(i) receive a copy of the digital image;

(ii) create a reference plane relative to one or more teeth featured within the digital image;

(iii) position a line that runs perpendicular from the reference plane and runs tangential to a height of maximum convexity of each of the one or more teeth;

(iv) measure an area of undercut between such perpendicular line and an exterior surface of each of the one or more teeth;

(v) repeat steps (i) - (iv) at a plurality of points along a perimeter of each of the one or more teeth; and

(vi) construct a three-dimensional model that represents a compilation of each area of undercut calculated by the system for each of the one or more teeth; and

(c) producing the removable orthodontic aligner to exhibit interior dimensions that are configured to mate with and retentively sit adjacent to the undercut area for each of the one or more teeth, whereby

the removable orthodontic aligner further comprises one or more anti-relapse features, wherein the anti-relapse features are configured to discourage or prevent relapse movement of an underlying tooth.

10. The removable orthodontic aligner of claim 9, which further comprises an attachment that is configured to (a) be affixed to the one or more teeth and (b) enhance retention of the removable orthodontic aligner to the one or more teeth.

11. The removable orthodontic aligner of claim 10, wherein a size and configuration of the attachment is optimized by the system.

12. The removable orthodontic aligner of claim 9, wherein the attachment is configured to be affixed to the one or more teeth at a position that is optimized by the system.

13. The removable orthodontic aligner of any one of claims 9 to 12, wherein the anti-relapse features comprise one or more bumps, dots, dimples, divots, depressions, ridges, or combinations of the foregoing, which exhibit a configuration and are positioned within the aligner to discourage or prevent relapse movement of an underlying tooth.

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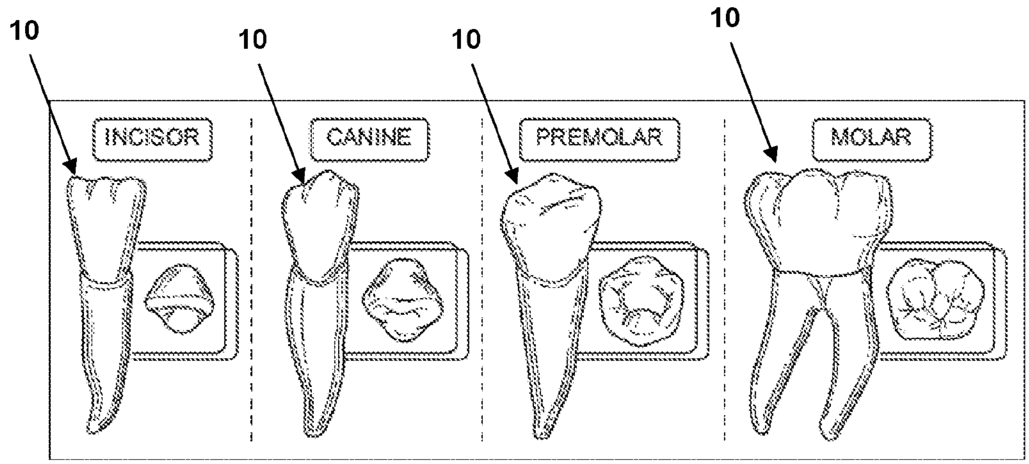


