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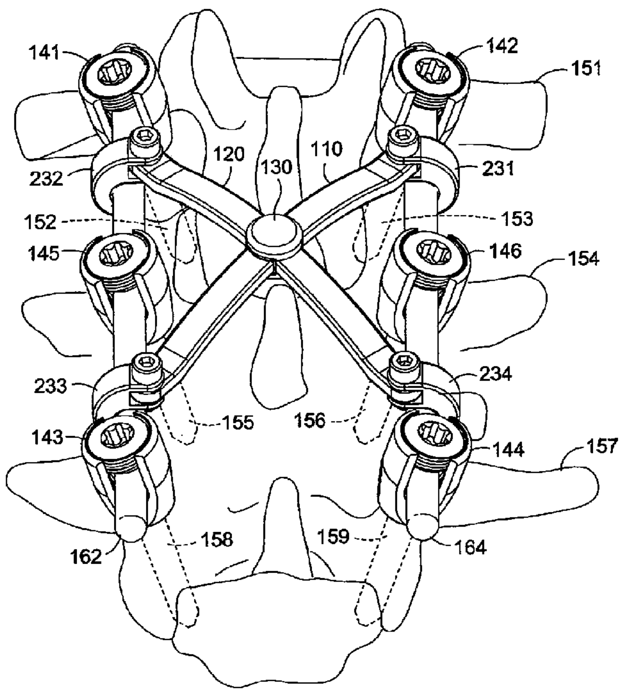

FIG. 2D

(57) Abstract: The present invention may provide various improvements over conventional cross connectors. For example, the present invention may provide various types of Real-X cross connectors, which may have an arch shape X-bridge that curves above the spinal bone segments of the patient. As such, the Real-X cross connectors may be more adaptive to the patient's spinal provide and provide better protect for the patient's the spinal bone segments. Moreover, the Real-X cross connectors may incorporate a complementary pivot joint configuration for smoothening the stress distribution and reducing the stress concentration around the center of the arch shape X-bridge. Advantageously, the complementary pivot joint configuration may enhance the rigidity and stability of the Real-X cross connectors.

WO 2012/054356 A2

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CROSS CONNECTORS

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of application no. 12/962,996, entitled "CROSS CONNECTORS," filed on December 8, 2010, which is a continuation-in-part of application no. 12/906,991, entitled "CROSS CONNECTORS," filed on October 18, 2010. The aforementioned related applications are assigned to the assignee hereof and hereby expressly incorporated by reference herein.

BACKGROUND

[0002] 1. Field

[0003] The present invention relates generally to the field of medical devices used in posterior spinal fixation surgery, and more particularly to cross connectors.

[0004] 2. Description of the Related Art

[0005] Posterior spinal fixation surgery is a common procedure for patients who suffer from severe spinal conditions, such as spinal displacement, spinal instability, spinal degeneration, and/or spinal stenosis. Among other therapeutic goals, a successful posterior spinal fixation surgery may lead to the stabilization and fusion of several spinal bone segments of a patient. During a posterior spinal fixation surgery, a spine surgeon may insert several pedicle screws into one side of several spinal bone segments of the patient to establish several anchoring points. Then, the spine surgeon may engage and secure a stabilizing rod to the several anchoring points to restrict or limit the relative movement of the spinal bone segments.

[0006] Next, this procedure may be repeated on the other side of the spinal bone segments, such that two stabilizing rods may be anchored to both sides of the spinal bone segments of the patient. To further restrict or limit the relative movement of the spinal bone segments, a connector may be used to connect the two stabilizing rods, so that the two stabilizing rods may maintain a relatively constant distance from each other. When the posterior spinal fixation surgery is completed, the operated spinal bone segments may be substantially stabilized such that they may be in condition for spinal fusion.

[0007] Conventional connectors may suffer from several drawbacks. For example, some conventional connectors may be made of flat and straight arms, such that surgeons may have a difficult time in adjusting these connectors to fit the contour the of patient's spinal bone segments. Accordingly, the implantation of these conventional connectors may require the removal of the patient's spinous process from one or more spinal bone segments because they may not be adaptive to the spinal bone structure of the patient. Moreover, most conventional connectors may not be able to protect any damaged spinal bone segment of the patient because they are can only cover a small area. Furthermore, most conventional connectors lack pre-fixation flexibility, such that they may not be adjusted to fit patients with various spinal bone widths or asymmetrical spinal bone profile.

[0008] Thus, there are needs to provide cross connectors with improved features and qualities.

SUMMARY

[0009] The present invention may provide various improvements over conventional connectors. For example, the present invention may provide various types of Real-X cross connectors, which may have an arch shape X-bridge that curves above the spinal bone segments of the patient. As such, the Real-X cross connectors may be more adaptive to the patient's spinal bone contour and provide better protect for the patient's spinal bone segments. For another example, the present invention may provide various types of Real-O cross connectors, which may have a protection ring that may surround the patient's spinous process. Because of its protection ring, the implantation of one of the Real-O cross connectors may eliminate the need of spinous process removal. Furthermore, as provided by the present invention, the Real-O cross connector may be combined with the Real-X cross connector to form a Real-XO cross connector, which may inherit the functional benefits of both Real-X and Real-O cross connectors.

[0010] In one embodiment, the present invention may provide a cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments. The cross connector may include a plurality of arms including first, second, third, and fourth arms, the first arm and the third arm aligning along a first reference plane, the second arm and the fourth arm aligning along a second reference plane intersecting the first reference plane along a pivot axis, a bottom plate centered along the pivot axis and substantially perpendicular to the first and second reference planes, a pair of bottom side walls connected to the bottom plate so as to define a bottom valley having a plurality of bottom curved sections, each of the pair of bottom side walls connected to the first arm or the third arm to form a first contiguous arc segment, a top plate snugly fitted within the bottom valley and engaging the bottom plate to provide a pivot point along the pivot axis, and a pair of top side walls connected to the top plate so as to define a top valley having a plurality of top curved sections for embracing the bottom plate, each of the pair of top side walls connected to the second arm or the fourth arm to form a second contiguous arc segment.

[0011] In another embodiment, the present invention may provide a cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments. The cross connector may include a first connector including a first pair of arms and a first joint positioned between the first pair of arms, the first joint having a first platform having a first bell-shaped ridge connecting the first pair of arms to form a first contiguous arc along a first reference plane, the first bell-shaped ridge furnished with a first convex edge, and a first bracket formed on the first platform, the first bracket having a first vertical concave contour substantially parallel to the first reference plane, and a first horizontal concave contour intersecting the first vertical concave contour and substantially perpendicular to the first reference plane, a second connector including a second pair of arms and a second joint positioned between the second pair of arms, the second joint having a complementary configuration with respect to the first joint, the second joint connecting the second pair of arms to form a second contiguous arc along a second reference plane intersecting the first reference plane alone a center axis, and a pivoting means for pivoting the first connector against the second connector along the center axis, thereby allowing a limited range of angular movement between the first pair of arms and the second pair of arms.

[0012] In yet another embodiment, the present invention may include a cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments. The cross connector may include a first link including a first pair of arms, a lower platform, and two upper brackets, the lower platform having two bottom bow-shaped ridges connecting the first pair of arms to form a first contiguous arc along a first reference plane, the two bottom bow-shaped ridges each furnished with a bottom convex edge, the two upper brackets positioned between the two bottom bow-shaped ridges and each having an upper ventral concave surface facing away from one of the first pair of arms, a second link including a second pair of arms, an upper platform, and two lower brackets, the upper platform having two upper bow-shaped ridges connecting the second pair of arms to form a second contiguous arc along a second reference plane intersecting the first reference plane alone a center axis, the two upper bow-shaped ridges each furnished with an upper convex edge, the two lower brackets positioned between the two upper bow-shaped ridges and each having a lower ventral concave surface facing away from one of the first pair of arms, and a pivoting member connected to the lower and upper platforms, thereby pivoting the first link against the second link along the center axis while substantially restricting a lateral movement between the first link and the second link.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Other systems, methods, features, and advantages of the present invention will be or will become apparent to one skilled in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims. Component parts shown in the drawings are not necessarily to scale, and may be exaggerated to better illustrate the important features of the present invention. In the drawings, like reference numerals designate like parts throughout the different views, wherein:

[0014] FIGS. 1A – 1C show various views of a Real-X cross connector according to an embodiment of the present invention;

[0015] FIGS. 1D – 1G show various views of the Real-X cross connector being anchored to three spinal bone segments according to an embodiment of the present invention;

[0016] FIGS. 2A – 2C show various views of a Real-X cross connector with four anchoring devices according to an embodiment of the present invention;

[0017] FIGS. 2D – 2F show a top perspective view and the top views of the Real-X cross connector with four hook members being anchored to three spinal bone segments according to an embodiment of the present invention;

[0018] FIGS. 3A – 3C show various views of a Real-X cross connector with four articulated rods as the connecting devices according to an embodiment of the present invention;

[0019] FIGS. 3D – 3H show a top perspective view and the top views of the Real-X cross connector with four articulated rods being anchored to three spinal bone segments according to an embodiment of the present invention;

[0020] FIGS. 4A – 4C show various views of a Real-X cross connector with adjustable arms according to an embodiment of the present invention;

[0021] FIGS. 4D – 4F show the cross-sectional side views of several configurations of the arm length adjustable device according to various embodiments of the present invention;

[0022] FIGS. 4G – 4I show various configurations of the Real-X cross connector with the adjustable arms according to various embodiments of the present invention;

[0023] FIGS. 5A – 5C show various views of a fulcrum member according to an embodiment of the present invention;

[0024] FIGS. 6A – 6C show various views of an alternative fulcrum member according to an embodiment of the present invention;

[0025] FIGS. 7A – 7C show various views of a Real-X cross connector with two adjustable rods as the connecting devices according to an embodiment of the present invention;

[0026] FIGS. 8A – 8B show a perspective view and a cross-sectional side view a Real-O cross connector (ROCC) according to an embodiment of the present invention;

[0027] FIGS. 8C – 8D show a perspective view and a cross sectional side view of an alternative Real-O cross connector (ROCC) according to another embodiment of the present invention;

[0028] FIG. 8E shows a top view of the ROCC being anchored between two stabilizing rods according to an embodiment of the present invention;

[0029] FIGS. 8F – 8G show the top views of the alternative ROCC being anchored between two stabilizing rods according to an embodiment of the present invention;

[0030] FIGS. 9A – 9B show a perspective view and a cross-sectional side view of a Real-O cross connector with an adjustable ring according to an embodiment of the present invention;

[0031] FIGS. 10A – 10H show the Real-O cross connector with rings of various shapes according to various embodiments of the present invention;

[0032] FIGS. 11A – 11D show various views of a Real-XO cross connector(RXOCC) according to an embodiment of the present invention;

[0033] FIGS. 11E – 11G show various configurations of the RXOCC according to various embodiments of the present invention;

[0034] FIGS. 12A – 12E show various views of an alternative lockable joint member according to an embodiment of the present invention;

[0035] FIGS. 13A – 13C show various views of a Real-X cross connecting pedicle screw (RXCCPS) system according to an embodiment of the present invention;

[0036] FIG. 14 shows an exploded view of a Real-X cross connector with an integrated fulcrum member according to an embodiment of the present invention;

[0037] FIG. 15 shows a top view of a semi-adjustable length Real-X cross connector with spherical joints according to an embodiment of the present invention;

[0038] FIG. 16 shows a top view of a fully adjustable Real-X cross connector with spherical joints according to an embodiment of the present invention;

[0039] FIGS. 17A – 17C show various views of the joint receiving pedicle screw according to an embodiment of the present invention;

[0040] FIGS. 18A – 18D show various views of the set screw according to an embodiment of the present invention;

[0041] FIGS. 19A – 19C show various views of a joint receiving pedicle screw according to an embodiment of the present invention;

[0042] FIGS. 20A – 20C show various views of an alternative joint receiving pedicle screw according to an embodiment of the present invention;

[0043] FIG. 21 shows a perspective view of an RXB cross connector according to a first alternative embodiment of the present invention;

[0044] FIGS. 22A – 22B show a front view and a back view of the RXB cross connector according to the first alternative embodiment of the present invention;

[0045] FIGS. 23A – 23B show a left side view and a front side view of the RXB cross connector according to the first alternative embodiment of the present invention;

[0046] FIG. 24 shows an exploded view of the RXB cross connector according to the first alternative embodiment of the present invention;

[0047] FIGS. 25A – 25E show various views of a top link of the RXB cross connector according to the first alternative embodiment of the present invention;

[0048] FIGS. 26A – 26E show various views of a bottom link of the RXB cross connector according to the first alternative embodiment of the present invention;

[0049] FIGS. 27 shows a perspective view of an RXC cross connector according to a second alternative embodiment of the present invention;

[0050] FIGS. 28A – 28B show a front view and a back view of the RXC cross connector according to the second alternative embodiment of the present invention;

[0051] FIGS. 29A – 29B show a left side view and a front side view of the RXC cross connector according to the second alternative embodiment of the present invention;

[0052] FIG. 30 shows an exploded view of the RXC cross connector according to the second alternative embodiment of the present invention;

[0053] FIGS. 31A – 31E show various views of a top link of the RXC cross connector according to the second alternative embodiment of the present invention;

[0054] FIGS. 32A – 32E show various views of a bottom link of the RXC cross connector according to the second alternative embodiment of the present invention;

[0055] FIG. 33A shows a perspective view of a stress test set up for the RXB cross connector according to the first alternative embodiment of the present invention;

[0056] FIG. 33B shows a perspective view of a stress test set up for the RXC cross connector according to the second alternative embodiment of the present invention;

[0057] FIG. 34A shows a chart of a stress test result of the RXB cross connector according to the first alternative embodiment of the present invention;

[0058] FIG. 34B shows a chart of a stress test result of the RXC cross connector according to the second alternative embodiment of the present invention;

[0059] FIG. 35 shows a perspective view of a pedicle screw utilizing a spherical joint according to an embodiment of the present invention;

[0060] FIGS. 36A – 36B show various views of the disassembled pedicle screw utilizing the spherical joint according to the embodiment shown in FIG. 35;

[0061] FIGS. 37A – 37B show various views of the disassembled pedicle screw utilizing the spherical joint according to the embodiment shown in FIG. 35 connecting with a spherical connecting rod;

[0062] FIG. 38 shows a perspective view of a Real-X cross connector utilizing a spherical joint at each arm according to an embodiment of the present invention;

[0063] FIG. 39 shows a perspective view of the disassembled Real-X cross connector utilizing a spherical joint at each arm according to the embodiment shown in FIG. 38;

[0064] FIGS. 40A – 40B show perspective views of a first connector and a second connector of the Real-X cross connector utilizing a spherical joint at each arm according to the embodiment shown in FIG. 38;

[0065] FIGS. 41A – 41C show various views of spherical connecting rods and an associated set screw for connecting the spherical connecting rods to the arms of the Real-X cross connector utilizing a spherical joint at each arm;

[0066] FIG. 42 shows a perspective view of an alternative Real-X cross connector utilizing a spherical joint at each arm according to an embodiment of the present invention;

[0067] FIG. 43 shows a perspective view of a Real-X cross connector utilizing a spherical joint at a fulcrum according to an embodiment of the present invention;

[0068] FIG. 44 shows a perspective view of the disassembled Real-X cross connector utilizing a spherical joint at a fulcrum according to the embodiment shown in FIG. 43;

[0069] FIGS. 45A – 45B show perspective views of a first connector and a second connector of the Real-X cross connector utilizing a spherical joint at a fulcrum according to the embodiment shown in FIG. 43;

[0070] FIGS. 46A – 46B show various views of a set screw for connecting the first connector to the second connector via a spherical joint at a fulcrum of the Real-X cross connector according to an embodiment of the present invention;

[0071] FIG. 47 shows a perspective view of a spinal bridge utilizing a spherical joint but without a crossed configuration according to an embodiment of the present invention;

[0072] FIG. 48 shows a perspective view of the disassembled spinal bridge according to the embodiment shown in FIG. 47;

[0073] FIGS. 49A – 49B show perspective views of a dimpled surface of a Real-X cross connector according to an embodiment of the present invention;

[0074] FIGS. 50A – 50B show various views of a collapsible minimally invasive cross connector according to an embodiment of the present invention; and

[0075] FIGS. 51A – 51C show various views of a geared minimally invasive cross connector according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0076] Apparatus, systems and methods that implement the embodiment of the various features of the present invention will now be described with reference to the drawings. The drawings and the associated descriptions are provided to illustrate some embodiments of the present invention and not to limit the scope of the present invention. Throughout the drawings, reference numbers are re-used to indicate correspondence between reference elements. In addition, the first digit of each reference number indicates the figure in which the element first appears.

[0077] FIGS. 1A – 1C show various views of a Real-X cross connector (RXCC) **100** according to an embodiment of the present invention. As shown in FIG. 1A, the RXCC **100** may include a first elongated member (first arm) **110**, a second elongated member (second arm) **120**, a fulcrum member **130**, and four connecting devices **131**, **132**, **133**, and **134**. Generally, as shown in FIG. 1B, the first and second elongated members **110** and **120** may have first ends **112** and **122**, second ends **116** and **126**, and pivot segments **114** and **124**.

[0078] In one embodiment of the present invention, the fulcrum member **130** may engage both the pivot segment **114** of the first elongated member **110** and the pivot segment **124** of the second elongated member **120**. Consequently, as shown in FIG. 1C, the first elongated member **110** may have a range of pivotal movement with the second elongated member **120**. Advantageously, the RXCC **100** may be adjusted to have a minimum width L_{10} and a maximum width L_{12} between the first ends **112** and **122** and/or the second ends **116** and **126**. In one embodiment, the minimum width L_{10} may be about 5 mm while the maximum width L_{12} may be about 120 mm. In another embodiment, the minimum width L_{10} may be about 10 mm while the maximum width L_{12} may be about 100 mm. In yet another embodiment, the minimum width L_{10} may be about 12 mm while the maximum width L_{12} may be about 88 mm.

[0079] As shown in FIG. 1B, the first and second elongated members **110** and **120** may each have an arch. In one embodiment, the pivot segments **114** and **124** may form the top parts of the arch, whereas the first and second ends **112**, **122**, **116**, and **126** may form the bottom parts of the arch. Together, the first and second elongated members **110** and **120** may form an X-shape protection bridge with a convex profile, which may fit and adapt to a posterior contour of several spinal bone segments. Advantageously, the RXCC **100** may be placed across one or more spinal bone segments for protecting a defected bone segment or a partially exposed spinal cord (not shown).

[0080] Moreover, the RXCC **100** may be equipped with the first connecting device **131**, the second connecting device **132**, the third connecting device **133**, and the fourth connecting device **134**. More specifically, the first connecting device **131** may be coupled to the first end **112** of the first elongated member **110**, the second connecting device **132** may be coupled to the first end **122** of the second elongated member **120**, the third connecting device **133** may be coupled to the second end **116** of the first elongated member **110**, and the fourth connecting device **134** may be coupled to the second end **126** of the second elongated member **120**.

[0081] The four connecting devices **131**, **132**, **133**, and **134** may be used for connecting the RXCC **100** to a group of pedicle screws or two stabilizing rods, both of which may be anchored to one or more spinal bone segments. As such, the RXCC **100** may substantially reduce or minimize the relative movement among the pedicle screws or among the two stabilizing rods. Advantageously, the RXCC **100** may provide extra support and stability to one or more spinal bone segments by virtue of connecting to the group of pedicle screws or the two stabilizing rods.

[0082] FIGS. 1D – 1F show various views of the Real-X cross connector (RXCC) **100** being anchored to three spinal bone segments **151**, **154**, and **157** according to an embodiment of the present invention. Generally, as shown in FIG. 1D, a pedicle screw **140** may include a set screw **147**, a threaded shaft **150**, and a base member **149**. More specifically, the threaded shaft **150** may be used for drilling into a spinal bone segment, the base member **149** may have a pair of receiving ports **148** for receiving a stabilizing rod **160**, and the set screw **147** may be used for securing the stabilizing rod **160** to the base member **149**.

[0083] Referring to FIG. 1E, six pedicle screws **141**, **142**, **143**, **144**, **145**, and **146** may be used to anchor the spinal bone segments **151**, **154**, **157**. For example, the pedicle screws **141** and **142** may be drilled into the spinal bone segments **151** via the left pedicle **152** and the right pedicle **153** respectively. For another example, the pedicle screws **145** and **146** may be drilled into the spinal bone segments **154** via the left pedicle **155** and the right pedicle **156** respectively. For yet another example, the pedicle screws **143** and **144** may be drilled into the spinal bone segments **157** via the left pedicle **158** and the right pedicle **159** respectively.

[0084] After the anchoring process, the first stabilizing rod **162** may be received and secured by the anchored pedicle screws **141**, **143**, and **145**, while the second stabilizing rod **164** may be received and secured by the anchored pedicle screws **142**, **144**, and **146**. Accordingly, the first stabilizing rod **162** may be anchored to the spinal bone segments **151**, **154**, and **157** along a left pedicle line defined by the left pedicles **152**, **155**, and **158**, and the second stabilizing rod **164** may be anchored to the spinal bone segments **151**, **154**, and **157** along a right pedicle line defined by the right pedicles **153**, **156**, and **159**. Depending on the particular group of spinal bone segments being operated on, the left and right pedicle lines may be parallel to each other or they may be angularly positioned.

[0085] Next, the RXCC **100** may be placed over the spinal bone segments **151**, **154**, and **157**. For example, as shown in FIGS. 1E and 1F, the first connecting member **131** may connect the first end **112** of the first elongated member **110** to the second stabilizing rod **164** between the pedicle screws **142** and **146**, the second connecting member **132** may connect the first end **122** of the second elongated member **120** to the first stabilizing rod **162** between the pedicle screws **141** and **145**, the third connecting member **133** may connect the second end **126** of the second elongated member **120** to the second stabilizing rod **164** between the pedicle screws **146** and **144**, and the fourth connecting member **134** may connect the second end **116** of the first elongated member **110** to the first stabilizing rod **161** between the pedicle screws **145** and **143**.

[0086] After the RXCC **100** is connected to the first and second stabilizing rods **162** and **164**, the RXCC **100** may form the X-shape protection bridge over and across one or more spinal bone segments. In one configuration, the RXCC **100** may form the X-shape protection bridge for protecting the spinal bone segment **154**. In another configuration, the RXCC **100** may form the X-shape protection bridge for protecting the spinal bone segment **151**. In yet another configuration, the RXCC **100** may form the X-shape protection bridge for protecting the spinal bone segment **157**.

[0087] Advantageously, because the first and second elongated members **110** and **120** may have the range of relative pivotal movement as shown in FIG. 1C, the RXCC **100** may be adjusted to adapt to spinal bone segments with various widths. Moreover, as shown in FIGS. 1F and 1G, the convex profile of the X-shape protection bridge may arch over the bone protrusions of one or more spinal bone segments, such that no additional surgical procedure may be required to remove any of these bone protrusions. Furthermore, the RXCC **100** may further stabilize the spinal bone segments **151, 154** and **157** by restricting and/or limiting a relative movement between the first and second stabilizing rods **162** and **164**.

[0088] According to an embodiment of the present invention, FIGS. 2A – 2C show various views of a Real-X cross connector (RXCC) **200** with four anchoring devices **231, 232, 233,** and **234**. The RXCC **200** may be similar to the RXCC **100** in several aspects. For example, the RXCC **200** may include the first elongated member (first arm) **110**, the second elongated member (second arm) **120**, and the fulcrum member **130**. For another example, the first and second elongated members **110** and **120** may have first ends **112** and **122**, second ends **116** and **126**, and pivot segments **114** and **124**. For yet another example, RXCC **200**

may form an X-shape protection bridge, which may have similar structural and functional features as the X-shape protection bridge of the RXCC **100**.

[0089] Despite these similarities, the RXCC **200** may be different from the RXCC **100** in at least one embodiment. For example, the RXCC **200** may incorporate four anchoring devices **231**, **232**, **233**, and **234** to perform the functions of the connecting devices **131**, **132**, **133**, and **134** of the RXCC **100** as shown in FIGS. 1A – 1F. According to an embodiment of the present invention, the four anchoring devices **231**, **232**, **233**, and **234** may share the structural and functional features of an anchoring device **240** as shown in FIG. 2B.

[0090] Generally, the anchoring device **240** may include a locking screw **241**, a joint member **242**, and a hook member **243**. More specifically, the joint member **242** may be attached to the hook member **243** while the locking screw **241** may be a separate structure. The joint member **242** may have a first disc member **245**, a second disc member **246**, and a space defined therebetween. In order to properly receive one of the first ends **112** or **122** or one of the second ends **116** or **126**, the space may have a height L_{21}, which may be slightly greater than the thickness of each of the first and second ends **112**, **122**, **116**, and **126**. Moreover, in order to properly receive the locking screw **241**, both the first and second discs **245** and **246** may each have an opening with a diameter slightly greater than a diameter of the locking screw **241**.

[0091] Referring to FIG. 2C, which shows the operation of the anchoring device **231**, the first end **112** of the first elongated member **110** may be inserted into the space between the first and second disc members **245** and **246** of the joint member **242**, and the hook member **243** may engage a segment of a stabilizing rod **260**. Next, the locking screw **241** may penetrate the first and second disc members **245** and **246** as well as the first end **112** received therebetween. Consequentially, the first end **112** may be secured to the anchoring device **231** and it may freely rotate about the locking screw **241**.

[0092] In order to limit the movement of the first end **112** relative to the anchoring device **231**, the locking screw **241** may fully engage the first and second disc members **245** and **246**. The locking screw **241** may cooperate with the first and second disc members **245** and **246** to assert a pair of vertical forces against the top and bottom surfaces of the first end **112**. Accordingly, the friction between the joint member **242** and the first end **112** may increase substantially, and the relative movement of the first end **112** may be locked at a particular angular position in relative to the hook member **243**.

[0093] The above assembling procedures may be repeated for the first end **122** of the second elongated member **120**, the second end **116** of the first elongated member **110**, and the second end **126** of the second elongated member **120**. Accordingly, the first anchoring device **231** may be coupled to the first end **112**, the second anchoring device **232** may be coupled to the first end **122**, the third anchoring device **233** may be coupled to the second end **116**, and the fourth anchoring device **234** may be coupled to the second end **126**.

[0094] After the initial assembling process, the hook member **243** may be used to engage a segment of the stabilizing rod **260**. When the anchoring device is properly positioned, the locking screw **241** may be driven further to contact the segment of the stabilizing rod **260**. In one embodiment of the present invention, the locking screw **241** may assert a compression force against a top part of the stabilizing rod **260**, which may redirect the compression force against a bottom section of the hook member **243**. As a result, the bottom section of the hook member **243** may react to the compression force and produce a reaction force, which may be asserted against a bottom part of the stabilizing rod **260**. Accordingly, the compression force may cooperate with the reaction force to secure the segment of stabilizing rod **260** within the hook member **243**.

[0095] FIG. 2D shows a top perspective view of the RXCC **200** anchored to three spinal bone segments **151**, **154**, and **157** via the pedicle screws **141**, **142**, **143**, **144**, **145**, and **146** and the stabilizing rods **162** and **164**. Generally, the pedicle screws **141, 142, 143, 144, 145**, and **146** and the stabilizing rods **162** and **164** may be first anchored to the left and right pedicles of the spinal bone segment **151, 154**, and **157** as discussed in FIGS. 1E and 1F. Like the RXCC **100**, the RXCC **200** may form the X-shape protection bridge above and across the spinal bone segment **151, 154**, or **157**.

[0096] For example, to form the X-shape protection bridge above and across the spinal bone segment **154**, the anchoring device **231** may engage the first stabilizing rod **162** between the pedicle screws **141** and **145**, the anchoring device **234** may engage first stabilizing rod **162** between the pedicle screws **145** and **143**, the anchoring device **232** may engage the second stabilizing rod **164** between the pedicle screws **142** and **146**, and the anchoring device **233** may engage the second stabilizing rod **164** between the pedicle screws **146** and **144**.

[0097] At this stage, the respective locking screws **241** may be free from contacting the first and second stabilizing rods **162** and **164**, such that the RXCC **200** may still be free to slide along the first and second stabilizing rods **162** and **164**. Advantageously, the X-shape protection bridge may be conveniently maneuvered to cover an area which may need to be protected. After the X-shape protection bridge is properly positioned, the respective locking screws **241** may be applied to secure the first and second rods **162** and **164** to the RXCC **200**. Consequentially, the RXCC **200** may be anchored to the first and second rods **162** and **164** via the anchoring devices **231, 232, 233**, and **234**. At this stage, the RXCC **200** may remain relatively stationary with respect to the first and second stabilizing rods **162** and **164**, the pedicle screws **141, 142, 143, 144, 145**, and **146**, and the spinal bone segments **151, 154**, and **157**.

[0098] As shown in FIGS. 2E and 2F, the RXCC **200** may be adjusted to adapt to spinal bone segments with various width. In one configuration, the RXCC **200** may be adjusted to reduce the distance between the first ends **112** and **122** or between the second ends **116** and

126 if the spinal bone segments have a narrow width L_{22}. Accordingly, the first and second anchoring devices **231** and **232** may be positioned closer to the pedicle screws **141** and **142**, while the third and fourth anchoring devices **233** and **234** may be positioned closer to the pedicle screws **143** and **144**. In another configuration, the RXCC **200** may be adjusted to increase the distance between the first ends **112** and **122** or between the second ends **116** and **126** if the spinal bone segments have a wide width L_{23}. Accordingly, the first and second anchoring devices **231** and **232** may be positioned farther away from the pedicle screws **141** and **142**, while the third and fourth anchoring devices **233** and **234** may be positioned farther away from the pedicle screws **143** and **144**.

[0099] FIGS. 3A – 3C show various views of a Real-X cross connector (RXCC) **300** with four articulated rods **331, 332, 333,** and **334**. The RXCC **300** may be similar to the RXCC **100** in several aspects. For example, the RXCC **300** may include the first elongated member (first arm) **110**, the second elongated member (second arm) **120**, and the fulcrum member **130**. For another example, the first and second elongated members **110** and **120** may have first ends **112** and **122**, second ends **116** and **126**, and pivot segments **114** and **124**. For yet another example, the RXCC **300** may form an X-shape protection bridge, which may have similar structural and functional features as the X-shape protection bridge formed by the RXCC **100**.

[0100] Despite these similarities, the RXCC **300** may be different from the RXCC **100** in at least one aspect. For example, the RXCC **300** may incorporate four articulated rods **331, 332, 333,** and **334** to perform the functions of the connecting devices **131, 132, 133,** and **134** of the RXCC **100** as shown in FIGS. 1A – 1F. The four articulated rods **331, 332, 333,** and **334** may share the structural and functional features of an articulated rod **340** as shown in FIG. 3B.

[0101] Generally, the articulated rod **340** may include a locking screw **341**, a joint member **342**, and a rod member **343**. More specifically, the joint member **342** may be attached to the rod member **343** while the locking screw **341** may be a separate structure. The joint member **342** may have a first disc member **345**, a second disc member **346**, and a space defined therebetween. In order to properly receive one of the first ends **112** or **122** or one of the second ends **116** or **126**, the space may have a height L_{31} slightly greater than the thickness of each of the first and second ends **112**, **122**, **116**, and **126**. Moreover, in order to properly receive the locking screw **341**, both the first and second discs **345** and **346** may each have an opening with a diameter slightly greater than a diameter of the locking screw **341**.

[0102] Referring to FIG. 3C, which shows the operation of the articulated rod **331**, the first end **112** of the first elongated member **110** may be inserted into the space between the first and second disc members **345** and **346** of the joint member **342**, and the rod member **343** may be secured by the pedicle screw **140**. Next, the locking screw **341** may penetrate the first and second disc members **345** and **346** as well as the first end **112** positioned therebetween. Consequentially, the first end **112** may be secured to the articulated rod **331** and it may freely rotate about the locking screw **341**.

[0103] In order to limit the movement of the first end **112** in relative the anchoring device **331**, the locking screw **341** may fully engage the first and second disc members **345** and **346**. The locking screw **341** may cooperate with the first and second disc members **345** and **346** to assert a pair of vertical forces against the surfaces of the first end **112**. As such, the friction between the first and second disc members **345** and **346** and the first end **312** may increase significantly, and the relative movement of the first end **112** may thus be substantially reduced or limited.

[0104] The above assembling procedures may be repeated for the first end **122** of the second elongated member **120**, the second end **116** of the first elongated member **110**, and the second end **126** of the second elongated member **120**. Accordingly, the first articulated rod **331** may be coupled to the first end **112**, the second articulated rod **332** may be coupled to the first end **122**, the third articulated rod **333** may be coupled to the second end **116**, and the fourth articulated rod **334** may be coupled to the second end **126**.

[0105] After the initial assembling process, the rod member **343** may be received by and secured to the pedicle screw **140**, which may include components as previously shown in FIG. 1D. For example, the pedicle screw **140** may have the set screw **147**, the base member **149** with the pair of receiving ports **148**, and the threaded shaft **150** for drilling the spinal bone segment. Initially, the rod member **343** may be inserted into the receiving ports **148** of the pedicle screw **140**. When coupled to the base member **149**, the set screw **147** may apply a compression force against a top part of the rod member **343**, which may redirect the compression force to the base member **149**. In reacting to the compression force, the base member **149** may assert a reaction force against a bottom part of the rod member **343**. As such, the reaction force may cooperate with the compression force to secure a segment of the rod member **343** to the pedicle screw **140**.

[0106] The rod member **343** may have similar structural and physical properties as the conventional stabilizing rods **162** and **164** as previously shown and discussed in FIGS. 1D – 1F and in FIGS. 2D – 2F. Accordingly, the rod member **343** may be made of a similar material as the conventional stabilizing rods **162** and **164**, and it may have a diameter $\mathbf{D_{31}}$ similar to those of the conventional stabilizing rods **162** and **164**. Nevertheless, the rod member **343** may be substantially shorter than the convention stabilizing rods **162** and **164** because it may only be required to extend for a relatively shorter distance. Moreover, the rod member **343** may have a flat top surface and a flat bottom surface, such that it may be secured by the pedicle screw **140** more efficiently.

[0107] FIG. 3D shows a top perspective view of the RXCC **300** anchored to three spinal bone segments **151**, **154**, and **157** via the pedicle screws **141**, **142**, **143**, and **144**. According to an embodiment of the present invention, the RXCC **300**, when equipped with the several articulated rods **331**, **332**, **333**, and **334**, may provide similar functions as the conventional stabilizing rods **162** and **164** as previously shown in FIGS. 1A – 1F and 2A – 2F. For example, the first and second elongated members **110** and **120** may substantially reduce the relative movement among the spinal bone segments **151**, **154**, and **157** when the articulated rods **331**, **331**, **333**, and **334** are properly anchored to the spinal bone segments **151** and **157** via the pedicle screws **141**, **142**, **143**, and **144**. Because the RXCC **300** may extend vertically and horizontally, it may provide both vertical and horizontal stabilizations to the spinal bone segments **151**, **154**, and **157**. Advantageously, this bidirectional stabilization substantially improves the unidirectional stabilization provided by the conventional stabilizing rods **162** and **164** because it may better address the horizontal instability among several spinal bone segments.

[0108] Moreover, the RXCC **300** may obviate the need for applying the pedicle screws **145** and **146** to the spinal bone segment **154**. Furthermore, the RXCC 300 may be applied to two or more fixation levels of spinal bone segments. Accordingly, the RXCC **300** may reduce the number of implantable devices and the number of procedures for installing these implantable devices. Advantageously, using the RXCC **300** may help reduce the cost and time for performing posterior spinal surgery, thereby rendering it more affordable for the patients and more efficient for the surgeons.

[0109] FIGS. 3E – 3H show various configurations of the RXCC **300** according to various embodiments of the present invention. Similar to the RXCC **100** and the RXCC **200**, the RXCC **300** may be adjustable to adapt to spinal bone segments with various widths.

Moreover, the extra length and maneuverability provided by the articulated rods **331**, **332**, **333**, and **334** may allow the RXCC **300** to have a wider range of adjustment.

[0110] In one embodiment, for example, the RXCC **300** may be adjusted to adapt to the spinal bone segments with a small width L_{32} as shown in FIG. 3E. In another embodiment, for example, the RXCC **300** may be adjusted to adapt to the spinal bone segments with a large width L_{33} as shown in FIG. 3F. In another embodiment, for example, the RXCC **300** may be adjusted to adapt to the spinal bone segments with a large top width L_{33} but a small bottom width L_{32} as shown in FIG. 3G. Particularly, the rod members **343** of the first and second articulated rods **331** and **332** may be positioned horizontally while the rod members **343** of the third and fourth articulated rods **333** and **334** may be positioned vertically. In yet another embodiment, for example, the RXCC **300** may be adjusted to adapt to the spinal bone segments with a medium top width L_{34} and a small bottom width L_{32} as shown in FIG. 3H. Particularly, the rod members **343** of the first and second articulated rods **331** and **332** may positioned diagonally while the third and fourth articulated rods **333** and **334** may be positioned vertically.

[0111] Besides the configurations as shown in FIGS. 3E – 3F, the RXCC **300** may be adjusted to adapt to a wide range of symmetrical spinal bone segments as well as asymmetrical spinal bone segments. The rod members **343** may be highly maneuverable about the respective joint members **342**, and thus, they can be configured to turn in any planar direction before they are firmly secured by the respective pedicle screws **140**. Advantageously, the RXCC **300** may provide a dynamic range of configurations, which may be more adjustable and adaptable than the configurations provided by conventional cross connectors and the conventional stabilizing rods.

[0112] The discussion now turns to arm length adjusting feature of the Real-X cross connector. FIGS. 4A – 4C show various views of a Real-X cross connector (RXCC) **400**

with adjustable arms **410** and **420** according to an embodiment of the present invention. The RXCC **400** may be similar to the RXCC **100** in several aspects.

[0113] For example, the RXCC **400** may include a first elongated member (first arm) **410**, a second elongated member (second arm) **420**, the fulcrum member **130**, and four connecting devices **131**, **132**, **133**, and **134**. The four connecting devices **131**, **132**, **133**, and **134** may be implemented by the anchoring device **240** as shown in FIG. 2B, the articulated rod **340** as shown in FIG. 3B, or any other connecting devices, as long as they may connect the RXCC **400**, directly or indirectly, to a set of readily anchored pedicle screws.

[0114] For another example, the first and second elongated members **410** and **420** may have first ends **412** and **422**, second ends **416** and **426**, and pivot segments **414** and **424**. For another example, the fulcrum member **130** may engage and pivot the pivot segments **414** and **424**, such that the first and second elongated members **410** and **420** may have a relative pivotal movement about the fulcrum member **130**.

[0115] For yet another example, RXCC **400** may form an X-shape protection bridge, which may have similar structural and functional features as the X-shape protection bridge formed by the RXCC **100**.

[0116] Despite these similarities, the RXCC **400** may be different from the RXCC **100** in at least one aspect. For example, the RXCC **400** may incorporate four arm length adjusting devices (ALADs) **431**, **432**, **433**, and **434** to allow the first and second elongated members **410** and **420** to extend and/or retract their respective length. According to an embodiment of the present invention, the four ALADs **431**, **432**, **433**, and **434** may share the structural and functional features of an ALAD **440** as shown in FIG. 4B-4C.

[0117] Generally, the ALAD **440** may include a locking screw **441**, a nut member **448**, a female member **442**, and a male member **443**. The female member **442** may be a receiving structure with a hollow core. As such, the female member **442** may include a top plate **444**, a bottom plate **445** and a side wall **446**. The side wall **446** may connect the top and bottom plates **444** and **445**, which may define an opening and a space for receiving the male member **443**. The male member **443** may have an insertion member **447** for inserting into the space of the female member **442**.

[0118] In one embodiment, the female member **442** may be coupled to an end of the RXCC **400**, which may be one of the first or second ends **112, 122, 116,** or **126**, while the male member **443** may be coupled to the pivot segment **414** or **424**. In another embodiment, the male member **443** may be coupled to an end of the RXCC **400**, which may be one of the first or second ends **112, 122, 116,** or **126**, while the female member **442** may be coupled to the pivot segment **414** or **424**.

[0119] Generally, the insertion member **447** may slide into or outside of the space of the female member **442** before the locking mechanism is triggered. In one embodiment, the insertion member **447** and the space may each have a length $\mathbf{L_{40}}$, which may range, for example, from 2 mm to about 20 mm. As such, the ALAD **440** may have a retracted length which may range, for example, from about 2 mm to about 20 mm, as well as an extended length which may range, for example, from about 4 mm to about 40 mm.

[0120] After the female member **442** and the male member **443** are properly adjusted to achieve a desirable arm length, the locking mechanism may be triggered. Generally, the locking mechanism may be actuated by a coupling between the locking screw **441** and the nut member **448** or by any other methods that may affix the insertion member **447** within the space of the female member **442**. As shown in FIG. 4C, the top and bottom plates **444** and **445** of the female member **442** may each have a penetration port for receiving the locking screw **441**, and the insertion member **447** may have a narrow slit **449** for allowing the passage of the locking screw **441**. In one embodiment, the locking screw **441** may pass through the opening of the top plate **444**, then the narrow slit **449**, and then the opening of the bottom plate **445**.

[0121] After the locking screw **441** successfully penetrates the top plate **444**, the insertion member **447** and the bottom plate **445**, the nut member **448** may be coupled to the locking screw **441**. Accordingly, a bolt of the locking screw **441** and the nut member **448** may apply a pair of compression forces against the top and bottom plates **444** and **445** respectively. The top and bottom plates **444** and **445** may then convert the pair of compression forces to a pair of frictional forces against the surfaces of the insertion member **447**. As the pair of frictional forces increase, the insertion member **447** may become less free to slide along the space of the female member **442**, and eventually, the insertion member **447** may be locked at a particular position.

[0122] FIGS. 4D – 4F show the cross-sectional side views of several configurations of the ALAD **440** according to various embodiments of the present invention. As shown in FIG. 4D, the ALAD **440** may have a full retraction configuration, in which the insertion member **447** may be substantially inside of the space of the female member **442**. As such, the ALAD **440** may have a fully retracted length $\mathbf{L_{41}}$, which may be substantially the same as the length of the insertion member $\mathbf{L_{40}}$. As shown in FIG. 4E, the ALAD **440** may have a partial extension configuration, in which the insertion member **447** may be partially inside of the space of the female member **442**. As such, the ALAD **440** may have a partial extended length $\mathbf{L_{42}}$, which may be greater than the fully retracted length $\mathbf{L_{41}}$. As shown in FIG. 4F, the ALAD **440** may have a full extension configuration, in which the insertion member 447 may be substantially outside of the space of the female member **442**. As such, the ALAD **440** may have a fully extended length $\mathbf{L_{43}}$, which may be greater than the partial extended length $\mathbf{L_{42}}$.

[0123] The aforementioned adjustment procedures and ALAD configurations may be applied to each of the ALADs **431**, **432**, **433**, and **434**. Advantageously, the RXCC **400** may have a dynamic range of arm length configurations for fitting patients with various spinal bone structures. FIGS. 4G – 4I may help illustrate the benefit of the dynamic arm length configurations of the RXCC **400**. For example, as shown in FIG. 4G, the RXCC **400** may have a symmetric-Y configuration **486** according to an embodiment of the present invention. With the symmetric-Y configuration **486**, the RXCC **400** may be fitted to a patient with spinal bone structure that is symmetric along the Y-axis but asymmetric along the X-axis. More specifically, the first ALAD **431** may have the same arm length configuration **450** as the second ALAD **432** and the third ALAD **433** may have the same arm length configuration **470** as the fourth ALAD **434**, while the first ALAD **431** may have a different arm length configuration as the third ALAD **433**.

[0124] For another example, as shown in FIG. 4H, the RXCC **400** may have a symmetric-X configuration **487** according to an embodiment of the present invention. With the symmetric-X configuration **487**, the RXCC **400** may be fitted to a patient with spinal bone structure that is symmetric along the X-axis but asymmetric along the Y-axis. More specifically, the first ALAD **431** may have the same arm length configuration **450** as the third ALAD **433** and the second ALAD **432** may have the same arm length configuration **470** as the fourth ALAD **434**, while the first ALAD **431** may have a different arm length configuration as the second ALAD **432**.

[0125] For yet another example, as shown in FIG. 4I, the RXCC **400** may have a fully asymmetric configuration **488** according to an embodiment of the present invention. With the fully asymmetric configuration **488**, the RXCC **400** may be fitted to a patient with spinal bone structure that is asymmetric along the Y-axis and along the X-axis. More specifically, the first ALAD **431** may have a different arm length configuration from the second ALAD **432**, which may have a different arm length configuration from the fourth ALAD **434**.

[0126] It is understood that the X-axis and the Y-axis are relative terms and they should not be construed to represent any absolute orientation. For example, the Y-axis may be parallel to an approximate orientation of a patient's spine column. For another example, the X-axis may be parallel to the approximate orientation of the patient's spine column.

[0127] The discussion now turns to the structural and functional features of the fulcrum member **130**. Generally, the fulcrum member **130** may be coupled to the pivot segments **114** and **124**. As such, the fulcrum member **130** may perform as a pivot device for facilitating the pivotal movement between the first and second elongated members **110** (or **410**) and **120** (or **420**) as shown previously.

[0128] FIGS. 5A – 5C show a perspective view, an exploded view, and a top view of a fulcrum member **500**, which may be used to realize the fulcrum member **130** according to an embodiment of the present invention. Generally, the fulcrum member **500** may include a cover member **520**, a base member **530**, and a pivot pole member **540**. The cover member **520** may have a top section **522** and an internal threaded section **521** formed along the inner surface cover member **520**. The base member **530** may have a bottom section **533**, a side wall **531** formed along the edge of the bottom section **533**. Moreover, the base member **530** may be formed along the pivot segment **114** of the first elongated member **110**, such that the side wall **531** may be attached, coupled, or connected to the first and second ends **112** and **116** of the first elongated member **110**. Advantageously, the fulcrum member **500** may be partially integrated with the first elongated member **110** so that the number of assembly components, as well as the number of assembling steps, may be substantially reduced in forming the Real-X cross connector.

[0129] As shown in FIG. 5B, the side wall **531** may define a cylindrical space between the top section **521** and the bottom section **533**, such that the pivot pin member **540** may be located along a central axis of the cylindrical space. Moreover, the side wall **531** may form a first receiving port **532** and a second receiving port **534** directly opposite to the first receiving port **532**. Consequentially, the pivot segment **124** of the second elongated member **120** may be received within the cylindrical space and in between the first and second receiving ports **532** and **534**.

[0130] As the pivot segment **124** of the second elongated member **120** descends into the receiving ports **532** and **534** of the base member **530**, the pivot pin member **540** may penetrate a pivot hole **125** of the second elongated member **120**, such that the pivot segment **114** of the first elongated member **110** may engage the pivot segment **124** of the second elongated member **120**. When the pivot segment **124** is positioned substantially inside the cylindrical space, the cover member **520** may close the top space of the base member **530** by having the internal threaded section **522** to engage an external threaded section of the pivot pin member **540**. Accordingly, the fulcrum member **500** may be formed, such that the second elongated member **120** and the first elongated member **110** may have the relative pivotal movement about the fulcrum member **500**.

[0131] As shown in FIG. 5C, the second elongated member **120** may have a clockwise angular movement **514** and a counterclockwise angular movement **512** about the first and second openings **532** and **534**. Generally, the first and second openings **532** and **534** may each have a width $\mathbf{L_{51}}$ which may be wider than a width $\mathbf{L_{52}}$ of the second elongated member **120**. Accordingly, the range of clockwise and/or counterclockwise angular movements **512** and **514** of the second elongated member **120** may be controlled by a difference between the width $\mathbf{L_{51}}$ and $\mathbf{L_{52}}$.

[0132] FIGS. 6A – 6C show a perspective view, an exploded view, and a top view of an alternative fulcrum member **600**, which may be used to realized the functions of the fulcrum member **130** according to an alternative embodiment of the present invention. Generally, the alternative fulcrum member **600** may include a first (bottom) joint member **610**, a second (top) joint member **620**, a pivot pin member **630** and a pivot cap member **631**. As shown in FIGS. 6A and 6B, the first joint member **610** may be formed as part of the pivot segment **114**, and the second joint member **620** may be formed as part of the pivot segment **124**.

[0133] Accordingly, the first joint member **610** may be coupled to the first and second ends **112** and **116** of the first elongated member, and the second joint member **620** may be coupled to the first and second ends **122** and **126** of the second elongated member. Advantageously, the alternative fulcrum member **600** may be fully integrated with the first and second elongated members **110** and **120** so that the number of assembly components, as well as the number of assembling steps, may be substantially reduced.

[0134] More specifically, the first joint member **610** may have first and second buffer regions **611** and **613** and a middle bar **612**, which may connect the first and second buffer regions **611** and **613**. Similarly, the second member **620** may have first and second buffer regions **621** and **623** and a middle bar **622**, which may connect the first and second buffer regions **621**. In order to facilitate the proper coupling between the first and second joint members **610** and **620**, the pivot pin member **630** may be formed on the middle bar **612**, and a pivot hole **624** may be extended through the middle bar **622**. Alternatively, the pivot pin member **630** may be formed on the middle bar **622**, and a pivot hole (not shown) may be defined and extended through the middle bar **612** according to another embodiment of the present invention.

[0135] The second joint member **620** may engage the first joint member **610** by allowing the pivot hole **624** to slide down the pivot pin member **630**. Because both the middle bars

612 and **622** may have a combined thickness that may be less than or equal to the thickness of the first elongated member **610** or the second elongated member **620**, the middle bars **612** and **622** may be free from contacting each other. Additionally, an optional spacer (not shown) may be inserted between the middle bars **612** and **622** to provide additional stability between the first and second joint members **610** and **620**. After the first and second joint members **610** and **620** are properly coupled, the pivot cap **631** may be secured to the pivot pin **630** for locking the first and second joint members **610** and **620** together.