FIGURE 1

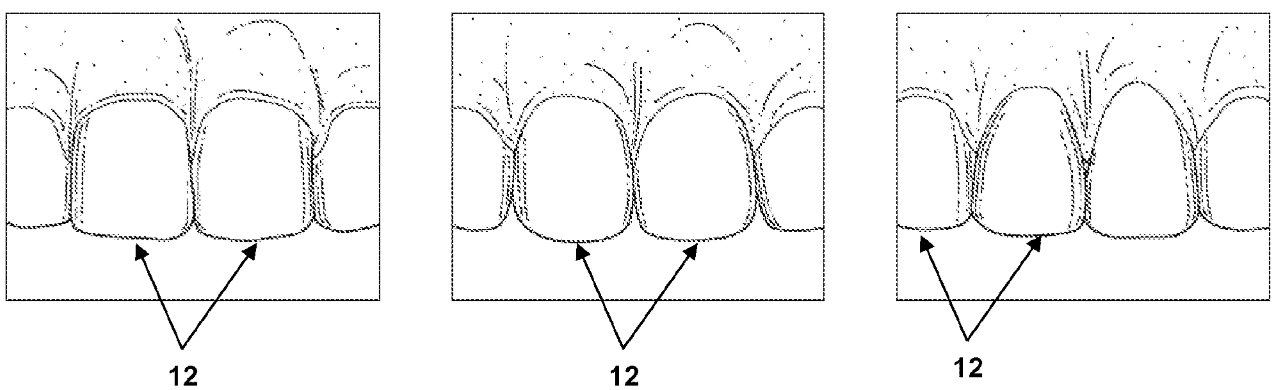


FIGURE 2

Date Reçue/Date Received 2022-01-21

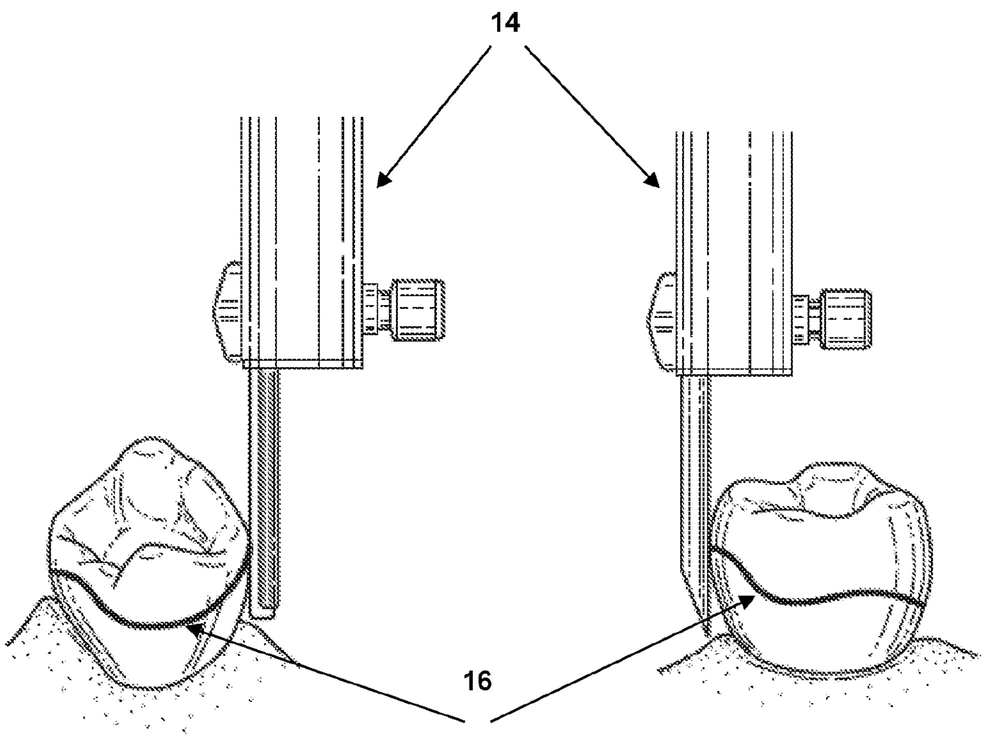
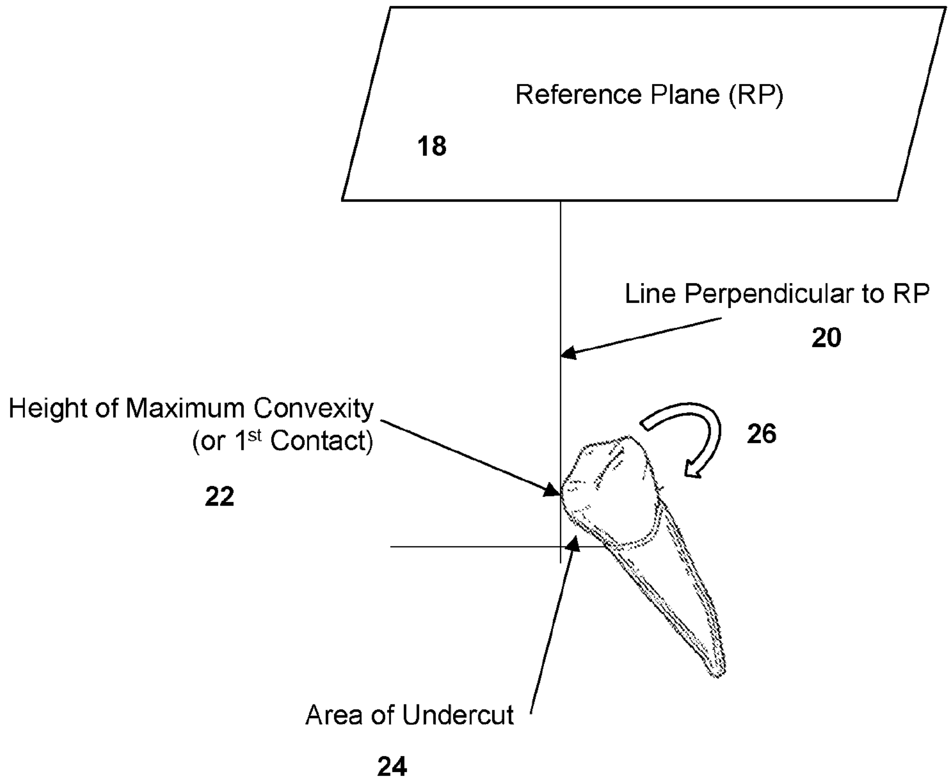


FIGURE 3



Reference Plane (RP)
18
Line Perpendicular to RP
20
Height of Maximum Convexity
(or 1st Contact)
22
26
Area of Undercut
24

FIGURE 4

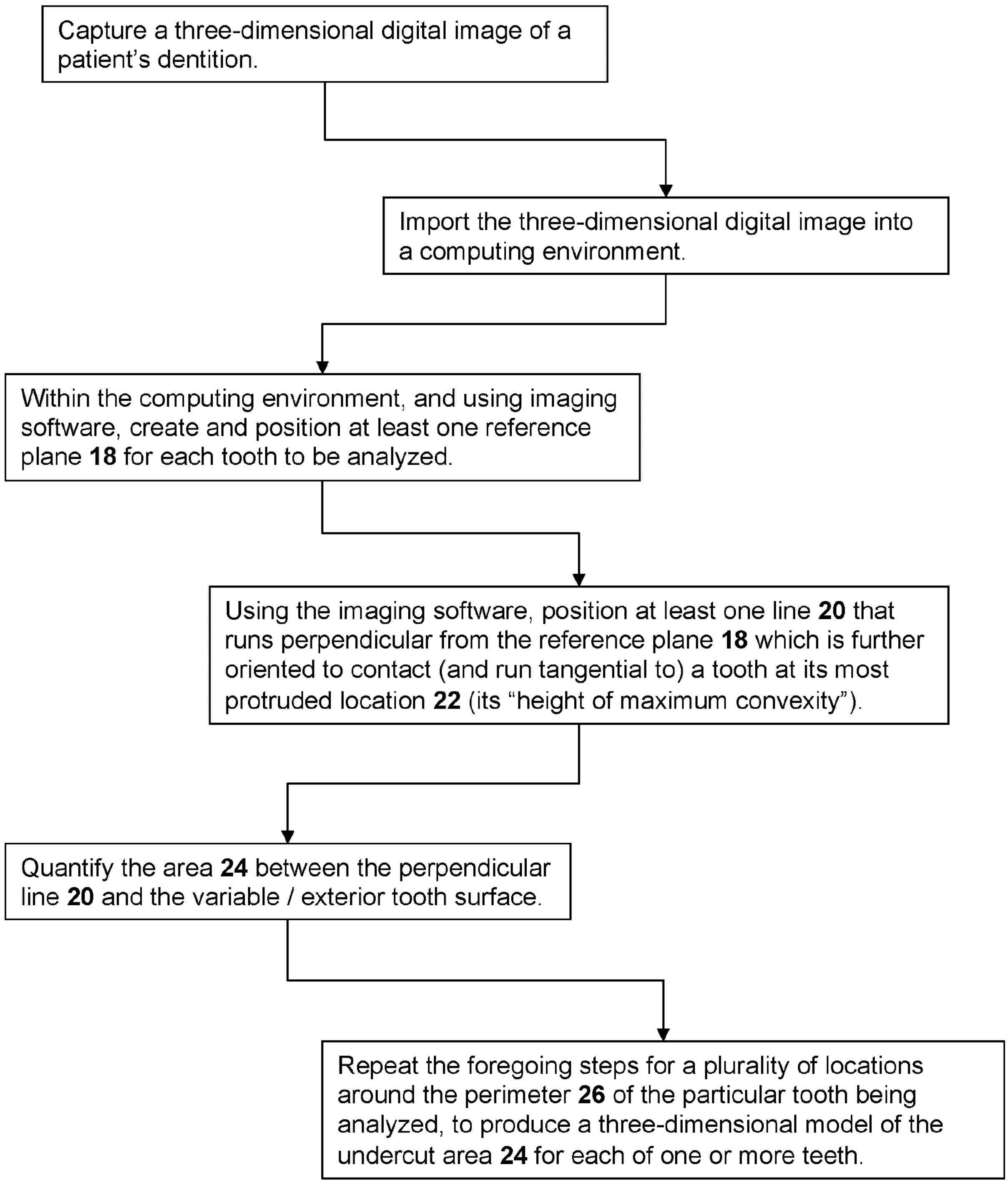


FIGURE 5

Date Reçue/Date Received 2022-01-21

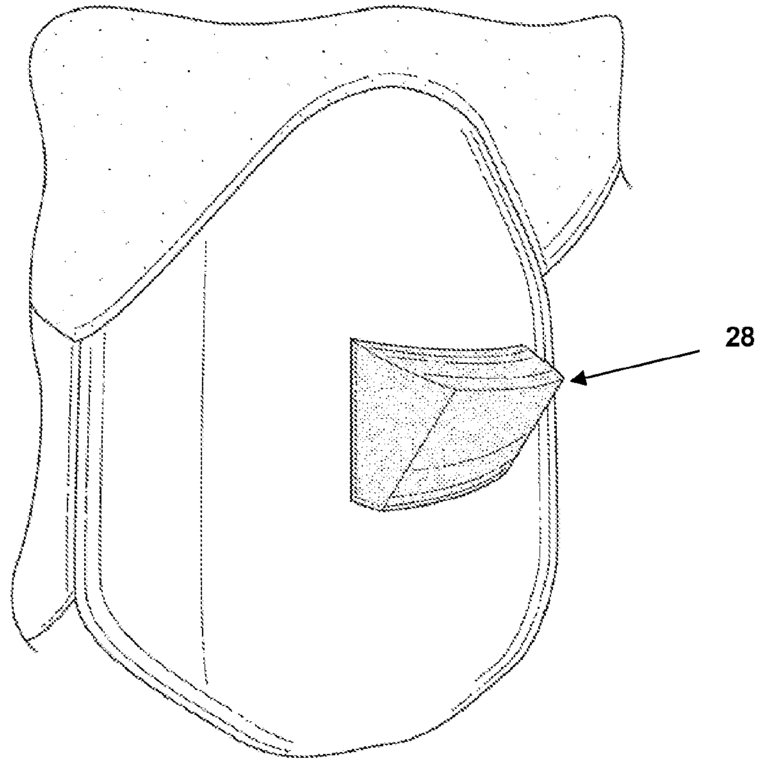


FIGURE 6