[0136] As shown in FIG. 6C, the first and second ends **112** and **116** of the first elongated member **610** may have clockwise and counterclockwise angular movements **646** and **648** about the pivot pin member **630**. Similarly, the first and second ends **122** and **126** of the second elongated member **620** may have clockwise and counterclockwise angular movements **644** and **642** about the pivot pin member **630**. Because the first and second buffer regions **611**,**621**, **613**, and **623** may be slightly sloped, the impact between the first and second elongated members **610** and **620** may be substantially minimized.

[0137] FIGS. 7A – 7C show various views of a Real-X cross connector (RXCC) **700** with first and second adjustable rod assemblies (ARAs) **710** and **720** as the connecting devices according to an embodiment of the present invention. Generally, the RXCC **700** may incorporate several structural and functional features of the RXCC **400**. For example, the RXCC **700** may incorporate the X-shape protection bridge and the benefits thereof. For another example, the RXCC **700** may incorporate the arm length adjustable devices (ALADs) **431**, **432**, **433**, and **433**, and the benefits thereof. Like the RXCC **400**, the RXCC **700** may have a dynamic range of arm length configurations for patients with various spinal bone structures.

[0138] Despite these similarities, the RXCC **700** may be different from the RXCC **400** in at least one aspect. For example, the RXCC **700** adopted two ARAs **710** and **720** as the connecting devices according to an embodiment of the present invention. From a design standpoint, the ARAs **710** and **720** may provide an integrated solution for conventional cross connectors.

[0139] Mainly, the ARAs **710** and **720** may incorporate the structural and functional features of the pair of stabilizing rods **162** and **164** as shown in FIG. 1E as well as the structural and functional features of the several connecting devices discussed so far. As such, the RXCC **700** may be pre-assembled and pre-adjusted according to a surgeon's assessment of a patient's spinal bone structure before the actual spinal fixation surgery is being performed. Advantageously, the ARAs **710** and **720** may improve conventional spinal fixation surgery by reducing the number of surgical steps, the time spent on performing the surgery, and the surgical risk associates with the lengthy surgical procedures.

[0140] As shown in FIG. 7A, the first ARA **710** may include first and second articulated ring members **731** and **734**, first and second rod segments **713** and **716**, and a rod adjustment device **714**. Particularly, the first articulated ring member **731** may engage the first rod segment **713**, the second articulated ring member **734** may engage the second rod segment **716**, and the rod adjustment device **714** may be engaged to both the first and second rod segments **713** and **716**. Moreover, the first articulated ring member **731** may be coupled to the first end **112** of the first elongated member **110**, and the second articulated ring member **734** may be coupled to the second end **126** of the second elongated member **120**.

[0141] Similar to the first ARA **710**, the second ARA **720** may include first and second articulated ring members **732** and **733**, first and second rod segments **723** and **726**, and a rod adjustment device **724**. Particularly, the first articulated ring member **732** may engage the first rod segment **723**, the second articulated ring member **733** may engage the second rod segment **726**, and the rod adjustment device **724** may be engaged to both the first and second rod segments **723** and **726**. Moreover, the first articulated ring member **732** may be coupled to the first end **122** of the first elongated member **120**, and the second articulated ring member 733 may be coupled to the second end **116** of the second elongated member **110**.

[0142] According to an embodiment, the functions of the rod adjustment devices **714** and **724** may be realized by a rod adjustment assembly **740** as shown in FIG. 7B. Generally, the rod adjustment assembly **740** may include a sleeve member **744**, a first insertion member **743**, and a second insertion member **746**. Particularly, the first insertion member **743** may be coupled to the first rod segment 713 or the first rod segment **723**, and the second insertion member **746** may be coupled to the second rod segment **716** or the second rod segment **726**.

[0143] More particularly, the first and second insertion member **743** and **746** may have external threaded surfaces **742** and **745** respectively, and the sleeve member **744** may have an internal threaded surface 747. When the external threaded surfaces **742** and **745** engage the internal threaded surface 747, the first and second insertion members **743** and **746** may be screwed into or out of the sleeve member **744**. Accordingly, the rod adjustment assembly **740** may have an adjustable length depending on the relative positions of the first and second rod segments **743** and **746** with respect to the sleeve member **744**.

[0144] In one embodiment, the function of the articulated ring members **731**, **732**, **733**, and **734** may be realized by an articulated ring assembly **750** as shown in FIG. 7C. Generally, the articulated ring assembly **750** may have a locking screw **751**, a joint member **752**, and a ring member **753**. Particularly, the joint member **752** may cooperate with the locking screw **751** for engaging and securing one of the first or second end **112**, **122**, **116**, or **126**. Depending on the design goal, the joint member **752** may be permanently or temporarily coupled to the ring member **753**.

[0145] The ring member **753** may have a receiving port **755** for receiving a rod segment **743**, which may be one of the first rod segment **713** of the first ARA **710**, the second rod segment **716** of the first ARA **710**, the first rod segment **723** of the second ARA **720**, or the second rod segment **726** of the second ARA **720**. Moreover, the ring member **753** may have one or more locking mechanism for preventing the rod segment **743** from sliding pass the receiving port **755** while allowing the rod segment **743** to have a free rotational movement about its central axis $\mathbf{A_{71}}$.

[0146] To implement the locking mechanism, the ring member **753** may include one or more protrusion ring(s) **754** disposed along the inner surface of the receiving port **755** according to an embodiment of the present invention. As shown in FIG. 7C, the rod segment **741** may have one or more corresponding intrusion ring(s) **741** for engaging the one or more protrusion ring(s) **754** of the ring member **753**. Advantageously, the rod segment **743** may be rotated about the central axis $\mathbf{A_{71}}$ while being secured by the ring member **753**.

[0147] The discussion now turns to a Real-O cross connector (ROCC), which may be used as an alternative device of the Real-X cross connector as discussed previously. FIGS. 8A – 8B show a perspective view and a cross sectional side view of a ROCC **800** according to an embodiment of the present invention. Generally, the ROCC **800** may include a center member **803**, a first arm **810** and a second arm **820**, and first and second anchoring devices **842** and **844**. Particularly, the first and second anchoring devices **842** and **844** may be coupled to the first and second arms **810** and **820** respectively. The first and second anchoring devices **842** and **844** may be used for anchoring the ROCC **800** to two stabilizing rods, which may be anchored to several spinal bone segments by several pedicle screws. Accordingly, the structural and functional features of the first and second anchoring devices **842** and **844** may be realized by the anchoring device **240** of FIG. 2B.

[0148] In one embodiment, the first and second arm **810** and **820** may be connected to the center member **803** to form an arch bridge **801** as shown in FIG. 8B. The center member **803** may include first and second ends **833** and **834**, and first and second bracket **831** and **832**, which may join each other at the first and second ends **833** and **834**. Together, the first and second brackets **831** and **832** may form a protection ring **835** at the center of the ROCC **800**.

[0149] The arch bridge **801** may define a space underneath the center member **803**, and the protection ring **835** may create an opening at the center of the ROCC **800**. Hence, the ROCC **800** may be place direct above a spinal bone segment and may avoid contacting the spinal bone segment's superior articular process, Mamillary process, accessory process, and inferior articular process. Furthermore, the protection ring **835** may help protect and preserve the spinous process by laterally surrounding a base of the spinous process, such that the spinous process of the spinal bone segment may protrude from the protection ring **835**. Advantageously, the ROCC **800** may be placed directly across the spinal bone segment without removing the spinous process thereof, and thus, the ROCC **800** may also help prevent symptoms of pseudoarthritis.

[0150] Referring to FIG. 8E, the ROCC **800** may be anchored to and positioned in between the first and second stabilizing rods **162** and **164** according to an embodiment of the present invention. Generally, the first stabilizing rod **162** may be anchored to the left pedicles **152** and **155** via the pedicle screws **141** and **145**, while the second stabilizing rod **164** may be anchored to the right pedicles **153** and **156** via the pedicle screws **142** and **146**. As such, the first and second stabilizing rods **162** and **164** may provide a vertical stabilization for the spinal bone segments **151** and **154**.

[0151] In order to provide a horizontal stabilization, the ROCC **800** may be anchored to the first stabilizing rod **162** by using the first anchoring device **842** and to the second stabilizing rod **164** by using the second anchoring device **844**. Because of the opening defined by the protection ring **835** and the space underneath the arched bridge **801**, the ROCC **800** may be conveniently placed above and across the spinal bone segment **151** without removing the spinous process **807** thereof. Advantageously, the ROCC **800** may improve the conventional spinal fixation surgery by making it safer and less intrusive to the patient's body. The above procedure may be repeated for other spinal bone segments. For example, another ROCC **800** may be placed above and across the spinal bone segment **154**, such that the protection ring **835** may be placed around the base section of the spinous process **809**.

[0152] FIGS. 8C – 8D show a perspective view and a cross-sectional of an alternative ROCC **850** according to another embodiment of the present invention. Generally, the ROCC **850** may share several structural and functional features with the ROCC **800**. For example, the ROCC **850** may have the first and second arms **810** and **820**, the first and second anchoring devices **842** and **844**, and a center member **860**, which may be connected between the first and second arms **810** and **820**. For another example, the center member **860** of the ROCC **850** may include the first and second brackets **831** and **832**, which may be joined at the first and second ends **833** and **834** respectively to form the protection ring **835**. Moreover, the ROCC **850** may form an arched bridge **802**, which may have similar structure and provide similar functionalities as the arched bridge **801**.

[0153] Despite these similarities, the ROCC **850** may be different from the ROCC **800** in at least one aspect. For example, the center member **860** of the ROCC **850** may include a first joint member **862** for engaging the first arm **810** and a second joint member **864** for engaging the second arm **820**. Generally, the first and second joint member **862** and **864** may function as two pivoting devices for the protection ring **835**.

[0154] More specifically, the first and second joint member **862** and **864** may include certain joint mechanism to allow each of the first and second arms **810** and **820** to have a range of angular movement about the first and second ends **833** and **834** so that the ROCC **850** may be adjusted to adapt to various spinal bone structures. Meanwhile, the first and second joint member **862** and **864** may include certain locking mechanism to lock each of the first and second arms **810** and **820** once the ROCC **850** is properly adjusted. In one embodiment, for example, the functional features of the joint members **862** and **863** may be implemented by the joint member **242** as shown and discussed in FIG. 2B.

[0155] Referring to FIGS. 8F – 8G, the ROCC **850** may be anchored to and positioned in between the first and second stabilizing rods **162** and **164** according to an embodiment of the present invention. Generally, the first stabilizing rod **162** may be anchored to the left pedicles **152** and **155** via the pedicle screws **141** and **145**, while the second stabilizing rod **164** may be anchored to the right pedicles **153** and **156** via the pedicle screws **142** and **146**. As such, the first and second stabilizing rods **162** and **164** may provide the vertical stabilization for the spinal bone segments **151** and **154**, and the ROCC **850** may provide the horizontal stabilization for the first and second stabilizing rods **162** and **164**.

[0156] In addition to the advantages of the ROCC **800**, the ROCC **850** may include other advantages. For example, the joint members **862** and **864** may provide the ROCC **850** with more adjustability in terms of selecting the pair of anchoring points. As shown in FIG. 8F, each of the spinal bone segments **151** and **154** may have a bone width **W**, which may be shorter than the combined length of the first and second arms **810** and **820**. Because the joint members **862** and **864** allow the first and second arms **810** and **820** to fold up or down from the center member **860**, the anchoring devices **842** and **844** may established various anchor points along the first and second stabilizing rods **162** and **164**.

[0157] In order to adapt to the narrow spinal bone segments **151** and **154**, the first and second arms **810** and **820** may be folded upward to reach a pair of higher anchored points, so as to reduce the distance between the protection ring **835** and the first and second stabilizing rods **162** and **164**. This adjustment process may be repeated for adapting the ROCC **850** to spinal bone segments with a range of spinal bone widths. Advantageously, the ROCC **850** may be installed to patients with spinal bone segments of various widths.

[0158] Furthermore, the adjustability provided by the first and second joint members **862** and **864** may allow the ROCC **850** to adapt to asymmetric spinal bone segments. As shown in FIG. 8G, the spinous process **807** of the spinal bone segment **151** may be closer to the left pedicle **152** than to the right pedicle **153**. In order to adapt to the asymmetry of the spinal bone segment **152**, the first arm **810** may be folded with a larger downward angle than the second arm **820**. Accordingly, the distance between the protection ring and the first stabilizing rod **162** may be less than the distance between the protection ring and the second stabilizing rod **164**. This adjustment process may be repeated for adapting the ROCC **850** to spinal bone segments with various degrees of asymmetry. Advantageously, the ROCC **850** may be applied to fit patients with asymmetric spinal bone segments.

[0159] FIGS. 9A – 9B show various views of a Real-O cross connector (ROCC) **900** with an adjustable ring according to an embodiment of the present invention. Generally, the ROCC **900** may incorporate the structural and functional features of the ROCC **800** and/or the ROCC **850**. Additionally, the ROCC **900** may include an adjustable center member **930** in replacing the center member **803** and/or **860**. The adjustable center member **930** may include a first adjustable bracket **910** and a second adjustable bracket **920**. More particularly, the first and second adjustable brackets **910** and **920** may have first segments **912** and **922**, second segments **916** and **926**, and length adjustable devices **914** and **924**.

[0160] The length adjustable device **914** may engage the first and second segments **912** and **916** of the first adjustable bracket **910**, and the length adjustable device **914** may change the relative position between the first and second segments **912** and **916**. Accordingly, the length adjustable device **914** may change the length of the first adjustable bracket **910**. Similarly, the length adjustable device **924** may engage the first and second segments **922** and **926** of the first adjustable bracket **920**, and the length adjustable device **924** may change the relative position between the first and second segments **922** and **926**. Accordingly, the length adjustable device **924** may change the length of the first adjustable bracket **920**.

[0161] The functional features of the length adjustable devices **914** and **924** may be realized by any compatible mechanical components. In one embodiment, for example, the length adjustable devices **914** and **924** may each be implemented by the arm length adjustable device **440** as described and discussed in FIGS. 4B – 4F.

[0162] The discussion now turns to the various shapes of the protection rings of the Real-O cross connectors according to various embodiments of the present invention. As shown in FIG. 10A, the protection ring **1012** may, for example, have a shape of a vertical oval. As shown in FIG. 10B, the protection ring **1014** may, for example, have a shape of a horizontal vertical oval. As shown in FIG. 10C, the protection ring **1022** may, for example, have a shape of a horizontal rectangle. As shown in FIG. 10D, the protection ring **1024** may, for example, have a shape of a vertical rectangle. As shown in FIG. 10E, the protection ring **1032** may, for example, have a shape of a vertical rhombus. As shown in FIG. 10F, the protection ring **1034** may, for example, have a shape of a horizontal rhombus. As shown in FIG. 10G, the protection ring **1042** may, for example, have a shape of a square. As shown in FIG. 10H, the protection ring **1044** may, for example, have a shape of a circle. The aforementioned shapes of the protection rings are only for illustrative purpose since the protection ring may have other shapes that may be adaptive to various contour of the base section of the spinous process.

[0163] The discussion now turns to a Real-XO cross connector (RXOCC), which may be used as an alternative device of the Real-X cross connector (RXCC) and the Real-O cross connector (ROCC). FIGS. 11A – 11D show various views of an RXOCC **1100** according to an alternative embodiment of the present invention. Generally, the RXOCC **1100** may incorporate several structural and functional features of the Real-X cross connectors (RXCC) and the Real-O cross connectors (ROCC) as discussed previously. For example, the RXOCC **1100** may include a protection ring **1110**, four joint members **1121**, **1122**, **1123**, and **1124**, four elongated members **1141**, **1142**, **1143**, and **1144**, four arm length adjustable devices (ALADs) **1145**, **1146**, **1147**, and **1148**, and four connecting devices **1161**, **1162**, **1163**, and **1164**.

[0164] In one embodiment, the joint members **1121**, **1122**, **1123**, and **1124** may secure the elongated members **1141**, **1142**, **1143**, and **1144** to the protection ring **1110**. In another embodiment, the ALADs **1145**, **1146**, **1147**, and **1148** may be adjustable so that the elongated members **1141**, **1142**, **1143**, and **1144** may each have an adjustable length. In yet another embodiment, the connecting devices **1161**, **1162**, **1163**, and **1164** may connect the RXOCC to one or more spinal bone segments via several pedicle screws and/or a pair of elongated stabilizers. Although the connecting devices **1161**, **1162**, **1163**, and **1164** are implemented by the articulated rod **1170** as shown in FIG. 11A, they may be implemented by other devices, such as the anchoring device **240** as shown in FIG. 2B.

[0165] Specifically, the elongated members **1141**, **1142**, **1143**, and **1144** may be distributed along the edge of the protection ring **1110**. When the joint members **1121**, **1122**, **1123**, and **1124** are unlocked, the elongated members **1141**, **1142**, **1143**, and **1144** may be free to be angularly displaced about the respective joint members. Alternatively, the elongated members **1141**, **1142**, **1143**, and **1144** may be free to move along the edge of the protection ring **1110** when the respective joint members **1121**, **1122**, **1123**, and **1124** are unlocked. When the joint members **1121**, **1122**, **1123**, and **1124** are locked, the elongated members **1141**, **1142**, **1143**, and **1144** may each be affixed to a particular position in relative to the protection ring **1110**.

[0166] At the locking mode, the RXOCC **1100** may form a hybrid X-shaped protection bridge, which may arch over a space directly underneath the protection ring **1110** while allowing the space to extend through an opening defined by the protection ring **1110**. Advantageously, the hybrid X-shaped protection bridge may inherit the benefits of the Real-X cross connector (RXCC) and the Real-O cross connector (ROCC).

[0167] As shown in FIG. 11B, the four joint members **1121, 1122, 1123**, and **1124** may each be implemented by a lockable joint **1130** according to an embodiment of the present invention. The lockable joint **1130** may include a locking screw **1131**, a first plate **1132**, a second plate **1133**, and a side body **1134**. The side body **1134** may be coupled to the edge of the protection ring **1110**, such that the lockable joint **1130** may receive an end member **1135** along an outer circumferential surface (the edge) of the protection ring **1110**. As discussed herein, the end member **1135** may be one of the first, second, third, or fourth elongated member **1141, 1142, 1143**, or **1144**. Moreover, the first and second plates **1132** and **1133** may be separated by a space for receiving the end member **1135**, and they may each have an opening for receiving the locking screw **1131**.

[0168] Before the locking screw **1131** substantially engages the second plate **1133**, the end member **1135** may be freely rotated about the locking joint member **1130**. Correspondingly, the first, second, third, and fourth elongated members **1141, 1142, 1143**, and **1144** may be adjusted to different angular positions with respect to the protection ring **1110**. Advantageously, the RXOCC **1100** may be adjustable to form X-shape protection bridges with various angular positions.

[0169] In order to lock the lockable joint **1130**, the locking screw **1131** may be used for substantially engaging the second plate **1133**. The locking screw **1131** may cooperate with the second plate **1133** to produce a pair of compression forces, which may be asserted against the end member **1135**. As such, the frictional forces between the end member **1145** and the inner surfaces of the first and second plates **1132** and **1133** may be increased significantly. As a result, the end member **1135** may be locked in a particular position with respect to the lockable joint member **1130**. Correspondingly, the first, second, third, and fourth elongated members **1141, 1142, 1143,** and **1144** may each be locked at a particular angularly position with respect to the protection ring **1110**.

[0170] FIG. 11C shows a cross-sectional side view of an ALAD **1150**, which may realize the functional features of the first, second, third and fourth ALADs **1145**, **1146**, **1147**, and **1148**. In one embodiment, for example, the ALAD **1150** may include the same components as the ALAD **440** (see FIGS. 4B and 4C), and it may thus incorporate the functional features of the ALAD **440**. Generally, the ALAD **1150** may include a locking screw **1151** a male member **1152**, which may have an insertion member **1153**, a female member **1154**, which may have first and second plates **1155** and **1156** to define a space for receiving the insertion member **1153**.

[0171] More specifically, the insertion member **1153** may be slid in and out of the space before the locking screw **1151** substantially engages the second plate **1156**. As such, the distance between the male and female member **1152** and **1154** may be adjusted. However, when the locking screw **1151** substantially engages the second plate **1156**, the insertion member **1153** may be locked within a particular position within the space defined within the female member **1154**. Accordingly, the male and female members **1152** and **1154** may be substantially stabilized and they may thus form an adjusted distance between them.

[0172] FIG. 11D shows a cross-sectional side view of an articulated rod **1170**, which may realize several functional features of the first, second, third, and fourth connecting devices **1161**, **1162**, **1163**, and **1164** as discussed earlier. In one embodiment of the present invention, for example, the articulated rod **1170** may include the same components as the articulated rod **340** (see FIG. 3B and 3C), and it may thus incorporate the functional features of the articulated rod **340**. Generally, the articulated rod **1170** may include a lockable joint member **1174** and a rod member **1176**, which may be connected to the lockable joint member **1174**.

[0173] The lockable joint member **1174** may be similar to the lockable joint member **1130**. As such, the lockable joint member **1174** may be used to secure an end member **1175**, which may be one of the first, second, third, or fourth elongated member **1141**, **1142**, **1143**, or **1144**. Specifically, the locking joint member **1171** may include first and second plates **1172** and **1173**, which may define a space for receiving the end member **1175**, and a locking screw **1171** for locking the end member **1175** between the first and second plates **1172** and **1173**. The rod member **1176** may share similar functionalities as a conventional stabilizing rod such that the rod member **1176** may be received and secured by a conventional pedicle screw, which may be anchored to a spinal bone segment.

[0174] Because the RXOCC **1100** may be fully adjustable before the several locking mechanisms are applied, the X-shape protection bridge **1112** may have several configurations for fitting patients with various spinal bone structures. In FIG. 11E, the spinal bone segments **151** and **154** may have a pair of parallel inter-segment lines and a pair of parallel intra-segment lines. The pair of inter-segment lines may include a first inter-segment line **1182** defined by the pedicle screws **141** and **145**, and a second inter-segment line **1184** defined by the pedicle screws **142** and **146**. Moreover, the pair of intra-segment lines may include a first intra-segment line **1181** defined by the pedicle screws **141** and **142**, and a second intra-segment line **1185** defined by the pedicle screws **145** and **146**. As such, the X-shape protection bridge may have a fully symmetrical configuration according to an embodiment of the present invention, and in which the protection ring **1110** may surround a base section of a spinous process **1181** of the spinal bone segment **151**.

[0175] Referring to FIG. 11F, the spinal bone segments **151** and **154** may have a pair of diverging intra-segment lines **1182** and **1184** and a pair of parallel inter-segment lines **1183**

and **1185**. As such, the X-shape protection bridge may be adjusted to have a partial symmetrical configuration according to another embodiment of the present invention. Referring to FIG. 11G, the spinal bone segments **151** and **154** may have a pair of diverging intra-segment lines **1182** and **1184** and a pair of diverging inter-segment lines **1183** and **1185**. As such, the X-shape protection bridge may be adjusted to have a fully asymmetrical configuration according to yet another embodiment of the present invention.

[0176] The discussion now turns to an alternative lockable joint member. Although the lockable joint member with the two-plate configuration has been discussed with respect to various embodiments of the present invention, an alternative lockable joint member with a multi-axial joint may be used for realizing several functional features of the lockable joint member. As shown in FIG. 12A, an alternative lockable joint member **1200** may generally include a locking screw **1201**, a housing **1205**, a socket **1203** located within the housing **1202**, a bearing **1204**, and a handle member **1202**. More specifically, the housing may have a top surface and a side wall, such that a top receiving port may be formed on the top surface and a side receiving port may be formed on the side wall.

[0177] As shown in FIG. 12B, the socket **1203** may receive the bearing **1204**, and it may have a socket surface for contacting the bearing 1204 and thereby allowing the bearing **1204** to rotate therein. The handle member **1202** may be coupled to the bearing **1204** and it may protrude from the side wall of the housing **1205** via the side receiving port. The handle member **1202** may have a range of multi-axle movement about a center of the bearing **1204** or about the side receiving port. Depending on the other functions of the lockable joint member **1200**, the housing **1205** may be coupled to a rod member in one embodiment or a hook member in another embodiment. The handle member **1202** may be coupled to an end of an elongated member (arm), such that the housing **1205** may rotate about the end of the elongated member.

[0178] As shown in FIG. 12C, the locking screw **1201** may descend into the top opening of the housing **1205**. When the external threaded section **1212** of the locking screw **1201** substantially engages the internal threaded section of the housing **1205**, the inner concave surface **1214** may assert a compression force against the bearing **1204**. Consequentially, the compression force may cooperate with the surface of the socket **1203** to lock the bearing **1204** at a particular position.

[0179] As shown in FIG. 12D, the locking screw **1201** may have a bearing socket **1216** for receiving a driving force. The driving force may cause the external threaded section **1212** of the locking screw **1201** to substantially engage the internal threaded section of the housing **1205**. In FIG. 12E, which shows the bottom view of the locking screw **1201**, the bottom concave surface **1214** may be used for engaging the bearing **1204** and thus locking the bearing **1204** in a particular position. In one embodiment, the bottom concave surface **1214** may be distributed with compressible rings. In another embodiment, the bottom concave surface **1214** may be distributed with small protrusions. In yet another embodiment, the inner concave surface **1214** may be a rough surface, which may cause a significant amount of friction upon contact.

[0180] The discussion now turns to a cross connecting pedicle screw system, which may be used for stabilizing and protection one or more fixation levels of spinal bone segments. In FIG. 13A, a perspective view of a Real-X cross connecting pedicle screw (RXCCPS) system **1300** is shown according to an embodiment of the present invention. From a high level standpoint, the RXCCPS system **1300** may incorporate some of the functions of the Real-X cross connector and the pedicle screws. For example, the RXCCPS system **1300** may be anchored to two or more spinal bone segments. For another example, the RXCCPS system **1300** may provide vertical and horizontal fixations to the spinal bone segments.

[0181] Generally, the RXCCPS **1300** may include a Real-X cross connector **1310** and four joint receiving (JR) pedicle screws **1320, 1330, 1340**, and **1350**. The JR pedicle screws **1320, 1330, 1340**, and **1350** may be used for anchoring the Real-X cross connector **1310** to two or more spinal bone segments. The Real-X cross connector **1310** may stabilize the relative positions among the four JR pedicle screws **1320, 1330, 1340**, and **1350**. As a result, the RXCCPS system **1300** may be used for substantially stabilizing two or more spinal bone segments.

[0182] FIG. 13B shows a semi-exploded view of the RXCCPS system **1300**. Generally, the Real-X cross connector **1310** may include a first elongated member **1304**, a second elongated member **1306**, and a fulcrum member **1302**. The first elongated member **1304** may be a single structure, which may include a first arched segment **1305** connecting to first and second flat ends **1312** and **1314**, a first spherical joint **1316** connecting to the first flat end **1312**, and a second spherical joint **1318** connecting to the second flat end **1314**. Similarly, the second elongated member **1306** may also be a single structure, which may include the second arched segment **1305** connecting to third and fourth flat ends **1313** and **1315**, a third spherical joint **1317** connecting to the third flat end **1313**, and a fourth spherical joint **1319** connecting to the fourth flat end **1315**.

[0183] The fulcrum member **1302** may engage and pivot the first and second arched segments **1305** and **1307**, such that the first and second elongated members **1304** and **1306** may form an adjustable X-shape bridge. Particularly, the first and second elongated members **1304** and **1306** may have a scissor-like movement, which may be advantageous for adapting to patients with various spinal bone widths. Moreover, the first and second elongated members **1304** and **1306** may each have an adjustable length (see FIGS. 4A – 4I), which may be advantageous for adapting to patients with asymmetric spinal bone configurations.

[0184] The centers of the first, second, third, and fourth spherical joints **1316**, **1317**, **1318**, and **1319** may define a base plane S_{1310}. The adjustable X-shaped bridge may arch over the base plane S_{1310}, which may be occupied by two or more spinal bone segments. As such, the adjustable X-shaped bridge may extend across and protect one or more fixation levels of the spinal bone segments.

[0185] Moreover, the first spherical joint **1316** may define a first joint axis A_{1316}, the second spherical joint **1318** may define a second joint axis A_{1318}, the third spherical joint **1317** may define a third joint axis A_{1317}, and the fourth spherical joint **1319** may define a fourth joint axis **A1319**. The first, second, third, and fourth joint axes A_{1316}, A_{1318}, A_{1317}, and A_{1319} may be substantially perpendicular to base plane S_{1310}, and they may represent the orientations of the respective first, second, third, and fourth spherical joints **1316**, **1318**, **1317**, and **1319**.

[0186] The four joint receiving (JR) pedicle screws may include a first JR pedicle screw **1320**, a second JR pedicle screw **1330**, a third JR pedicle screw **1340**, and a fourth JR pedicle screw **1350**. The first JR pedicle screw **1320** may have a cradle **1322** for engaging the first spherical joint **1316** and a threaded shaft **1326** for anchoring the cradle **1322** to a first spinal bone segment. The second JR pedicle screw **1330** may have a cradle **1332** for engaging the second spherical joint **1318** and a threaded shaft **1336** for anchoring the cradle **1332** to a second spinal bone segment. The third JR pedicle screw **1340** may have a cradle **1342** for engaging the third spherical joint **1317** and a threaded shaft **1346** for anchoring the cradle **1342** to the second spinal bone segment. The fourth JR pedicle screw **1350** may have a cradle **1352** for engaging the fourth spherical joint **1319** and a threaded shaft **1356** for anchoring the cradle **1352** to the first spinal bone segment.

[0187] Generally, the first, second, third, and fourth JR pedicle screws **1320**, **1330**, **1340**, and **1350** may each have a multi-axle movement about the respective first, second, third, and fourth spherical joints **1316**, **1318**, **1317**, and **1319**. Particularly, the cradles **1322**, **1332**, **1342**, and **1352** may rotate about the respective first, second, third, and fourth joint axes A_{1316}, A_{1318}, A_{1317}, and A_{1319}. Because the cradles **1322**, **1332**, **1342**, and **1352** may be fully adjustable around the first, second, third, and fourth spherical joints **1316**, **1318**, **1317**, and **1319**, the RXCCPS system **1300** may be used under a wide range of pedicle insertion angles.

[0188] In FIG. 13C, a side view of the RXCCPS system **1300** is shown according to an embodiment of the present invention. The first JR pedicle screw **1320** may have a cradle axis A_{1322} defined by the cradle **1322** and a shaft axis A_{1326} defined by the threaded shaft **1326**. The second JR pedicle screw **1330** may have a cradle axis A_{1332} defined by the cradle **1332** and a shaft axis A_{1336} defined by the threaded shaft **1336**. The third JR pedicle screw **1340** may have a cradle axis A_{1342} defined by the cradle **1342** and a shaft axis A_{1346} defined by the threaded shaft **1346**. The fourth JR pedicle screw **1350** may have a cradle axis A_{1352} defined by the cradle **1352** and a shaft axis A_{1356} defined by the threaded shaft **1356**.

[0189] The joint axis, the cradle axis and the shaft axis may align with one another when no adjustment is made to a particular spherical joint. However, the shaft axis may deviate from the cradle axis to achieve a first multi-axle movement, and the cradle axis may deviate from the joint axis to achieve a second multi-axle movement. Accordingly, the RXCCPS **1300** may provide two levels of multi-axle movement, and it may thus improve the adjustability and flexibility of conventional pedicle screw and stabilizing rod systems.

[0190] For example, regarding the first RJ pedicle screw **1320**, the shaft axis A_{1326} may align with the cradle axis A_{1322}. As such, the threaded shaft **1326** may sustain a minimal first multi-axle movement. However, the cradle axis A_{1322} may deviate from the first joint axis A_{1316}, such that the cradle **1322** may achieve a limited second multi-axle movement.

[0191] For another example, regarding the second RJ pedicle screw **1330**, the shaft axis A1336 may deviate from the cradle axis A_{1332}. As such, the threaded shaft **1336** may achieve a limited first multi-axle movement. However, the cradle axis A_{1332} may align with the second joint axis A_{1318}, such that the cradle **1332** may sustain a minimal second multi-axle movement.

[0192] For another example, regarding the third RJ pedicle screw **1340**, the shaft axis A_{1346} may deviate from the cradle axis A_{1342}. As such, the threaded shaft **1346** may achieve a limited first multi-axle movement. Moreover, the cradle axis A_{1342} may deviate from the third joint axis A_{1317}, such that the cradle **1342** may achieve a limited second multi-axle movement.

[0193] For yet another example, regarding the fourth RJ pedicle screw **1350**, the shaft axis A_{1356} may align with the cradle axis A_{1352}. As such, the threaded shaft **1356** may sustain a minimal first multi-axle movement. Moreover, the cradle axis A_{1352} may align with the fourth joint axis A_{1319}, such that the cradle **1352** may sustain a minimal second multi-axle movement.

[0194] The discussion now turns to the structural and functional features of the Real-X cross connector **1310**. FIG. 14 shows an exploded view of the Real-X cross connector **1310** with an integrated fulcrum member **1302**. Generally, the first elongated member **1304** may include a first pivot member **1410** positioned within the first arched segment **1305**, and the second elongated member **1306** may include a second pivot member **1420** positioned within the second arched segment **1307**. The first and second pivot members **1410** and **1420** may pivot each other so as to facilitate a relative movement between the first and second elongated members **1304** and **1306**. The first and second pivot members **1410** and **1420** may be implemented with various structures capable of actuating a scissor-like motion between the first and second elongated members **1304** and **1306**.

[0195] For example, the first pivot member **1410** may include a pivot ring **1412**, and the second pivot member **1420** may include a pivot base **1426**, a pivot pin **1422** attached on the pivot base **1426**, and a pair of pivot alignment bumps **1424**. Particularly, the pivot pin **1422** may be used for engaging and pivoting the pivot ring **1412**, and the pair of pivot alignment bumps **1412** may contact and guide the pivoting movement of the pivot ring **1412**. In order to secure the first elongated member **1304** to the second elongated member **1305**, a cap **1430** may be used for engaging the pivot pin **1422**.

[0196] Moreover, the cap **1430** may be used for substantially restricting the relative movement between the first and second elongated members **1304** and **1305**. The cap **1430** may press the pivot ring **1412** against the pivot base **1426** by substantially engaging the pivot pin **1422**. This may increase the frictional force between the pivot ring **1422** and the pivot base **1426** and the frictional force between the pivot ring **1422** and the cap **1430**. As a result, the increased frictional forces may lock the first and second elongated members **1304** and **1306** at a particular position to form a rigid X-shaped bridge.

[0197] Although FIG. 14 shows that the first and second elongated members **1304** and **1306** are two single-piece components, the first and second elongated members **1304** and **1306** may incorporate other components to enhance the functionalities thereof. For example, the first and second arched segments **1305** and **1307** may incorporate one or more arm-length adjustment devices (ALAD), which may be used for adjusting the length and curvature thereof. For another example, each of the first, second, third, and fourth flat ends **1312**, **1314**, **1313**, and **1315** may incorporate a flexible joint, which may be used for adjusting the orientations of the first, second, third, and fourth spherical joints **1316**, **1318**, **1317**, and **1319**.

[0198] In FIG. 15, a top view of a semi-adjustable length Real-X cross connector **1500** is shown according to an embodiment of the present invention. Generally, the Real-X cross connector **1500** may include a first elongated member **1504**, a second elongated member **1506**, and a fulcrum member **1520**. The first elongated member **1504** may include a first V-shaped arched segment **1505**, which may be coupled to the first and second spherical joints

1316 and **1318**. The second elongated member **1506** may include a second V-shaped arched segment **1507**, which may be coupled to the third and fourth spherical joints **1317** and **1319**. Together, the first and second V-shaped arched segments **1505** and **1507** may form the X-shaped bridge.

[0199] The first elongated member **1504** may be combined with the fulcrum member **1520**, which may include a channel **1522** and a knob **1524**. When the knob is relaxed, the peak of the second V-shaped arched segment **1507** may travel along the channel **1522**. As such, the knob **1524** may be used for adjusting a peak-to-peak length **1530**, which is measured between the peaks of the first and second V-shaped arched segment **1505** and **1507**. Moreover, the second V-shaped arched segment **1507** may rotate about the knob **1524**. The fulcrum member **1520** may facilitate a relative movement between the first and second elongated members **1504** and **1506**, so that they may be adjusted to adapt to patients with various spinal bone configurations. After the proper adjustment is made, the knob **1524** may be tightened to restrict the relative movement between the first and second elongated members **1504** and **1506**.

[0200] In FIG. 16, a top view of a fully adjustable Real-X cross connector **1600** is shown according to an embodiment of the present invention. Generally, the fully adjustable Real-X cross connector **1600** may include a first elongated member **1604**, a second elongated member **1606**, and a fulcrum member **1620**. The first elongated member **1604** may include a first semi-arched segment **1616** connected to the first spherical joint **1316** and a second semi-arched segment **1618** connecting to the second spherical joint **1318**. Similarly, the second elongated member **1606** may include a third semi-arched segment **1617** connecting to the third spherical joint **1316** and a fourth semi-arched segment **1619** connecting to the fourth spherical joint **1319**. The fulcrum member **1620** may include a channel **1622**, a first knob **1624**, and a second knob **1626**.

[0201] The first knob **1624** may be used for adjusting a first angle A_{1602} between the first and second semi-arched segments **1616** and **1618**. Similarly, the second knob **1626** may be used for adjusting a second angle A_{1604} between the third and fourth semi-arched segments **1617** and **1619**. Together, the first and second knobs **1624** and **1626** may be used for controlling the peak-to-peak distance **1630** between the first and second elongated members **1604** and **1606**. Accordingly, the spherical joints **1316**, **1318**, **1317**, and **1319** may be adjusted angularly and longitudinally, so that the fully adjustable Real-X cross connector **1600** may adapt to patients with various spinal bone configurations.

[0202] Although FIGS. 13A – 13B and FIGS. 14 – 16 show that the Real-X cross connector is used in the RXCCPS system **1300**, the Real-O cross connector and/or the Real-XO cross connector may be used in forming alternative cross connecting pedicle screw systems. For example, the alternative cross connecting pedicle screw systems may include a ring member, which may be used for surrounding and preserving the spinous process of the patient. More specifically, the connecting devices of the Real-O cross connector and/or the Real-XO cross connector may be replaced by the spherical joints **1316**, **1318**, **1317**, and **1319**. To that end, the conventional pedicle screws may be replaced by the JR pedicle screws **1320**, **1330**, **1340**, and **1350**. Accordingly, the alternative cross connecting pedicle screw systems may incorporate the functional features of the Real-O and Real-XO connectors and the advantages provided by the cross connector spherical joints and the RJ pedicle screws.

[0203] The discussion now turns to structural and functional features of the joint receiving (JR) pedicle screws. FIGS. 17A – 17C show various views of the JR pedicle screw **1700** according to an embodiment of the present invention. Generally, the JR pedicle screw **1700** may include a set screw **1702**, a cradle **1704**, a cylindrical adaptor **1706**, and a screw member **1708**. The cradle **1704** may include a side wall **1731** and a base **1733**. Together, the side wall **1731** and the base **1733** may define a cylindrical space and a cradle axis along the cylindrical space. The cylindrical adaptor **1706** may have a pair of locking members (locking flanges) **1722**, and it may be secured within the cylindrical space defined by the cradle **1704**.

[0204] The side wall **1731** of the cradle **1704** may have an inner threaded surface **1732** for engaging the set screw **1702** and one or more receiving ports **1734** for receiving the spherical joint **1750**, which may be one of the four spherical joints **1316**, **1318**, **1317**, and **1319** as shown in FIG. 13B. Particularly, the size of the receiving ports **1734** may limit the second multi-axle movement (See FIG. 13C) between the cradle **1704** and the spherical joint **1750**.

[0205] The screw member **1708** may include a semi-spherical joint **1741** and a threaded shaft **1745**. The semi-spherical joint **1741** may have a first concave surface **1742**, a hemispherical surface **1743** formed on the opposite side of the first concave surface **1742**, and a bearing socket **1745** formed on the first concave surface **1742**. The threaded shaft **1745** may be coupled to the hemispherical surface **1743** of the semi-spherical joint **1741**, and it may protrude from the base **1733** of the cradle **1704**. When the locking members **1722** of the cylindrical adaptor **1704** are deployed, the semi-spherical joint **1741** may be retained within the cylindrical space defined by the cradle **1704**.

[0206] The bearing socket **1745** may be used for receiving a drilling force to drive the threaded shaft **1745** into a particularly bone segment, thereby anchoring the cradle **1704** to that bone segment. After being anchored, the base **1733** of the cradle **1704** may engage and pivot the hemispherical surface **1743** of the semi-spherical joint **1741**, such that the threaded shaft **1745** may have the first multi-axle movement (See FIG. 13C) about the cradle axis. In one embodiment, the base **1733** may include a convex pivot ring (not shown), which may be used for pivoting the hemispherical surface **1743** of the semi-spherical joint **1741**. In another embodiment, the base **1733** may pivot the hemispherical surface **1743** of the semi-spherical joint **1741** via the cylindrical adaptor **1706**, which may have one or more convex pivot rings **1724**.

[0207] The first concave surface **1742** of the semi-spherical joint **1741** may be used for receiving, contacting, and engaging the spherical joint **1750**. As such, the spherical joint **1750** may move freely around the first concave surface **1742**. The free movement of the spherical joint **1750** may facilitate part of the second multi-axle movement since the semi-spherical joint **1741** may become an integral part of the cradle **1704**.

[0208] Generally, as shown in FIG. 17C and FIGS. 18A – 18D, the set screw **1702** may have a socket **1712**, a threaded side wall **1714**, and a second concave surface **1716**. Particularly, the socket **1712** may be used for receiving a locking force, the second concave surface **1716** may be positioned on the opposite side of the socket **1712**, and the threaded side wall **1714** may be coupled between the socket **1712** and the second concave surface **1716**.

[0209] To secure the spherical joint **1750**, the threaded side wall **1714** may engage the inner threaded surface **1732** of the cradle **1704** until the second concave surface **1716** makes contact with the spherical joint **1750**. At that point, the spherical joint **1750** may move freely around the second concave surface **1716**. The free movement of the spherical joint may facilitate part of the second multi-axle movement since the set screw **1712** may become an integral part of the cradle **1704**. Together, the first and second concave surfaces **1742** and **1716** may cooperatively engage the spherical joint **1750**, such that the cradle **1704** may achieve the second multi-axle movement about the spherical joint **1750**.

[0210] To lock the spherical joint **1750** in position, the threaded side wall **1714** of the set screw **1702** may convert the locking force received from the socket **1712** to a compression force. The second concave surface **1716** may apply the compression force against the spherical joint **1750**. Moreover, the compression force may be redirected to the base **1733** of the cradle **1704**, which may respond by generating a reaction force. Eventually, the first concave surface **1742** of the semi-spherical joint **1741** may redirect the reaction force against the spherical joint **1750**. Together, the compression force and the reaction force may cooperate with each other, and they may cause a simultaneous reduction of the first and second multi-axle movements. Accordingly, the spherical joint **1750** may be locked in a particular position within the cradle **1704**.

[0211] FIGS. 19A – 19C show various views of another joint receiving (JR) pedicle screw **1900** according to another embodiment of the present invention. The JR pedicle screw **1900** may include a set screw **1910**, a cradle **1920**, and a screw member **1930**. The cradle **1920** may enclose part of the screw member **1930**, and it may receive and secure the spherical joint **1942** after being engaged by the set screw **1910**. The spherical joint **1942** may be coupled to the flat end member **1940**, which may be part of the Real-X, Real-O, or Real-XO cross connector.

[0212] Referring to FIG. 19B, which shows the exploded view of the JR pedicle screw **1900**, the screw member **1930** may include a joint holder **1932** and a threaded shaft **1934** coupled to the joint holder **1932**. The joint holder **1932** may have a concave inner surface **1936** and a convex outer surface **1938**. Initially, the joint holder **1932** may be received by the cradle **1920**, while the threaded shaft **1934** may protrude from the base of the cradle **1920**. The cradle **1920** may be anchored to a spinal bone segment by the screw member **1930**. Particularly, the screw member **1930** may have a bearing socket **1933** for receiving a surgical ranch, which may drive the threaded shaft **1934** into the spinal bone segment around the pedicle region. Because the cradle **1920** is engaged by the convex outer surface **1938** of the joint holder **1932**, the cradle **1920** may be anchored to the spinal bone segment via the threaded shaft **1934**.

[0213] After being anchored to the spinal bone segment, the cradle **1920** may move around the joint holder **1932**. As shown in FIG. 19C, the cradle **1920** may have a convex pivot ring **1926** located adjacent to the base opening **1928**. The convex pivot ring **1926** may be used for pivoting the outer convex surface **1938** of the joint holder **1932**. In relation to the cradle **1920**, the threaded shaft **1934** may have a first multi-axial movement **1964**. The size of the base opening **1928** of the cradle **1920** may limit the range of the first multi-axial movement **1964**.

[0214] The cradle **1920** may receive the spherical joint **1942**. After the spherical joint **1942** is positioned within the cradle **1920**, the flat end member **1940** may protrude from the cradle **1920** via one of the receiving ports **1924**. The concave inner surface **1936** of the joint holder **1932** may be used for contacting the spherical joint **1942**. As such, the spherical joint **1942** may move around the concave inner surface **1936**.

[0215] The set screw **1910** may have a bearing socket **1912**, a contact surface **1916** positioned on the opposite side of the bearing socket **1912**, and a threaded side wall **1914** coupled between the bearing socket **1912** and the contact surface **1916**. The bearing socket **1912** may be used for receiving a locking force applied by a surgical ranch. The threaded side wall **1914** may engage the inner threaded side wall **1922** of the cradle **1920** while the bearing socket **1912** is receiving the locking force. As the set screw **1910** descends into the cradle **1920**, the contact surface **1916** may contact and engage the spherical joint **1942**. The contact surface **1916** may be flat, convex, or concave. In one embodiment, the contact surface **1916** may be convex, which may establish a single contact point with the spherical joint **1942**. In another embodiment, the contact surface **1916** may be concave, which may establish a plurality of contact points with the spherical joint **1942**.

[0216] The contact surface **1916** may cooperate with the concave inner surface **1936** to allow the spherical joint **1942** to freely rotate within the cradle **1920**. Accordingly, the flat end member **1940** may have a second multi-axle movement **1940** in relative to the cradle

1920. The size of the receiving ports **1924** may limit the range of the second multi-axle movement **1962**.

[0217] When the threaded side wall **1914** of the set screw **1910** is substantially engaged to the inner threaded side wall **1922** of the cradle **1920**, the locking force may be converted to a compression force **1952**. The contact surface **1916** of the set screw **1910** may apply the compression force **1952** against the spherical joint **1942**. The compression force **1952** may be redirected to the base of the cradle **1920**. As a result, the convex pivot ring **1926** of the cradle **1920** may apply a reaction force **1954** along a circular path and against the outer convex surface **1938** of the joint holder **1932**. In turn, the joint holder **1932** may redirect the reaction force **1954** to the spherical joint **1942**.

[0218] The compression force **1952** may cooperate with the reaction force **1954** to substantially restrain the relative movements among the spherical joint **1942**, the joint holder **1932**, and the cradle **1920**. By tightening the set screw **1910** into the cradle **1920**, the first and second multi-axle movements **1964** and **1962** may be simultaneously reduced and suspended. To prevent the joint holder **1932** from sliding within the cradle **1920**, the convex pivot ring **1926** may be depressible, the feature of which may increase the friction between the outer convex surface **1938** and the base section of the cradle **1920**. To prevent the spherical joint **1940** from moving along the joint holder **1932**, the inner concave surface **1936** may include one or more depressible bumps, rings, or protrusions, which may be used for increasing the friction between the inner concave surface **1936** and the spherical joint **1942**. Compared to conventional pedicle screws, the JR pedicle screw **1900** may be easier to manufacture and assemble because it has fewer components and installation steps.

[0219] FIGS. 20A – 20C show various views of an alternative joint receiving (JR) pedicle screw **2000** according to an alternative embodiment of the present invention. Generally, the alternative JR pedicle screw **2000** may include a cap member **2010** and a base member **2020**.

The alternative JR pedicle screw **2000** may be used in conjunction with a cross connector having a spherical ring joint **2032**, which may be connected to the flat end member **2030** of the cross connector.

[0220] The spherical ring joint **2032** may serve similar functions as the spherical joints as discussed in FIG. 13B, and it may be combined with the Real-X, Real-O, and/or Real-XO cross connectors. Moreover, the spherical ring joint **2032** may include a double conical channel (hour-glass channel) along one of its central axes. The double conical channel may have a first inner conical surface **2033**, a second inner conical surface **2034**, and an inner neck **2035** connecting the first and second inner conical surfaces **2033** and **2034**. The spherical ring joint **2032** may have a toroidal mid-section **2036**, which may have a convex surface similar to the middle section of a sphere.

[0221] The base member **2020** may include a threaded head **2021**, a pivot pole **2022** coupled to the threaded head **2021**, a first (bottom) joint holder **2024** peripherally coupled to the pivot pole **2022**, and a threaded shaft **2026** coupled to the pivot pole **2022**. The threaded head **2021** may include a bearing socket **2025**, which may be driven by a surgical ranch. As such, the threaded shaft **2026** may be driven into a spinal bone segment and thereby anchoring the base member **2020** to the spinal bone segment.

[0222] After being anchored, the base member **2020** may receive the spherical ring joint **2032**. Particularly, the double conical channel of the spherical ring joint **2032** may be penetrated by the pivot pole **2022** of the base member **2020**. The first joint holder **2024** of the base member **2020** may have a first concave surface **2023** for contacting the toroidal section **2036** of the spherical ring joint **2032**. The spherical ring joint **2032** may move around the first concave surface **2023**, such that the flat end member **2030** may have a wide range of relative movement with respect to the threaded shaft **2026**.

[0223] After receiving the spherical ring joint **2036**, the base member **2020** may be engaged by the cap member **2010**. Particularly, the cap member **2010** may have a set screw **2012** and a second (top) joint holder **2014** coupled to the set screw **2012**. The set screw **2012** may have an inner threaded section **2013** for engaging the threaded head **2021** of the base member **2020**. The second joint holder **2014** may contact the spherical ring joint **2032** as the set screw **2012** is further engaged to the screw head **2021**.

[0224] The set screw **2012** and the threaded head **2021** may cooperatively lock the second joint holder **2014** at a particular position, thereby retaining the spherical ring joint **2032** in between the first and second concave surfaces **2023** and **2016**. As such, the spherical ring joint **2023** may be anchored to the spinal bone segment.

[0225] The first and second concave surfaces **2023** and **2016** may engage the toroidal mid-section **2036** of the spherical ring joint **2032**, thereby allowing the spherical ring joint **2032** to freely rotate. Moreover, the first and second inner conical surfaces **2033** and **2034** may facilitate a wide range of movement between the spherical ring joint **2032** and the pivot pole **2022**. As such, the flat end member **2030** may have a multi-axle movement **2062** along a circular space **2064**, which may be defined between the first and second joint holders **2024** and **2014**.

[0226] When the threaded wall **2013** of the set screw **2012** is substantially engaged to the threaded head **2021**, the second concave surface **2016** may assert a compression force **2052** against the spherical ring joint **2032**. Particularly, the compression force **2052** may be applied along a circular path on the toroidal mid-section **2036**. The compression force **2052** may be redirected to the first concave surface **2023**. In response, the first concave surface **2023** may generate a reaction force **2054**, which may be applied along another circular path on the toroidal mid-section **2036**.

[0227] Together, the compression force **2052** may cooperate with the reaction force **2054** to substantially restrain the relative movement between the spherical ring joint **2032** and the pivot pole **2022**. As a result, the multi-axle movements **2062** may be reduced and suspended in one single step. To prevent the spherical ring joint **2032** from moving along the first and second concave surfaces **2023** and **2016**, each of the first and second concave surfaces **2023** and **2016** may include one or more depressible bumps, rings, or protrusions, which may be used for increasing the friction between the spherical ring joint **2032** and the first and second concave surfaces **2023** and **2016**. Compared to conventional pedicle screws, the alternative JR pedicle screw **2000** may be easier and less costly to manufacture and assemble because it has fewer components and installation steps.

[0228] The discussion now turns to two alternative embodiments with enhanced stress redistribution. The first alternative embodiment encompasses a Real-X cross connector with an enhanced stress redistribution structure and a fortified pivoting means. Similarly, the second alternative embodiment encompasses a Real-X cross connector with an enhanced stress redistribution structure and a fortified pivoting means, as well as a spinous-process adaptive contour for fitting around the spinous process of a patient. In the following sections, FIGS. 21 – 26 will disclose the structural and functional features of first alternative embodiment, while FIGS. 27 – 32 will disclose the structural and functional features of the second alternative embodiment.

[0229] FIG. 21 shows a perspective view of an RXB cross connector **2100** according to a first alternative embodiment of the present invention. The RXB cross connector **2100** may be used for stabilizing and protecting one or more fixation levels of spinal bone segments. In practice, the RXB cross connector **2100** may be adjustably equipped with several conventional rod segments, such as a first rod **2101**, a second rod **2102**, a third rod **2103**, and a fourth rod **2104**. The RXB cross connector **2100** may be affixed to two or more spinal bone segments by anchoring the conventional rod segments (e.g., the first rod **2101**, the second rod **2102**, the third rod **2103**, and/or the fourth rod **2104**) to the pedicle areas of these spinal bone segments. For example, one or more pedicle screws can be used as anchoring devices for anchoring the conventional rod segments to the pedicle areas of the spinal bone segments.

[0230] The RXB cross connector **2100** may include a first connector (top link) **2110**, a second connector (bottom link **2150**), and a pivot joint **2130**. In order to form an X-shaped bridge across the targeted spinal bone segments, the pivot joint **2130** may pivot the mid section of the first connector **2110** against the mid section of the second connector **2150**. In one implementation, for example, the pivot joint **2130** may be an integral part of the first connector **2110** and the second connector **2150**. In another implementation, for example, the pivot joint **2130** may be a separate part of the first connector **2110** and/or the second connector **2150**. In yet another implementation, for example, the pivot joint **2130** may be partially integrated with the first connector **2110** and/or the second connector **2150**.

[0231] FIGS. 22A and 22B show a front view and a back view of the RXB cross connector **2100**, the first connector **2110** may include a first arm **2112**, a third arm **2114**, and an upper platform **2116**, while the second connector **2150** may include a second arm **2152**, the fourth arm **2154**, and a lower platform **2156**. As discussed herein, the numerical terms, such as "first," "second," "third," and "fourth," are relative terms such that they may be used interchangeably. Moreover, as discussed herein, the positioning terms, such as "upper," "lower," "top," and, "bottom," are relative terms such that they may also be used interchangeably.

[0232] The first arm **2112** may be pivotally connected to the first rod **2101** via a first screw **2105**. When the first screw **2105** is not fastened, the first rod **2101** may have a range of radial movement about the first screw **2105**. When the first screw **2105** is substantially fastened, the first rod **2101** may be tightly connected to the first arm **2112** such that the relative motion between the first rod **2101** and the first arm **2112** may be substantially restricted.

[0233] The third arm **2114** may be pivotally connected to the fourth rod **2104** via a fourth screw **2108**. When the fourth screw **2108** is not fastened, the fourth rod **2104** may have a range of radial movement about the fourth screw **2108**. When the fourth screw **2108** is substantially fastened, the fourth rod **2104** may be tightly connected to the third arm **2114** such that the relative motion between the fourth rod **2104** and the third arm **2114** may be substantially restricted.

[0234] The second arm **2152** may be pivotally connected to the second rod **2102** via a second screw **2106**. When the second screw **2106** is not fastened, the second rod **2102** may have a range of radial movement about the second screw **2106**. When the second screw **2106** is substantially fastened, the second rod **2102** may be tightly connected to the second arm **2152** such that the relative motion between the second rod **2102** and the second arm **2152** may be substantially restricted.

[0235] The fourth arm **2154** may be pivotally connected to the third rod **2103** via a third screw **2107**. When the third screw **2107** is not fastened, the third rod **2103** may have a range of radial movement about the third screw **2107**. When the third screw **2107** is substantially fastened, the third rod **2103** may be tightly connected to the fourth arm **2154** such that the relative motion between the third rod **2103** and the fourth arm **2154** may be substantially restricted.

[0236] The upper platform **2116** may connect the first arm **2112** to the third arm **2114**, such that the first arm **2112** and the third arm **2114** may form a contiguous arc segment along a first reference plane **S2201**. Similarly, the lower platform **2156** may connect the second arm **2152** to the fourth arm **2154**, such that the second arm **2152** and the fourth arm **2154** may form another contiguous arc segment along a second reference plane **S2202**. When viewed from the top and the bottom of the RXB cross connector **2100**, these two contiguous arc segments may appear as two straight and elongated members crossing each other to form an X-shaped protection bridge. Hence, the first reference plane **S2201** may intersect with the second reference plane **S2202** along a center axis (pivot axis) **Ax**.

[0237] As shown in FIGS. 23A – 23B, the upper platform **2116** may interpose the lower platform **2156** along and about the center axis **Ax**. The lower platform **2156** may include one or more components for engaging the upper platform **2116**. Such an engagement may provide a pivoting means for the RXB cross connector **2100**, thereby allowing the RXB cross connector **2100** to have an adjustable length **2330** and an adjustable width **2340**. This aspect of the first alternative embodiment will be further illustrated and discussed in FIG. 24.

[0238] Moreover, the upper platform **2116** may establish a complementary relationship with the lower platform **2156**. In one configuration, the upper platform **2116** may include an upper plate (top plate) **2121** and one or more lower brackets, such as the lower bracket **2123**. The lower brackets (e.g., the lower bracket **2123**) may join the upper plate **2121** at its edges to form one or more upper (upside-down) valleys, the detail of which will be further illustrated and discussed in FIG. 25B. In another configuration, the lower platform **2156** may include a lower plate (bottom plate) **2161** and one or more upper brackets, such as the upper bracket **2163**. The upper brackets (e.g., the upper bracket **2163**) may join the lower plate **2161** at its edges to form one or more lower valleys, the detail of which will be further illustrated and discussed in FIG. 26B.

[0239] Because the upper platform **2116** and the lower platform **2156** are complementarily configured and positioned, the upper plate **2121** may be snugly fitted within the lower valley while the lower plate **2161** may be snugly fitted within the upper valley. The upper valley may help redistribute and redirect the mechanical stress received by the bottom plate **2161**. Similarly, the lower valley may help redistribute and redirect the mechanical stress received by the upper plate **2121**. Because of the mutual stress redistribution and redirection, the upper platform **2116** may cooperate with the lower platform **2156** to enhance the rigidity and stability of the RXB cross connector **2100**. This functional feature of the RXB cross connector **2100** will be further illustrated discussed in FIGS. 25A – 25E and 26A – 26E.

[0240] Referring to FIG. 24, the RXB cross connector **2100** may include several pivoting points. The first pivoting point, for example, may be located at a distal end **2111** of the first arm **2112**. When the first screw **2105** partially engages the first distal end **2111** and the first rod **2101**, the first rod **2101** may freely rotate about the shaft of the first screw **2105**. When the first screw **2105** substantially engages the first distal end **2111**, the first screw **2105** may help tighten the lips of the first distal end **2111**, thereby substantially restricting the movement of the first rod **2101**. As such, the first rod **2101** can be locked in a particular position with respect to the first distal end **2111** of the first arm **2112**.

[0241] The second pivoting point, for example, may be located at a distal end **2151** of the second arm **2152**. When the second screw **2106** partially engages the second distal end **2151** and the second rod **2102**, the second rod **2102** may freely rotate about the shaft of the second screw **2106**. When the second screw **2106** substantially engages the second distal end **2151**, the second screw **2106** may help tighten the lips of the second distal end **2151**, thereby substantially restricting the movement of the second rod **2102**. As such, the second rod **2102** can be locked in a particular position with respect to the second distal end **2151** of the second arm **2152**.

[0242] The third pivoting point, for example, may be located at a distal end **2113** of the third arm **2114**. When the third screw **2107** partially engages the third distal end **2113** and the third rod **2103**, the third rod **2103** may freely rotate about the shaft of the third screw **2107**. When the third screw **2107** substantially engages the third distal end **2113**, the third screw **2107** may help tighten the lips of the third distal end **2113**, thereby substantially restricting the movement of the third rod **2103**. As such, the third rod **2103** can be locked in a particular position with respect to the third distal end **2113** of the third arm **2114**.

[0243] The fourth pivoting point, for example, may be located at a distal end **2153** of the fourth arm **2154**. When the fourth screw **2108** partially engages the fourth distal end **2153** and the fourth rod **2104**, the fourth rod **2104** may freely rotate about the shaft of the fourth screw **2108**. When the fourth screw **2108** substantially engages the fourth distal end **2153**, the fourth screw **2108** may help tighten the lips of the fourth distal end **2153**, thereby substantially restricting the movement of the fourth rod **2104**. As such, the fourth rod **2104** can be locked in a particular position with respect to the fourth distal end **2153** of the fourth arm **2154**.

[0244] The distal ends (e.g., the first distal end **2111**, the second distal end **2151**, the third distal end **2113**, and/or the fourth distal end **2153**) may define the reach of the RXB cross connector **2100**. The pivoted rods (e.g., the first rod **2101**, the second rod **2102**, the third rod **2103**, and/or the fourth rod **2104**) may provide the anchoring points for the RXB cross connector **2100**.

[0245] Generally, the upper platform **2116** and the lower platform **2156** may each include one or more physical structures for effectuating the pivoting therebetween. In one configuration, for example, the lower platform **2156** may include a hollow pole **2157** with a threaded interior surface **2158**, while the upper platform **2116** may include a top opening **2117** with a top stopper **2118**. To engage the upper platform **2116** to the lower platform **2156**, the hollow pole **2157** may be inserted into the top opening **2117**. After the insertion, the first connector **2110** may be free to rotate about the pivot axis **Ax** and with respect to the second connector **2150**. A set screw **2109** may be used for securing the upper platform **2116** against the lower platform **2156**.

[0246] When the set screw **2109** partially engages the threaded interior surface **2158** of the hollow pole **2157**, the first connector **2110** may freely rotate about the pivot axis **Ax** while the upper platform **2116** remains substantially in contact with the lower platform **2156**. When the set screw **2109** substantially engages the threaded interior surface **2158**, the set top portion of the set screw **2109** may push downward and against the top stopper **2118** of the upper platform **2116**. Simultaneously, the threaded shaft of the set screw **2109** may pull the lower platform **2156** upward and against upper platform **2116**. As a result, a pair of action and reaction forces may be asserted against the inner surfaces of the upper platform **2116** and the lower platform **2156**. The action and reaction forces may substantially restrict the relative rotational movement between the upper platform **2116** and the lower platform **2156**, thereby locking the RXB cross connector **2100** into a particular angle. Together, the set screw **2109**, the upper platform **2116**, and the lower platform **2156** may form pivoting group **2410** for providing a pivoting means for the RXB cross connector **2100**.

[0247] The discussion now turns to the structure and functional features of the first connector (top link) **2110** and the second connector (bottom link) **2150** of the RXB cross connector **2100**. Referring to FIGS. 25A – 25E, the upper platform **2116** may be subdivided into several sections, including but not limited to, a top plate **2121**, a first top side wall **2512**, and a second top side wall **2514**. The first top side wall **2512** may connect the top plate **2121** to the first arm **2112**, while the second top side wall **2514** may connect the top plate **2121** to the third arm **2114**.

[0248] Generally, the top plate **2121** may have a radius that is much larger than a width of the first arm **2112** and/or the third arm **2114**. The first top side wall **2512** may provide a geometric transition from the first arm **2112** to the top plate **2121**, while the second top side wall **2514** may provide another geometric transition from the third arm **2114** to the top plate **2121**. Such geometric transitions may help reduce the stress concentration at the junction of the top plate **2121** and the first arm **2112**, as well as the stress concentration at the junction of the top plate **2121** and the third arm **2114**.

[0249] Referring to FIGS. 26A – 26E, the lower platform **2156** may be subdivided into several sections, including but not limited to, a bottom plate **2161**, a first bottom side wall **2652**, and a second bottom side wall **2654**. The first bottom side wall **2652** may connect the bottom plate **2161** to the second arm **2152**, while the second bottom side wall **2654** may connect the bottom plate **2161** to the fourth arm **2154**.

[0250] Similar to the top plate **2121**, the bottom plate **2161** may have a radius that is much larger than a width of the second arm **2152** and/or the fourth arm **2154**. The first bottom side wall **2652** may provide a geometric transition from the second arm **2152** to the bottom plate **2161**, while the second bottom side wall **2654** may provide another geometric transition from the fourth arm **2154** to the bottom plate **2161**. Such geometric transitions may help reduce the stress concentration at the junction of the bottom plate **2161** and the second arm **2152**, as well as the stress concentration at the junction of the bottom plate **2161** and the fourth arm **2154**.

[0251] Next, the structural and functional features of the upper platform **2116** will be discussed in conjunction with those of the lower platform **2156**. The top plate **2121** may have a first upper bell-shaped ridge (bow-shaped ridge) **2521** and a second upper bell-shaped ridge (bow-shaped ridge) **2522**. Each of the bell-shaped ridges may have an upper convex edge **2122**. Similarly, the bottom plate **2161** may have a first lower bell-shaped ridge (bow-shaped ridge) **2621** and a second lower bell-shaped ridge (bow-shaped ridge) **2622**. Each of the bell-shaped ridges may have a lower convex edge **2162**.

[0252] Each of the top side walls may include a lower bracket. Developing from the upper platform **2116**, the first top side wall **2512** may include a first lower bracket **2123** while the second top side wall **2514** may include a second lower bracket **2124**. The first lower bracket **2123** may be opposing the first second lower bracket **2124** in such a manner that they can form an upper (inverse) valley with the top plate **2121**. The upper valley may align with the first reference plane **S2201**, and it may define a receiving cradle for embracing the bottom plate **2162**.

[0253] More specifically, the first lower bracket **2123** may have a first lower ventral concave surface **2532** facing away from the first arm **2112**, while the second lower bracket **2124** may have a second lower ventral concave surface **2534** facing away from the third arm **2114**. The first lower ventral concave surface **2532** may define a first lower vertical concave contour **2523** and a first lower horizontal concave contour **2516**. Similarly, the second lower ventral concave surface **2534** may define a second lower vertical concave contour **2524** and a second lower horizontal concave contour **2518**. On one hand, the first lower vertical concave contour **2523** and the second lower vertical concave contour **2524** may be parallel with the first reference plane **S2201**. On the other hand, the first lower horizontal concave contour **2516** and the second lower horizontal concave contour **2518** may be perpendicular with the first reference plane **S2201**.

[0254] The first lower vertical concave contour **2523** and the second lower vertical concave contour **2524** may have a complementary arrangement with the lower convex edges **2162** of the first lower bell-shaped ridge **2621** and the second lower bell-shaped ridge **2622**. As such, the lower vertical concave contours (e.g., the first lower vertical concave contour **2523** and/or the second lower vertical concave contour **2524**) may fit with the lower convex edges (e.g., the lower convex edges **2122** of the first lower bell-shaped ridge **2621** and the second lower bell-shaped ridge **2622**) along an orientation that is parallel with the first reference plane **S2201**.

[0255] The first lower horizontal concave contour **2516** and the second lower horizontal concave contour **2518** may have a complementary arrangement with the first lower bell-shaped ridge **2621** and the second lower bell-shaped ridge **2622**. As such, the lower horizontal concave contours (the first lower horizontal concave contour **2516** and the second lower horizontal concave contour **2518**) may fit with the lower bell-shaped ridges (e.g., the first lower bell-shaped ridge **2621** and the second lower bell-shaped ridge **2622**) along an orientation that is perpendicular to the first reference plane **S2201**. Because of these various complementary arrangements, the bottom plate **2156** may fit snugly within the upper (inverse) valley.

[0256] The lower platform **2156** may have a similar configuration as the upper platform **2116**. For instance, each of the bottom side walls may include a lower bracket. Developing from the lower platform **2156**, the first bottom side wall **2652** may include a first upper bracket **2163** while the second bottom side wall **2654** may include a second upper bracket **2164**. The first upper bracket **2163** may be opposing the first second upper bracket **2164** in such a manner that they can form a lower valley with the bottom plate **2161**. The lower valley may align with the second reference plane **S2202**, and it may define a receiving cradle for embracing the top plate **2121**.

[0257] More specifically, the first upper bracket **2163** may have a first upper ventral concave surface **2632** facing away from the second arm **2152**, while the second upper bracket **2164** may have a second upper ventral concave surface **2634** facing away from the fourth arm **2154**. The first upper ventral concave surface **2632** may define a first upper vertical concave contour **2623** and a first upper horizontal concave contour **2616**. Similarly, the second upper ventral concave surface **2634** may define a second upper vertical concave contour **2624** and a second upper horizontal concave contour **2618**. On one hand, the first upper vertical concave contour **2623** and the second upper vertical concave contour **2624** may be parallel with the second reference plane **S2202**. On the other hand, the first upper horizontal concave contour

2616 and the second upper horizontal concave contour **2618** may be perpendicular with the second reference plane **S2202**.

[0258] The first upper vertical concave contour **2623** and the second upper vertical concave contour **2624** may have a complementary arrangement with the upper convex edges **2122** of the first upper bell-shaped ridge **2121** and the second upper bell-shaped ridge **2122**. As such, the upper vertical concave contours (e.g., the first upper vertical concave contour **2623** and/or the second upper vertical concave contour **2624**) may fit with the upper convex edges (e.g., the upper convex edges **2122** of the first upper bell-shaped ridge **2121** and the second upper bell-shaped ridge **2122**) along an orientation that is parallel with the second reference plane **S2202**.

[0259] The first upper horizontal concave contour **2616** and the second upper horizontal concave contour **2618** may have a complementary arrangement with the first upper bell-shaped ridge **2121** and the second upper bell-shaped ridge **2122**. As such, the upper horizontal concave contours (the first upper horizontal concave contour **2616** and the second upper horizontal concave contour **2618**) may fit with the upper bell-shaped ridges (e.g., the first upper bell-shaped ridge **2121** and the second upper bell-shaped ridge **2122**) along an orientation that is perpendicular to the second reference plane **S2202**. Because of these various complementary arrangements, the top plate **2156** may fit snugly within the lower valley.

[0260] The interposing of the upper valley with the top plate **2121**, as well as the interposing of the lower valley with the bottom plate **2121**, may provide at least two benefits. First, the concave sections of the valleys may properly absorb, redirect, and/or redistribute the stress lines built up in the convex edges of the respective plates. Second, the concave sections of the valleys may provide one or more smooth contact surfaces for restricting the lateral movements of the respective plates. Such a restriction may minimize the wearing of the joint segment (e.g., the total contact surfaces of the first connector **2110** and the second connector **2150**) while enhancing the stability and rigidity of RXB cross connector **2100**.

[0261] The discussion now turns to various dimensions of the first connector **2110** and the second connector **2150**. Referring to FIG. 25B, the upper valley may have a valley width **L2501**, the lower brackets **2123** and **2124** may have a bracket width **L2502**, and the upper platform **2116** may have a platform length **L2503**. In one configuration, the valley width **L2501** may be about 12.08 mm, the bracket width **L2502** may be about 15.03 mm, and the platform length **L2503** may be about 25.07 mm. The top plate **2121** may have a plate thickness **L2504** and the upper valley may have a valley height **L2505**. In one configuration, the plate thickness **L2504** may be about 3.25 mm, and the valley height **L2505** of about 3.25 mm as well. Accordingly, the upper platform **2116** may have a total platform height **L2506** of about 6.5 mm.

[0262] Each of the first arm **2112** and the third arm **2114** may have an arm thickness **L2509**, an inner curvature **R2501**, and an outer curvature **R2502**. In one configuration, the arm thickness **L2509** may be about 4 mm, the inner curvature **R2501** may have a radius of about 74 mm, and the outer curvature **R2502** may have a radius of about 75 mm. Each of the first distal end **2111** and the third distal end **2113** may have a distal end height **L2507** and an inter-lip space **L2507**. In one configuration, the distal end height **L2507** may be about 7.5 mm, and the inter-lip space may be about 4 mm.

[0263] Referring to FIG. 25D, the first connector **2110** may have a connector length **L2510** and a connector width **L2511**. In one configuration, the connector length **L2510** may be about 72 mm, and the connector width **L2511** may be about 6 mm. Moreover, the top plate may have a plate radius **R2503**, the top opening **2117** may define an open radius **R2504**, the top stopper **2118** may define an inner diameter **D2501**, and the distal ends **2111** and **2113** may each define a pivot opening with a distal diameter **D2502**. In one configuration, the plate radius **R2503** may be about 6.5 mm, the open radius **R2504** may be about 3.5 mm, the inner diameter **D2501** may be about 5.5 mm, and the distal diameter **D2502** may be about 3.5 mm.

[0264] The corresponding and/or matching parts of the second connector **2150** may have dimensions that are similar to those of the first connectors **2110**. Additionally, the hollow pole **2157** of the lower platform **2156** may have a pole height and a pole diameter. In one configuration, the pole height may range from 1 mm to about 3 mm, while the pole diameter may range from 4 mm to about 6 mm. In another configuration, the pole height may be about 2 mm, and the pole diameter may be about 5.5 mm.

[0265] The discussion now turns to the second alternative embodiment, which is directed to an RXC cross connector **2700**, the various views of which are shown in FIGS. 27, 28A – 28B, 29A – 29B, and 30. Generally, the RXC cross connector **2700** may have structure and functional features that are similar to those of the RXB cross connector **2100**. In one configuration, for example, the RXC cross connector **2700** may be used for protecting and stabilizing two or more spinal bone segments. The RXC cross connector **2700** may be anchored to the spinal bone segments via several rods (e.g., the first rod **2101**, the second rod **2102**, the third rod **2103**, and/or the fourth rod **2104**), each of which may be pivotally connected to the RXC cross connector **2700** by a screw (e.g., the first screw **2105**, the second screw **2106**, the third screw **2107**, or the fourth screw **2108**).

[0266] In another configuration, for example, the RXC cross connector **2700** may adopt a pivoting means (e.g., the pivot joint **2130**) and a stress redistributing mechanism (e.g., the complementary arrangements between the upper platform **2116** and the lower platform **2156**) that are essentially the same as the RXB cross connector **2100**. One skilled in the art may readily understand and appreciate these similar features by referencing the previous discussion. As such, the detail description of pivoting means and stress redistributing mechanism will not be repeated in the following sections.

[0267] Notwithstanding these similar features, the RXC cross connector **2700** may be distinguished from the RXB cross connector **2100** based on the shape of the various arms. Primarily, when viewed from the top or from the bottom, the arms of the RXB cross connector **2100** may form a straight X-shape bridge while the arms of the RXC cross connector **2700** may form a deflected X-shape bridge. The deflected X-shape bridge may provide the benefit of better fitting around the spinous process of the spinal bone segment.

[0268] More specifically, each of the arms may have an arm extension that curves away and deviates from the respective reference plane. In one configuration, the first connector (bottom link) **2710** may have a first arm **2712**, a third arm **2714** and a lower platform **2156**. The lower platform **2156** may connect the first arm **2712** to the third arm **2714** to form a first arc along the first reference plane **S2201**. The first arm **2712** may have a first arm extension **2715** deviating from the first reference plane **S2201**. The first arm extension **2715** may form a first (left) slanted V-shape strip protruding outwardly from the first reference plane **S2201**. The third arm **2714** may have a third arm extension **2716** bending inwardly from the first reference plane **S2201**.

[0269] In another configuration, the second connector (top link) **2750** may have a second arm **2752**, a fourth arm **2754** and an upper platform **2116**. The upper platform **2116** may connect the second arm **2752** to the fourth arm **2754** to form a second arc along the second reference plane **S2202**. Viewing from the top and from the bottom, the first arc and the second arc may join at the pivot axis Ax to form the deflected X-shape bridge. The fourth arm **2754** may have a fourth arm extension **2756** bending inwardly from the second reference plane **S2202**. The third arm extension **2716** and the fourth arm extension **2756** allows the third arm **2714** and the fourth arm **2754** to extend the vertical reach without sacrificing much of their respective horizontal reach. This reach can allow a surgeon to work around the specific anatomy of a given patient.

[0270] The second arm **2752** may have a second arm extension **2755** deviating from the second reference plane **S2202**. The second arm extension **2755** may form a second (right) slanted V-shape strip protruding outwardly from the second reference plane **S2202**. Together, the first and second slanted V-shape strips allows the first arm **2712** and the second arm **2752** to extend the horizontal reach without substantially extending their respective vertical reach. Moreover, the first and second slanted V-shape strips may form a double-dipped valley for surrounding the base section of a spinous process. Although the second alternative embodiment shows that the deflected X-shape bridge has a double-dipped valley directly above the pivot joint **2130**, the RXC cross connector **2700** may include other types of deflected X-shape bridges that may conform to the shape of a spinous process or used in cases of cervical and/or thoracalumbar laminectomy where a portion of the spinous process is taken out, thus removing protection provided by the spinous process.

[0271] In order to provide several anchoring points for the RXC cross connector **2700**, each of the arm extensions may have a distal end for pivoting the rods. In one configuration, for example, the first arm extension **2715** may have a first distal end **2711**, the second arm extension **2755** may have a second distal end **2751**, the third arm extension **2716** may have a third distal end **2713**, and a fourth arm extension **2756** may have a fourth distal end **2753**. The rods may be inserted into the pedicle screw or system horizontally, vertically, or in any other configuration that allows the pedicle system to securely hold a portion of the rod when fastened. In an alternative configuration, one or more of the arm extensions (e.g., **2715**, **2755**, **2716**, **2756**) may have a longer length so as to mate with the pedicle system without the need for any connected rods (**2101**, **2102**, **2103**, **2104**).

[0272] The discussion now turns to various dimensions of the first connector (bottom link) **2710** and the second connector (top link) **2750**. Referring to FIG. 31D, the fourth arm **2754** may extend from the pivot axis by a first length **L3101**, the fourth arm **2754** may extend from the second arm **2752** by a second length **L3102**. In one configuration, the first length **L3101** may be about 29.7 mm, and the second length **L3102** may be about 42.9 mm. The V-shaped second arm extension **2755** may have a first segment and a second segment. The first segment may be adjacent to the second distal end **2751**, and it may have a fourth length. The second segment may be adjacent to the second arm **2752**, and it may have a fifth length **L3105**. In one configuration, the fourth length **L3104** may be about 8.66, and the fifth length **L3105** may be about 6.41.

[0273] A first angle **A3101** may be formed between the second arm **2752** and the second segment of the second arm extension **2755**, and a second angle **A3102** may be formed between the first segment and the second segment of the second arm extension **2755**. In one configuration, the first angle **A3101** may be about 225 degrees, and the second angle **A3102** may be about 255 degrees. In an alternative configuration, no bends or angles may be used.

[0274] Referring to FIG. 31B, a first curvature **R3101** may be defined by the second arm **2752** and the second arm extension **2755**, and a second curvature **R3102** may be defined by the fourth arm **2754** and the fourth arm extension **2756**. Generally, the first curvature **R3101** may be steeper than the second curvature **R3102**. In one configuration, for example, the first curvature **R3101** may have a radius of about 42.25 mm, while the second curvature **R3102** may have a radius of about 107.59 mm.

[0275] Referring to FIG. 31E, the transition angles between an arm and an arm extension may be smoothened by a particular curvature. Such an angle-smoothening construction may help reduce the stress concentration around the transition angels, thereby enhancing the rigidity of the RXC cross connector **2700**. A third curvature **R3104** may smoothen the transition angle between the fourth arm **2754** and the fourth arm extension **2756**. A fourth curvature **R3107** may smoothen the first transition angle **A3101**, and a fifth curvature **R3106** may smoothen the second transition angle **A3102**. In one configuration, the fourth curvature **R3107**, as well as the fifth curvature **R3106**, may each have a radius of about 6 mm.

[0276] The corresponding and/or matching parts of the second connector **2750** may have dimensions that are similar to those of the first connectors **2710**. As such, the dimensions of the second connector **2750** are disclosed by reference to FIGS. 31B – 31E. Moreover, the dimensions of several parts of the pivot joint **2130** are similar to those of the RXB cross connector **2100**, such that these dimensions are disclosed by reference to FIGS. 25A – 25E and 26A – 26E.

[0277] The discussion now turns to several performance tests of the RXB cross connector **2100** and the RXC cross connector **2700**. These performance tests were based on one or more computer aided design (CAD) models of the conventional cross connector (e.g., a horizontal connector connecting two segments of vertical rods), the RXB cross connector **2100**, and the RXC cross connector **2700**. Moreover, these performance tests were intended to compare the rigidity and stability of these cross connector under various ranges of bending load and torsion load. The CAD models of these cross connectors (i.e., the conventional cross connector, the RXB cross connector **2100**, and the RXC cross connector **2700**) were assembled to create virtual geometry consistent with the ASTM F1717 standard (a.k.a. "Standard Test Methods for Spinal Implant Constructs in a Vertebrectomy Model"). Finite element analysis (FEA) was performed on the virtual geometry using a validated modeling technique, including the material properties of these cross connectors (e.g., titanium) and the spinal bone segments (e.g., Ultra-high-molecular-weight polyethylene).

[0278] FIGS. 33A and 33B shows the perspective views of a stress test set up for the RXB cross connector **2100** the RXC cross connector **2700** respectively. The RXB cross connector **2100** and the RXC cross connector **2700** were separately and individually anchored to a first block **3310** and a second block **3320** by four pedicle screws **3305**. More specifically, the first arm **2112** (or the first arm **2712**) and the second arm **2152** (or the second arm **2752**) were anchored to the back side **3312** of the first block **3310**, while the third arm **2114** (the third arm **2714**) and the fourth arm **2154** (or the fourth arm **2754**) were anchored to the back side **3322** of the second block **3320**. Each of the first block **3310** and the second block **3320** were used to simulate the property of one or more spinal bone segments. The back sides **3312** and **3322** represented the sides on which the spinous processes developed, while the front sides **3314** and **3324** represented the sides to which a patient might face.

[0279] To conduct the linear displacement test, a bending load **3303** was applied to the first block **3310** along a reference axis **3301** while the second block **3320** was held at a constant position. The linear displacement test then measured the relative vertical displacement between the front side **3314** of the first block **3310** and the front side **3324** of the second block **3320**. Referring to FIG. 34A, which shows a chart of the linear displacement test results, both the RXB cross connector result **3420** and the RXC cross connector result **3430** outperformed the conventional cross connector result **3410** over a wide range of bending load (measured in Newton "N").

[0280] To conduct the angular displacement test, a torsion load **3302** was applied to the first block **3310** about the reference axis **3301** while the second block **3320** was held at a constant position. The angular displacement test then measured the relative angular displacement between the front surface **3314** of the first block **3310** and the front surface **3324** of the second block **3320**. Referring to FIG. 34B, which shows a chart of the angular displacement test results, both the RXB cross connector result **3425** and the RXC cross connector result **3435** outperformed the conventional cross connector result **3445** over a wide range of torsion load (measured in Newton-millimeter "N-mm").

[0281] The discussion now turns to alternative embodiments of Real-X cross connectors or spinal bridges incorporating spherical joints. Spherical joints may provide a more adaptable apparatus that can accommodate any angle of any degenerative spine. By easily adjusting to the various spinal shapes, sizes, or configurations of different patients, spherical joints can provide easier and/or less time consuming surgical installations. A spherical joint may used in a pedicle screw, similar to those previously discussed for FIGS. 13A-20C for connection to a variety of connecting rods, the structural and functional features disclosed by FIGS. 35 – 37B. Spherical joints may be used as arm joints in alternative embodiments of Real-X cross connectors, the structural and functional features disclosed by FIGS. 38 – 42. Moreover, a spherical joint may be used as a fulcrum in an alternative embodiment of a Real-X cross connector, the structural and functional features disclosed by FIGS. 43 – 46B. In addition, a spherical joint may also be incorporated into a spinal bridge without a crossed configuration, the structural and functional features disclosed by FIGS. 47 – 48.

[0282] FIG. 35 shows a perspective view of a pedicle screw **3540** utilizing a spherical joint. Similar to the pedicle screws **1320**, **1330**, **1340**, or **1350**, and as discussed for FIGS. 13A-20C, the pedicle screw **3540** may be used to anchor a Real-X cross connector or other mechanical components to a spinal bone segment. Multiple pedicle screws **3540** may be used to anchor the Real-X cross connector or other mechanical components to a plurality of spinal bone segments. Generally, the pedicle screw **3540** includes a set screw **3547**, a threaded shaft **3550**, and a base member **3549**. More specifically, the threaded shaft **3550** may be used for drilling into the spinal bone segment, the base member **3549** may have a pair of receiving ports **3548**, and the set screw **3547** may be used for securing a portion of a Real-X cross connector or other mechanical component (such as a stabilizing rod) to the base member **3549**.

[0283] FIG. 36A shows a disassembled view of the pedicle screw **3540** to better illustrate its component parts. In addition to the set screw **3547**, the threaded shaft **3550**, and the base member **3549**, a spherical compression saddle **3610** and an intermediate element **3620** fit within the base member **3549**. The set screw **3547** includes a threaded portion **3605** disposed along an outer circumference of the set screw **3547**. Similarly, the base member **3549** includes a threaded portion **3630** disposed along an inner circumference of the base member **3549**. The threaded portion **3630** of the base member **3549** is adapted to engage with the threaded portion **3605** of the set screw **3547** in order to secure the set screw **3547** to the base member **3549**. When assembled, the pedicle screw **3540** maintains the spherical compression saddle **3610** within the base member **3549** and beneath the set screw **3547**. The set screw **3547** may be a cannulated screw.

[0284] FIG. 36B is a zoomed-in view of the set screw **3547** and the spherical compression saddle **3610**. The spherical compression saddle **3610** contains a hollow or open portion and one or more openings or ports **3660** disposed along the walls surrounding the hollow or open portion. The spherical compression saddle **3610** is configured to accept a substantially spherical element, as shown and discussed in greater detail for FIGS. 37A and 37B. The set screw **3547** includes a semi-spherical depression **3650** configured to engage with the substantially spherical element that is can be accepted and positioned in the spherical compression saddle **3610**.

[0285] To better make frictional contact between the set screw **3547** and the substantially spherical element, the semi-spherical depression **3650** and/or the substantially spherical element may have a rough or uneven surface for improving the grip between the semi-spherical depression **3650** and the substantially spherical element when they are in contact with one another. The rough or uneven surface may be created by a plurality of protrusions and/or recessions. In one embodiment, the rough or uneven surface may be created via a plurality of concentric circles. Such concentric circles may be less prone to breaking, chipping or wearing down upon frictional contact with the substantially spherical element. In an alternative embodiment, a variety of other shapes or configurations may be used for creation of the rough or uneven surface. The rough or uneven surface may be formed by a variety of manufacturing processes, for example by brushing, sandblasting, milling and/or drilling.

[0286] FIG. 37A shows a disassembled view of the pedicle screw **3540** and also includes a connecting rod **3710** for engaging with the pedicle screw **3540**. The connecting rod **3710** may be a discrete component piece or may be a continuation of an extension arm of a Real-X cross connector. The connecting rod **3710** is shown with a substantially spherical element **3712** disposed on both its distal and proximal end. An alternative embodiment may utilize only one substantially spherical element **3712**. FIG. 37B shows a zoomed-in view of one of the substantially spherical elements **3712** of the connecting rod **3710** seated in the spherical compression saddle **3610**. Before being secured with the set screw **3547**, the connecting rod **3710** is free to rotate in three dimensions via the substantially spherical element **3712** seated in the spherical compression saddle **3610**. This range of rotation is limited by one of the ports **3660** of the spherical compression saddle **3610**, as shown in FIG. 36B.

[0287] The substantially spherical element **3712** has a rough or uneven surface for improved grip with the semi-spherical depression **3650** of the set screw **3547** when the substantially spherical element **3712** is engaged with the semi-spherical depression **3650**. Improving the frictional contact between the two components helps maintain the connecting rod **3710** in the desired position after installation is complete and helps prevent slippage that might otherwise occur between the substantially spherical element **3712** and the semi-spherical depression **3650**. As discussed for FIG. 36B, the rough or uneven surface may utilize a plurality of concentric circles as shown, or may utilize other shapes or configurations.

[0288] FIG. 38 shows a perspective view of a Real-X cross connector **3800** utilizing spherical joints according to one embodiment of the present invention. The Real-X cross connector **3800** may be used for stabilizing and protecting one or more fixation levels of spinal bone segments while providing an easily adjustable means of attachment to a patient's body. The Real-X cross connector **3800** may be similar to the cross connectors **2100** or **2700** previously discussed for FIGS. 21-32E. As such, one skilled in the art may readily understand and appreciate these similar features by referencing the previous discussion and thus the detailed description of certain previously described features will not be repeated or will not be repeated in full detail in the following sections. The Real-X cross connector **3800** may be adjustably equipped with several connecting rod segments having spherical joints, such as a first rod **3801**, a second rod **3802**, a third rod **3803**, and a fourth rod **3804**. Each of the first rod **3801**, the second rod **3802**, the third rod **3803**, and the fourth rod **3804** may be the same or similar to the double spherical rod **3710**, discussed above for FIGS. 37A and 37B. The Real-X cross connector **3800** may be affixed to a plurality of spinal bone segments by anchoring the connecting rod segments (e.g., the first rod **3801**, the second rod **3802**, the third rod **3803**, and/or the fourth rod **3804**) to the pedicle areas of these spinal bone segments. For example, one or more pedicle screws **3540**, discussed above for FIGS. 35-37B, may be used as anchoring devices for anchoring the connecting rod segments to the pedicle areas of the spinal bone segments.

[0289] The Real-X cross connector **3800** may include a first connector (bottom link) **3810**, a second connector (top link) **3850**, and a pivot joint **3830**. In order to form an X-shaped or a deflected X-shaped bridge across the targeted spinal bone segments, the pivot joint **3830** may pivot the mid section of the first connector **3810** against the mid section of the second connector **3850**. In one implementation, for example, the pivot joint **3830** may be an integral part of the first connector **3810** and the second connector **3850**. In another implementation, for example, the pivot joint **3830** may be a separate part of the first connector **3810** and/or the second connector **3850**. In yet another implementation, for example, the pivot joint **3830** may be partially integrated with the first connector **3810** and/or the second connector **3850**.

[0290] The first connector **3810** of the Real-X cross connector **3800** includes a first arm **3812** and a third arm **3814**. Similarly, the second connector **3850** of the Real-X cross connector **3800** includes a second arm **3852** and a fourth arm **3854**. As discussed herein, the numerical terms, such as "first," "second," "third," and "fourth" are relative terms such that they may be used interchangeably. Moreover, as discussed herein, the positioning terms, such as "top" and "bottom" are relative terms such that they may also be used interchangeably.

[0291] The first arm **3812** may be spherically connected to the first rod **3801** via a first screw **3805**. When the first screw **3805** is not fastened, the first rod **3801** may have a range of spherical movement about the end of the first arm **3812** or the first screw **3805**. When the first screw **3805** is substantially fastened, the first rod **3801** may be tightly connected to the first arm **3812** such that the relative motion between the first rod **3801** and the first arm **3812** may be substantially restricted.

[0292] The third arm **3814** may be spherically connected to the fourth rod **3804** via a fourth screw **3808**. When the fourth screw **3808** is not fastened, the fourth rod **3804** may have a range of spherical movement about end of the third arm **3814** or the fourth screw **3808**. When the fourth screw **3808** is substantially fastened, the fourth rod **3804** may be tightly connected to the third arm **3814** such that the relative motion between the fourth rod **3804** and the third arm **3814** may be substantially restricted.

[0293] The second arm **3852** may be spherically connected to the second rod **3802** via a second screw **3806**. When the second screw **3806** is not fastened, the second rod **3802** may have a range of spherical movement about end of the second arm **3852** or the second screw **3806**. When the second screw **3806** is substantially fastened, the second rod **3802** may be tightly connected to the second arm **3852** such that the relative motion between the second rod **3802** and the second arm **3852** may be substantially restricted.

[0294] The fourth arm **3854** may be spherically connected to the third rod **3803** via a third screw **3807**. When the third screw **3807** is not fastened, the third rod **3803** may have a range of spherical movement about the end of the fourth arm **3854** or the third screw **3807**. When the third screw **3807** is substantially fastened, the third rod **3803** may be tightly connected to the fourth arm **3854** such that the relative motion between the third rod **3803** and the fourth arm **3854** may be substantially restricted.

[0295] Turning now to FIG. 39, with reference to FIG. 38, a disassembled view of the Real-X cross connector **3800** is shown. The first connector **3810** (a lower transverse arm) includes a lower platform **3956**. The second connector **3850** (an upper transverse arm) includes an upper platform **3916**. The upper platform **3916** may connect the first arm **3812** to the third arm **3814**, such that the first arm **3812** and the third arm **3814** may form a contiguous arc segment making up the first connector **3810**. The first connector **3810** may be disposed along a first reference plane or may incorporate curves or other structural configurations as discussed in greater detail for FIGS. 40A and 40B. Similarly, the lower platform **3856** may connect the second arm **3852** to the fourth arm **3854**, such that the second arm **3852** and the fourth arm **3854** may form another contiguous arc segment making up the second connector **3850**. The second connector **3850** may be disposed along a second reference plane or may incorporate curves or other structural configurations as discussed in greater detail for FIGS. 40A and 40B. When mated together, the first connector **3810** and the second connector **3850** may appear as two elongated connector members crossing each other so as to form a substantially X-shaped or deflected X-shaped protection bridge. The first connector **3810** and/or second connector **3850** may be configured to accept one or more rods as discussed in greater detail below, or, in an alternative embodiment, may include as part of the first connector **3810** and/or second connector **3850**, one or more spherical ends.

[0296] A first opening **3901** in the first arm **3812** of the first connector **3810** is configured to receive a portion of the first rod **3801**. When received by the first opening **3901**, the first rod **3801** is permitted to rotate about the first arm **3812** in three dimensions before being secured by the first screw **3805**. The size and/or shape of the first opening **3901** will limit the degree of rotation that may be exhibited by the first rod **3801** before the first screw **3805** securely fastens the first rod **3801** to the first arm **3812**.

[0297] A second opening **3902** in the second arm **3852** of the second connector **3850** is configured to receive a portion of the second rod **3802**. When received by the second opening **3902**, the second rod **3802** is permitted to rotate about the second arm **3852** in three dimensions before being secured by the second screw **3806**. The size and/or shape of the second opening **3902** will limit the degree of rotation that may be exhibited by the second rod **3802** before the second screw **3806** securely fastens the second rod **3802** to the second arm **3852**.

[0298] A third opening **3903** in the fourth arm **3854** of the second connector **3850** is configured to receive a portion of the third rod **3803**. When received by the third opening **3903**, the third rod **3803** is permitted to rotate about the fourth arm **3854** in three dimensions before being secured by the third screw **3807**. The size and/or shape of the third opening **3903** will limit the degree of rotation that may be exhibited by the third rod **3803** before the third screw **3807** securely fastens the third rod **3803** to the fourth arm **3854**.

[0299] A fourth opening **3904** in the third arm **3814** of the first connector **3810** is configured to receive a portion of the fourth rod **3804**. When received by the fourth opening **3904**, the fourth rod **3804** is permitted to rotate about the third arm **3814** in three dimensions before being secured by the fourth screw **3808**. The size and/or shape of the fourth opening **3904** will limit the degree of rotation that may be exhibited by the fourth rod **3804** before the fourth screw **3808** securely fastens the fourth rod **3804** to the third arm **3814**.

[0300] FIG. 40A shows a zoomed-in view of the second connector **3850** (an underside view of the upper transverse arm) and FIG. 40B shows a zoomed-in view of the first connector **3810** (a topside view of the lower transverse arm). The distance between the openings at each end of the first and second connectors **3810** and **3850** (e.g., the first opening **3901**, the second opening **3902**, the third opening **3903**, and/or the fourth opening **3904**) may define the reach of the Real-X cross connector **3800**. The first connector **3810** and/or the second connector **3850** may also contain a number of curves or bends along their respective lengths to form a deflected X-shape bridge and providing the benefit of better fitting around the spinous process of the spinal bone segments. More specifically, first curve **4001**, second curve **4002**, third curve **4003**, fourth curve **4004**, fifth curve **4005**, and sixth curve **4006** along the first connector **3810** and the second connector **3850** are included to provide clearance around a patient's spinous process that might otherwise need to be removed for fitment of a bridge across the spinal bone segments. Moreover, the first connector **3810** and/or the second connector **3850** may also incorporate an arced configuration so as to extend the Real-X cross connector outwardly along the axis $\mathbf{A_{38}}$ and away from the spinal bone segments when the Real-X cross connector **3800** is installed in a patient. Such a configuration can provide an additional protective or safety benefit against impacts to the spinal bone segments from outside the body of the patient.

[0301] With reference to FIG. 38-39, the upper platform **3916** of the second connector **3850** may interpose the lower platform **3956** of the first connector **3810** along and about a center axis. The lower platform **3956** may include one or more components for engaging the upper platform **3916**. Such an engagement may provide a pivoting point for the Real-X cross connector **3800**, thereby allowing the Real-X cross connector **3800** to be adjustable in order to fit varying spinal proportions of different patients. For example, pivoting the first connector **3810** with respect to the second connector **3850** at the engagement of the lower platform **3956** to the upper platform **3916** can adjustably lengthen or shorten the distance between the ends of the first arm **3812** and the fourth arm **3854** or the ends of the second arm **3852** and the third arm **3814**. Similarly, pivoting the first connector **3810** with respect to the second connector **3850** at the engagement of the lower platform **3956** to the upper platform **3916** can adjustably lengthen or shorten the distance between the ends of the first arm **3812** and the second arm **3852** or the ends of the third arm **3814** and the fourth arm **3854**.

[0302] Moreover, the upper platform **3916** may establish a complementary relationship with the lower platform **3956**. In one configuration, the upper platform **3916** may include an opening **4017** and the lower platform **3956** may include a hollow protrusion or pole **4057**. The opening **4017** of the upper platform is configured to receive the hollow protrusion or pole **4057** of the lower platform **3956** such that when the upper platform **3916** and the lower platform **3956** are complementary configured and positioned, the first connector **3810** is snugly fitted with the second connector **3850** at the pivot joint **3830**. A center screw **3930** with a threaded shaft may fit within the opening **4017** of the upper platform **3916** and within the hollow protrusion or pole **4057**. A threaded interior surface **4058** of the hollow protrusion or pole **4057** engages with the threaded shaft of the center screw **3930** to secure the center screw **3930**, the upper platform **3916** and the lower platform **3956** together.

[0303] When the set screw **3930** partially engages the threaded interior surface **4058** of the hollow pole **4057**, the first connector **3810** may freely rotate about the pivot joint while the upper platform **3916** remains substantially in contact with the lower platform **3956**. When the set screw **3930** substantially engages the threaded interior surface **4058**, the lower platform **3956** is forced against the upper platform **3916**. As a result, a pair of action and reaction forces may be asserted against the inner surfaces of the upper platform **3916** and the lower platform **3956**. The action and reaction forces may substantially restrict the relative rotational movement between the upper platform **3916** and the lower platform **3956**, thereby locking the Real-X cross connector **3800** into a particular angle at the pivot joint **3830**. Other aspects of the pivoting means may be as described above in previous embodiments.