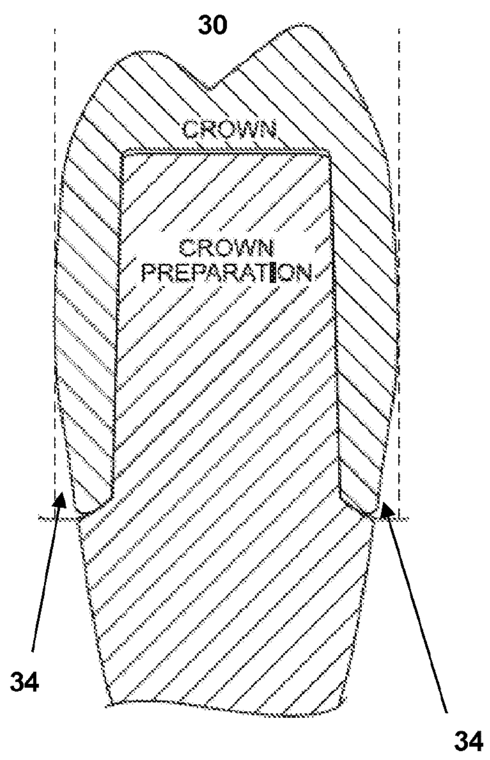


FIGURE 7

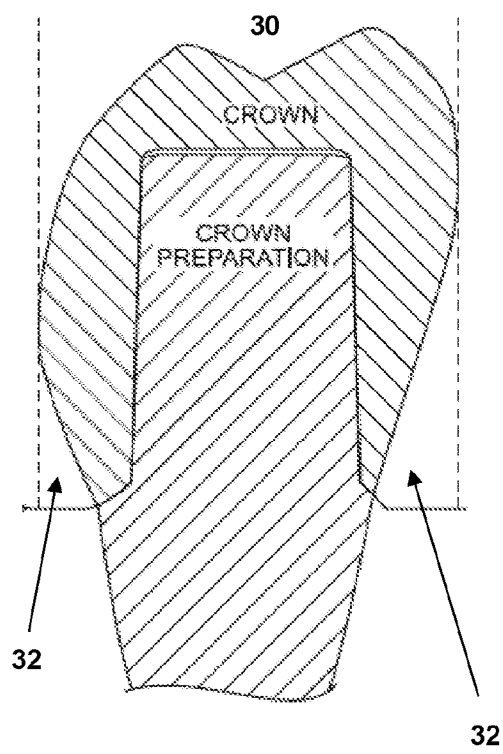


FIGURE 8

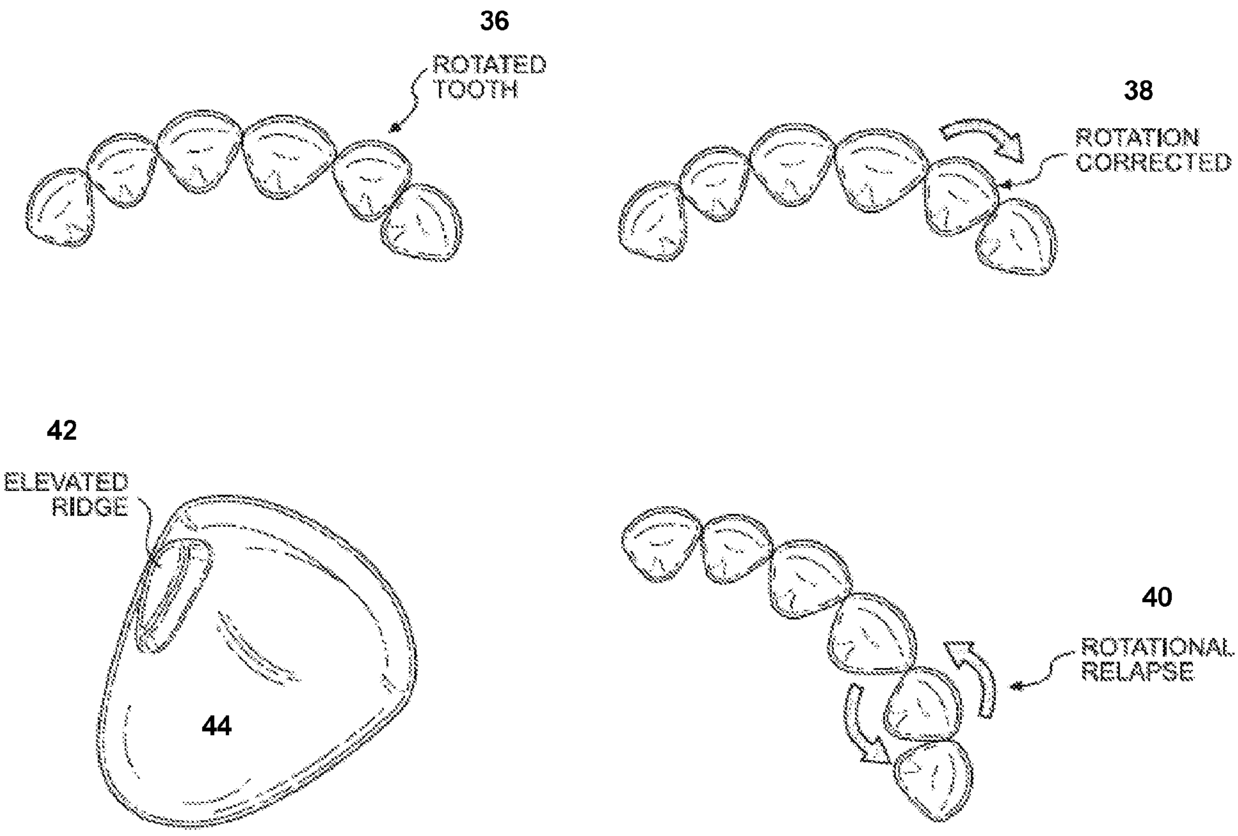

36
ROTATED
TOOTH
38