[0304] In addition to the pivot joint **3830** created substantially at the center of the Real-X cross connector **3800** by the connection between the upper platform **3916** and lower platform **3956**, four additional joint locations are disposed along the structural body of the Real-X cross connector **3800**. Rods connected at the additional joint locations may provide the anchoring means for fastening the Real-X cross connector **3800** to the spinal segments of a patient. As previously discussed for FIG. 39, the first opening **3901** in the first arm **3812** of the first connector **3810** is configured to receive a portion of the first rod **3801**. A second opening **3902** in the second arm **3852** of the second connector **3850** is configured to receive a portion of the second rod **3802**. A third opening **3903** in the fourth arm **3854** of the second connector **3850** is configured to receive a portion of the third rod **3803**. A fourth opening **3904** in the third arm **3814** of the first connector **3810** is configured to receive a portion of the fourth rod **3804**.

[0305] FIG. 41A shows a double spherical rod **4100** and a single spherical rod **4140**, each of which may be the same or similar to each of the first rod **3801**, the second rod **3802**, the third rod **3803** or the fourth rod **3804**. The double spherical rod **4100** has a first spherical end

4102 and a second spherical end 4104 connected by a middle portion 4103. The first spherical end 4102 may be smaller in diameter than the second spherical end 4104 (e.g. roughly 3mm in diameter versus roughly 5mm in diameter) or, in an alternative embodiment, the first spherical end 4102 may be the same size or greater in diameter than the second spherical end 4014. The first spherical end 4102 and/or the second spherical end 4104 may be formed with a rough or uneven surface, such as protruding or recessing concentric circles, for better making frictional contact with connecting components, as described in greater detail for FIG. 41C. The single spherical rod 4140 has a spherical end 4142 and a non-spherical end 4144 which may be cylindrical in shape. In one embodiment, the spherical end 4142 may be roughly 3mm in diameter and/or the non-spherical end 4144 may be roughly 13mm in length. The spherical end and/or the non-spherical end may be formed with a rough or uneven surface, similar to that of the double spherical rod 4100.

[0306] When used as the first rod 3801, the double spherical rod 4100 has the first spherical end 4102 sized and/or shaped to fit within the first opening 3901 of the first arm 3812. When used as the second rod 3802, the double spherical rod 4100 has the first spherical end 4102 sized and/or shaped so to fit within the second opening 3902 of the second arm 3852. When used as the third rod 3803, the double spherical rod 4100 has the first spherical end 4102 sized and/or shaped so to fit within the third opening 3903 of the fourth arm 3854. When used as the fourth rod 3804, the double spherical rod 4100 has the first spherical end 4102 sized and/or shaped so to fit within the fourth opening 3904 of the third arm 3814.

[0307] The first additional joint location of the Real-X cross connector 3800, for example, may be created at the first opening 3901. When the first screw 3805 has not securely engaged the first rod 3801 with the first arm 3812, the first rod 3801 may freely rotate in three dimensions about the end of the first arm 3812, limited by the size and/or shape of the first opening **3901**. When the first screw **3805** substantially engages the first rod **3801** with the first arm **3812**, the rotational movement of the first rod **3801** is substantially restricted. As such, the first rod **3801** can be locked in a particular position with respect to the end of the first arm **3812**.

[0308] The second additional joint location of the Real-X cross connector **3800**, for example, may be created at the second opening **3902**. When the second screw **3806** has not securely engaged the second rod **3802** with the second arm **3852**, the second rod **3802** may freely rotate in three dimensions about the end of the second arm **3852**, limited by the size and/or shape of the second opening **3902**. When the second screw **3806** substantially engages the second rod **3802** with the second arm **3852**, the rotational movement of the second rod **3802** is substantially restricted. As such, the second rod **3802** can be locked in a particular position with respect to the end of the second arm **3852**.

[0309] The third additional joint location of the Real-X cross connector **3800**, for example, may be created at the third opening **3903**. When the third screw **3807** has not securely engaged the third rod **3803** with the fourth arm **3854**, the third rod **3803** may freely rotate in three dimensions about the end of the fourth arm **3854**, limited by the size and/or shape of the third opening **3903**. When the third screw **3807** substantially engages the third rod **3803** with the fourth arm **3854**, the rotational movement of the third rod **3803** is substantially restricted. As such, the third rod **3803** can be locked in a particular position with respect to the end of the fourth arm **3854**.

[0310] The fourth additional joint location of the Real-X cross connector **3800**, for example, may be created at the fourth opening **3904**. When the fourth screw **3808** has not securely engaged the fourth rod **3804** with the third arm **3814**, the fourth rod **3804** may freely rotate in three dimensions about the end of the third arm **3814**, limited by the size and/or shape of the fourth opening **3904**. When the fourth screw **3808** substantially engages the fourth rod **3804** with the third arm **3814**, the rotational movement of the fourth rod **3804** is substantially restricted. As such, the fourth rod **3804** can be locked in a particular position with respect to the end of the third arm **3814**.

[0311] With reference to FIGS. 38-40B, FIG. 41B shows a set screw **4110** that may be the same or similar to any of the first screw **3805**, the second screw **3806**, the third screw **3807**, or the fourth screw **3808**. The set screw **4110** may be cannulated or non-cannulated. Furthermore, certain features of the locking screw **1201**, discussed for FIG. 12A-12D, and/or the set screw **4600**, discussed for FIG. 46A-46B may be the same or similar to features of the set screw **4110**. For example, the set screw **4110** may be configured to have a shallower profile and/or utilize a deeper or larger semi-spherical depression as shown for the set screw **4600**, discussed in greater detail below. Upon rotating either the first rod **3801**, the second rod **3802**, the third rod **3803**, or the fourth rod **3804** into a desired or particular position with respect to their respective ends of the Real-X cross connector **3800**, each rod is secured in that position to prevent their movement after the installation in the patient is complete. The set screw **4110** includes a threaded portion **4112** disposed along an outer circumference for engaging the set screw **4100** with a connecting surface configured to receive such threading. For example, first screw **3805**, which may be set screw **4110**, can engage the threaded portion **4112** with an inner surface or lip that at least partially defines the first opening **3901** in order to secure the first screw **3805** to first arm **3812**.

[0312] FIG. 41C shows a cross-section of the set screw **4110** to better illustrate its structural and functional features. A hollow portion **4120** at one end of the set screw **4110** provides an opening for the insertion of a screw driver or other mechanical component to facilitate the rotation of the screw into place via the engaging of the threaded portion **4112** with a receiving surface of one of the openings in the first or second connectors **3810** or **3850** (e.g., the first opening **3901**, the second opening **3902**, the third opening **3903**, or the fourth opening **3904**). A semi-spherical depression **4122** is disposed along a lower portion of the set screw **4110** and is configured to engage with a substantially spherical ball of a connecting rod or component. The semi-spherical depression may have a rough or uneven surface for better making frictional contact with the substantially spherical ball when the set screw **4110** is securely engaged with the substantially spherical ball. In one embodiment, the rough or uneven surface may be formed by a plurality of protruding or recessing concentric circles. Such concentric circles may maintain their uneven surface for longer periods due to the surface being more resistant to chipping or breaking when compared to smaller, non-contiguous protrusions making up the uneven surface.

[0313] In one example, the first rod **3801** may be the double spherical rod **4100** and the first screw **3805** may be the set screw **4110**. When the set screw **4110** is not securely engaged with the first rod **3801**, the first rod **3801** has minimal if any frictional contact with the semi-spherical depression of the first screw **3805** and is thus allowed to rotate in three dimensions about the first opening **3901** as previously discussed to a desired position. Upon securely engaging the first screw **3805** with the first rod **3801**, the semi-spherical depression **4122** of the first screw **3805** accepts the a portion of the spherical end of the first rod **3801** and makes frictional contact with the portion of the spherical end of the first rod **3801** via the rough or uneven surface present on the semi-spherical depression **4122** and/or the spherical end of the first rod **3801**. This frictional contact helps maintain the first rod **3801** in the desired position. The above description applies equally to the second rod **3802** with the second screw **3806**, the third rod **3803** with the third screw **3807**, and the fourth rod **3804** with the fourth screw **3808**.

[0314] The double spherical rod **4100** or the spherical rod **4140** may have a rigid or a flexible construction. In a rigid embodiment, the double spherical rod **4100** or the spherical rod **4140** are manufactured such that the body portion between the ends of the rods does not flex or bend. In a flexible embodiment, for example, the double spherical rod **4100** or the spherical rod **4140** may be manufactured such that at least a portion of the rod forms a spring-like orientation. The spring may be tightly wound so the rod is substantially rigid, but capable of slight flexing when pressure is applied to one or both of the ends of the rod. Slight flexing of the rods **4100** or **4140** may provide for even greater adaptability during installation to a specific spinal proportion of a given patient. In addition, the rods **4100** or **4140** can be formed with various sizes and/or dimensions so as accommodate the spinous process of various patients. The double spherical rod **4100** or the spherical rod **4140** may be manufactured of stainless steel, titanium, PEEK, or any other alloy. Similarly, the double spherical rod **4100** or the spherical rod **4140** may be coated or plated with a variety of the same or other materials.

[0315] An alternative embodiment of a Real-X cross connector **4200** utilizing connecting rods with only a single spherical end is shown in perspective view in FIG. 42. Generally, the Real-X cross connector **4200** may have certain structure and functional features that are similar to those of the Real-X cross connector **3800**, but is shown utilizing connecting rods **4201**, **4202**, **4203**, and **4204** without dual spherical ends. The connecting rods **4201**, **4202**, **4203**, and **4204** may be the spherical rod **4140** shown in FIG. 41A. The Real-X cross connector **4200** has a first connector **4210** having a first arm **4212** and a third arm **4214**. The first connector **4210** may be the same or similar to the first connector **3810** of the Real-X cross connector **3800**. Similarly, the Real-X cross connector **4200** has a second connector **4250** having a second arm **4252** and a fourth arm **4254**. Likewise, the second connector **4250** may be the same or similar to the second connector **2850** of the Real-X cross connector **3800**. A plurality of set screws **4205**, **4206**, **4207**, and **4208** are used to fasten the connecting rods **4201**, **4202**, **4203**, and **4204** to the first connector **4210** or second connector **4250** in the same or similar fashion as described above for the set screws **3805**, **3806**, **3807**, and **3808**. The

Real-X cross connector **4200** mates the first connector **4210** with the second connector **4250** at a pivot joint **4230**, the same or similar to the pivot joint **3830** of the Real-X cross connector **3800**.

[0316] Turning next to FIG. 43, a perspective view of a Real-X cross connector **4300** is shown. Generally, the Real-X cross connector **4300** may have certain structure and functional features that are similar to those of the Real-X cross connector **3800** or Real-X cross connector **4200**. Notwithstanding these similar features, the Real-X cross connector **4300** may be distinguished from the Real-X cross connector **3800** based primarily on the structure of a spherical center joint.

[0317] The Real-X cross connector **4300** may be adjustably equipped with several connecting rod segments, such as a first rod **4301**, a second rod **4302**, a third rod **4303**, and a fourth rod **4304**. Each of the first rod **4301**, the second rod **4302**, the third rod **4303**, and the fourth rod **4304** may be the same or similar to the connecting rods **2101**, **2102**, **2103**, or **2104**, discussed above for FIGS. 21-24. In an alternative embodiment, each of the first rod **4301**, the second rod **4304**, the third rod **4303**, and the fourth rod **4304** may be the same or similar to the connecting rods **3801**, **3802**, **3803**, and **3804** or **4201**, **4202**, **4203**, and **4204**. The Real-X cross connector **4300** may be affixed to two or more spinal bone segments by anchoring the connecting rod segments (e.g., the first rod **4301**, the second rod **4302**, the third rod **4303**, and/or the fourth rod **4304**) to the pedicle areas of these spinal bone segments as previously discussed.

[0318] The Real-X cross connector **4300** may include a first connector (bottom link) **4310**, a second connector (top link) **4350**, and a spherical joint **4330**. In order to form an adjustable X-shaped or deflected X-shaped bridge across the targeted spinal bone segments, the spherical joint **4330** permits rotation at the mid section of the first connector **4310** in three dimensions relative to the second connector **4350**. In one implementation, for example, the spherical joint **4330** may be an integral part of the first connector **4310** and the second connector **4350**. In another implementation, for example, the spherical joint **4330** may be a separate part of the first connector **4310** and/or the second connector **4350**. In yet another implementation, for example, the spherical joint **4330** may be partially integrated with the first connector **4310** and/or the second connector **4350**.

[0319] The first connector **4310** of the Real-X cross connector **4300** includes a first arm **4312** and a third arm **4314**. Similarly, the second connector **4350** of the Real-X cross connector **4300** includes a second arm **4352** and a fourth arm **4354**. As discussed herein, the numerical terms, such as "first," "second," "third," and "fourth" are relative terms such that they may be used interchangeably. Moreover, as discussed herein, the positioning terms, such as "top" and "bottom" are relative terms such that they may also be used interchangeably.

[0320] The first arm **4312** may be pivotally connected to the first rod **4301** via a first screw **4305**. When the first screw **4305** is not fastened, the first rod **4301** may have a range of pivotal movement about the end of the first arm **4312** or the first screw **4305**. When the first screw **4305** is substantially fastened, the first rod **4301** may be tightly connected to the first arm **4312** such that the relative motion between the first rod **4301** and the first arm **4312** may be substantially restricted.

[0321] The third arm **4314** may be pivotally connected to the fourth rod **4304** via a fourth screw **4308**. When the fourth screw **4308** is not fastened, the fourth rod **4304** may have a range of pivotal movement about end of the third arm **4314** or the fourth screw **4308**. When the fourth screw **4308** is substantially fastened, the fourth rod **4304** may be tightly connected to the third arm **4314** such that the relative motion between the fourth rod **4304** and the third arm **4314** may be substantially restricted.

[0322] The second arm **4352** may be pivotally connected to the second rod **4302** via a second screw **4306**. When the second screw **4306** is not fastened, the second rod **4302** may have a range of pivotal movement about end of the second arm **4352** or the second screw **4306**. When the second screw **4306** is substantially fastened, the second rod **4302** may be tightly connected to the second arm **4352** such that the relative motion between the second rod **4302** and the second arm **4352** may be substantially restricted.

[0323] The fourth arm **4354** may be pivotally connected to the third rod **4303** via a third screw **4307**. When the third screw **4307** is not fastened, the third rod **4303** may have a range of pivotal movement about the end of the fourth arm **4354** or the third screw **4307**. When the third screw **4307** is substantially fastened, the third rod **4303** may be tightly connected to the fourth arm **4354** such that the relative motion between the third rod **4303** and the fourth arm **4354** may be substantially restricted.

[0324] Although non-spherical rods are shown in FIG. 43, it is envisioned that an alternative embodiment may employ any other type of connecting rod segments as the first rod **4301**, the second rod **4302**, the third rod **4303** or the fourth rod **4304**. For example, the double spherical rod **4100** or the single spherical rod **4140** and associated fixation hardware may be used to connect to the Real-X cross connector **4300**. Such a configuration would allow for three dimensional rotation at not only the center spherical joint **4330**, but also at the ends of one or more of the first arm **4312**, the second arm **4352**, the third arm **4314**, or the fourth arm **4354**. An embodiment of this configuration may provide even greater installation flexibility in the body of a patient.

[0325] Turning now to FIG. 44, with reference to FIG. 43, a disassembled view of the Real-X cross connector **4300** is shown. The first connector **4310** includes a spherical housing **4420**. The second connector **4352** includes a sphere **4410**. A cannulated or non-cannulated set screw **4430** may be used to engage with the spherical housing **4420** and receive a portion of the sphere **4410**, as described in greater detail for FIGS. 46A-B. The spherical housing **4420** may connect the first arm **4312** to the third arm **4314**, such that the first arm **4312** and the third arm **4314** may form a contiguous arc segment making up the first connector **4310**. The first connector **4310** may be disposed along a first reference plane or may incorporate curves or other structural configurations as discussed in greater detail for FIGS. 45A and 45B. Similarly, the center sphere **4410** may connect the second arm **4352** to the fourth arm **4354**, such that the second arm **4352** and the fourth arm **4354** may form another contiguous arc segment making up the second connector **4350**. The second connector **4350** may be disposed along a second reference plane or may incorporate curves or other structural configurations as discussed in greater detail for FIGS. 45A and 45B. When mated together, the first connector **4310** and the second connector **4350** may appear as two elongated connector members crossing each other so as to form a substantially X-shaped or deflected X-shaped protection bridge. At the end of each arm a connecting rod (e.g. **4301**, **4302**, **4303**, **4304**) may be fastened with screws **4305**, **4306**, **4307** or **4308** to enable connection to a pedicle screw or other spinal bone segment attachment mechanism as previously discussed. Each connecting rod may be attached with a pivotal joint as shown and as described in greater detail for FIGS. 21-24 or may be attached with a spherical joint as described in greater detail for FIGS. 38-41C. In an alternative embodiment, other connecting rods may be attached without any pivoting or rotating capabilities.

[0326] FIG. 45A shows a zoomed-in view of the second connector **4350** and FIG. 45B shows a zoomed-in view of the first connector **4310**. The distance between the proximal end **4511** and the distal end **4513** of the first connector **4310** may define a first reach of the Real-X cross connector **4300**. Similarly, the distance between the proximal end **4553** and the distal end **4551** of the second connector **4350** may define a second reach of the Real-X cross connector **4300**. The first connector **4310** and/or the second connector **4350** may also contain a number of curves or bends along their respective lengths to form a deflected X-shape bridge and providing the benefit of better fitting around the spinous process of the spinal bone segments. More specifically, first curve **4501**, second curve **4502**, third curve **4503**, fourth curve **4504**, fifth curve **4505**, and sixth curve **4506** along the first connector **3810** and second connector **3850** are included to provide clearance around any spinous process that might otherwise need to be removed in order to fit a bridge across the spinal bone segments. The curves or bends may be formed as a gradual, smooth surface or may be formed as a sharp and abrupt bend. Moreover, the first connector **4310** and/or the second connector **4350** may also incorporate an arced configuration so as to extend the Real-X cross connector **4300** outwardly along the axis A_{43} and away from the spinal bone segments when the Real-X cross connector **4300** is installed in a patient.

[0327] With reference to FIGS. 43-44, the sphere **4410** of the second connector **4350** may be received by the spherical housing **4420** of the first connector **4310** which is complementary configured and positioned. In an alternative embodiment, the sphere **4410** and/or the spherical housing **4420** may be of any shape, substantially spherical or otherwise, that allows for rotation in three dimensions when the two components are received together. The sphere **4410** may snugly fit within the opening defined by the center sphere housing **4420**, but still be capable of rotational movement for adjusting the position of the first connector **4310** and the second connector **4350** with respect to each other. Engaging the sphere **4410** with the spherical housing **4420** provides a spherical rotation joint for the Real-X cross connector **4300**, thereby allowing the Real-X cross connector **4300** to be adjustable in three dimensions in order to fit varying spinal proportions of different patients. Not only can the first connector **4310** or the second connector **4350** rotate in relation to each other along the xy-plane, but the spherical joint enables rotation also along the z-axis, thus providing full three-dimensional rotation capabilities. The arms of the Real-X cross connector may thus be adjustably positioned both to accommodate not only the varying distances between a patient's spinal bone segments, but also may accommodate varying heights of the spinal bone segments by rotating the arms of the first connector **4310** and/or second connector **4350** along the z-axis. In an alternative embodiment, other shapes that permit rotation in three dimensions may be employed in place of the sphere **4410**. The sphere **4410** may be formed with a rough or uneven surface, such as protruding or recessing concentric circles, for better making frictional contact with connecting components, as described above. The entire sphere **4410** may have the rough or uneven surface, or only a portion of the sphere **4410** may have the rough or uneven surface.

[0328] The spherical housing **4420** contains a plurality of ports **4560** for accommodating the connection of the sphere **4410** to its respective arms **4352** and **4354** when the sphere **4410** is positioned in the spherical housing **4420**. The size and/or shape of the plurality of ports **4560** define the limits of the three dimensional rotation permitted by the first connector **4310** with respect to the second connector **4350**. For example, ports **4560** that are narrow in width by taller in height would allow for a smaller respective range of rotational motion in the xy-plane, but a larger respective range of rotational motion along the z-axis due. The spherical housing **4420** also includes an interior threaded surface **4512** for mating with the set screw **4430**, as discussed below for FIGS. 46A-B.

[0329] With reference to FIGS. 43-45B, FIG. 46A shows a set screw **4600** that may be the same or similar to the set screw **4430**. The set screw **4600** may be non-cannulated as shown or, in an alternative embodiment, may be a cannulated screw. Upon rotating the first connector **4310** and/or the second connector **4350** into a desired or particular position, the first and second connectors **4310** and **4350** are then secured or locked in that position to prevent their movement after the installation in the patient is complete by the set screw **4430**. The set screw **4600** includes a threaded portion **4612** disposed along an outer circumference for engaging the set screw **4600** with a connecting surface configured to receive such threading. For example, the set screw **4430**, which may be set screw **4600**, can engage the threaded portion **4612** with the interior threaded surface **4512** of the spherical housing **4420** in order to secure the first connector **4310** with the second connector **4350**.

[0330] FIG. 46B shows a cross-section of the set screw **4600** to better illustrate its structural and functional features. A hollow portion **4620** at one end of the set screw **4600** provides a opening for the insertion of a screw driver or other mechanical component to facilitate the rotation of the screw into place via the engaging of the threaded portion **4612** with a receiving surface (e.g., the interior threaded surface **4512** of the spherical housing **4420** of the first connector **4310**). The set screw **4600** may be cannulated or non-cannulated. A semi-spherical depression **4622** is disposed along a lower portion of the set screw **4600** and is configured to engage with a substantially spherical ball. The semi-spherical depression **4622** may have a rough or uneven surface for better making frictional contact with the substantially spherical ball (e.g. the sphere **4410**) when the set screw **4600** is securely engaged. In one embodiment, the rough or uneven surface may be formed by a plurality of protruding or recessing concentric circles as previously discussed.

[0331] For example, when the set screw **4430** is the set screw **4600** and is not securely engaged with the interior threaded surface **4512** of the spherical housing **4420**, the sphere **4410** of the second connector **4350** has minimal if any frictional contact with the semi-spherical depression **4622** of the set screw **4430** and is thus allowed to rotate in three dimensions as previously discussed to a desired position. Upon securely engaging the set screw **4430** with the threaded interior surface **4512** of the spherical housing **4420** containing the sphere **4410**, the semi-spherical depression **4622** of the set screw **4430** accepts a portion of the sphere **4410** and makes frictional contact with the center sphere **4410** via the rough or uneven surface present on the semi-spherical depression **4622** and/or the center sphere **4410**.

This frictional contact maintains the first connector **4310** and the second connector **4350** in the desired position with respect to one another.

[0332] The discussion now turns to various dimensions or orientations of the Real-X cross connectors **3800**, **4200**, and/or **4300**. The Real-X cross connectors **3800**, **4200**, and/or **4300** can be installed in a variety of configurations and locations along the spinal column of a patient. They may be installed across adjacent vertebrae of a patient's spinal column or may be installed to skip vertebrae. Advantageously, the Real-X cross connectors may be configured to accommodate a spinous process of a patient without requiring the removal of said spinous process. For example, the connecting rods **3801**, **3802**, **3803**, and/or **3804** of the Real-X cross connector **3800** may be orientated at a desired angle via their spherical joints so as to avoid making contact with a non-removed spinous process of the patient. Similar accommodations may be made utilizing non-spherical connecting rods or the joint at the fulcrum of a Real-X cross connector. This flexibility during installation of the Real-X cross connectors **3800**, **4200**, and/or **4300** also allows for adaptable placement of the given cross connector even if the spinous process of the patient is removed.

[0333] The Real-X cross connectors **3800**, **4200**, and/or **4300** can be created in a variety of sizes depending upon their expected placement locations in a patient. For example, a Real-X cross connector for placement in the cervical (neck) region of a patient may be smaller than a Real-X cross connector for placement in the lumbar region of a patient. In one embodiment, a first connector **3810**, **4210**, or **4310** and a second connector **3850**, **4250**, or **4350** may be sized to span a distance between 20-60 mm for a cervical region of a patient, but may be sized to span a distance between 40-80mm for a lumbar region of a patient. The Real-X cross connectors **3800**, **4200**, and/or **4300** may also be formed to curve or arc outwardly from the spinal cord of a patient and thus provide additional protection to the spine in the case of an impact to the back of the patient.

[0334] Turning our discussion now to FIG. 47, a perspective view of an alternative spinal bridge **4700** utilizing a spherical joint is shown. A first pedicle screw **4741**, a second pedicle screw **4742**, a third pedicle screw **4743**, and a fourth pedicle screw **4744** each have a threaded shaft **4750** for their respective attachment to a spinal bone segment of a patient. A first connecting rod **4762** is connected between the first pedicle screw **4741** and the second pedicle screw **4742**. Similarly, a second connecting rod **4764** is connected between the third pedicle screw **4743** and the fourth pedicle screw **4744**. The spinal bridge **4700** mechanically links the first connecting rod **4762** and the second connecting rod **4764**.

[0335] FIG. 48 shows a disassembled view of the bridge shown in FIG. 47 to better illustrate the component parts making up the spinal bridge **4700**. A first clamping member **4810** has a first clamping element **4807** at a proximal end, a spherical housing **4812** at a distal end, and an extension element **4802** connected there between. The spherical housing **4812** may be the same or similar to the spherical housing **4420**, as previously discussed for FIGS. 43-46B. Similarly, a second clamping member **4820** has a substantially spherical element **4806** at a proximal end, a clamping element **4805** at a distal end, and an extension element **4801** connected there between. The substantially spherical element **4806** may be the same or similar to the sphere **4511**, as previously discussed for FIGS. 43-46B, and be formed with a rough or uneven surface (e.g. concentric circles). The spherical housing **4812** of the first clamping member **4810** is configured to receive the substantially spherical element **4805** of the second clamping member **4820**. In one embodiment, the first clamping member **4810** may have a length of roughly 30mm, measured from the center of the spherical housing **4812** to the end of the first clamping element **4807** and the second clamping member **4820** may have a length of roughly 30mm measured from the center of the substantially spherical element **4806** to the end of the second clamping element **4805**. Thus, a maximum total distance of roughly 60mm may be obtained from the end of the first clamping element **4807** to the end of the second clamping element **4805** when the first clamping member and the second clamping member are engaged together and oriented within the same plane. An alternative embodiment may shorten or lengthen the respective clamping members in order to obtain a smaller or larger maximum total distance. An alternative embodiment may also utilize different connecting methods as previously described, for example the same or similar to the embodiments shown in FIGS. 1A-C, 2A-C, or with spherical joints or ends.

[0336] When the substantially spherical element **4805** is seated within the spherical housing **4812**, the second clamping member **4820** is permitted to rotate in three dimensions with respect to the first clamping member **4810**. The spherical housing **4812** contains a port **4860** for accommodating the extension element **4801** connected to the substantially spherical element **4806** when the substantially spherical element **4806** is positioned within the spherical housing **4812**. The size and/or shape of the port **4860** may define the limits of the three dimensional rotation permitted by the first clamping member **4810** with respect to the second clamping member **4820**. The spherical housing **4812** also includes an interior threaded surface **4814** for mating with a set screw **4830**. The set screw **4830** may be the same or similar to the center screw **4600**, previously discussed for FIG. 46. Upon rotating the first clamping member **4810** and/or the second clamping member **4820** into a desired or particular position, the first and second clamping members **4810** and **4820** are then secured or locked in that position to prevent their movement after the installation in the patient is complete by the set screw **4830**. The set screw **4830** includes a threaded portion **4815** disposed along an outer circumference for engaging the set screw **4830** with the interior threaded surface **4814** of the spherical housing **4812**. A semi-spherical depression **4850** receives and makes frictional contact with a portion of the substantially spherical element **4806** when the set screw **4830** is secured in position with the first clamping member **4810**. The semi-spherical depression **4850** may be the same or similar to the semi-spherical depression **4622**, as discussed for FIG.

46, and utilize the same or similar rough or uneven surface (e.g. concentric circles) to promote improved gripping capabilities.

[0337] The discussion now turns to alternative embodiments of spinal cross connectors or spinal bridges incorporating dimples or designed for minimally invasive surgery. Dimpling the surface of spinal cross connectors or bridges can provide a surface for improved attachment of bone grafts and may be used upon the surface of a Real-X cross connector, the structural and functional features disclosed by FIGS. 49A-49B. Spinal hardware designed for minimally invasive surgery may be adapted for insertion into a patient through a smaller incision than commonly utilized for open surgery procedures. One embodiment designed for minimally invasive procedures is a collapsible spinal cross connector, the structural and functional features disclosed by FIGS. 50A-50C. A second embodiment designed for minimally invasive procedures is a partially collapsible spinal cross connector with adjustment gearing, the structural and functional features disclosed by FIGS. 51A-51C.

[0338] FIG. 49A shows a perspective view of a Real-X cross connector **4900** that incorporates dimples upon its surface for improved bonding with bone grafts. The Real-X cross connector **4900** has a first connector **4910** and a second connector **4950** coupled together and configured to extend across adjacent spinal segments of a patient. A connecting rod **4940** may be connected at the ends of each of the first connector **4910** and/or the second connector **4950** for coupling with a pedicle screw or other attachment mechanism for mounting the Real-X cross connector **4900** to the spinal segments of a patient. The exposed surfaces of the Real-X cross connector **4900** are covered with a dimpled surface, as discussed in greater detail below.

[0339] FIG. 49B shows a zoomed in perspective view of the Real-X cross connector **4900** and shows a plurality of recessed dimples **4960** disposed on the surface. The dimples **4960** may be positioned both upon the outwardly-facing surfaces of the first connector **4910** and the second connector **4950**, and also upon any other exposed surface of the Real-X cross connector **4900** or its component parts (e.g. side-facing surface **4970**). Although the dimples **4960** are shown as round depressions upon the surface, in an alternative embodiment the dimples **4960** can be of any shape and/or size so as to facilitate bonding with a bone graft. While bone grafts are commonly placed upon the bone segments of a patient, the bone grafts may also be smeared or placed across the Real-X cross connector **4900** and thus bond with the dimples **4960**. Such a configuration may provide additional support and/or stability for coupling the Real-X cross connector **4900** with the spinal segments of the patient. The dimples **4960** may be disposed upon any or every exposed surface of the Real-X cross connector **4900**, including the connecting rods **4940**, the screw **4980** or any other exposed element. Dimpled surfaces may be utilized not only upon embodiments of Real-X cross connectors, but may also be incorporated upon any of the same or similar spinal connectors, bridges, or other components described or shown elsewhere in this application.

[0340] Turning next to spinal connectors designed for minimally invasive surgery, FIG. 50A shows a perspective view of a collapsible minimally invasive cross connector **5000**. The cross connector **5000** has a first arm **5012**, a second arm **5052**, a third arm **5014**, and a fourth arm **5054** rotatably connected together by a fulcrum member **5030**. As discussed herein, the numerical terms, such as "first," "second," "third," and "fourth" are relative terms such that they may be used interchangeably. Moreover, as discussed herein, the positioning terms, such as "top" and "bottom" are relative terms such that they may also be used interchangeably.

[0341] As seen in FIG. 50B, each of the first arm **5012**, the second arm **5052**, the third arm **5014**, and the fourth arm **5054** are configured to rotate with respect to one another at the fulcrum member **5030**. In an expanded configuration (see FIG. 50A), the arms may form a substantially X-shaped configuration for attachment across a patient's spinal bone segments.

In a collapsed configuration (see FIG. 50B), the arms may form a stack on top of one another, substantially reducing the overall dimensions of the cross connector **5000**. In the expanded configuration, the cross connector **5000** may act as a protective spinal bridge. However, open surgery is commonly needed for the installation of such a spinal bridge due to the overall larger shape and/or size of the bridge. In the collapsed configuration, however, a smaller incision in the patient may accommodate the reduced overall dimensions of the cross connector **5000**, thus allowing the cross connector **5000** to be installed in a patient through a minimally invasive surgical procedure.

[0342] FIG. 50C, with reference to FIG. 50A, shows an exploded perspective view of the cross connector **5000** for better demonstrating its structural and functional characteristics. At one end of the first arm **5012** is a first opening **5001**. The first opening **5001** provides an attachment location for connecting the first arm **5012** with a first connecting rod **5005**. The first opening **5001** may have a circular shape and be configured to receive a screw (not shown) in order to permit rotation of the first connecting rod **5005** about the first opening **5001** before securing the first connecting rod **5005** in position with the screw. In an alternative embodiment, any connecting means may be used (e.g., a spherical joint) to connect the first arm **5012** to the first connecting rod **5005**, or no connecting rod may be utilized. At the other end of the first arm **5012** is a first connecting ring **5031**. The first connecting ring **5031** may be formed as a part of the first arm **5012** or may be a discrete component that is mechanically fastened to the first arm **5012**. The first connecting ring **5031** is configured to accept a portion of the fulcrum member **5030**, as discussed below.

[0343] At one end of the second arm **5052** is a second opening **5002**. The second opening **5002** provides an attachment location for connecting the second arm **5052** with a second connecting rod **5006**. The second opening **5002** may have a circular shape and be configured to receive a screw (not shown) in order to permit rotation of the second connecting rod **5006** about the second opening **5002** before securing the second connecting rod **5006** in position with the screw. In an alternative embodiment, any connecting means may be used (e.g., a spherical joint) to connect the second arm **5052** to the second connecting rod **5006**, or no connecting rod may be utilized. At the other end of the second arm **5052** is a second connecting ring **5033**. The second connecting ring **5033** may be formed as a part of the second arm **5052** or may be a discrete component that is mechanically fastened to the second arm **5052**. The second connecting ring **5033** is configured to accept a portion of the fulcrum member **5030**, as discussed below.

[0344] At one end of the third arm **5014** is a third opening **5004**. The third opening **5004** provides an attachment location for connecting the third arm **5014** with a third connecting rod **5008**. The third opening **5004** may have a circular shape and be configured to receive a screw (not shown) in order to permit rotation of the third connecting rod **5008** about the third opening **5004** before securing the third connecting rod **5008** in position with the screw. In an alternative embodiment, any connecting means may be used (e.g., a spherical joint) to connect the third arm **5014** to the third connecting rod **5008**, or no connecting rod may be utilized. At the other end of the third arm **5014** is a third connecting ring **5034**. The third connecting ring **5034** may be formed as a part of the third arm **5014** or may be a discrete component that is mechanically fastened to the third arm **5014**. The third connecting ring **5034** is configured to accept a portion of the fulcrum member **5030**, as discussed below.

[0345] At one end of the fourth arm **5054** is a fourth opening **5003**. The fourth opening **5003** provides an attachment location for connecting the fourth arm **5054** with a fourth connecting rod **5007**. The fourth opening **5003** may have a circular shape and be configured to receive a screw (not shown) in order to permit rotation of the fourth connecting rod **5007** about the fourth opening **5003** before securing the fourth connecting rod **5007** in position with the screw. In an alternative embodiment, any connecting means may be used (e.g., a spherical joint) to connect the fourth arm **5054** to the fourth connecting rod **5007**, or no connecting rod may be utilized. At the other end of the fourth arm **5054** is a fourth connecting ring **5032**. The fourth connecting ring **5032** may be formed as a part of the fourth arm **5054** or may be a discrete component that is mechanically fastened to the fourth arm **5054**. The fourth connecting ring **5032** is configured to accept a portion of the fulcrum member **5030**, as discussed below.

[0346] The fulcrum member **5030** may have a protruding element that is received by each of the first connecting ring **5031**, the second connecting ring **5033**, the third connecting ring **5034**, and the fourth connecting ring **5032**. An end cap **5035** engages with the protruding element of the fulcrum member **5030** and operates to secure the fulcrum member **5030** with each of the connecting rings (e.g., **5031, 5033, 5034, 5032**) in order to maintain the cross connector **5000** as one unit. In one embodiment, each of the first connecting ring **5031**, the second connecting ring **5033**, the third connecting ring **5034**, and the fourth connecting ring **5032** may be configured to accept a portion of an adjacent connecting ring for fitment purposes when stacked together. Each of the arms (e.g. **5012, 5052, 5014, 5054**) are rotatable with respect to one another about the fulcrum member **5030**. By rotating the arms so that they stack on top of or below one another, the collapsed configuration seen in FIG. 50B can be obtained. By rotating the arms so that they expand outwardly from one another, the expanded configuration seen in FIG. 50A can be obtained. Although the cross connector **5000** is shown with substantially straight arms, it is envisioned that various features of other embodiments described in this application (e.g., arms incorporating curvatures or bends) may be utilized in an alternative embodiment.

[0347] FIG. 51A shows a perspective view of a geared minimally invasive cross connector **5100**. The cross connector **5100** includes a first arm **5112**, a second arm **5152**, a third arm **5114**, and a fourth arm **5154**. The first arm **5112** and the second arm **5152** are rotatably coupled together by a first screw **5131** at one end of each of the first arm **5112** and the second arm **5152**. Similarly, the third arm **5114** and the fourth arm **5154** are rotatably coupled together by a second screw **5132** at one end of each of the third arm **5114** and the fourth arm **5154**. As discussed herein, the numerical terms, such as "first," "second," "third," and "fourth" are relative terms such that they may be used interchangeably. Moreover, as discussed herein, the positioning terms, such as "top" and "bottom" are relative terms such that they may also be used interchangeably.

[0348] The first screw **5131** is coupled to a first platform **5160** and the second screw **5132** is coupled to a second platform **5162**. The first platform **5160** and the second platform **5162** are configured to engage with each other as discussed in greater detail herein. A cover **5130** may be positioned over a portion of the first platform **5160** and the second platform **5162** when they are engaged together to prevent bodily fluids or other particulates from interfering with the engagement of the first platform **5160** with the second platform **5162**. Although the cross connector **5100** is shown with substantially straight arms, it is envisioned that various features of other embodiments described in this application (e.g., arms incorporating curvatures or bends) may be utilized in an alternative embodiment.

[0349] As seen in FIG. 51B, the first arm **5112** and the second arm **5152** are configured to rotate with respect to one another at the first screw **5131** so that they may be stacked on top of or below one another. Similarly, the third arm **5114**, and the fourth arm **5154** are configured to rotate with respect to one another at the second screw **5132** so that they may be stacked on top of or below one another. In an expanded configuration (see FIG. 51A), the arms may form a substantially X-shaped configuration for attachment across a patient's spinal bone segments. Each arm may be positioned according to the spinal bone segments of a given patient and then secured in place by the tightening of either the first screw **5131** or the second screw **5132**. In a collapsed configuration (see FIG. 51B), certain arms may stack upon one another, thereby substantially reducing the overall dimensions of the cross connector **5100**. In the expanded configuration, the cross connector **5100** may act as a protective spinal bridge. Open surgery is commonly needed for the installation of a spinal bridge due to the overall shape and/or dimensions of the bridge, however, the reduced dimensions of the cross connector **5100** in the collapsed configuration may permit installation of the cross connector **5100** into a patient via a smaller incision, such as those used during minimally invasive surgical procedures.

[0350] FIG. 51C shows a zoomed perspective view of the cross connector **5100** for better demonstrating its structural and functional characteristics. The cover **5130** is shown removed from the first platform **5160** and the second platform **5162** so that the underlying engagement mechanism can be better viewed and described. The first platform **5160** is formed with or is connected to an engagement member **5138**. The second platform **5162** is formed with or is connected to a pair of guiding elements **5139** configured to receive the engagement member **5138** of the first platform **5160**. A plurality of gears, including a first gear **5133**, a second gear **5134**, a third gear **5135**, and a fourth gear **5136** are connected to the second platform **5162** and positioned between the pair of guiding elements **5139**. The first gear **5133**, the second gear **5134**, the third gear **5135**, and the fourth gear **5136** each operate to engage or mesh with a toothed surface of the engagement member **5138** in order to adjust and/or hold the first platform **5160** in a specific position with respect to the second platform **5162**.

[0351] When one of the first gear **5133**, the second gear **5134**, the third gear **5135**, or the fourth gear **5136** is rotated, the engagement member **5138** of the first platform **5160** is translated or moves with respect to the second platform **5162** within the guiding elements **5139** due to its engagement with one or more of the gears. In this manner, each of the first gear **5133**, the second gear **5134**, the third gear **5135**, and the fourth gear **5136** may cooperate to either extend or retract the first platform **5160** with respect to the second platform **5162**. In an alternative embodiment, no guiding elements **5139** may be utilized.

[0352] A locking gear **5137** is positioned and configured to provide a mechanical connection between the first gear **5133**, the second gear **5134**, the third gear **5135**, and the fourth gear **5136** such that, after any needed rotation of the first gear **5133**, the second gear **5134**, the third gear **5135**, or the fourth gear **5136** to adjust the position of the first platform **5160** with respect to the second platform **5162**, the adjusted position can be secured. By inserting the locking gear **5137** between the first gear **5133**, the second gear **5134**, the third gear **5135**, and the fourth gear **5136**, further rotation of those gears is prevented and the first platform **5160** is thus held in place with respect to the second platform **5162**. The locking gear **5137** may be a separate component as shown or, in an alternative embodiment, may be formed as part of the cover **5130** such that placement of the cover **5130** over the first platform **5160** and second platform **5162** inserts the locking gear **5137** into position. Such a design allows for adjustment of the cross connector **5100** either during surgery or after its installation within a patient without having to remove and re-install the same or a different cross connector if it is subsequently determined that alternative sizing is needed. Moreover, through knowledge of the gear ratios employed by the cross connector **5100**, precise rotation amounts can be determined in order to obtain specific extension or retraction distances.

[0353] Each of the first gear **5133**, the second gear **5134**, the third gear **5135**, and/or the fourth gear **5136** may contain an opening configured to accept a device that can rotate the respective gear when inserted into the opening. The gears may be manually rotated through the use of a hand-held device, such as a screwdriver, such that rotation of the hand-held device at any of the first gear **5133**, the second gear **5134**, the third gear **5135**, or the fourth gear **5135** causes translation of the first platform **5160** with respect to the second platform **5162**. Alternatively, the rotation may be accomplished with or assisted by an automatic rotation device, for example one capable of rotating according to predetermined and/or precise rotational amounts. Adjustments can thus be made to the cross connector **5100** through a small incision in the patient that needs only be large enough to accommodate a portion of the device for rotating the respective gear. An alternative embodiment may utilize any number of gears. In still another embodiment, alternative engagement means may be employed in place of or in addition to gears, such that the first platform **5160** can be extended or retracted with respect to the second platform **5162**.

[0354] Various structures and/or features have been disclosed throughout the illustrative embodiments presented above. It is expected that the structures and/or features for any of the embodiments so presented may be adapted and/or incorporated into the various other embodiments illustrated throughout. For example, components with spherical joints may be used in place of or in addition to components with non-spherical joints and vice versa to form a variety of alternative embodiments. In one example, the same or similar spherical joint described for FIGS. 43-46 may be applied to the RXB cross connector. In another example, the same of similar spherical end joints described for FIGS. 38-42 may be applied to the RXB cross connector.

[0355] Exemplary embodiments of the invention have been disclosed in an illustrative style. Accordingly, the terminology employed throughout should be read in a non-limiting manner. Although minor modifications to the teachings herein will occur to those well versed in the art, it shall be understood that what is intended to be circumscribed within the scope of the patent warranted hereon are all such embodiments that reasonably fall within the scope of the advancement to the art hereby contributed, and that that scope shall not be restricted, except in light of the appended claims and their equivalents.

CLAIMS

What is claimed is:

1. A cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments, the cross connector comprising:

a plurality of arms including first, second, third, and fourth arms, the first arm and the third arm aligning along a first reference plane, the second arm and the fourth arm aligning along a second reference plane intersecting the first reference plane along a pivot axis;

a bottom plate centered along the pivot axis and substantially perpendicular to the first and second reference planes;

a pair of bottom side walls connected to the bottom plate so as to define a bottom valley having a plurality of bottom curved sections, each of the pair of bottom side walls connected to the first arm or the third arm to form a first contiguous arc segment;

a top plate snugly fitted within the bottom valley and engaging the bottom plate to provide a pivot point along the pivot axis; and

a pair of top side walls connected to the top plate so as to define a top valley having a plurality of top curved sections for embracing the bottom plate, each of the pair of top side walls connected to the second arm or the fourth arm to form a second contiguous arc segment.

2. The cross connector of Claim 1, wherein:

the bottom plate includes a bottom convexly sloped edge for fitting with at least one of the plurality of top curved sections, and

the top plate includes a top convexly sloped edge for fitting with at least one of the plurality of bottom curved sections.

3. The cross connector of Claim 1, wherein:

the bottom valley has a bottom contour substantially matching a top radial cross section of the top plate, and

the top valley has a top contour substantially matching a bottom radial cross section of the bottom plate.

4. The cross connector of Claim 1, wherein:

the pair of bottom side walls provide a first geometric transition from the first arm and the third arm to the top plate and the bottom plate, and

the pair of top side walls provide a second geometric transition from the second arm and the fourth arm to the top plate and the bottom plate.

5. The cross connector of Claim 1, wherein:

the pair of bottom side walls each includes a bottom concave section,

the pair of top side walls each includes a top concave section, and

the bottom concave sections cooperate with the top concave section to restrict a relative lateral movement between the bottom plate and the top plate.

6. The cross connector of Claim 1, wherein:

the bottom valley has a bottom valley depth substantially equal to a top plate thickness of the top plate such that the pair of bottom side walls are flush with the top plate along the first reference plane, and

the top valley has a top valley depth substantially equal to a bottom plate thickness of the bottom plate such that the pair of top side walls are flush with the bottom plate along the second reference plane.

7. The cross connector of Claim 1, wherein:

the first arm has a first arm extension distal to the bottom plate and curving away from the first reference plane,

the second arm has a second arm extension distal to the top plate and curving away from the second reference plane, and

the first arm extension and the second arm extension form an adjustable bracket surrounding a base segment of a spinous process.

8. The cross connector of Claim 1, wherein:

the first arm has a first arm extension distal to the bottom plate and deviating from the first reference plane,

the second arm has a second arm extension distal to the top plate and deviating from the second reference plane, and

the first arm extension cooperates with the second arm extension to substantially conform with a contour of a spinous process.

9. A cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments, the cross connector comprising:

a first connector including a first pair of arms and a first joint positioned between the first pair of arms, the first joint having:

a first platform having a first bell-shaped ridge connecting the first pair of arms to form a first contiguous arc along a first reference plane, the first bell-shaped ridge furnished with a first convex edge, and

a first bracket formed on the first platform, the first bracket having a first vertical concave contour substantially parallel to the first reference plane, and a first horizontal concave contour intersecting the first vertical concave contour and substantially perpendicular to the first reference plane;

a second connector including a second pair of arms and a second joint positioned between the second pair of arms, the second joint having a complementary configuration with respect to the first joint, the second joint connecting the second pair of arms to form a second contiguous arc along a second reference plane intersecting the first reference plane alone a center axis; and

a pivoting means for pivoting the first connector against the second connector along the center axis, thereby allowing a limited range of angular movement between the first pair of arms and the second pair of arms.

10. The cross connector of Claim 9, wherein:

the first platform has a center region surrounding the center axis, the center region substantially wider than each of the first pair of arms, and

the first bell-shaped ridge provides a geometric transition from each of the first pair of arms to the center portion of the first platform.

11. The cross connector of Claim 9, wherein the pivoting means substantially restricts a relative displacement between the first joint and the second joint.

12. The cross connector of Claim 9, wherein:

at least on of the first pair of arms has a first arm extension distal to the first joint and curving away from the first reference plane,

at least on of the second pair of arms has a second arm extension distal to the top plate and curving away from the second reference plane, and the first arm extension cooperates with the second arm extension form an adjustable bracket surrounding a base segment of a spinous process.

13. The cross connector of Claim 9, wherein:

at least on of the first pair of arms has a first arm extension distal to the first joint and deviating from the first reference plane,

at least on of the second pair of arms has a second arm extension distal to the top plate and deviating from the second reference plane, and

the first arm extension cooperates with the second arm extension to substantially conform with a contour of a spinous process.

14. The cross connector of Claim 9, wherein the complementary configuration of the second connector includes:

a second platform having a second bell-shaped ridge connecting the second pair of arms to form the second contiguous arc along the second reference plane, the second bell-shaped ridge complementarily fitted with the first horizontal concave contour, the second bell-shaped ridge furnished with a second convex edge complementarily fitted with the first vertical concave contour of the first bracket.

15. The cross connector of Claim 14, wherein:

the second platform has a center region surrounding the center axis, the center region substantially wider than each of the second pair of arms, and

the second bell-shaped ridge provides a geometric transition from each of the second pair of arms to the center portion of the second platform.

16. The cross connector of Claim 14, wherein the complementary configuration of the second connector includes a second bracket formed on the second platform, the second bracket having:

a second vertical concave contour substantially parallel to the second reference plane and complementarily fitted with the first bell-shaped ridge, and

a second horizontal concave contour intersecting the second vertical concave contour and substantially perpendicular to the second reference plane, the second horizontal concave contour complementarily fitted with the first convex ridge.

17. The cross connector of Claim 15, wherein the first bracket cooperates with the second bracket to substantially restrict a lateral movement between the first platform and the second platform.

18. A cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments, the cross connector comprising:

a first link including a first pair of arms, a lower platform, and two upper brackets, the lower platform having two bottom bow-shaped ridges connecting the first pair of arms to form a first contiguous arc along a first reference plane, the two bottom bow-shaped ridges each furnished with a bottom convex edge, the two upper brackets positioned between the two bottom bow-shaped ridges and each having an upper ventral concave surface facing away from one of the first pair of arms;

a second link including a second pair of arms, an upper platform, and two lower brackets, the upper platform having two upper bow-shaped ridges connecting the second pair of arms to form a second contiguous arc along a second reference plane intersecting the first reference plane alone a center axis, the two upper bow-shaped ridges each furnished with an upper convex edge, the two lower brackets positioned between the two upper bow-shaped ridges and each having a lower ventral concave surface facing away from one of the first pair of arms; and

a pivoting member connected to the lower and upper platforms, thereby pivoting the first link against the second link along the center axis while substantially restricting a lateral movement between the first link and the second link.

19. The cross connector of Claim 18, wherein:

at least on of the first pair of arms has a first arm extension distal to the lower platform and curving away from the first reference plane,

at least on of the second pair of arms has a second arm extension distal to the top plate and curving away from the second reference plane, and

the first arm extension cooperates with the second arm extension form an adjustable bracket surrounding a base segment of a spinous process.

20. The cross connector of Claim 18, wherein:

the upper ventral concave surfaces are configured to substantially redistribute a top stress directed to the upper convex edges of the upper bow-shaped ridges, and

the lower ventral concave surfaces are configured to substantially redistribute a bottom stress directed to the lower convex edges of the lower bow-shaped ridges.

21. A cross connector for stabilizing and protecting one or more fixation levels of spinal bone segments, the cross connector comprising:

a first elongated connector having a first arm and a second arm connected by a first joint element, the first arm defining an opening;

a second elongated connector including a third arm and a fourth arm connected by a second joint element, the second joint element configured to receive at least a portion of the first joint element; and

a first connecting rod having a substantially spherical portion, the substantially spherical portion of the first connecting rod configured to be received by the first opening of the first arm of the first elongated connector.

22. The cross connector of claim 21 wherein the substantially spherical portion of the first connecting rod is formed with a surface having a plurality of protruding concentric circles.

23. The cross connector of claim 21 further comprising a screw configured to engage with the first arm of the first elongated connector for coupling the first arm with the first connecting rod, the screw having a semi-spherical depression for receiving at least a portion of the substantially spherical portion of the first connecting rod.

24. The cross connector of claim 21 wherein the first joint element comprises a substantially spherical element and the second joint element comprises a housing configured to receive at least a portion of the substantially spherical element, the substantially spherical element capable of three dimensional rotation within the housing of the second joint element.

25. The cross connector of claim 24 wherein the substantially spherical element is formed with a surface having a plurality of protruding concentric circles.

26. The cross connector of claim 24 further comprising a screw configured to engage with the first elongated connector or the second elongated connector, the screw having a semi-spherical depression for receiving at least a portion of the substantially spherical element.

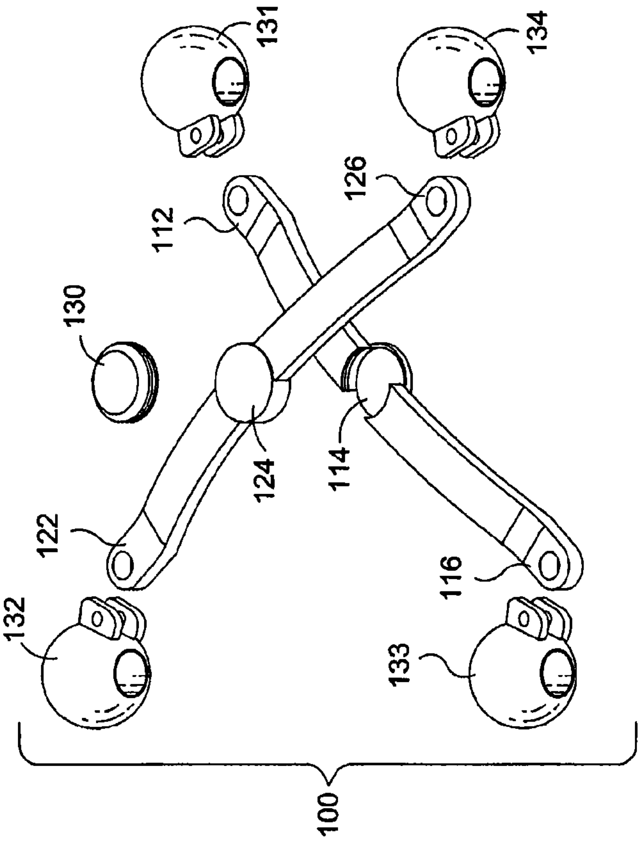

FIG. 1B

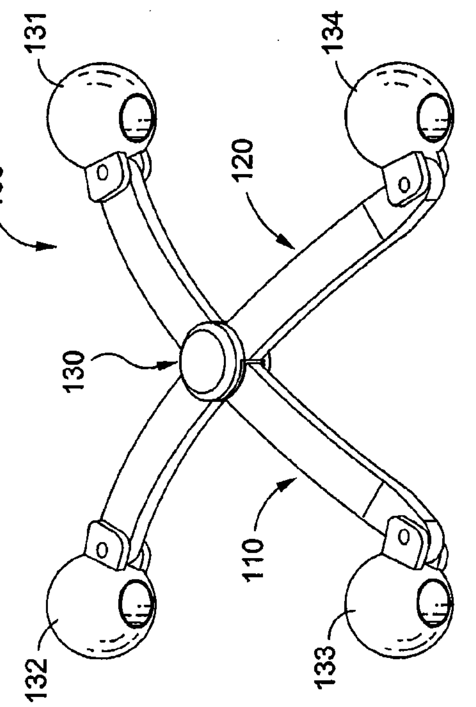

FIG. 1A

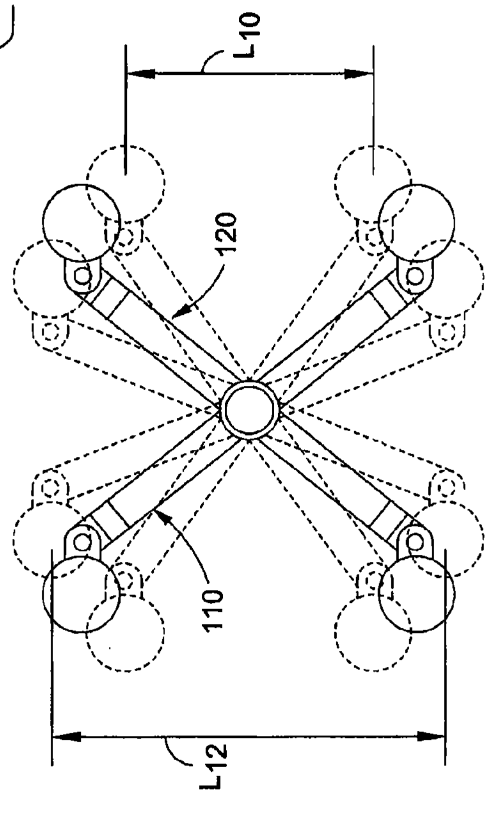

FIG. 1C

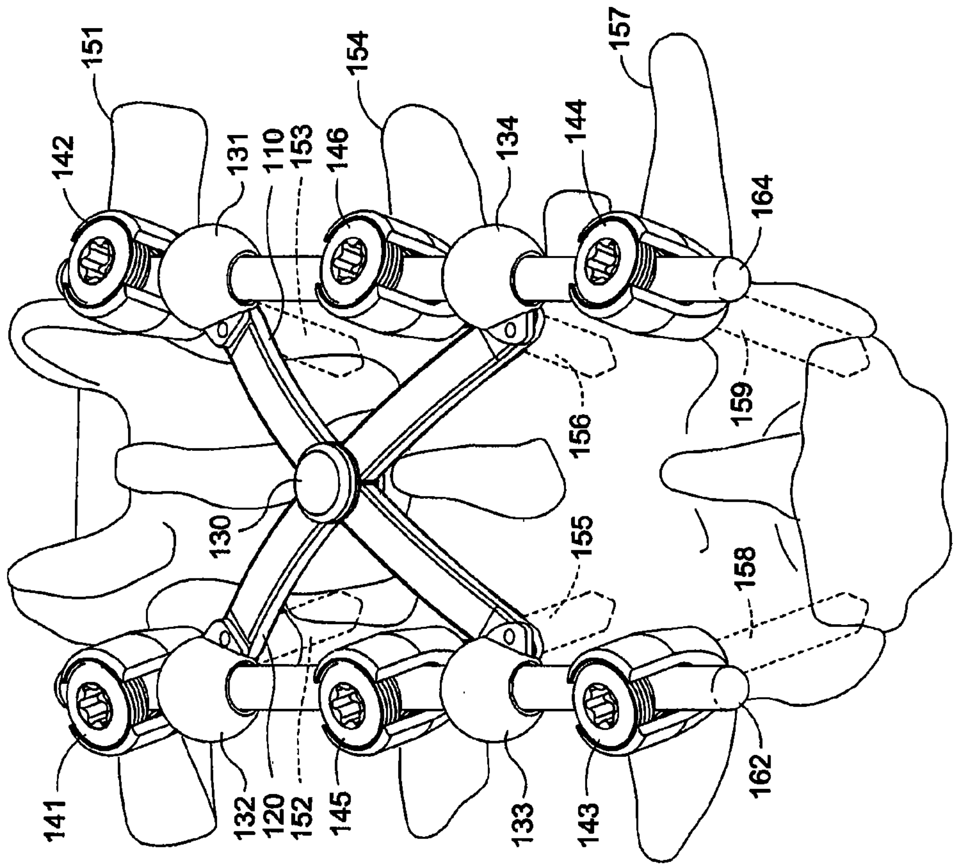
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FIG. 1E

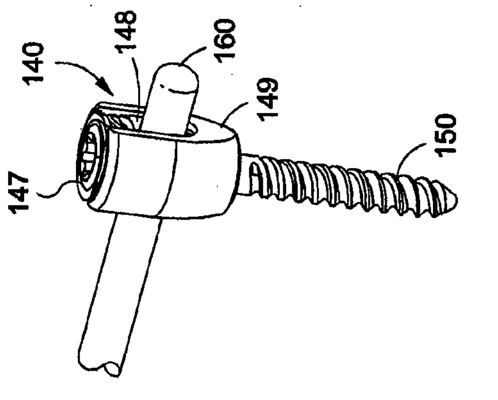
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FIG. 1D

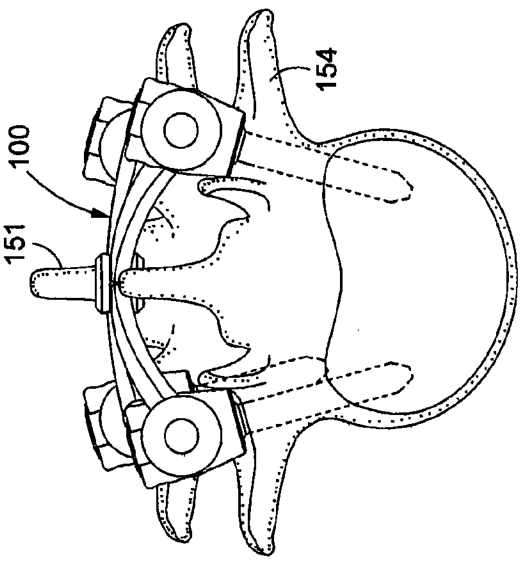
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FIG. 1G

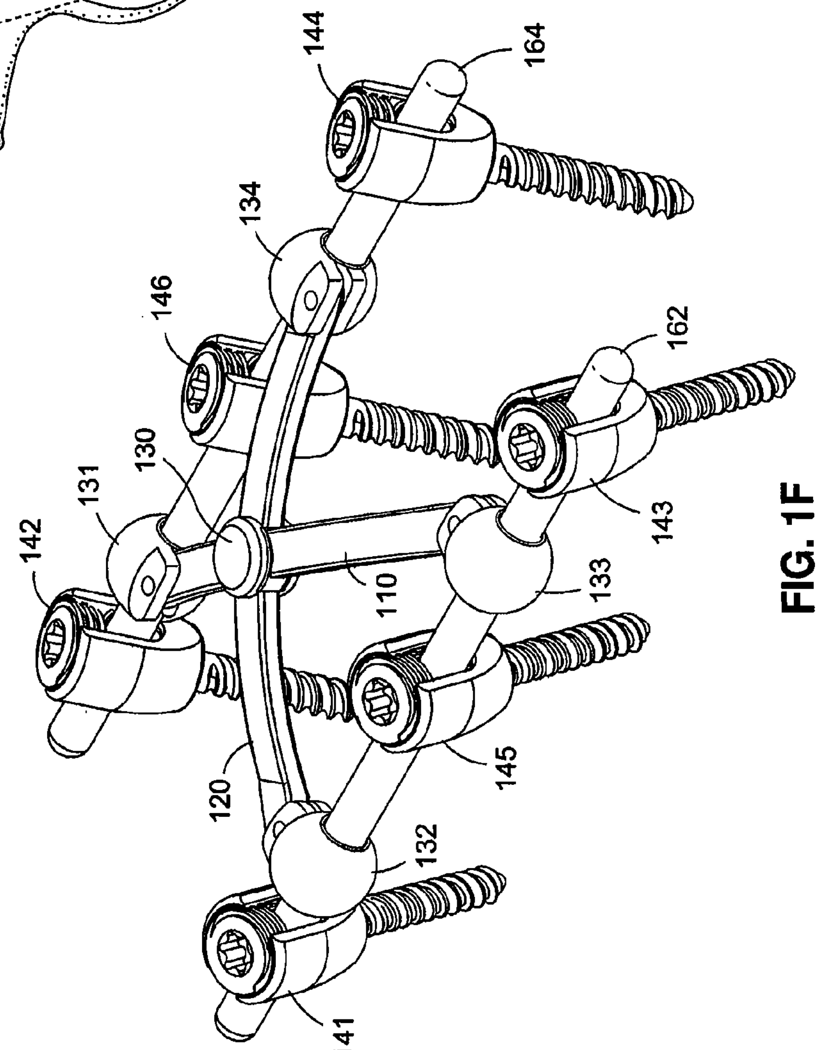
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FIG. 1F

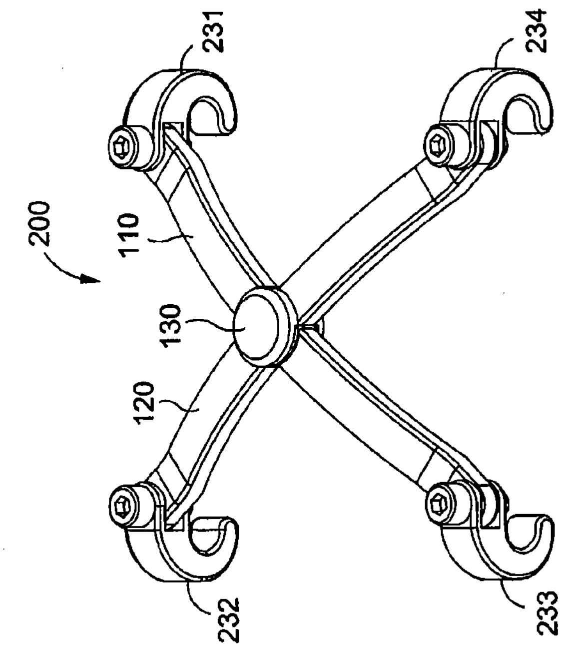


FIG. 2A

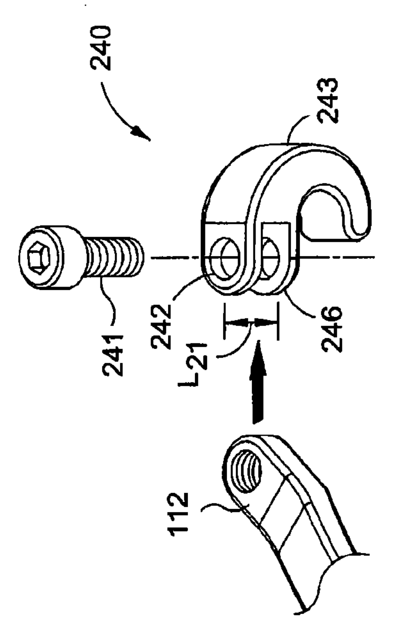


FIG. 2B

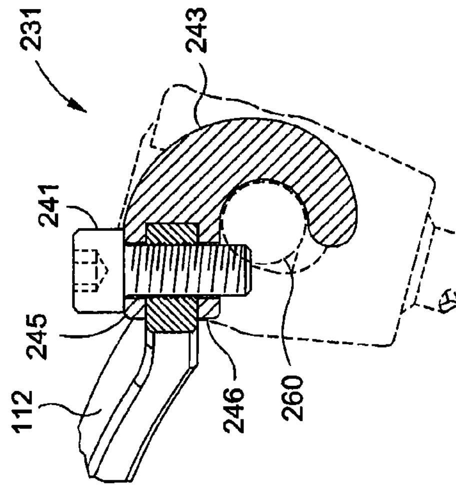


FIG. 2C

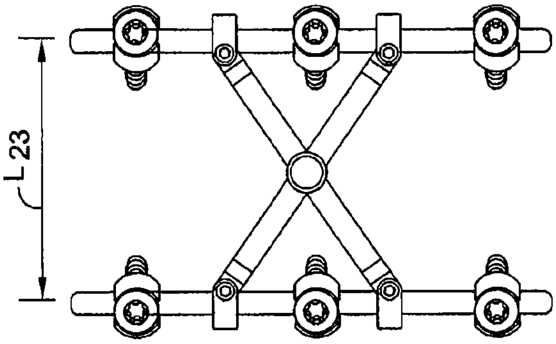


FIG. 2F

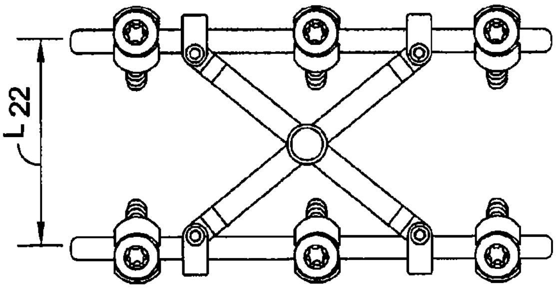


FIG. 2E

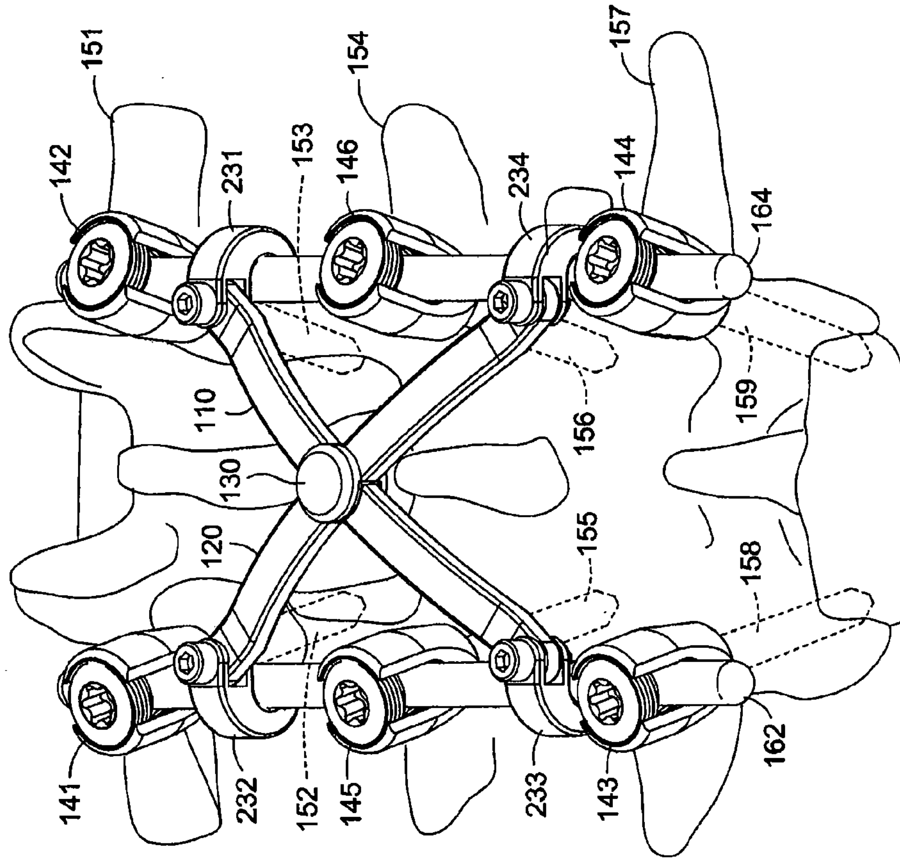


FIG. 2D

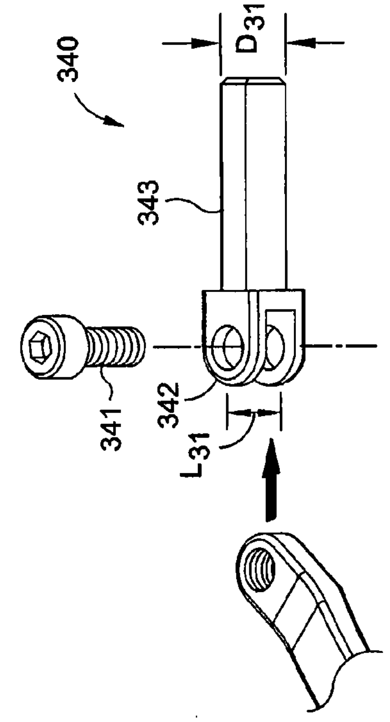


FIG. 3B

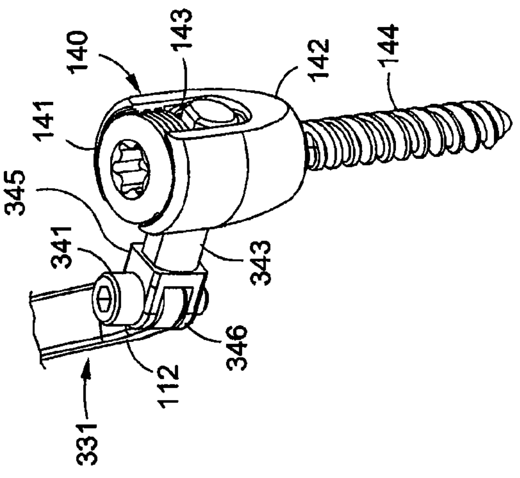


FIG. 3C

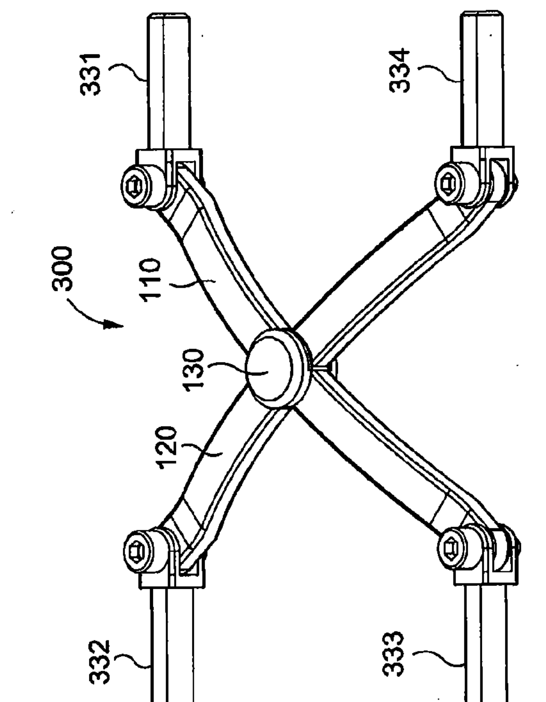
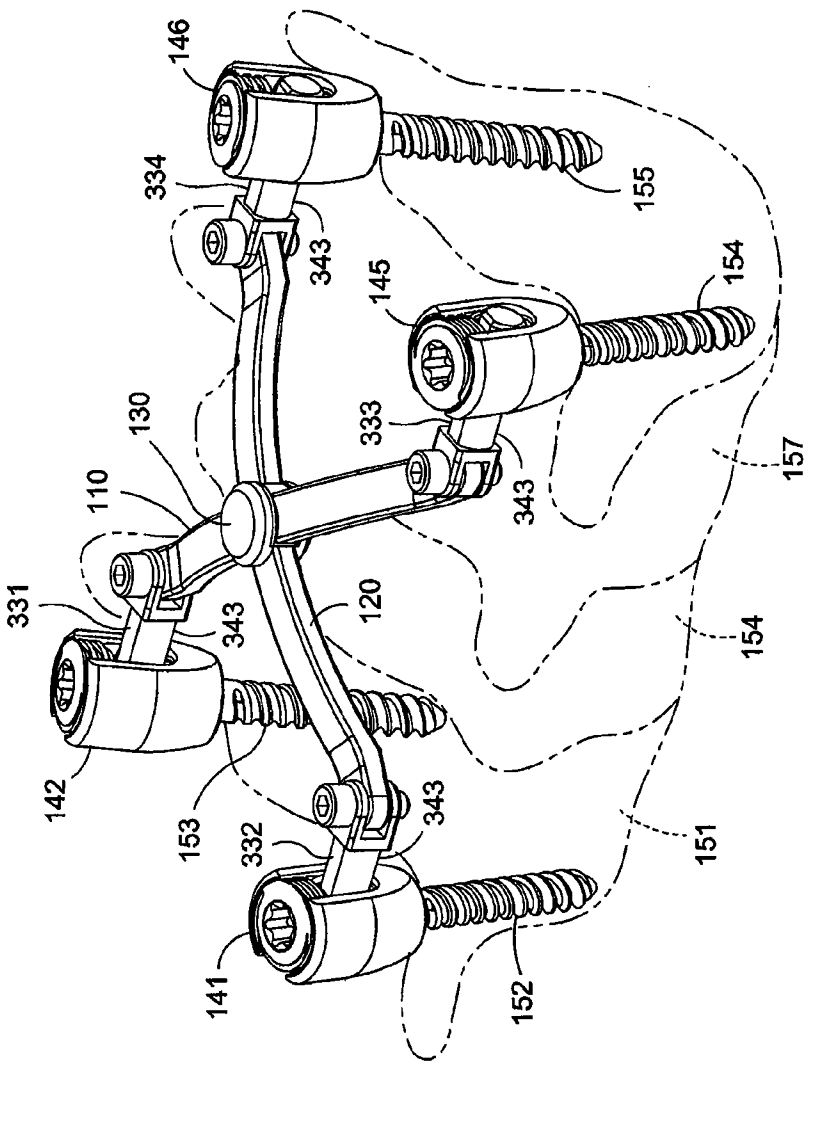


FIG. 3A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152

FIG. 3D

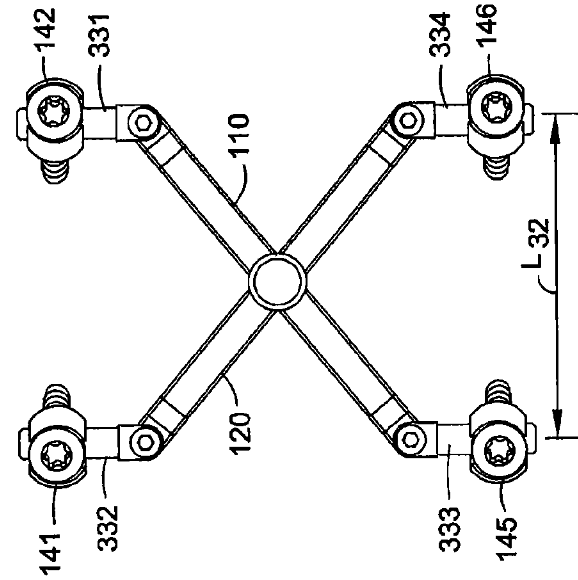

FIG. 3E

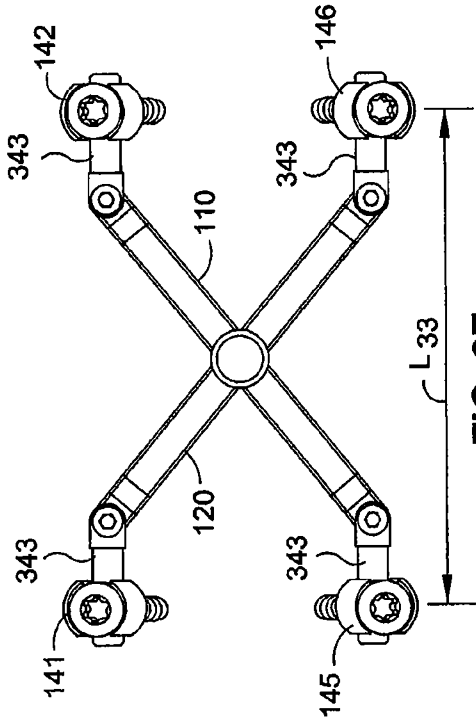

FIG. 3F

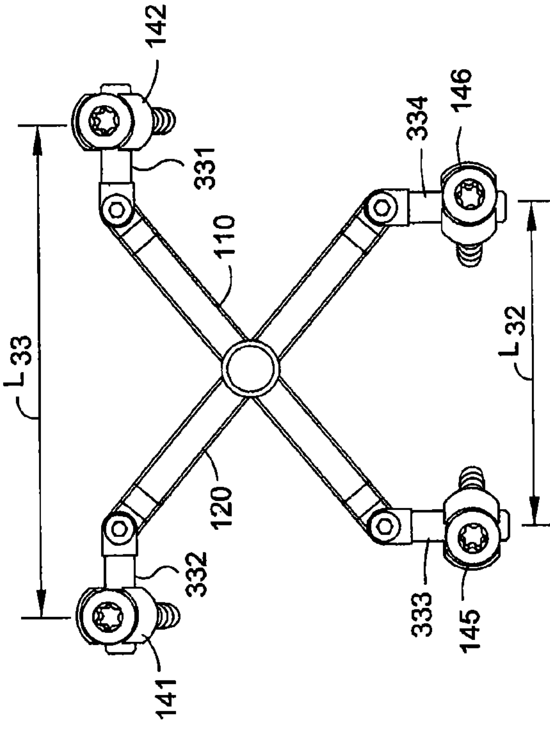

FIG. 3G

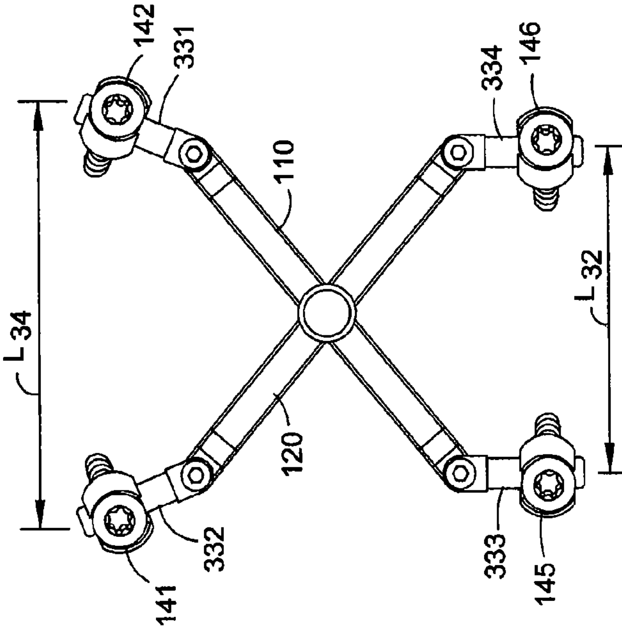

FIG. 3H

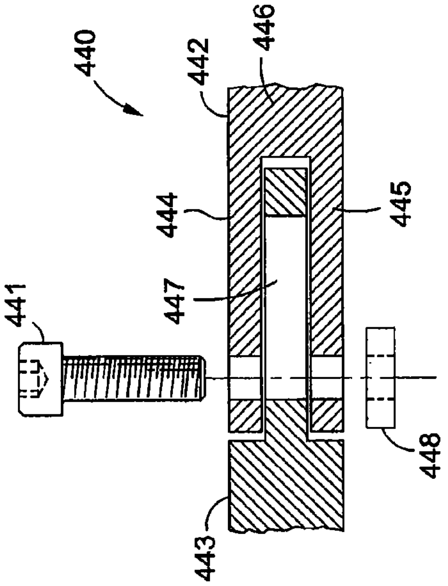

FIG. 4B

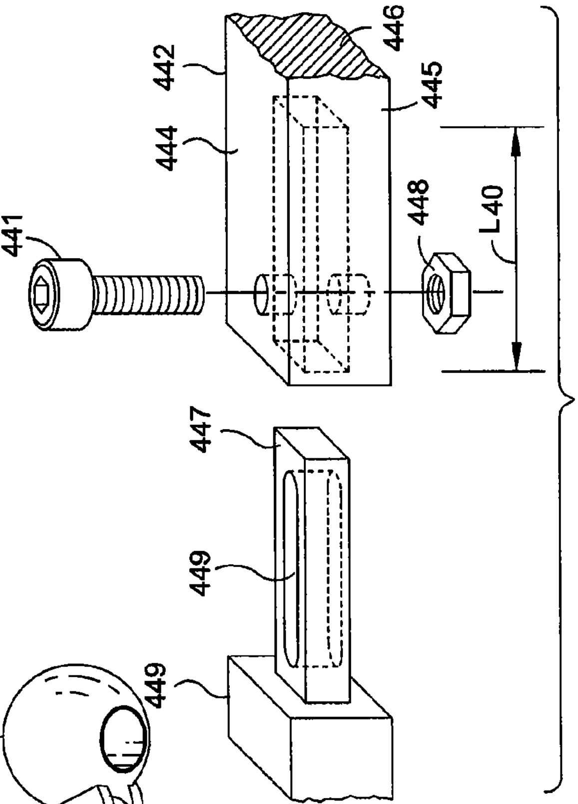

FIG. 4C

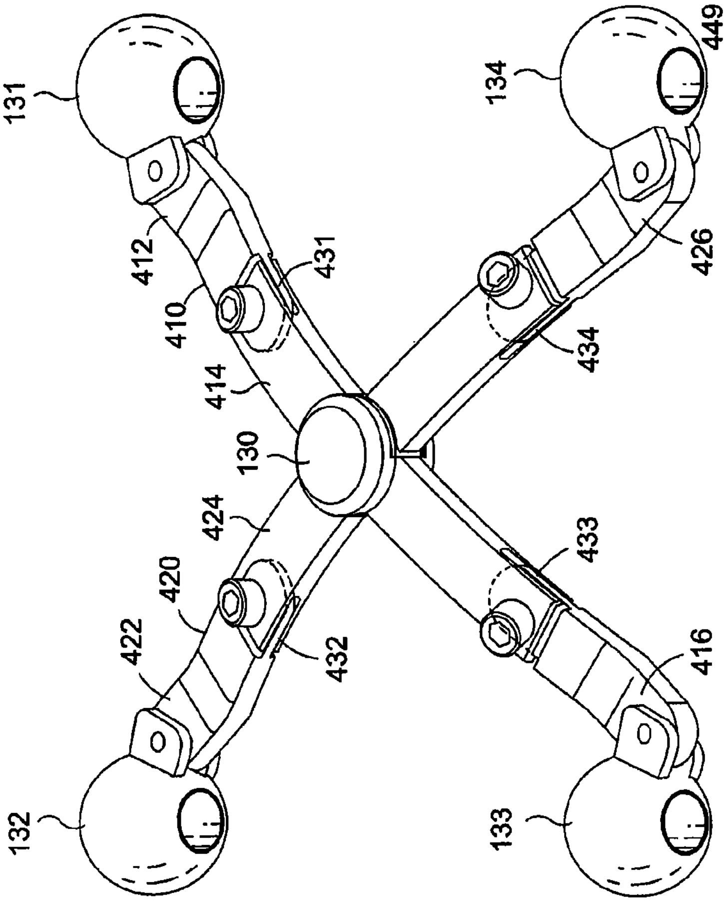

FIG. 4A

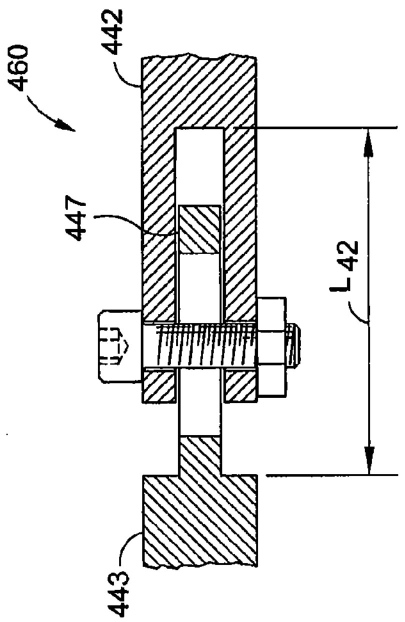

FIG. 4E

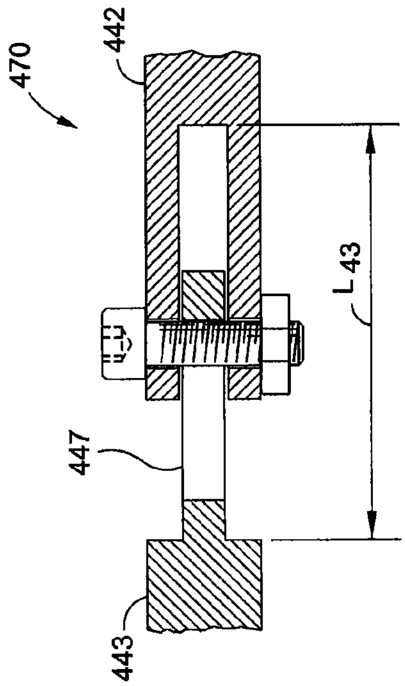

FIG. 4F

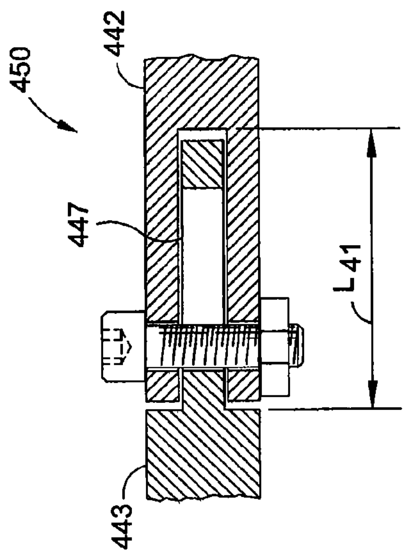

FIG. 4D

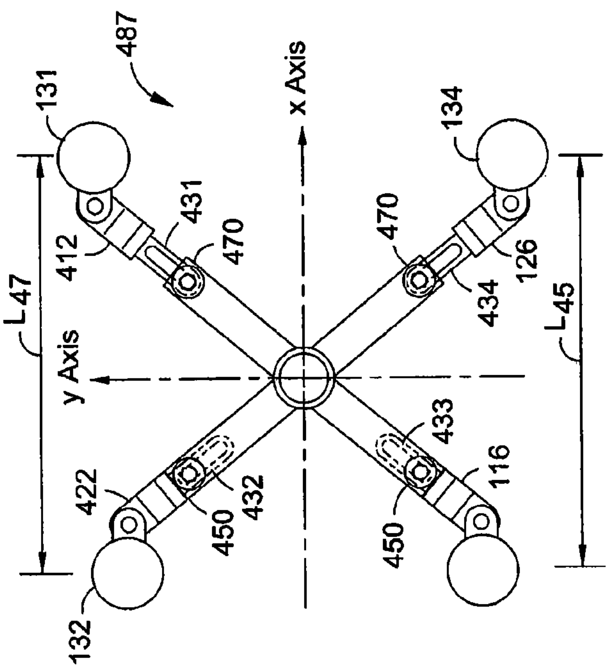

FIG. 4H

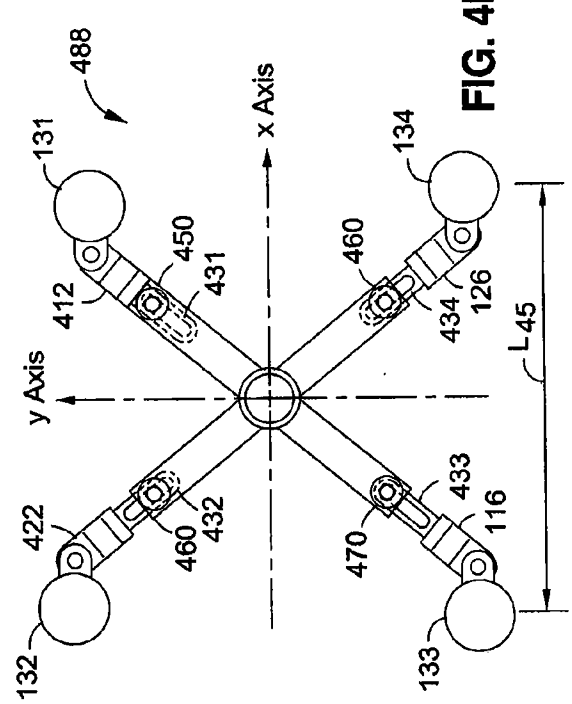

FIG. 4I

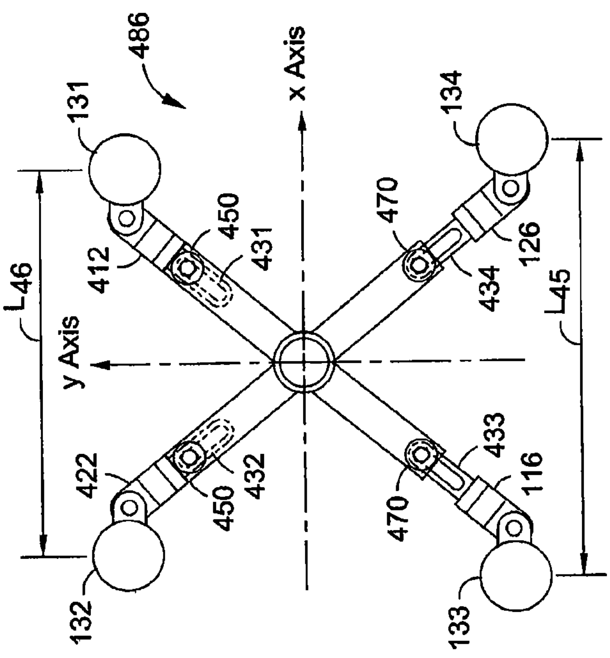

FIG. 4G

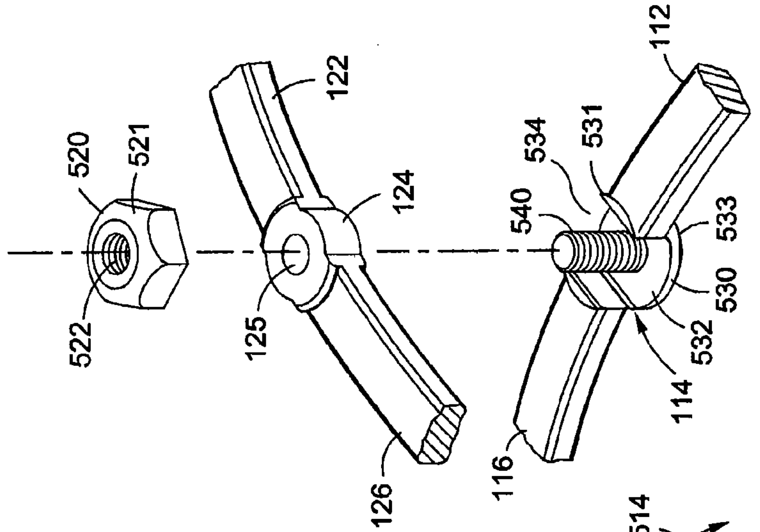

FIG. 5B

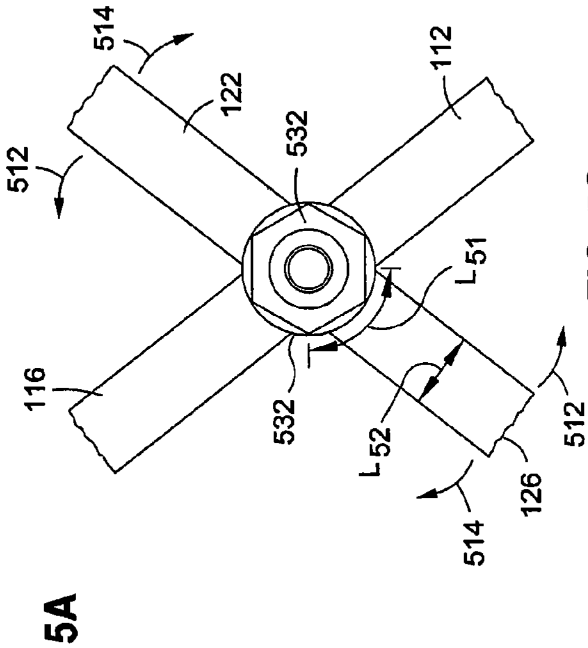

FIG. 5C

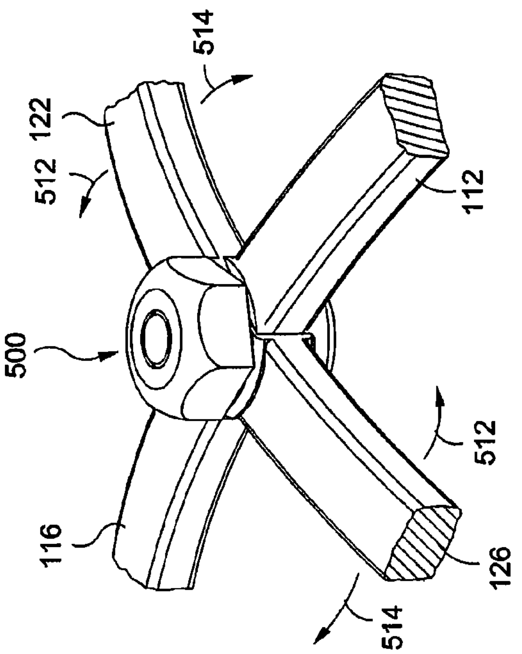

FIG. 5A

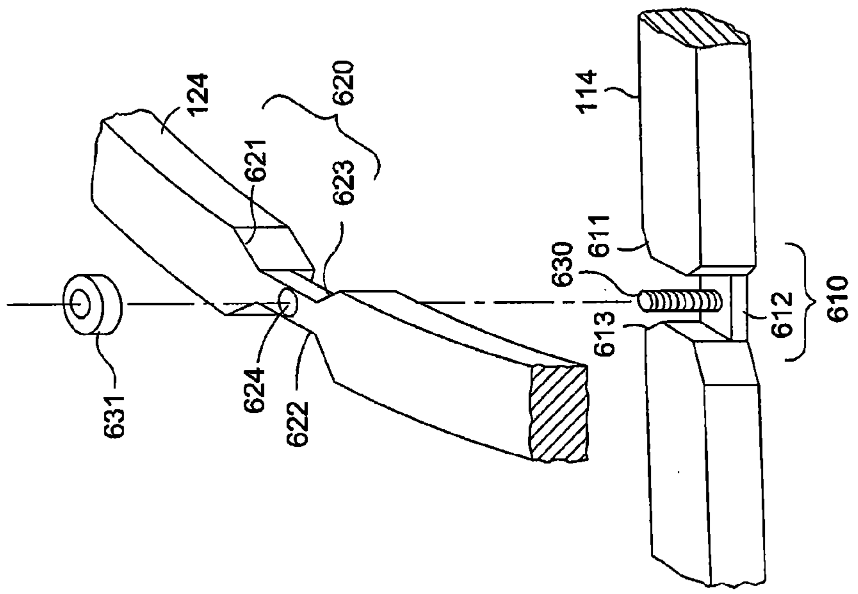

FIG. 6B

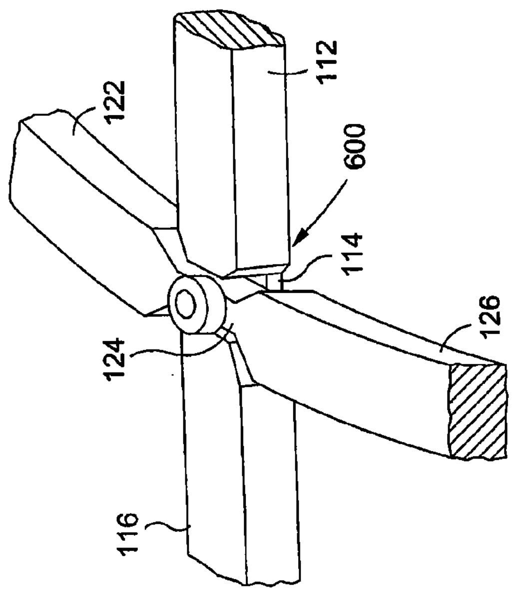

FIG. 6A

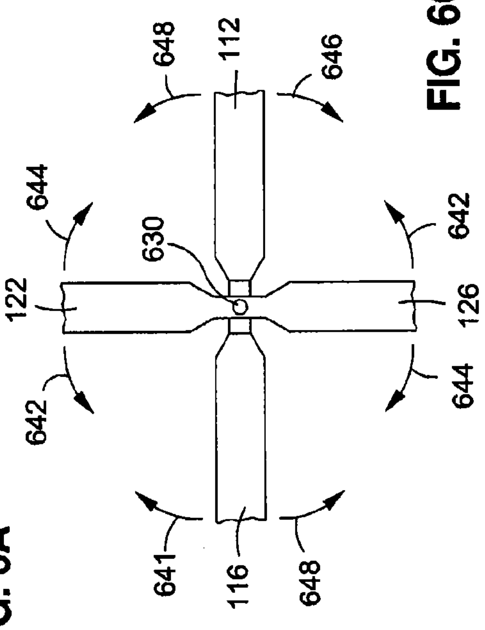

FIG. 6C

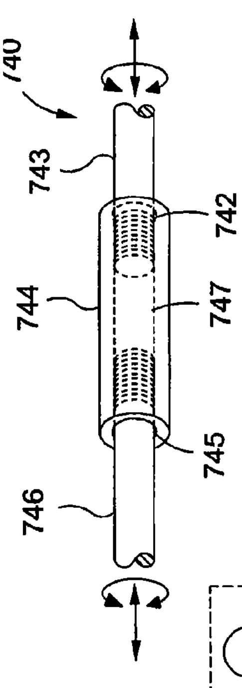

FIG. 7B

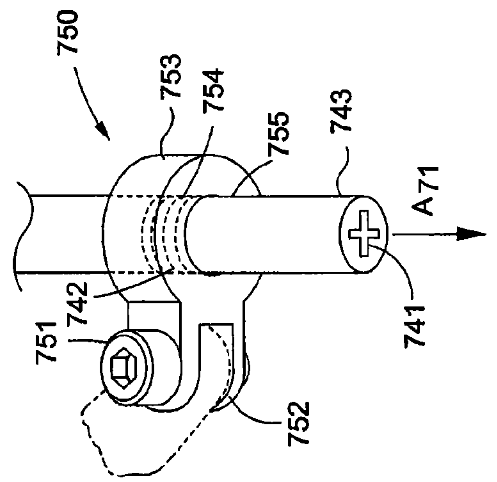

FIG. 7C

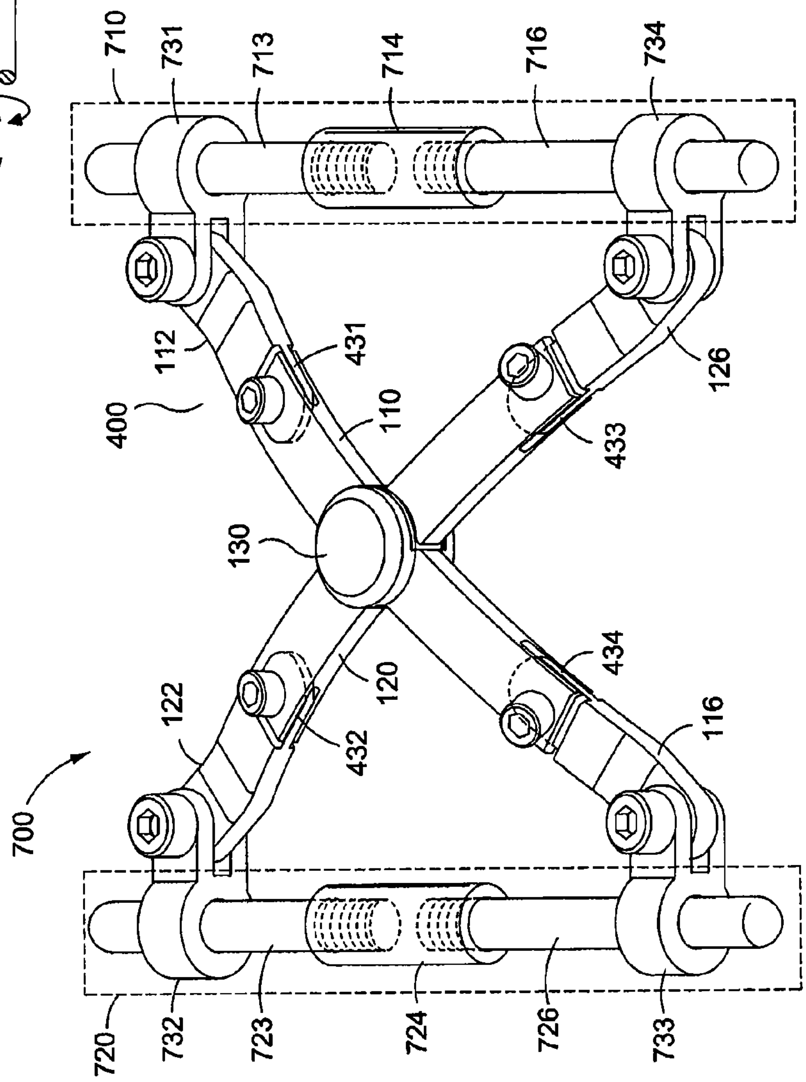

FIG. 7A

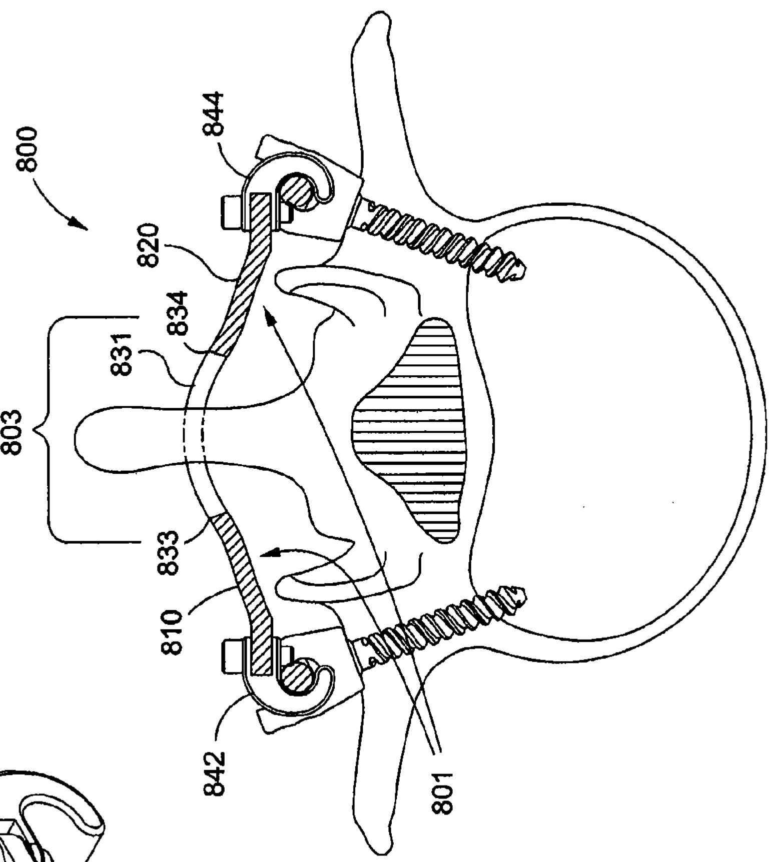
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FIG. 8B