ROTATION
CORRECTED
42
ELEVATED
RIDGE
44
40
ROTATIONAL
RELAPSE

FIGURE 9

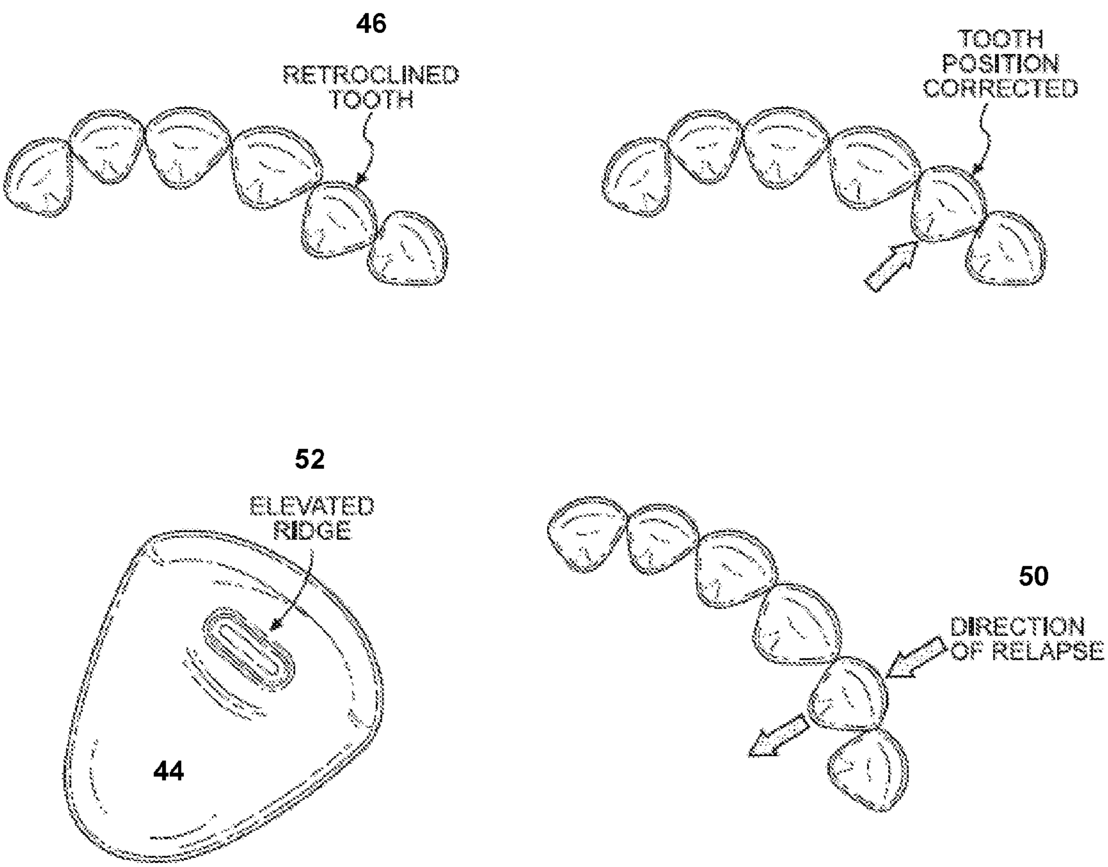

46
RETROCLINED TOOTH
48
TOOTH POSITION CORRECTED