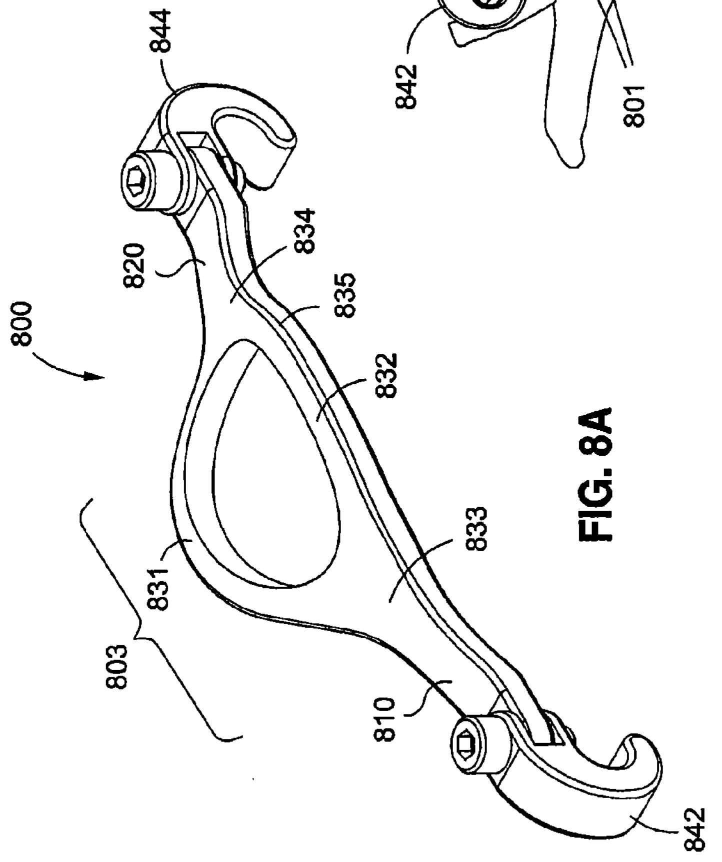
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FIG. 8A

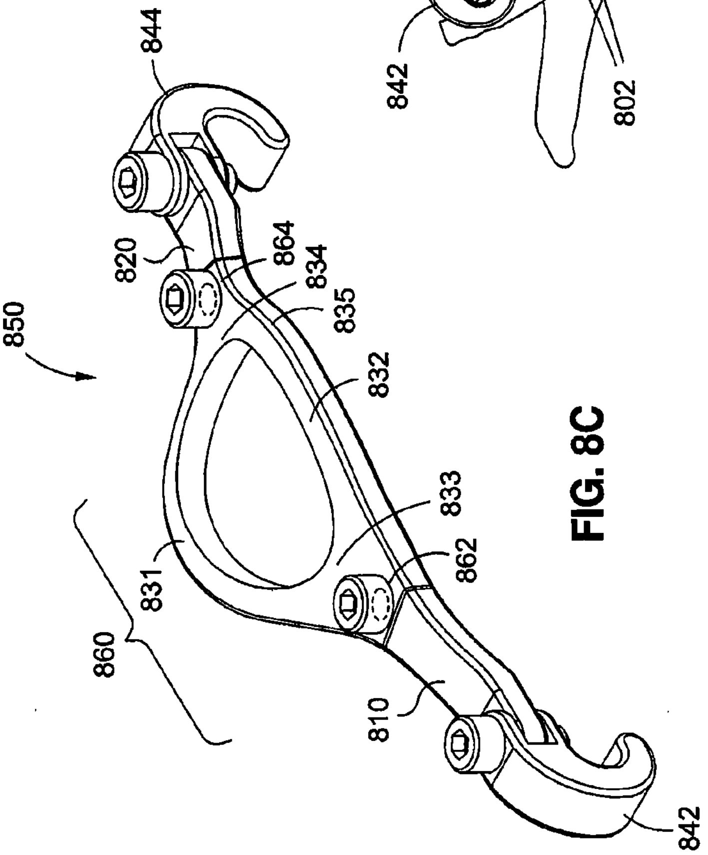
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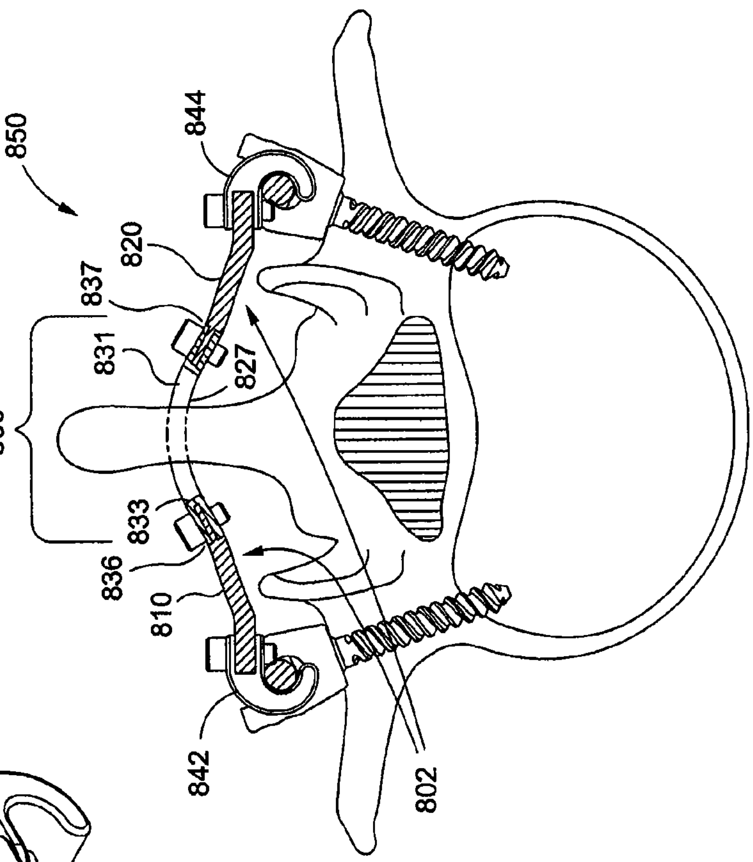
FIG. 8C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802

FIG. 8D

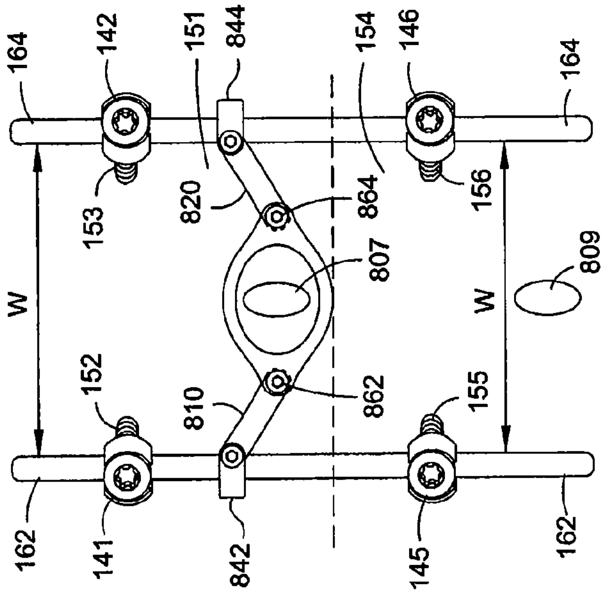


FIG. 8F

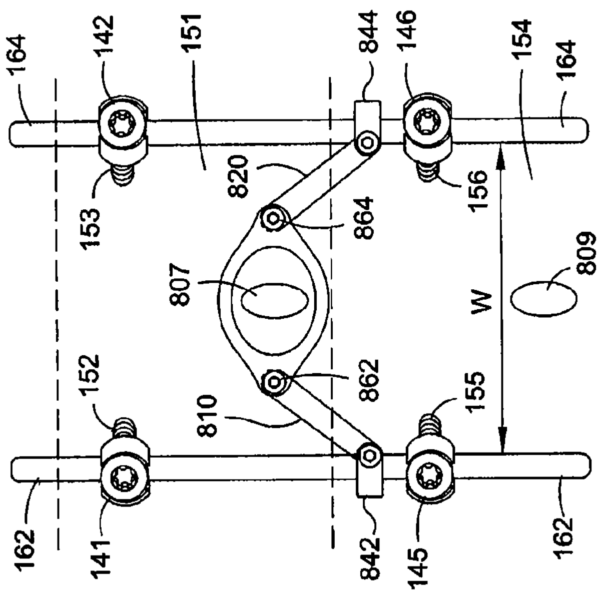


FIG. 8G

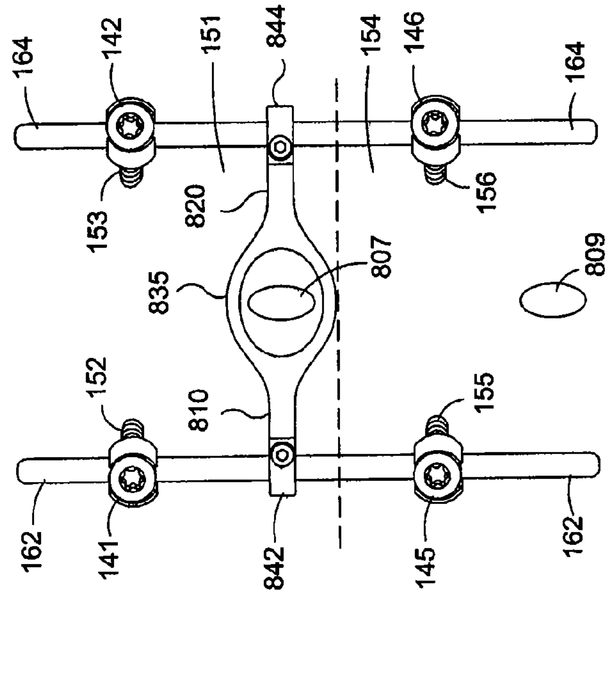
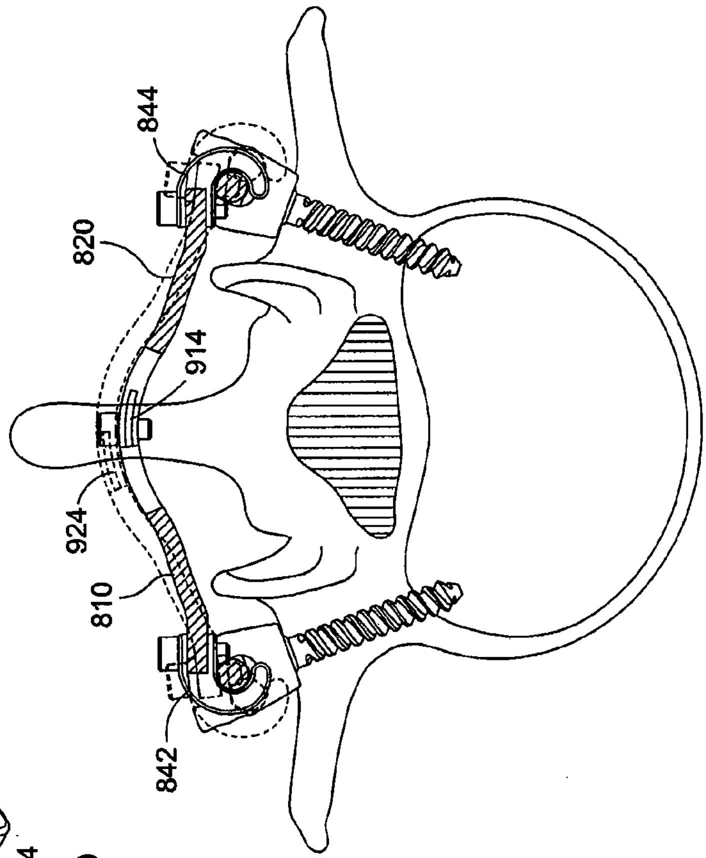


FIG. 8E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914
924
810
842

FIG. 9B

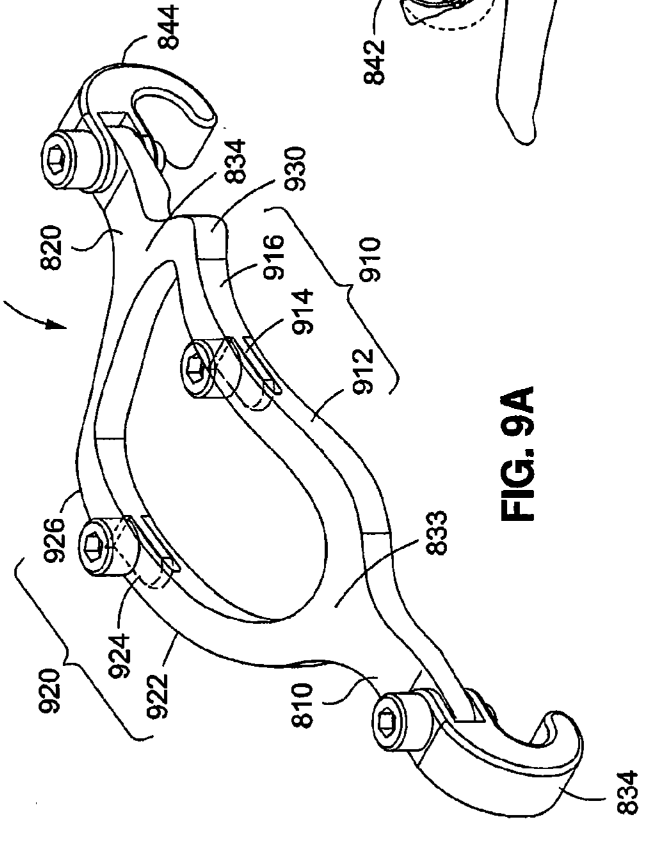
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FIG. 9A

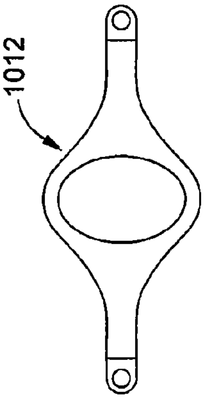

FIG. 10A

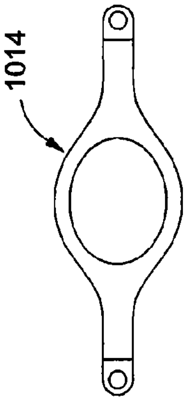

FIG. 10B

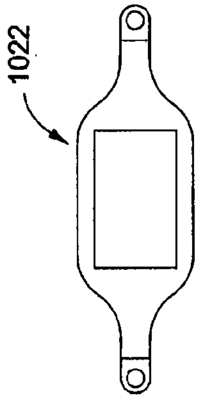

FIG. 10C

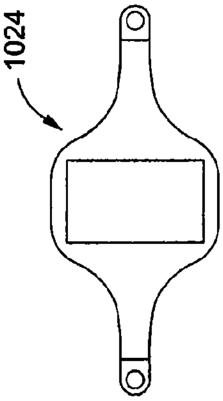

FIG. 10D

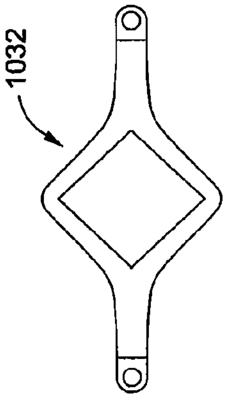

FIG. 10E

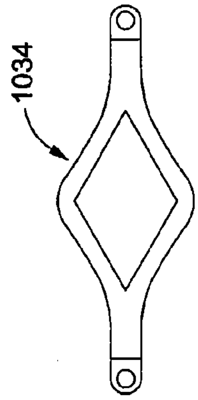

FIG. 10F

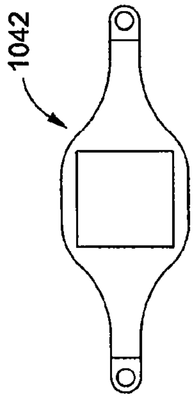

FIG. 10G

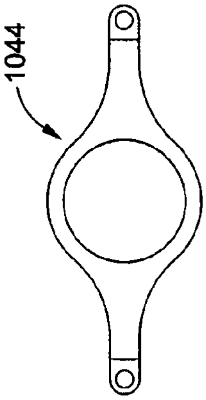

FIG. 10H

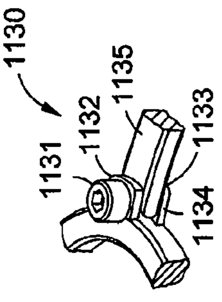

FIG. 11B

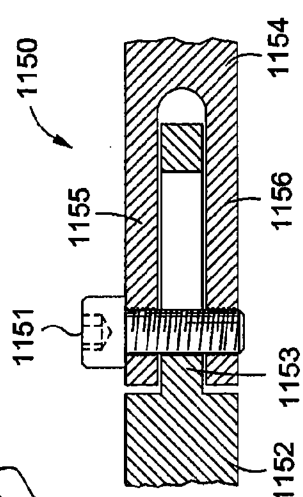

FIG. 11C

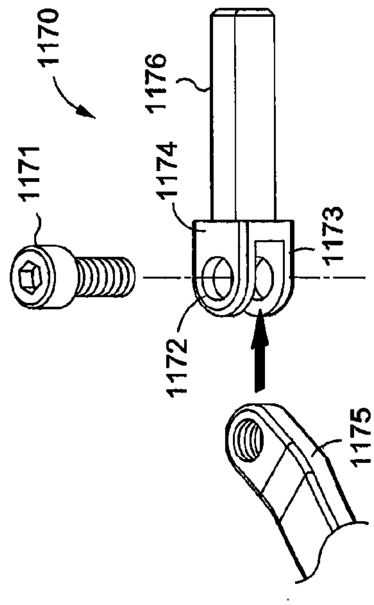

FIG. 11D

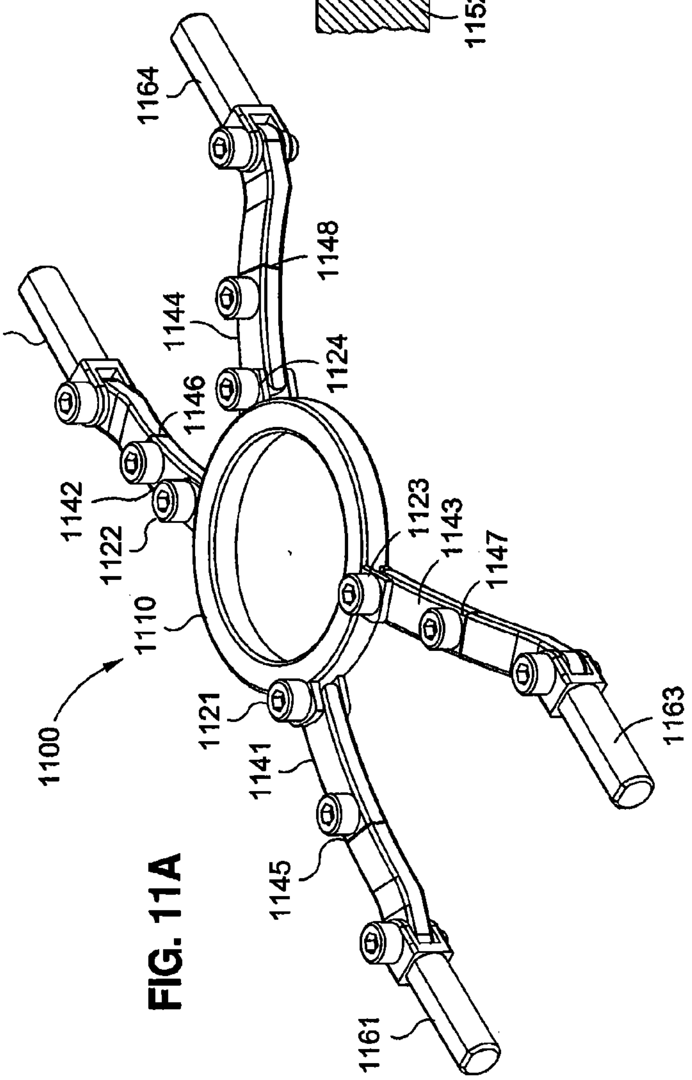

FIG. 11A

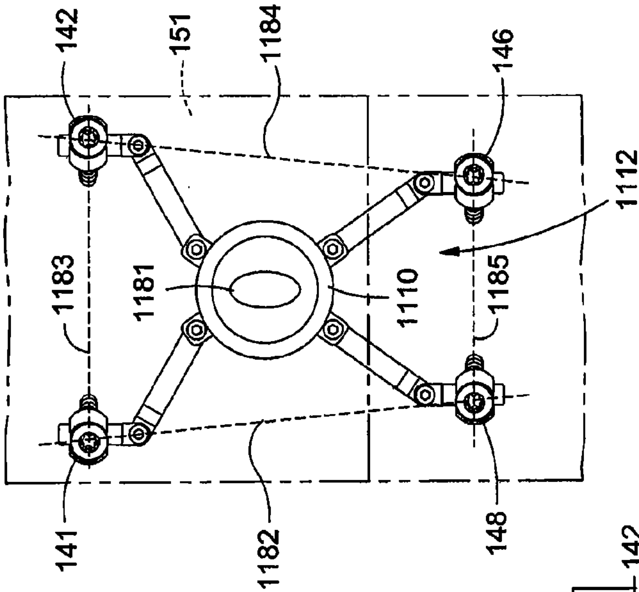

FIG. 11G

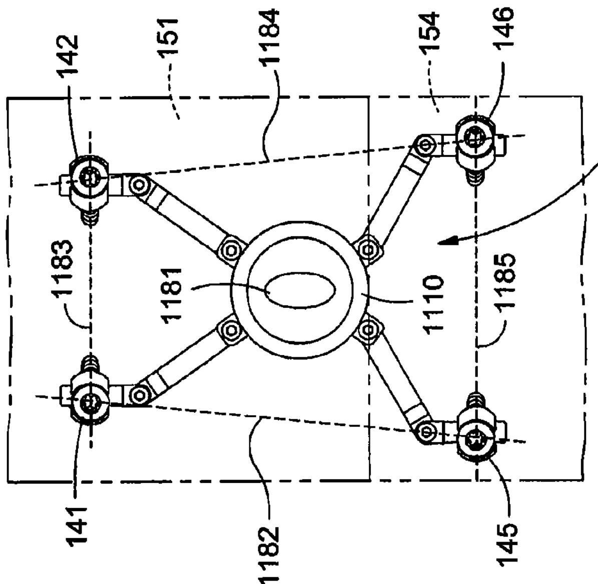

FIG. 11F

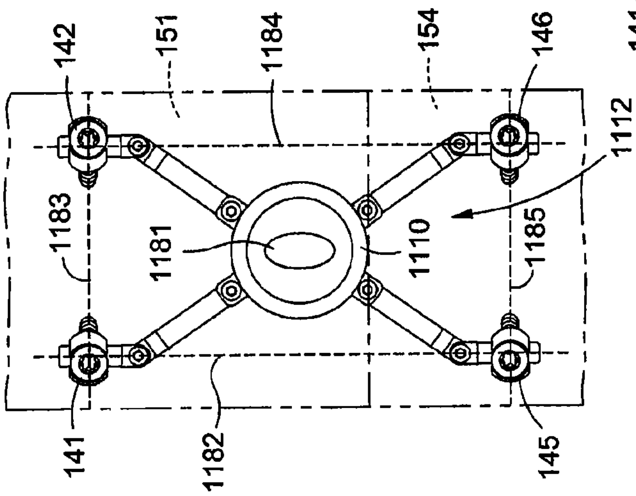

FIG. 11E

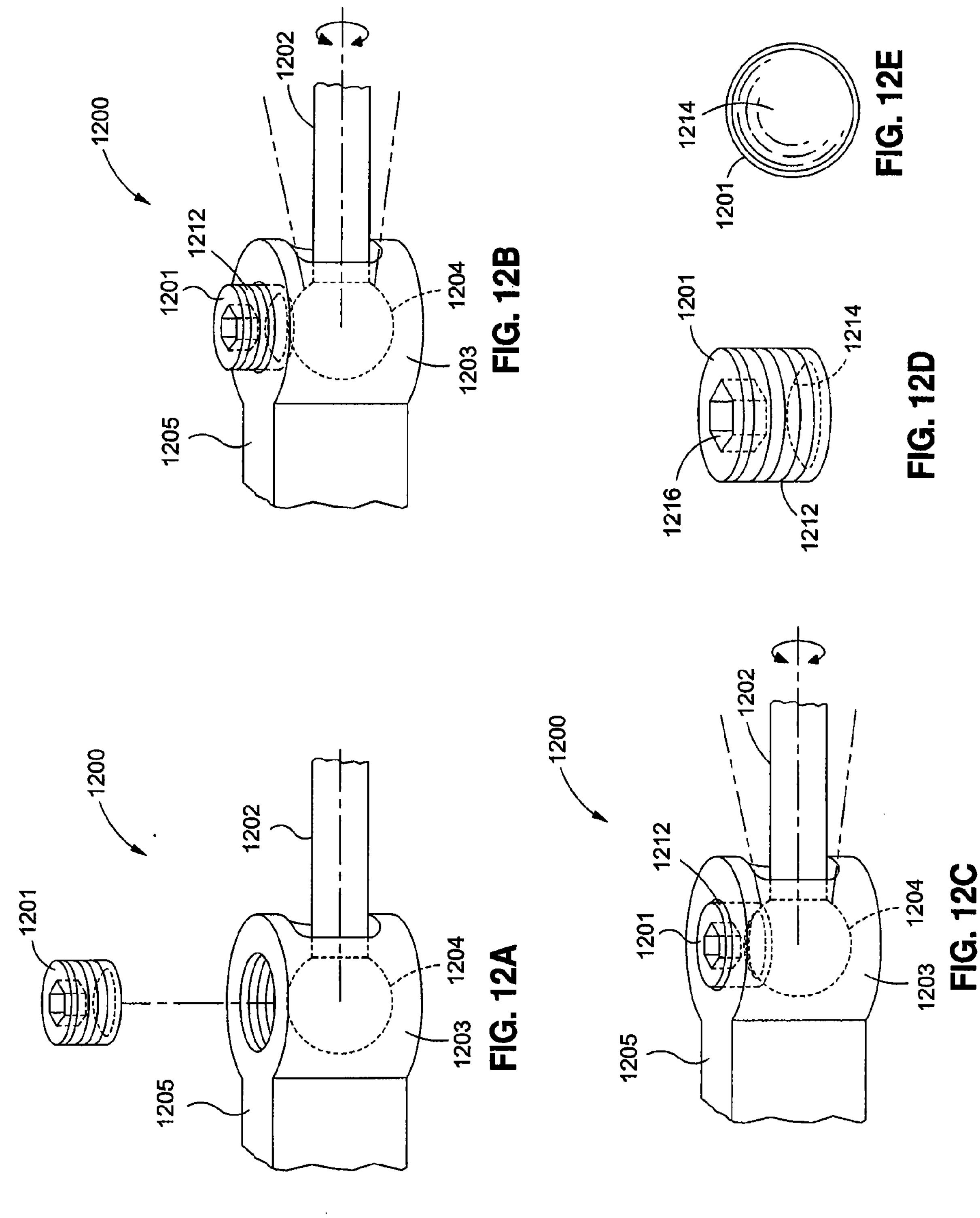

FIG. 12A

FIG. 12B

FIG. 12C

FIG. 12D

FIG. 12E

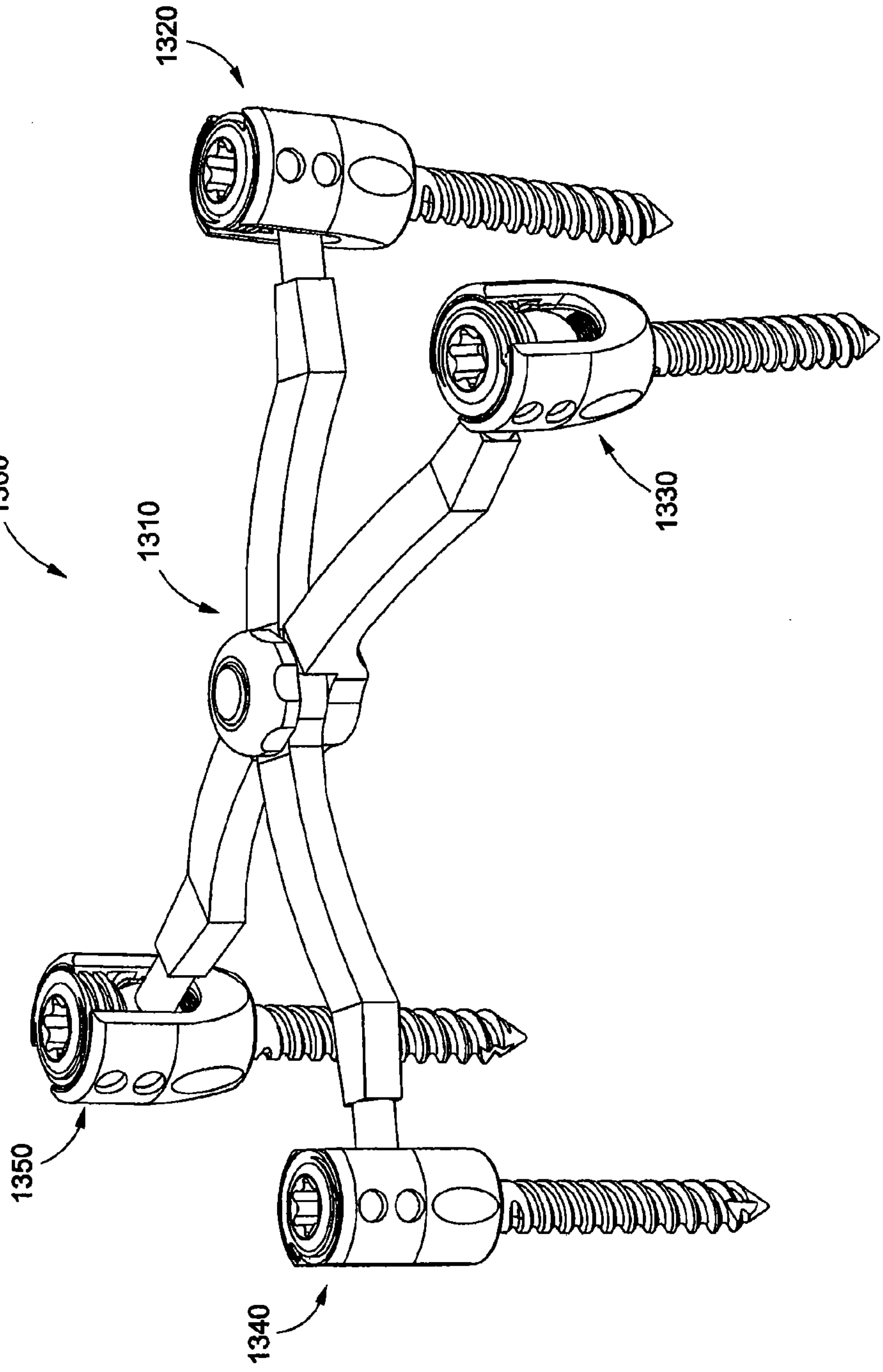

FIG. 13A

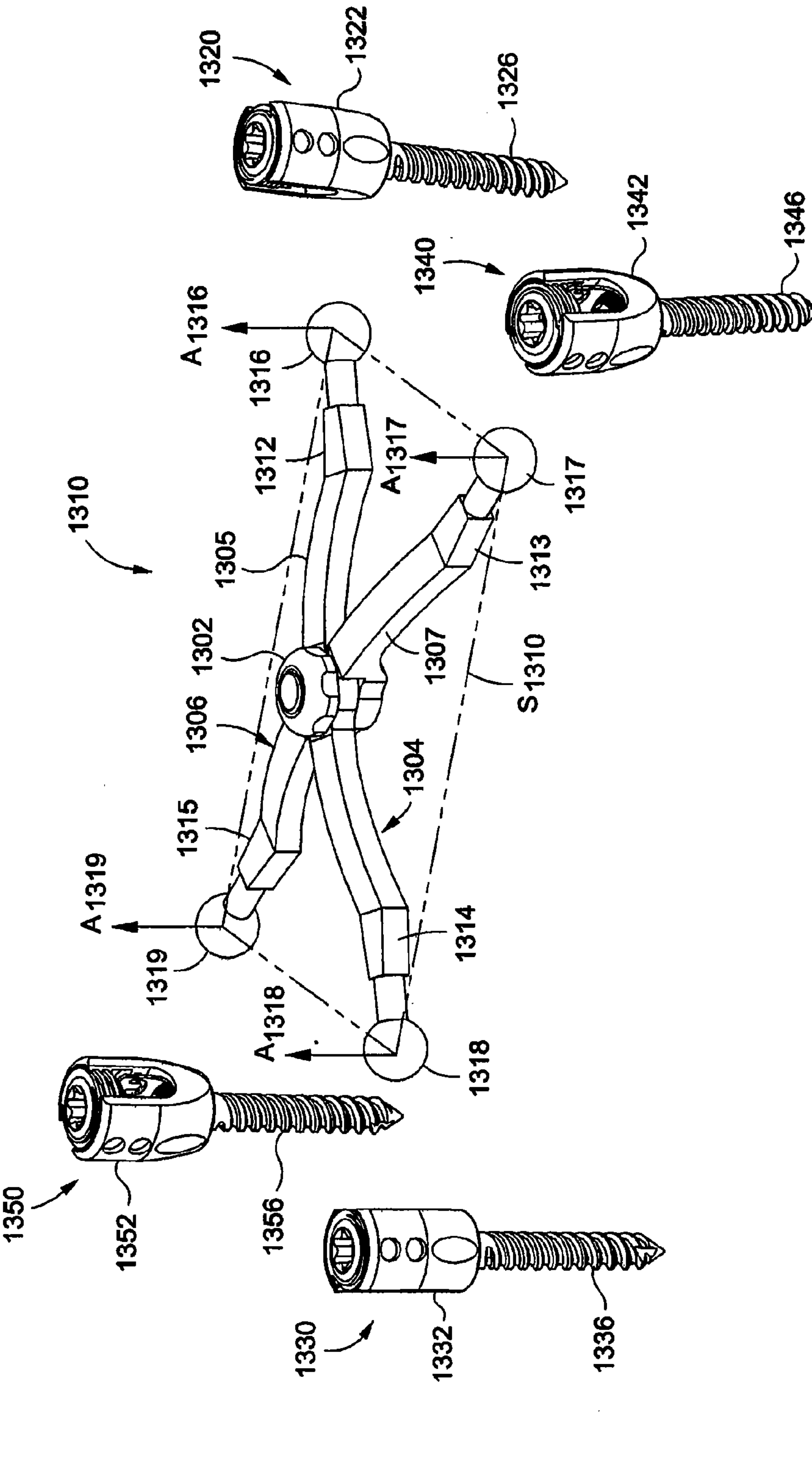
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FIG. 13B

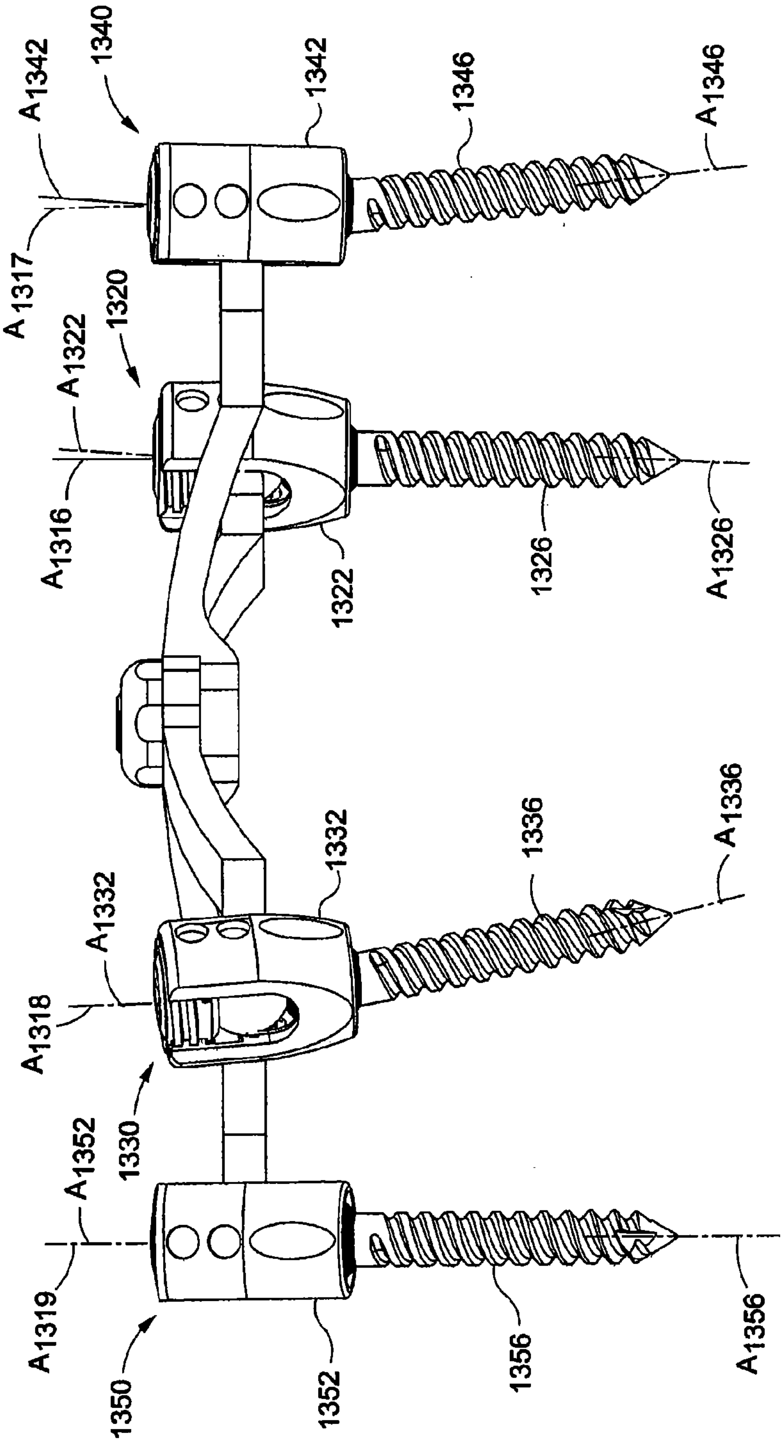
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FIG. 13C

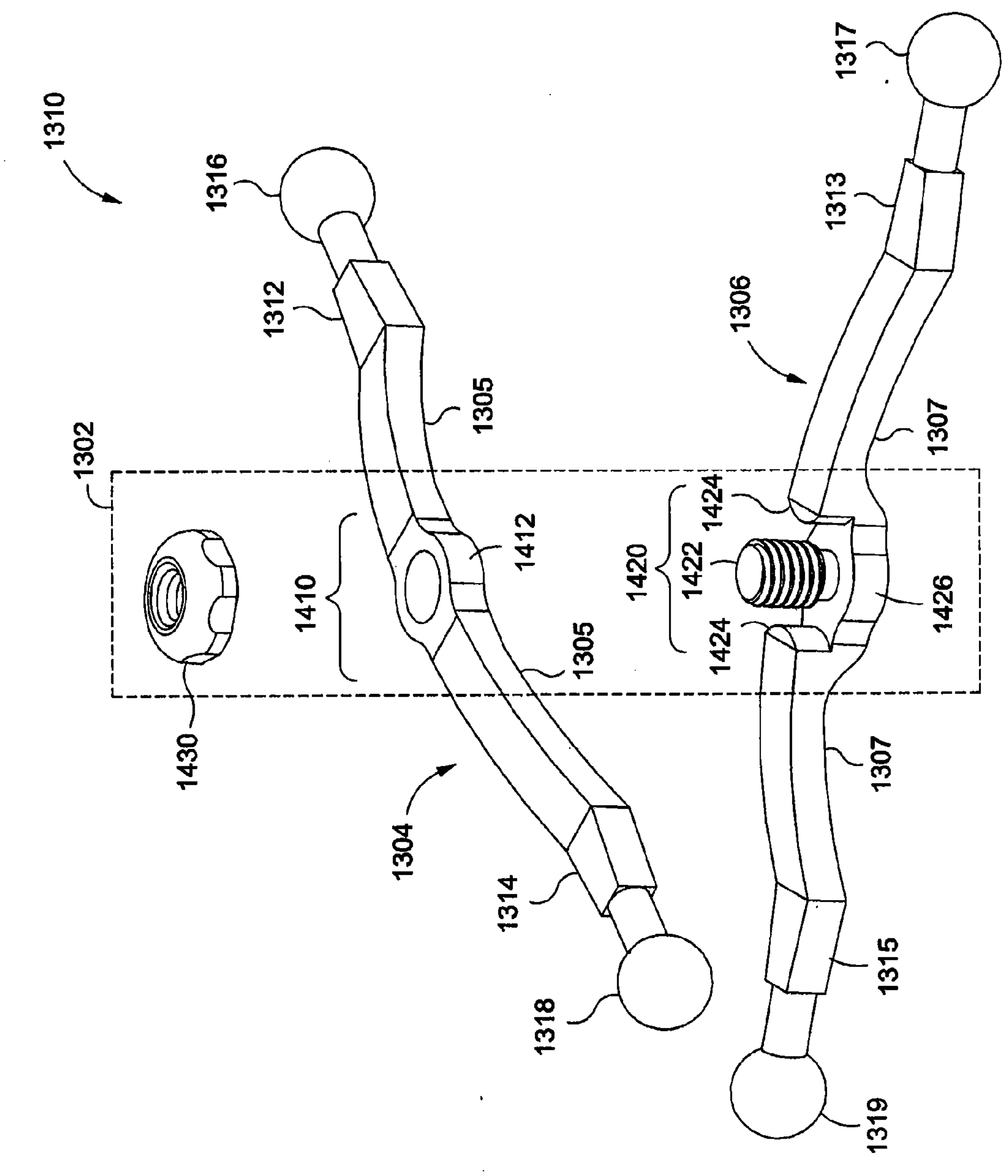
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FIG. 14

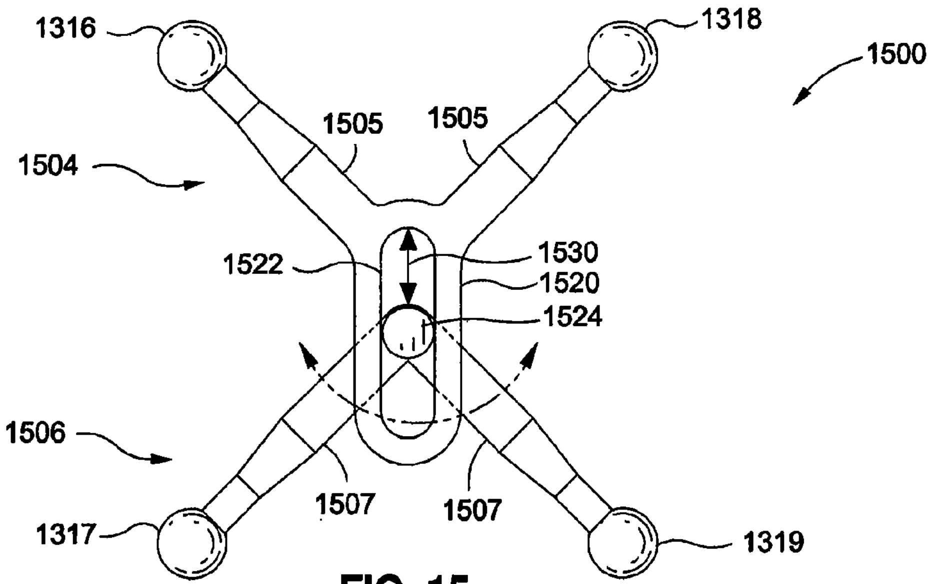
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FIG. 15

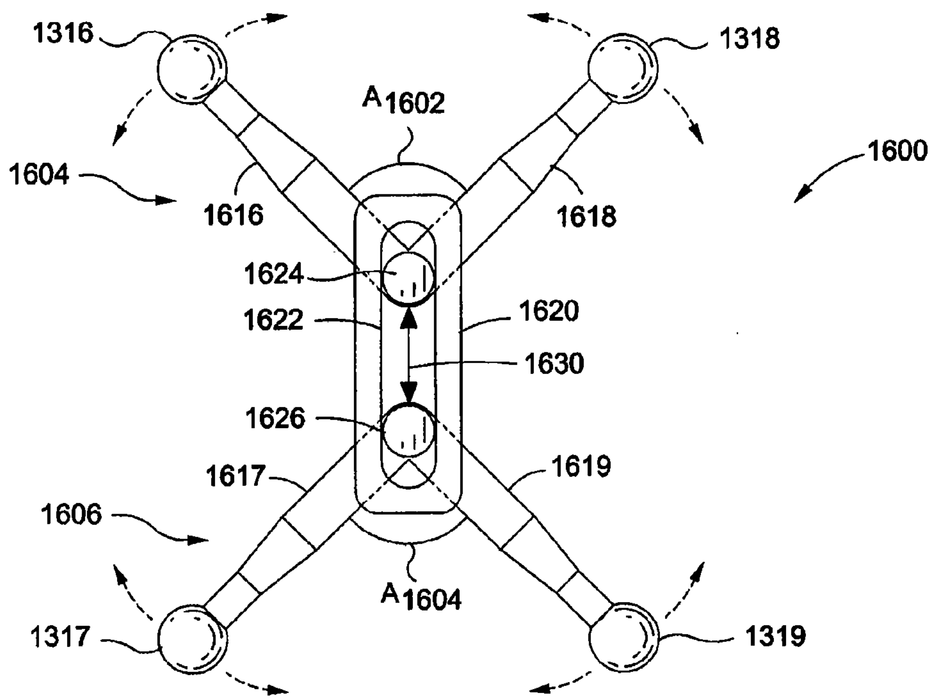
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FIG. 16

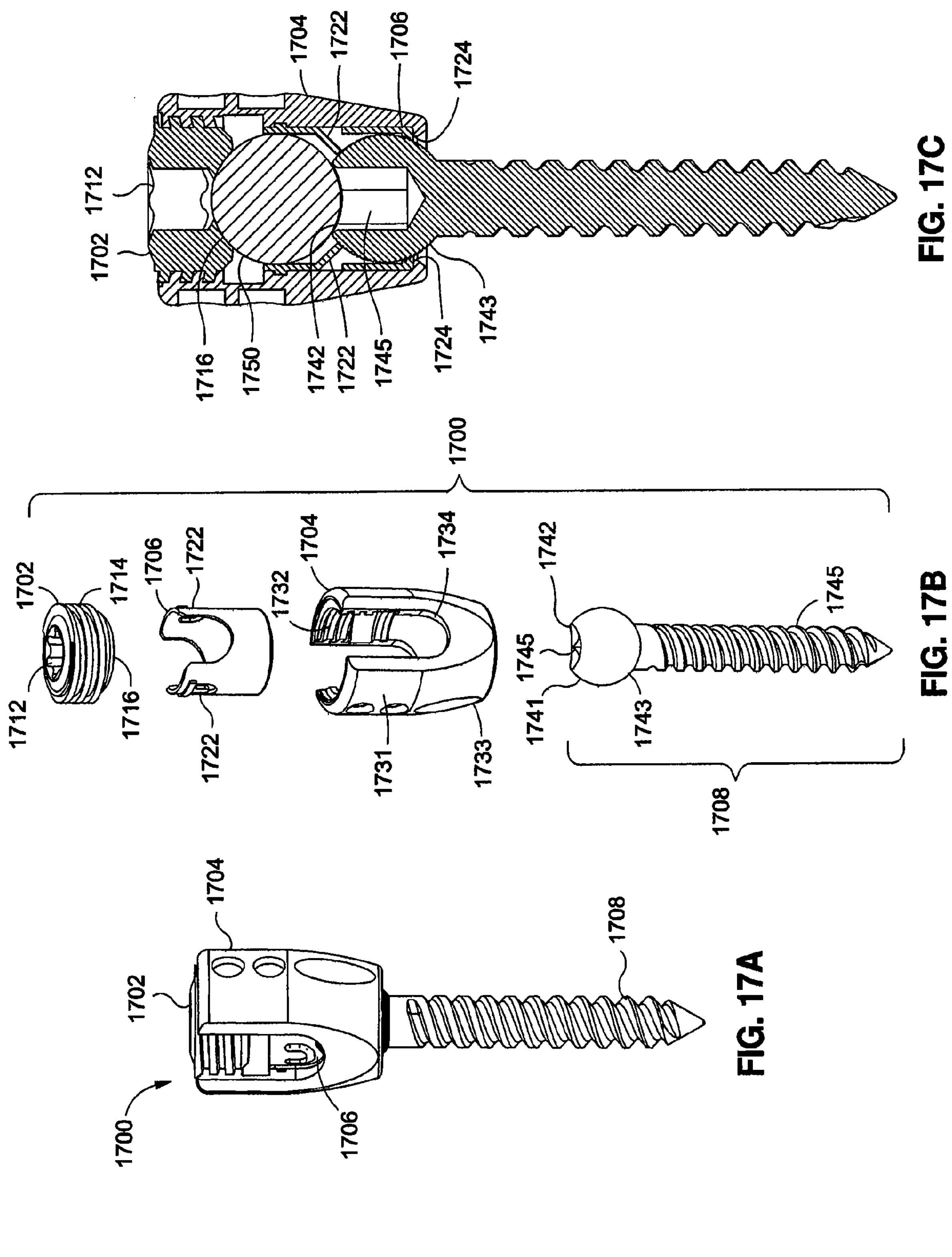

FIG. 17A

FIG. 17B

FIG. 17C

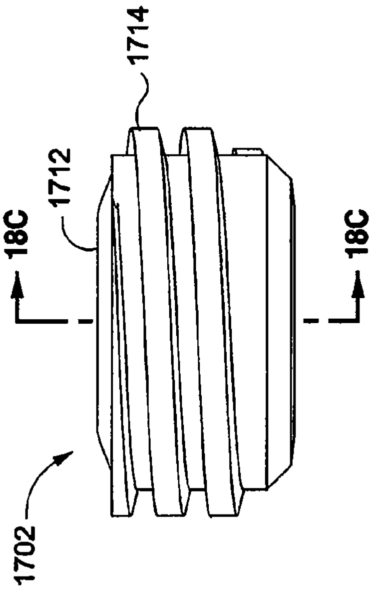

FIG. 18B

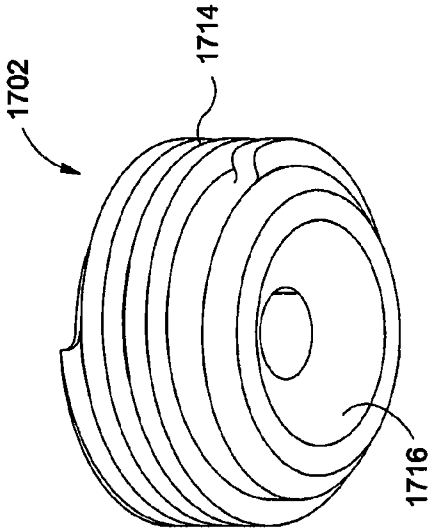

FIG. 18D

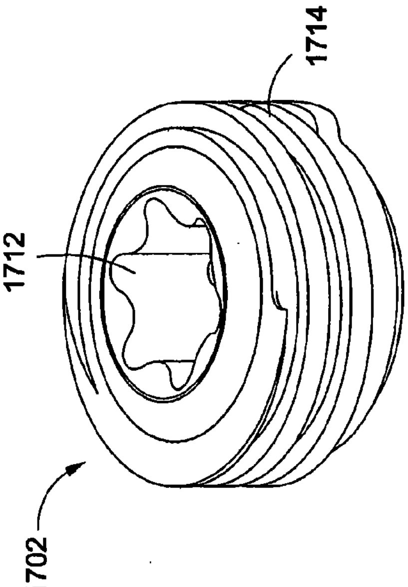

FIG. 18A

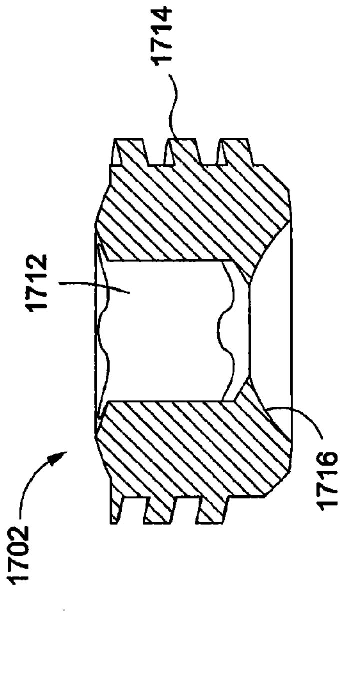

FIG. 18C

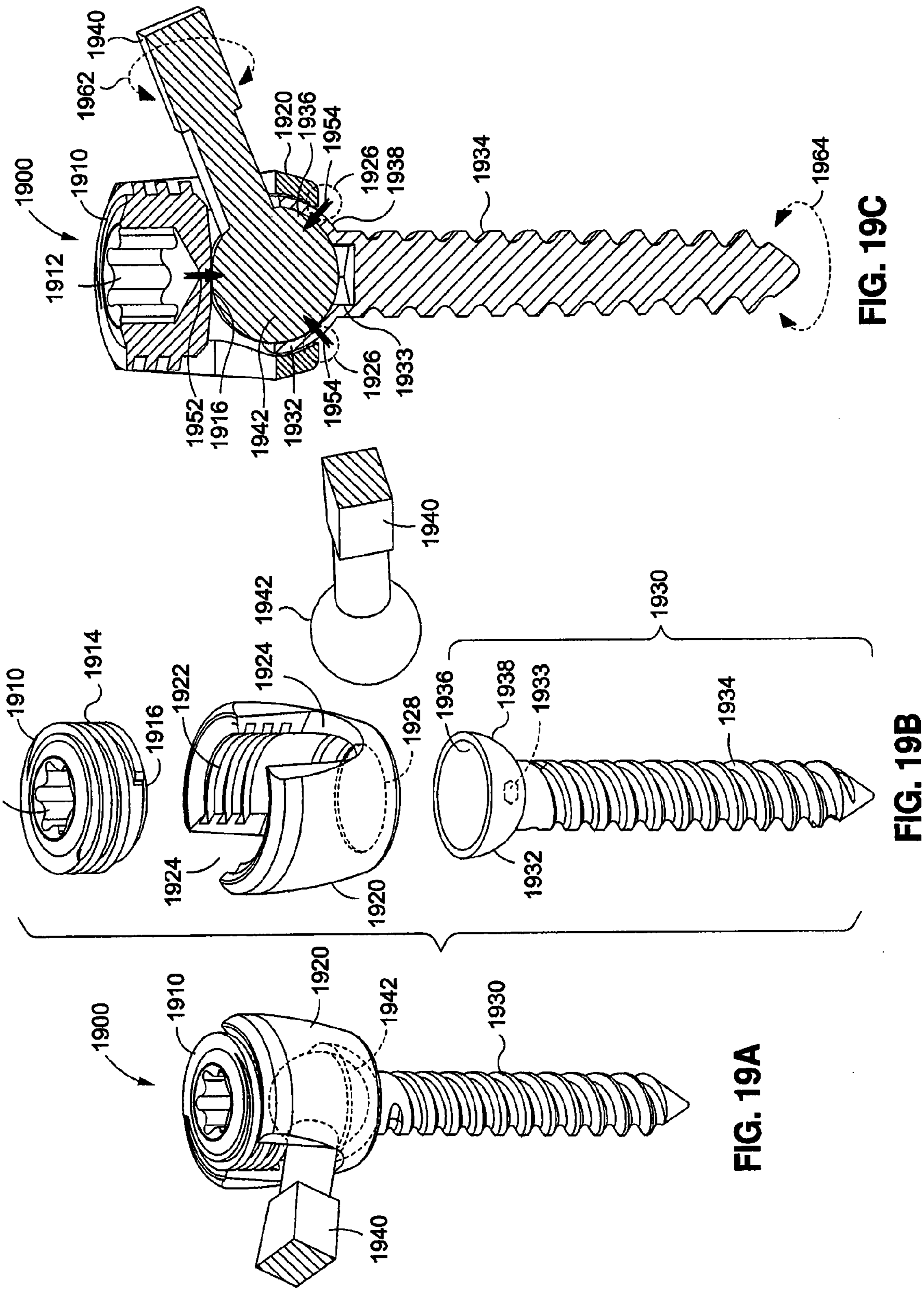

FIG. 19A

FIG. 19B

FIG. 19C

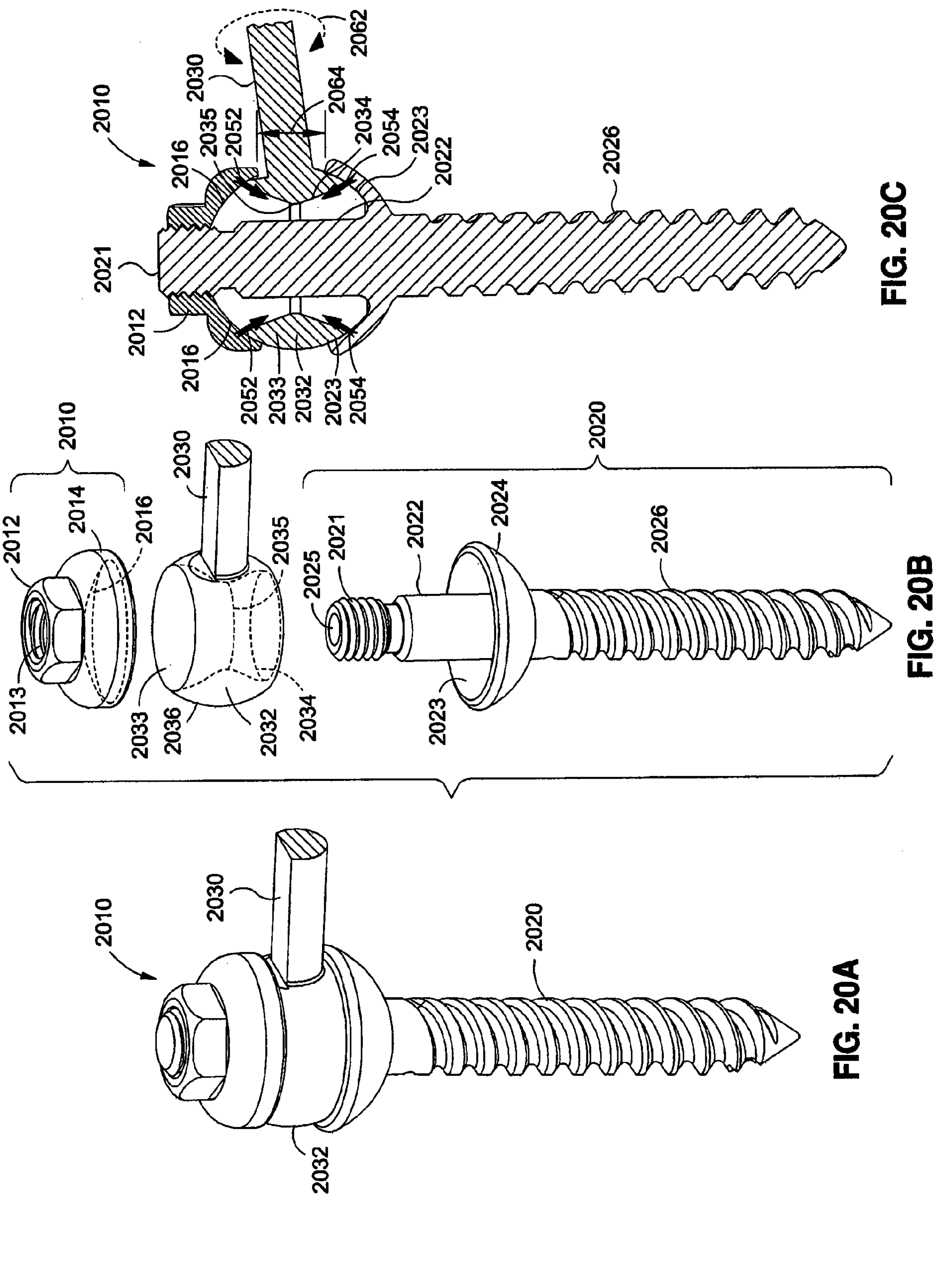

FIG. 20C

FIG. 20B

FIG. 20A

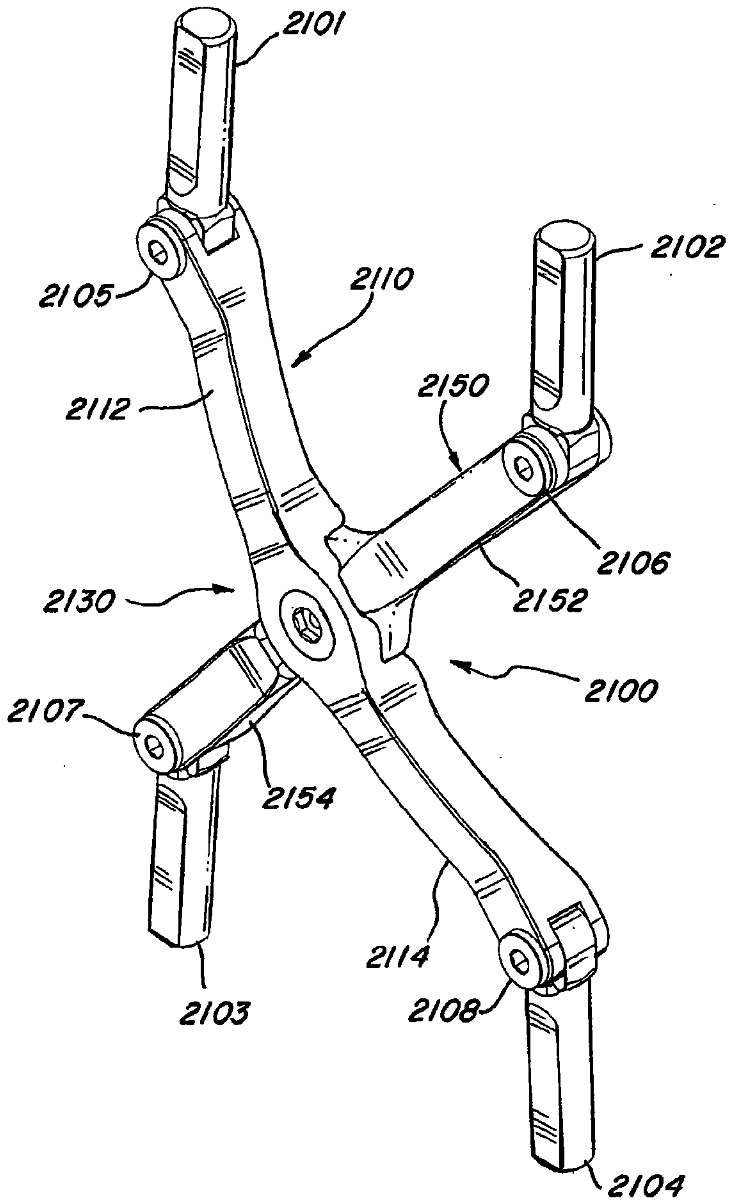
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FIG. 21

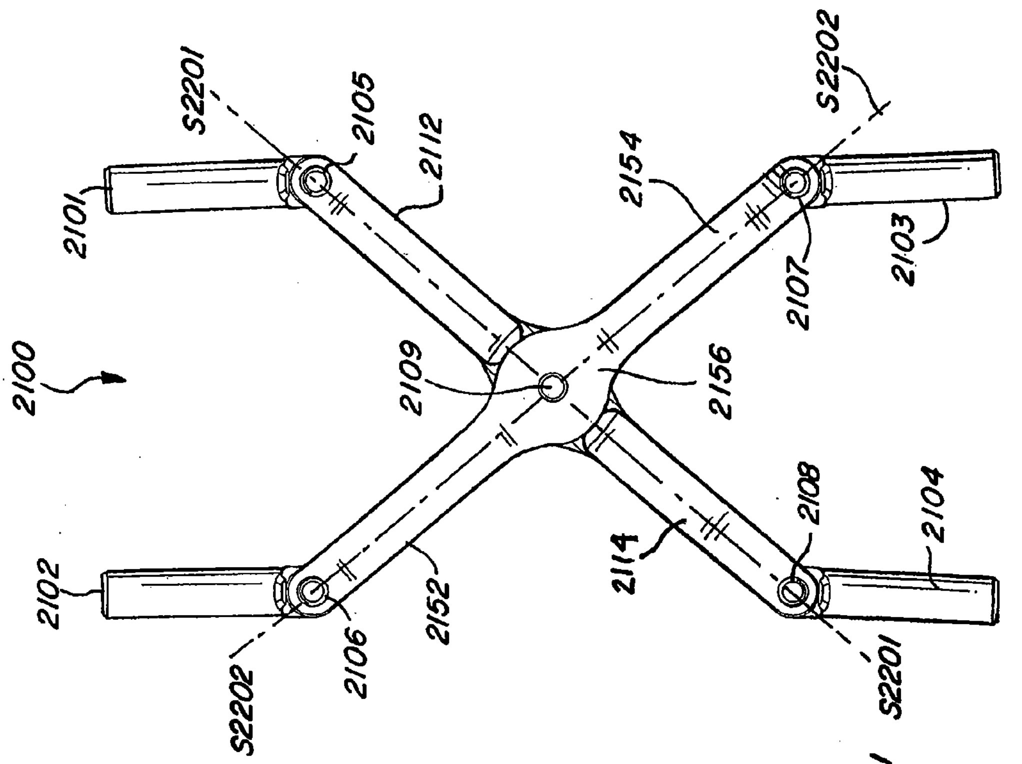


FIG. 22B

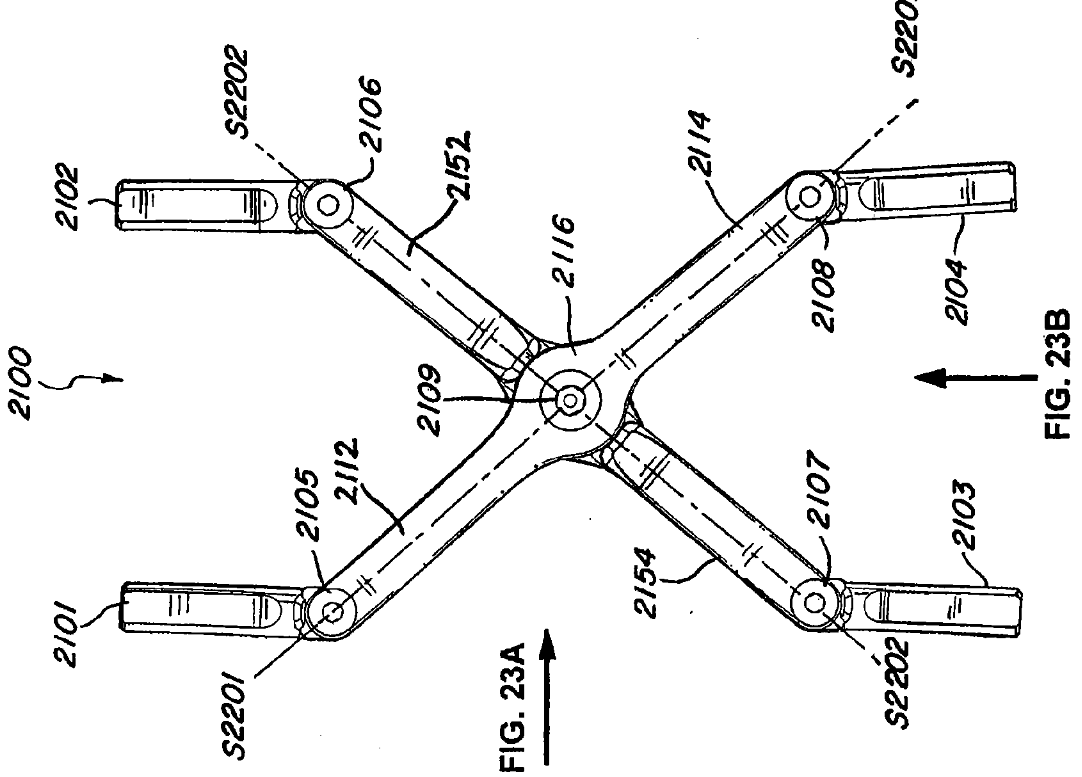


FIG. 22A

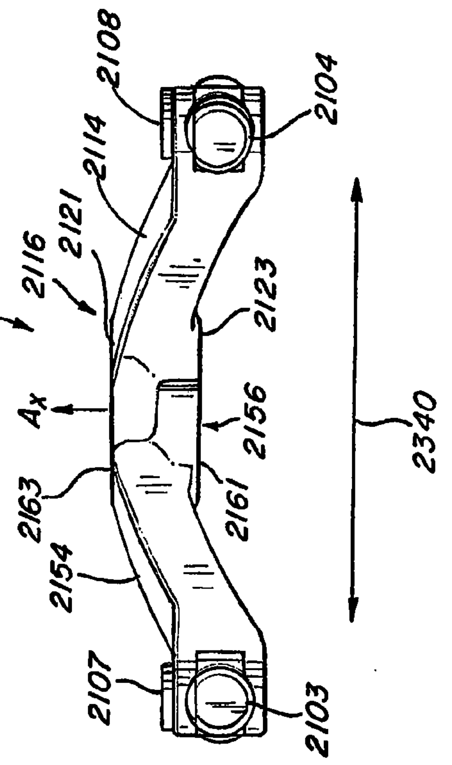


FIG. 23B

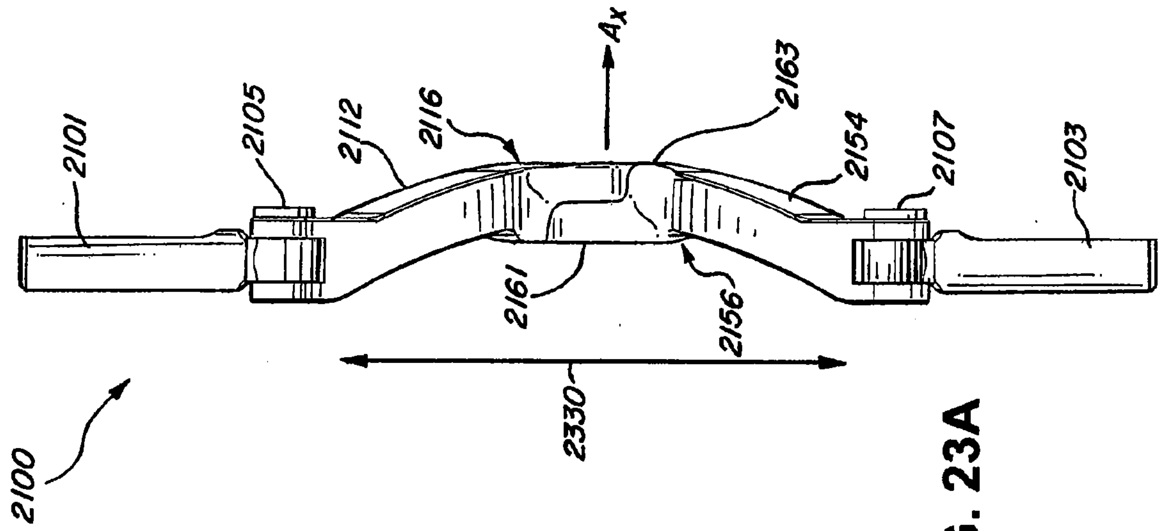
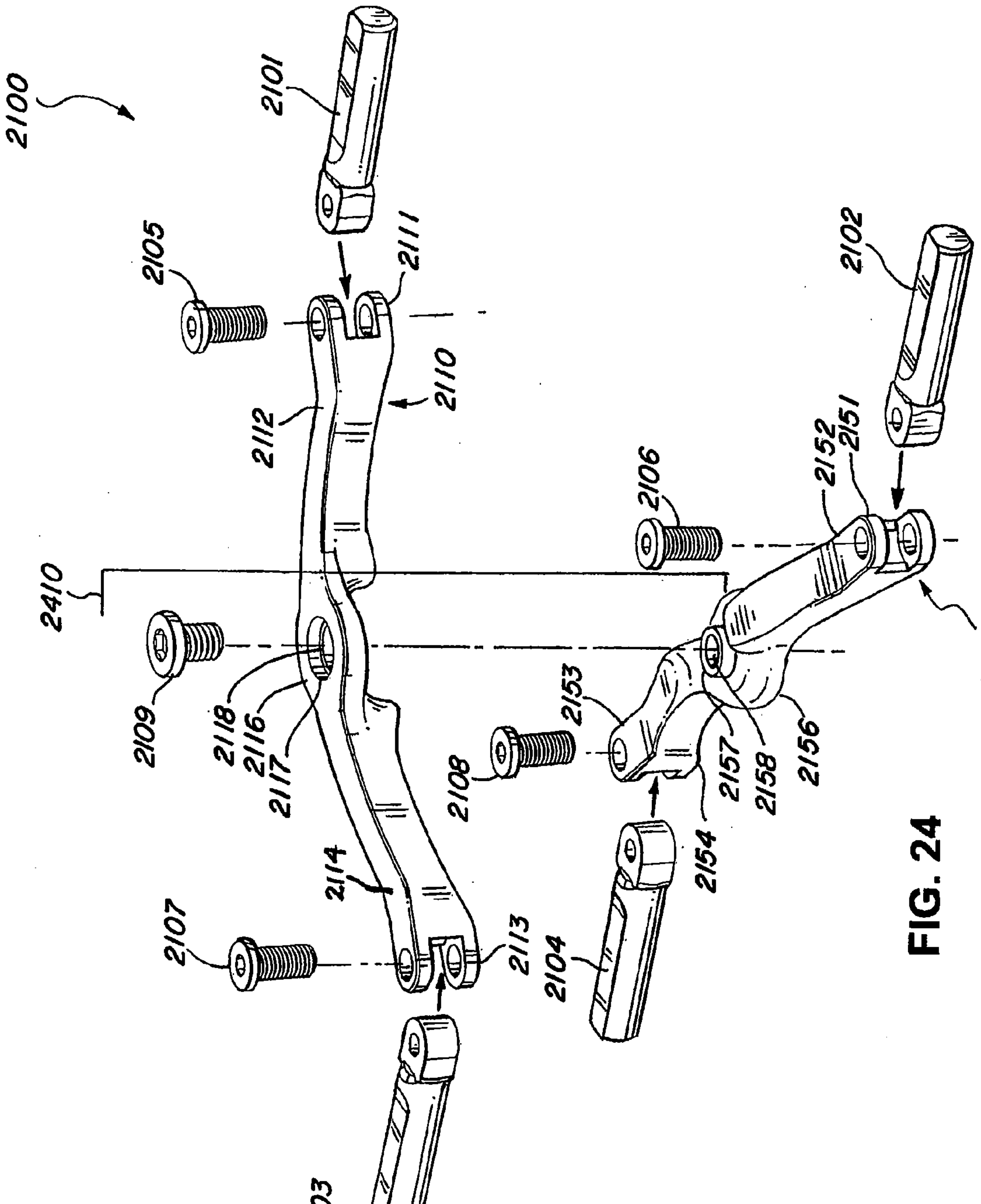


FIG. 23A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2102

FIG. 24

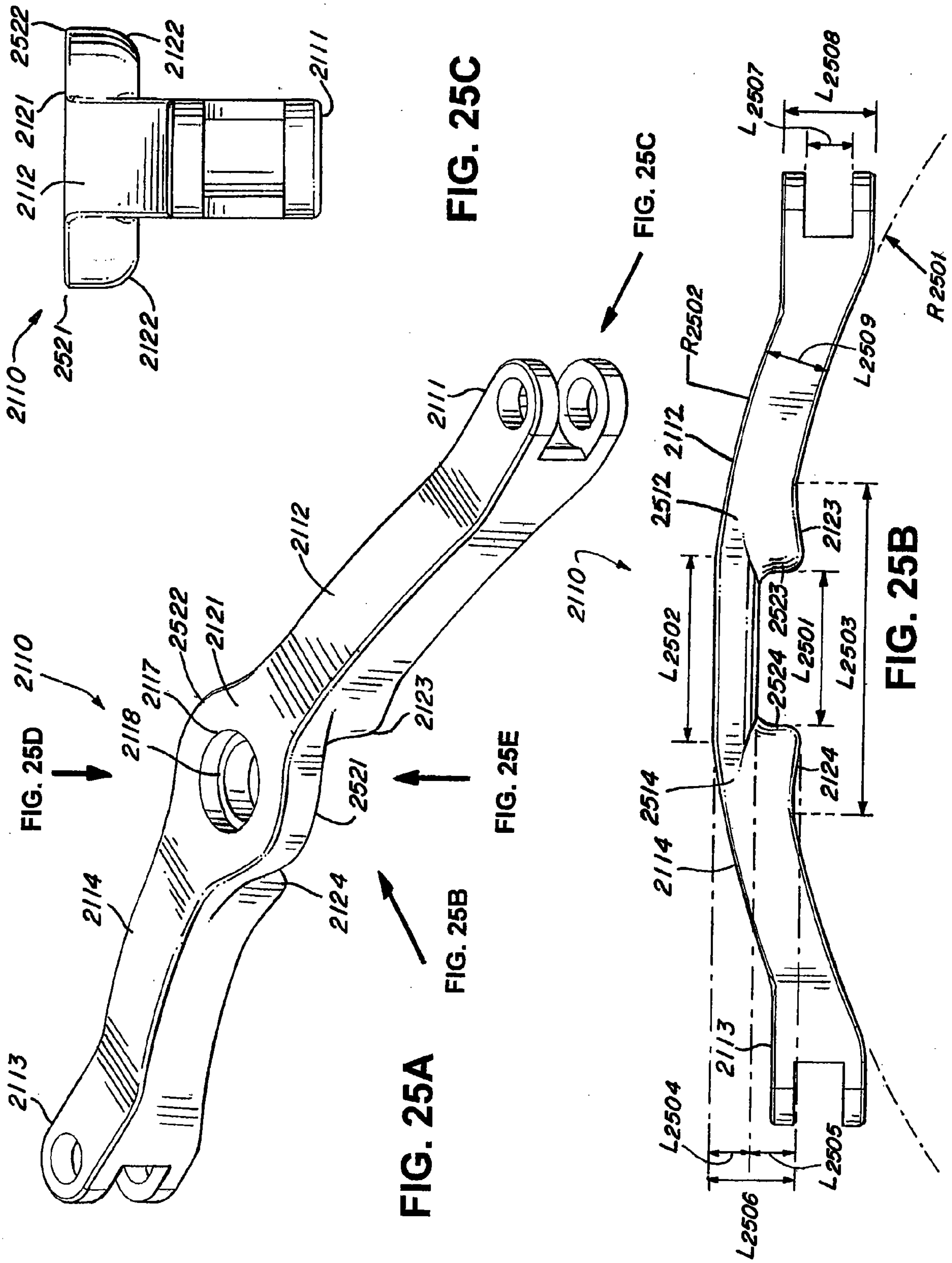

FIG. 25A

FIG. 25B

FIG. 25C

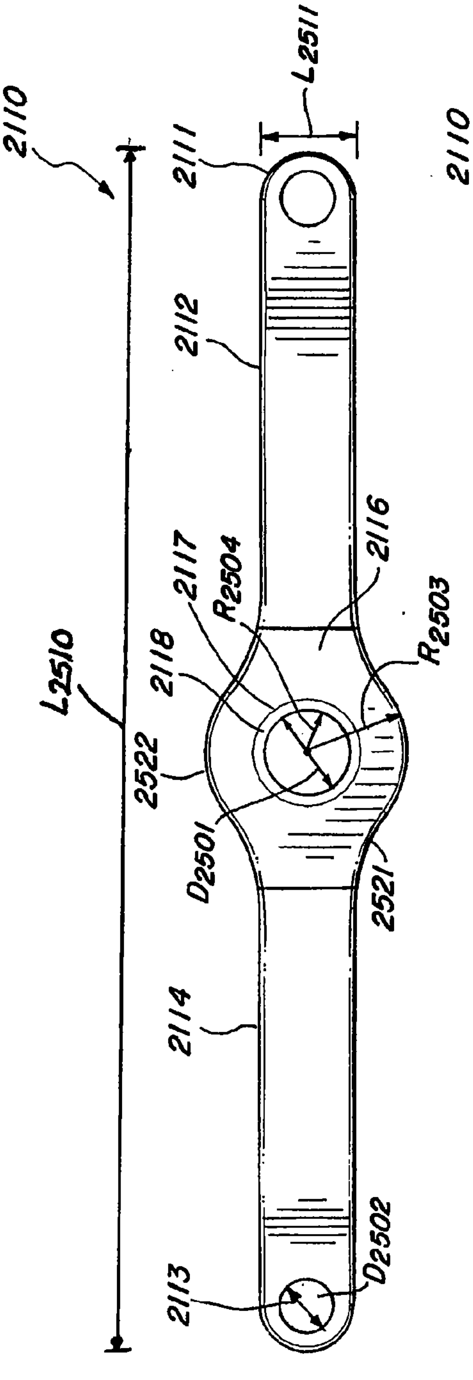

FIG. 25D

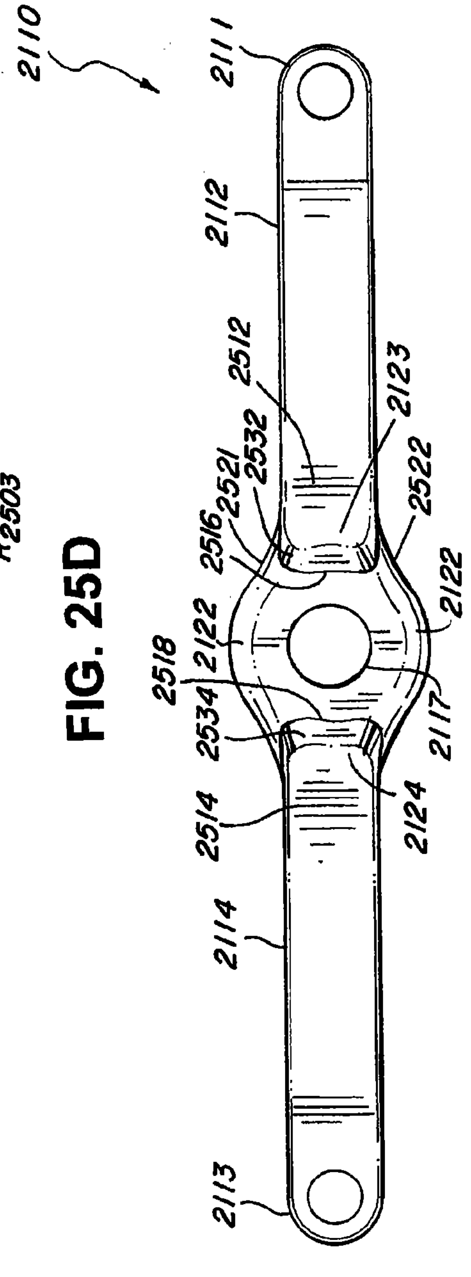

FIG. 25E

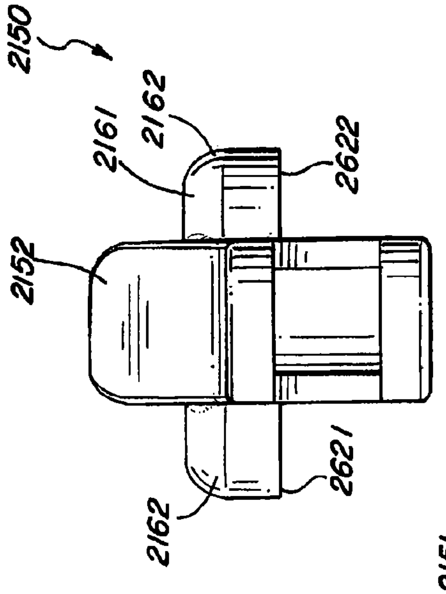

FIG. 26C

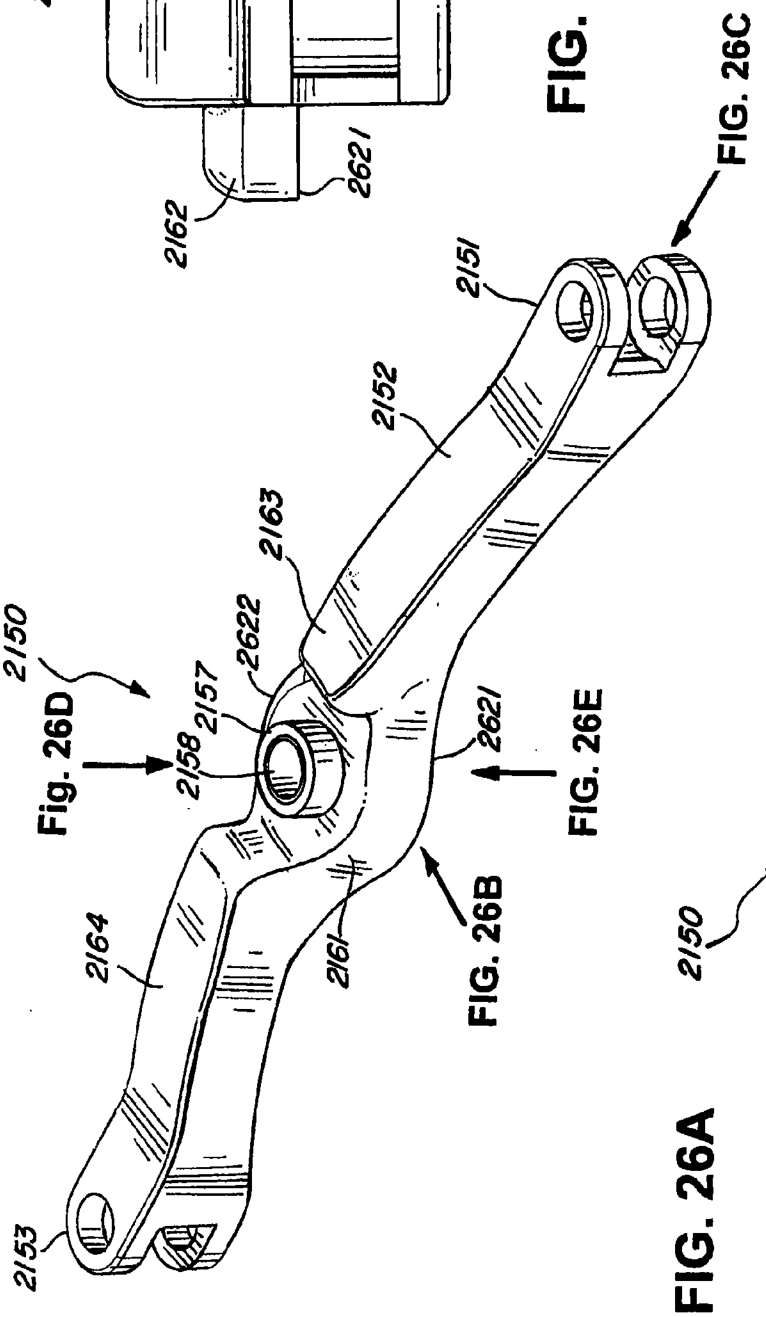

FIG. 26A

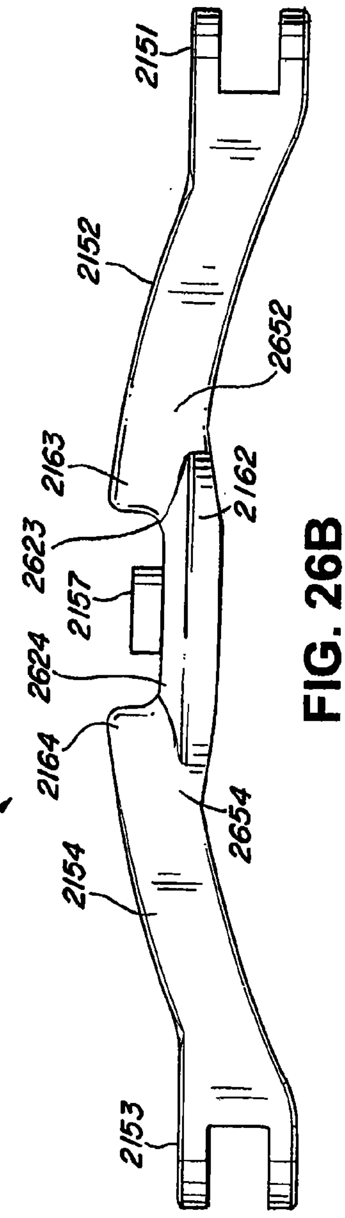

FIG. 26B

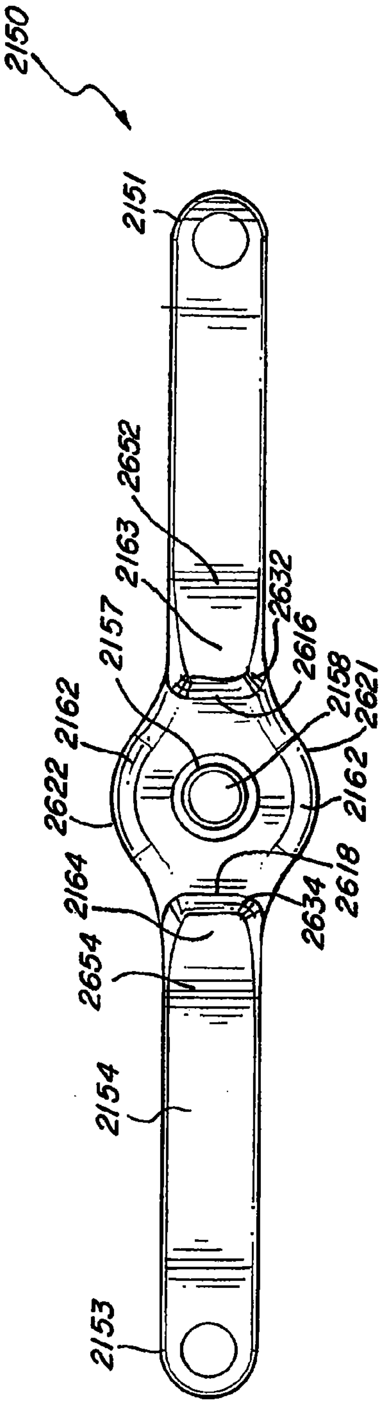

FIG. 26D

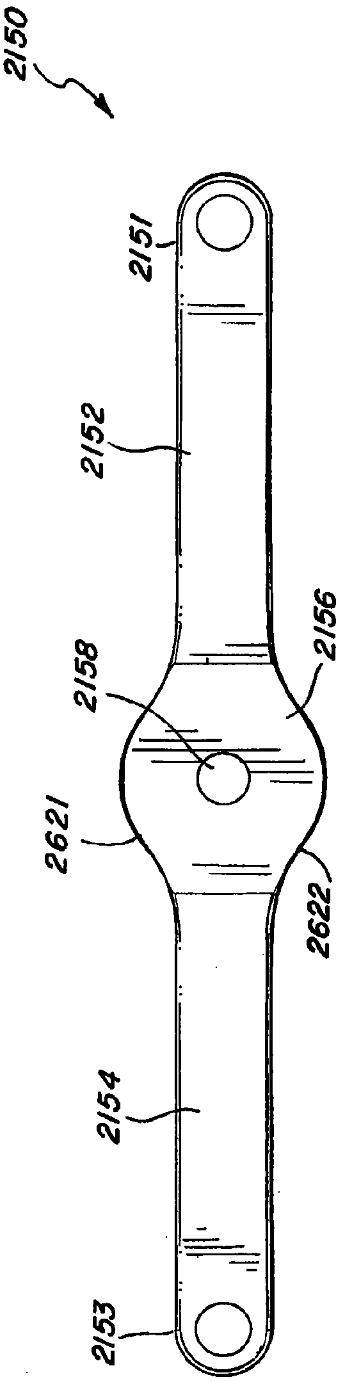

FIG. 26E

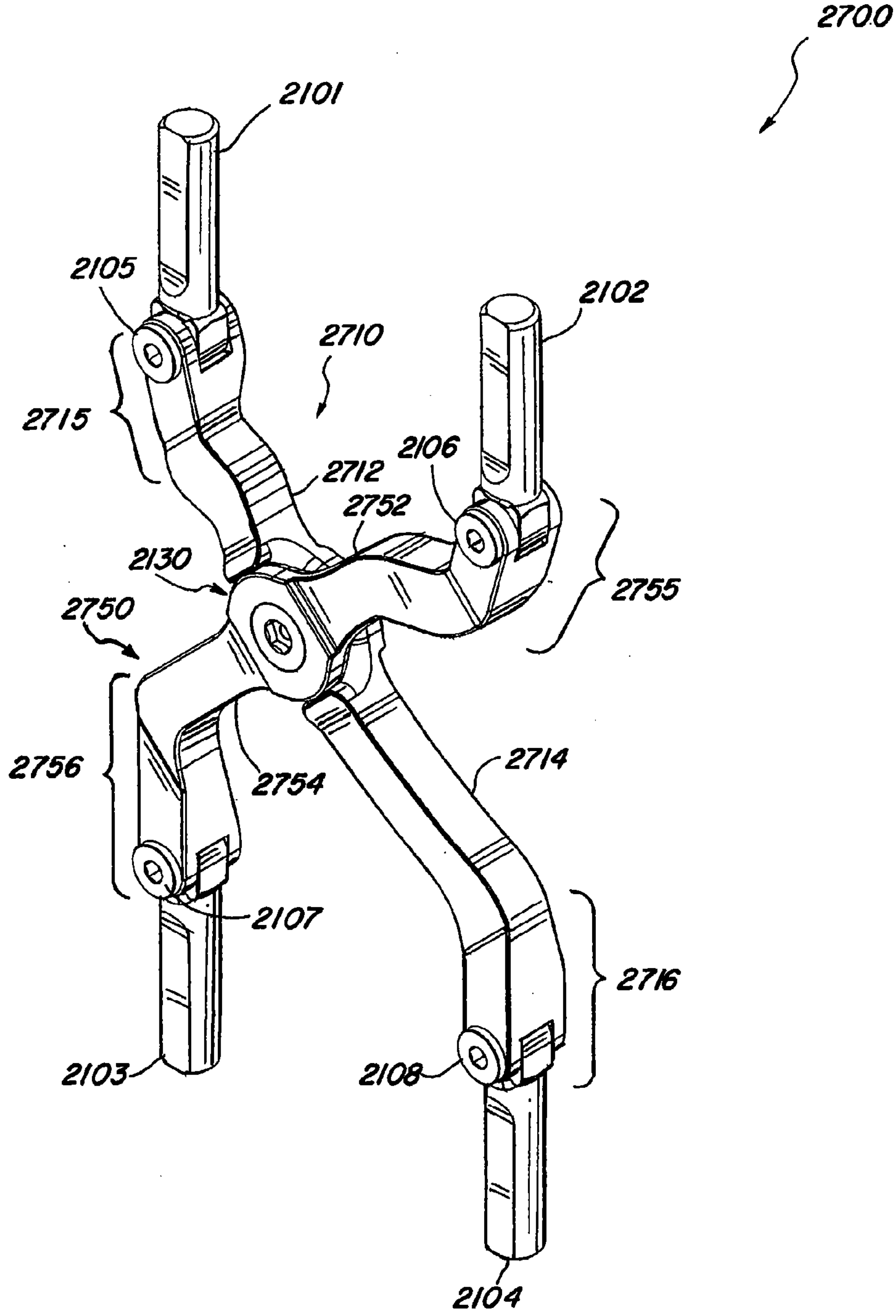
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FIG. 27