52
ELEVATED RIDGE
44
50
DIRECTION OF RELAPSE

FIGURE 10

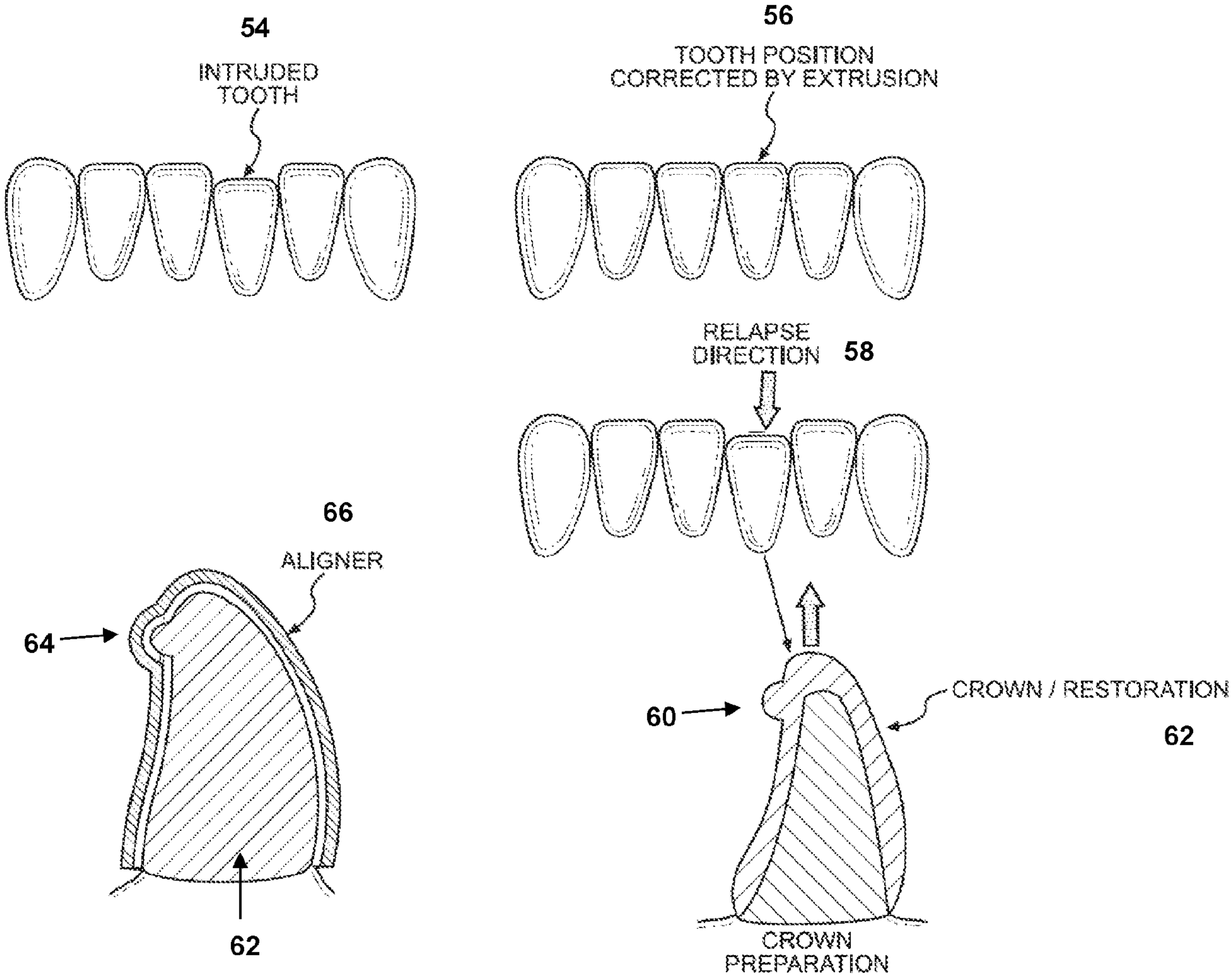


FIGURE 11

Date Reçue/Date Received 2022-01-21