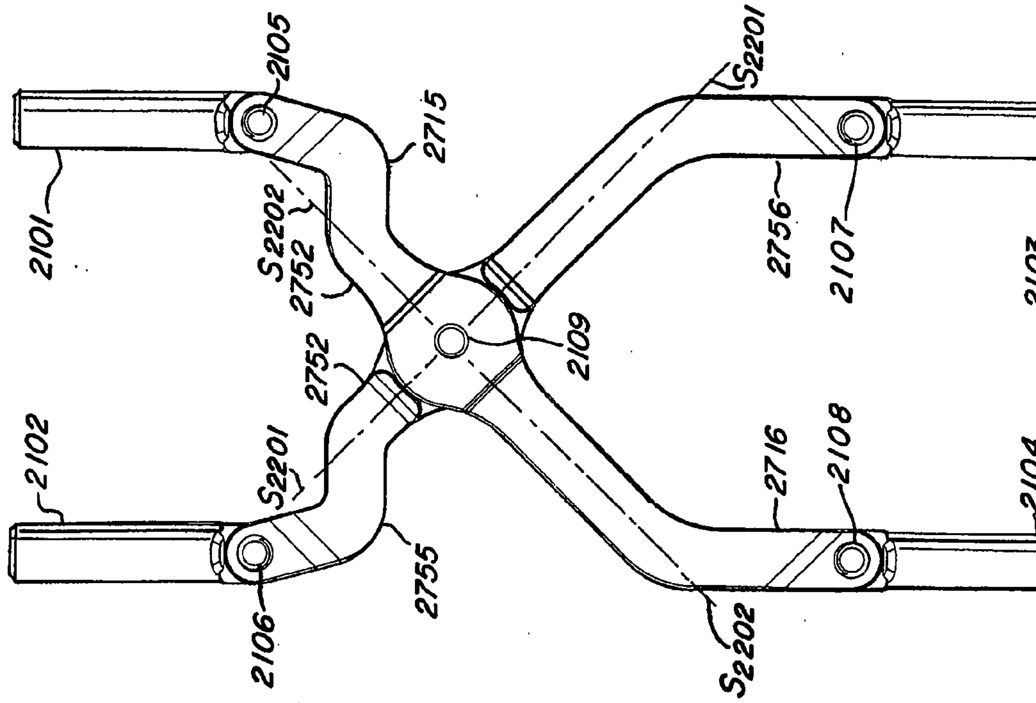


FIG. 28B

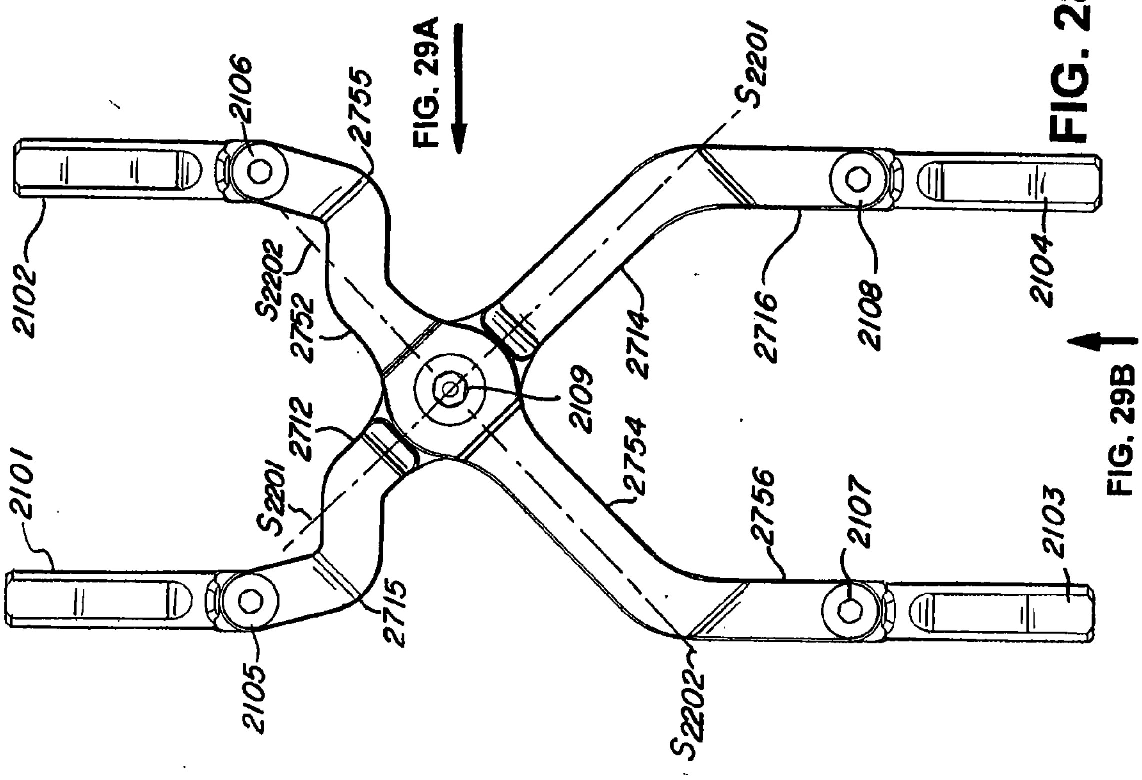


FIG. 28A

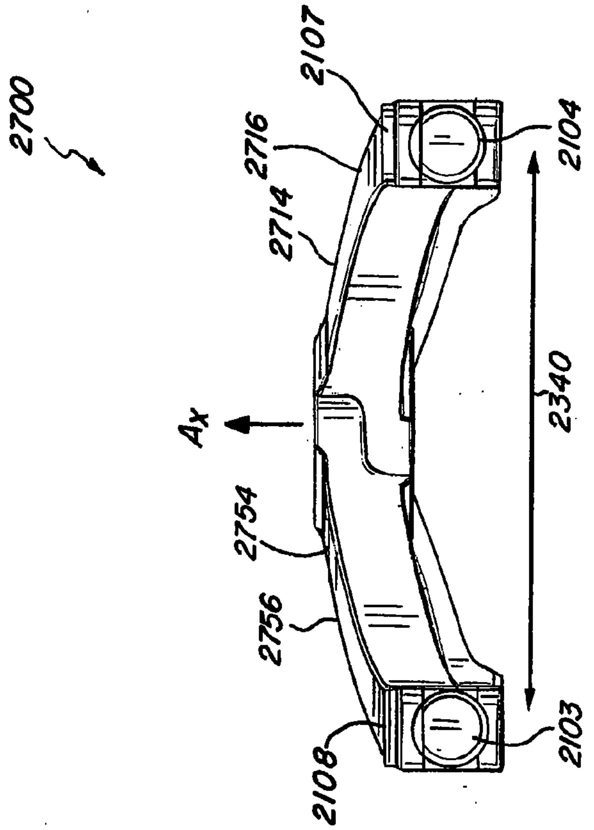


FIG. 29B

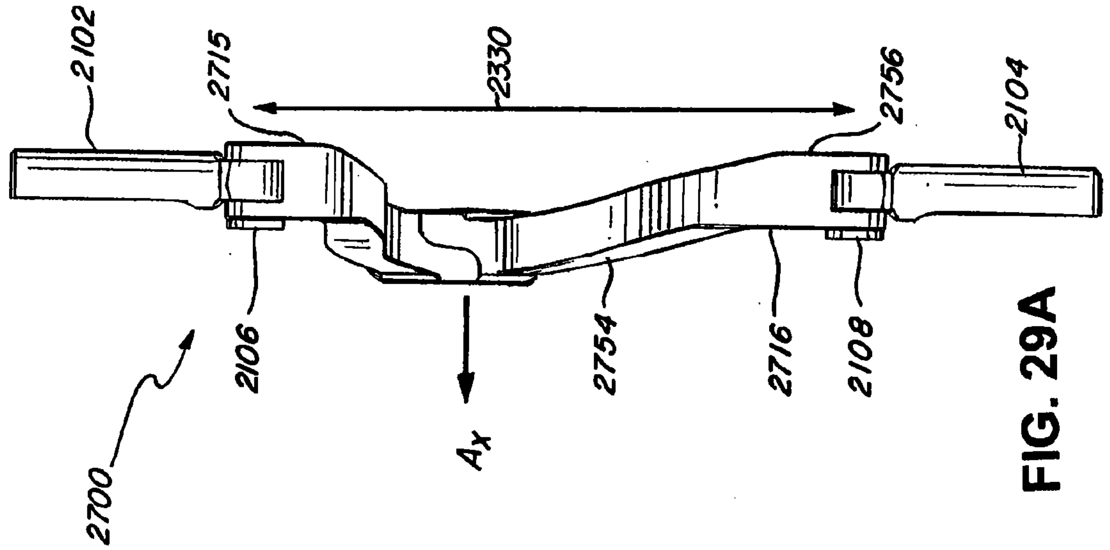
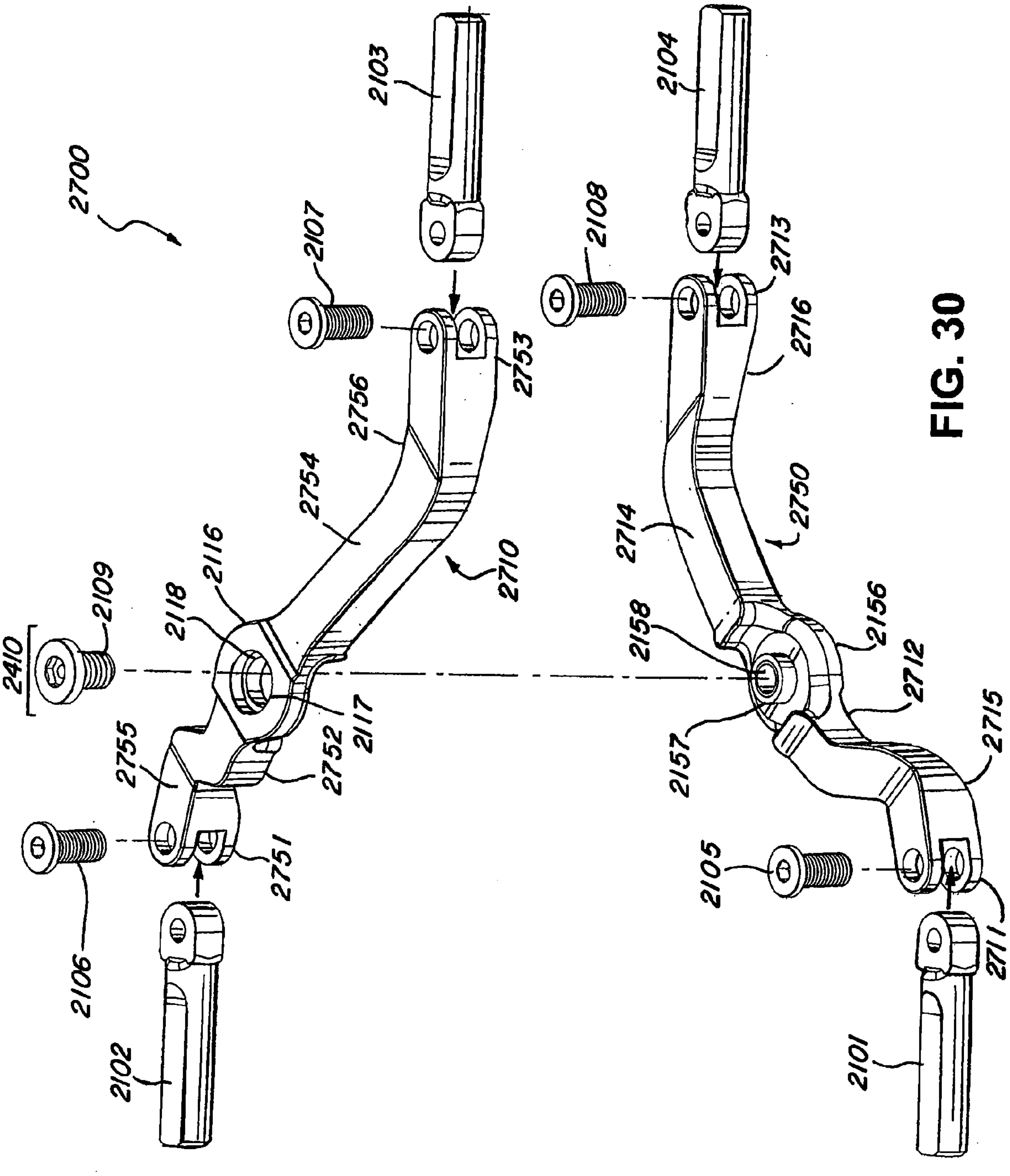


FIG. 29A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2101

FIG. 30

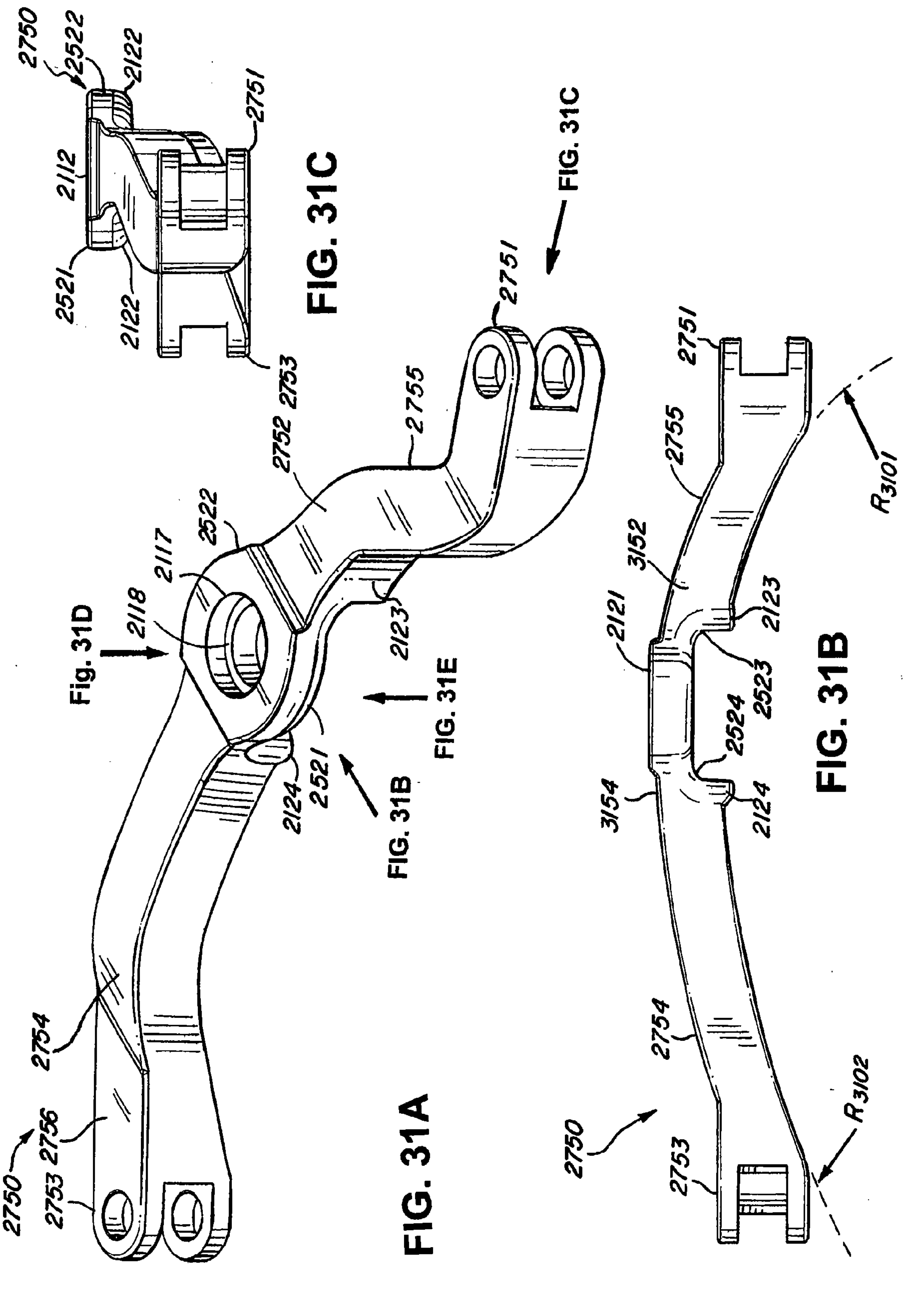


FIG. 31A

FIG. 31B

FIG. 31C

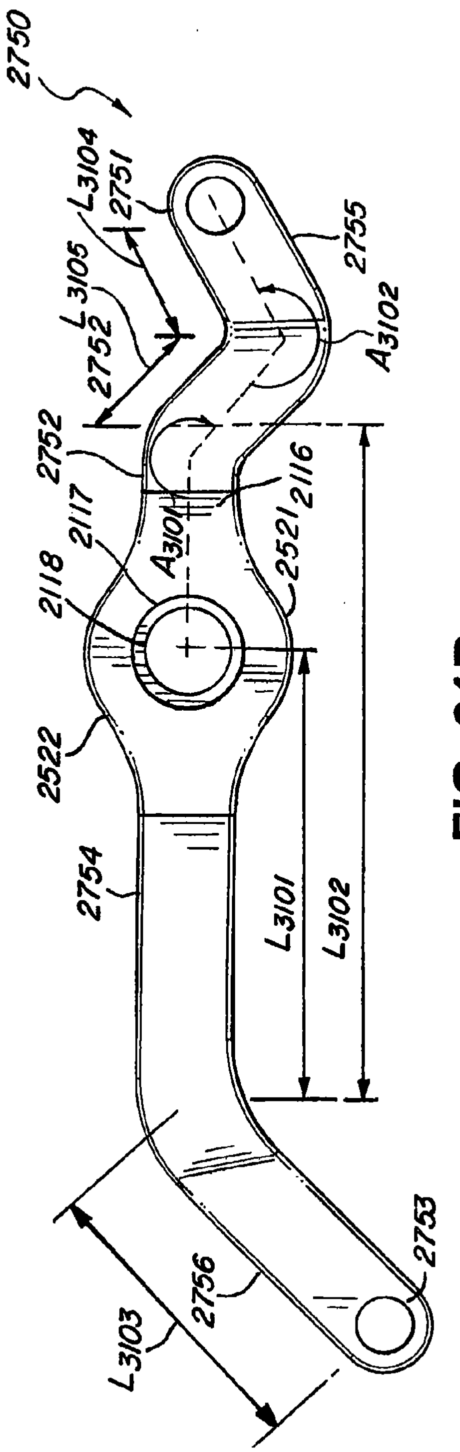


FIG. 31D

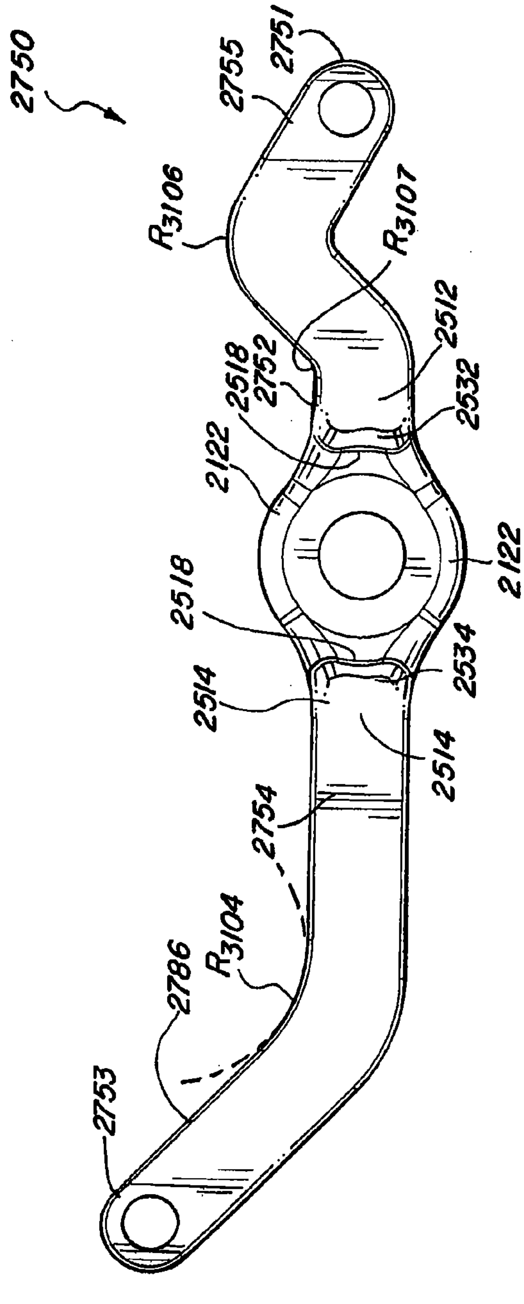


FIG. 31E

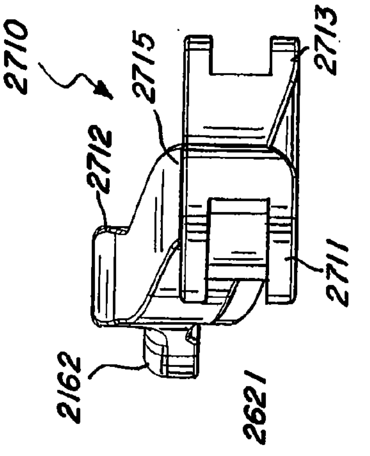


FIG. 32C

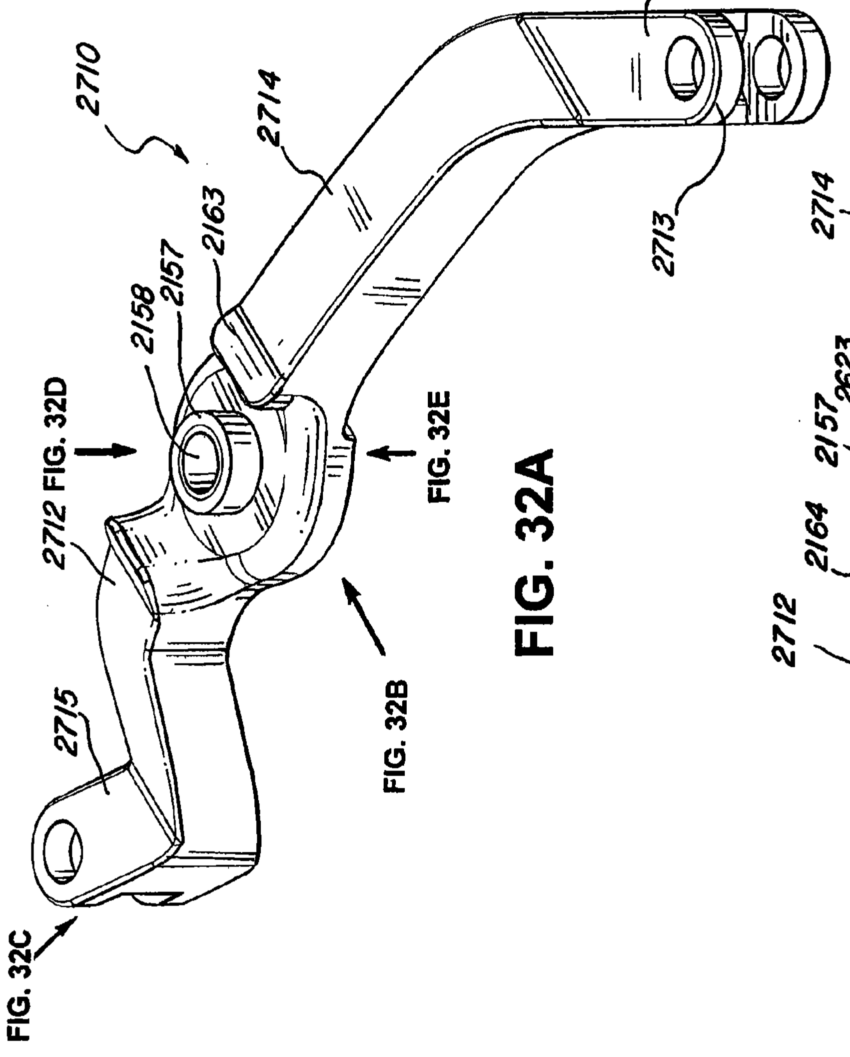


FIG. 32A

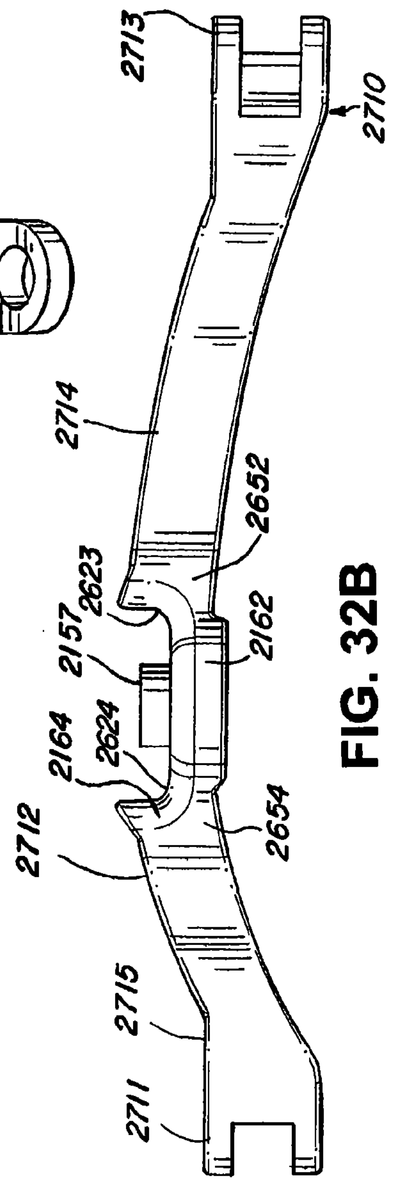


FIG. 32B

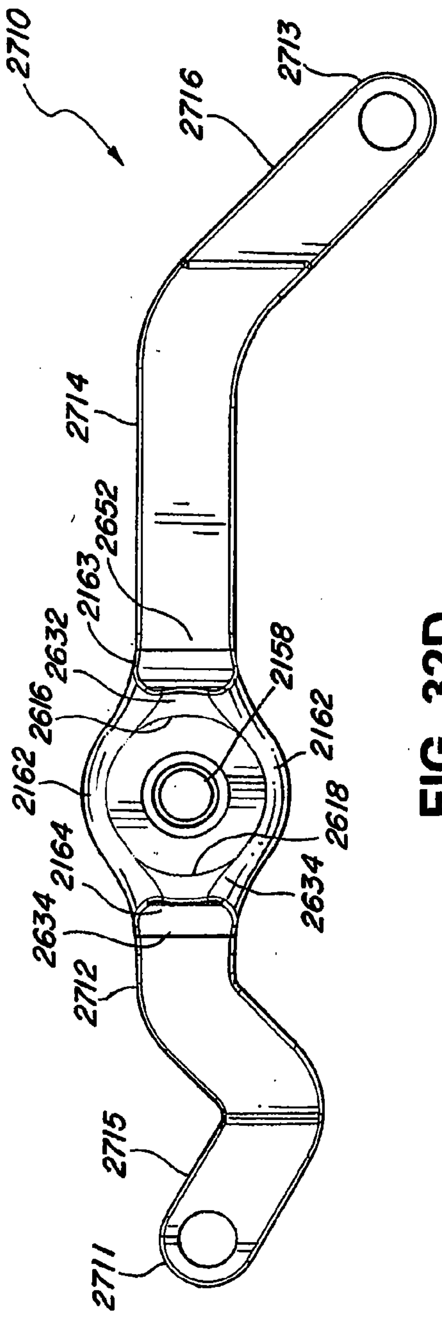


FIG. 32D

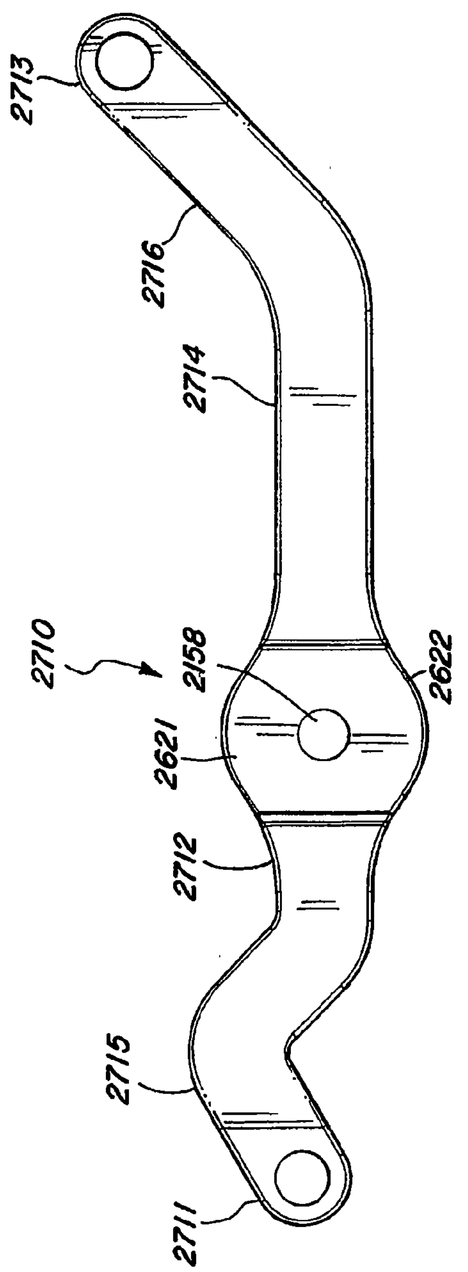
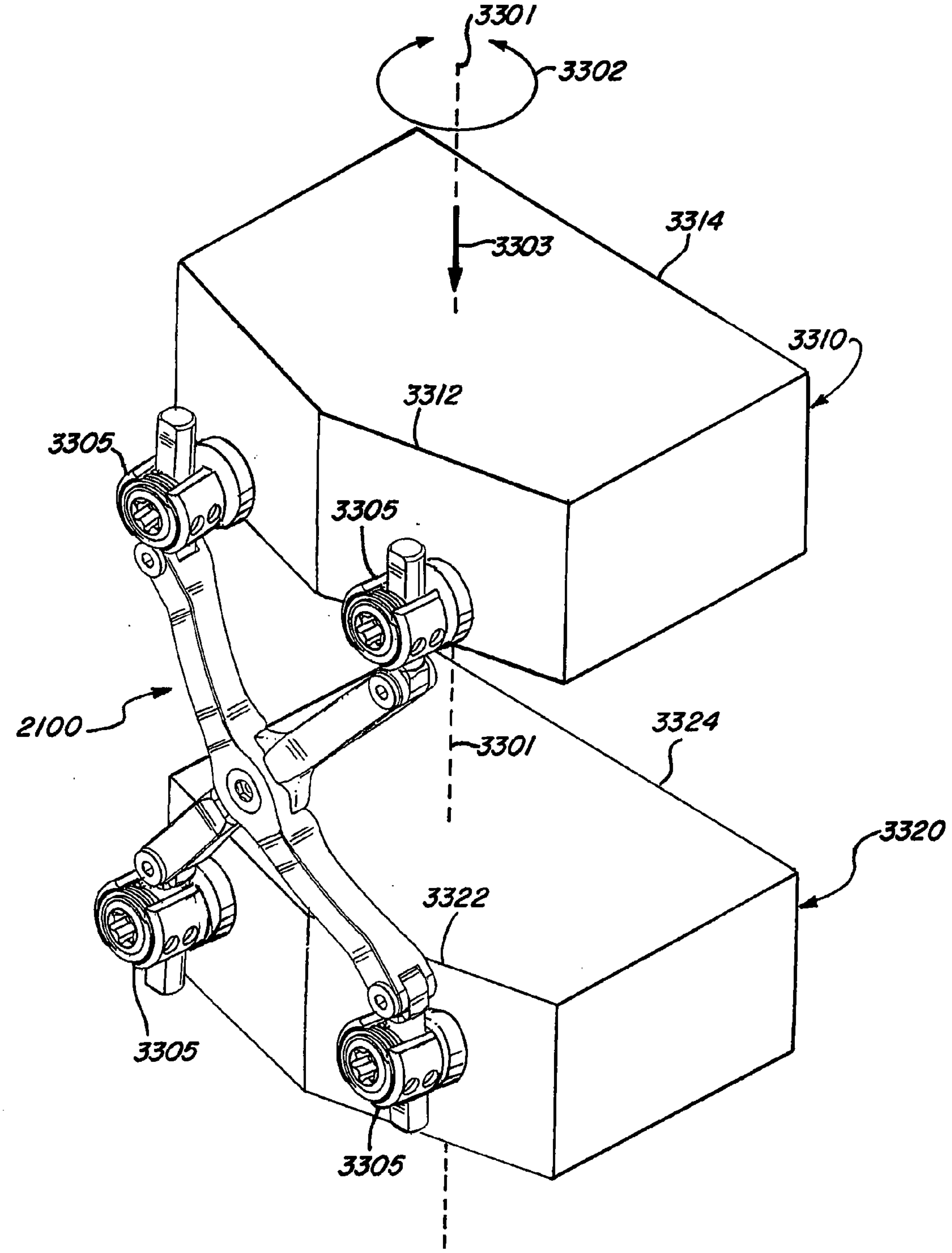


FIG. 32E


3301
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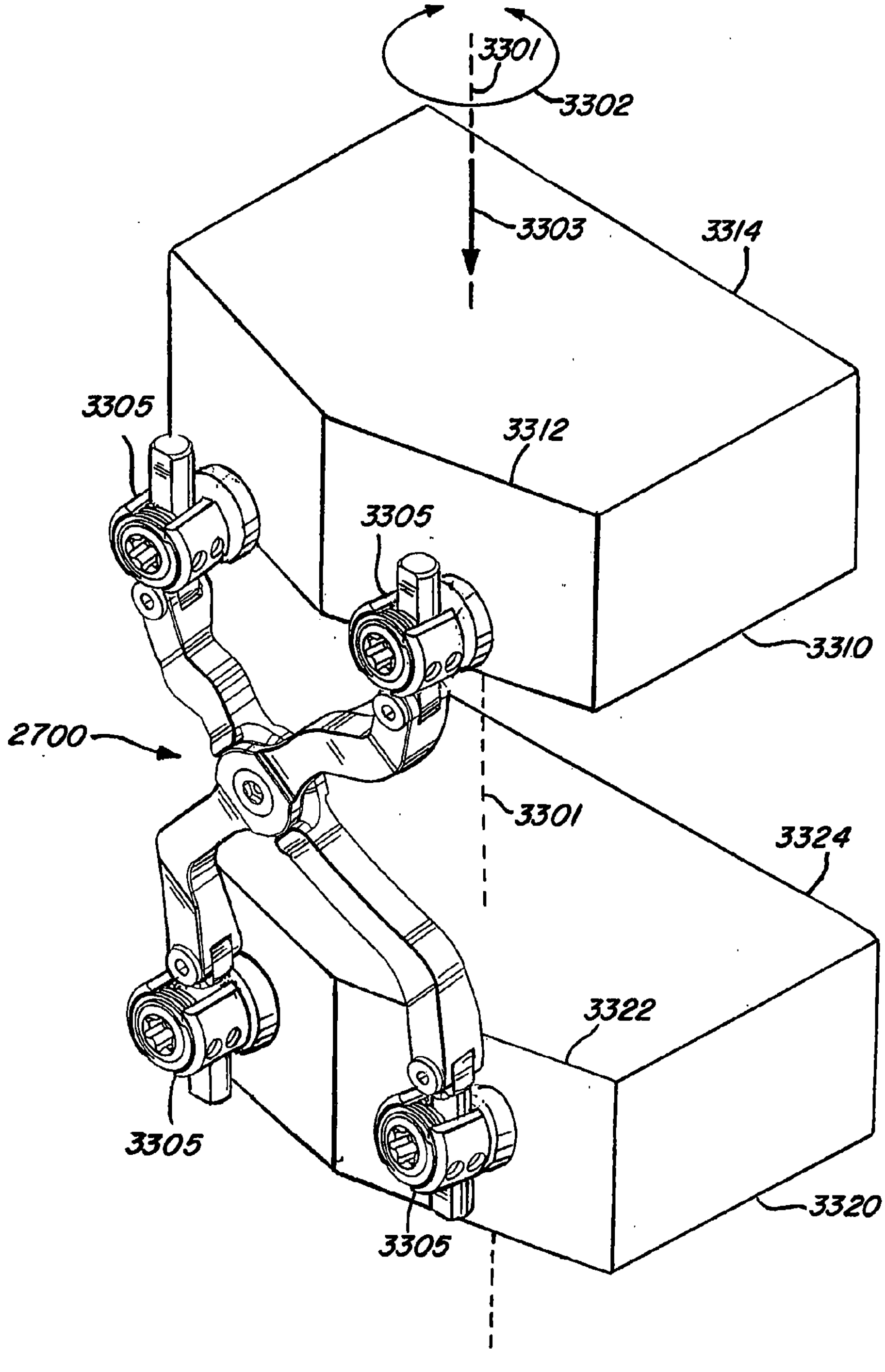
3305

FIG. 33A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3305

FIG. 33B

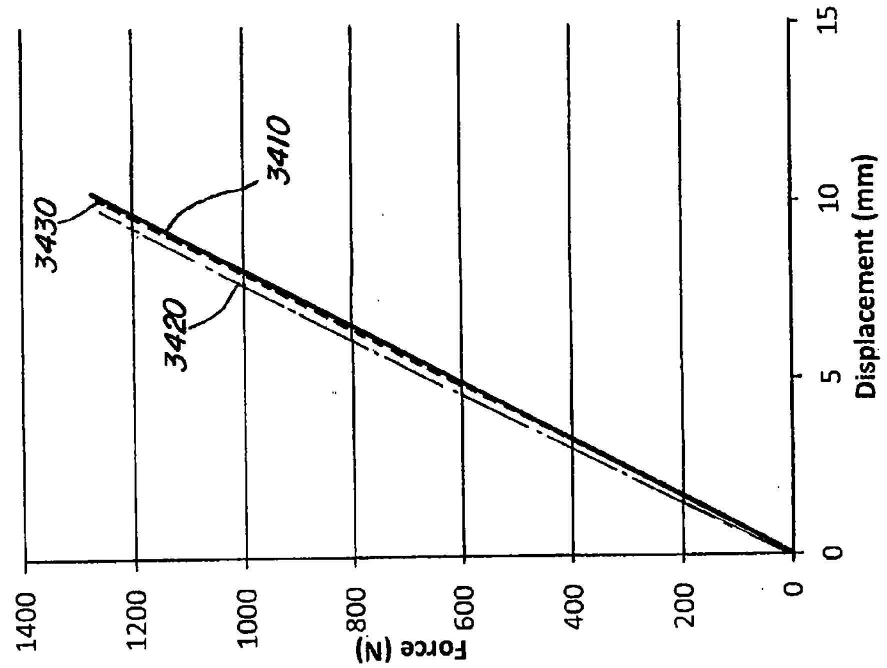


FIG. 34A

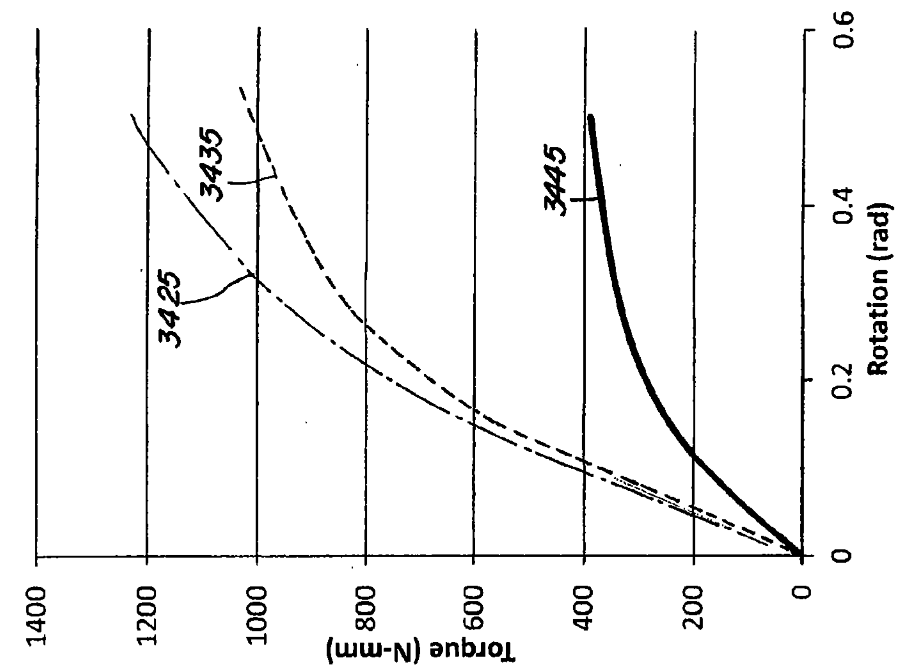


FIG. 34B

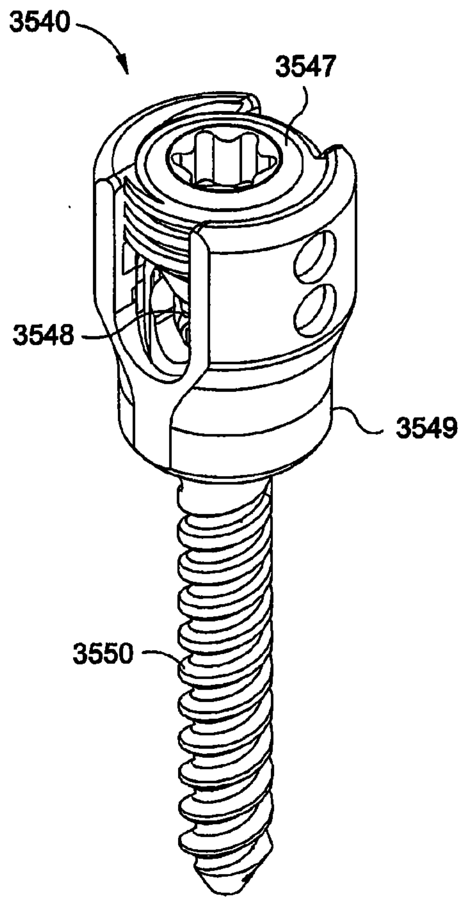


FIG. 35

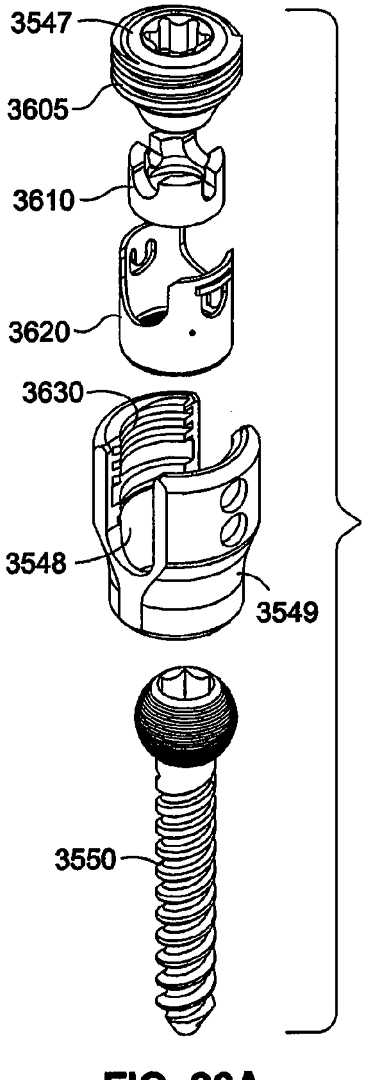


FIG. 36A

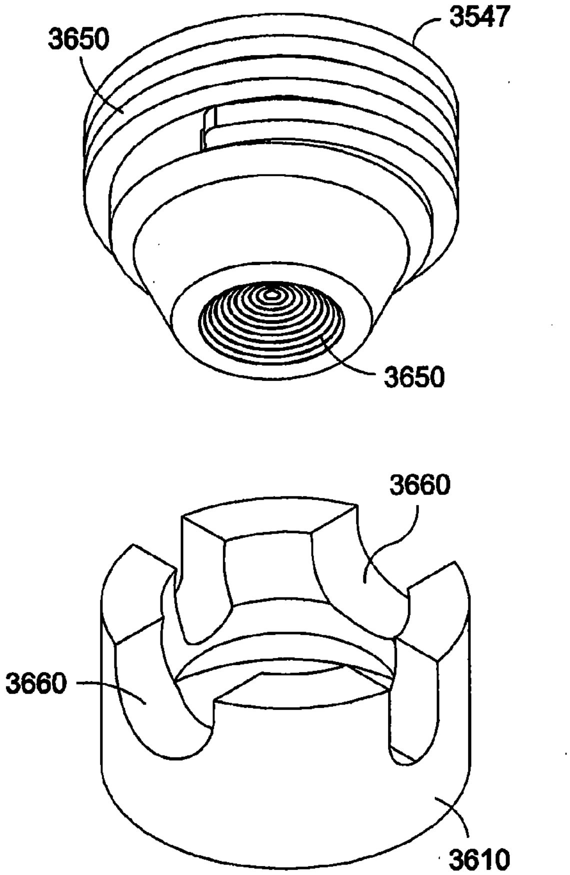


FIG. 36B

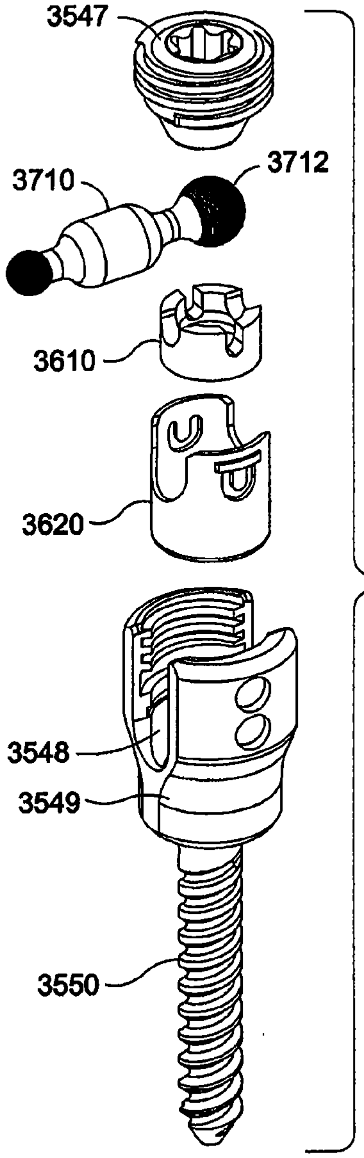


FIG. 37A

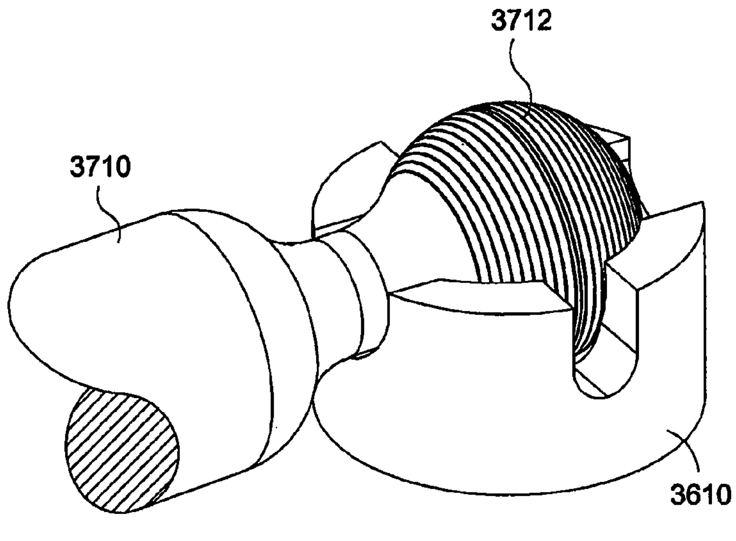
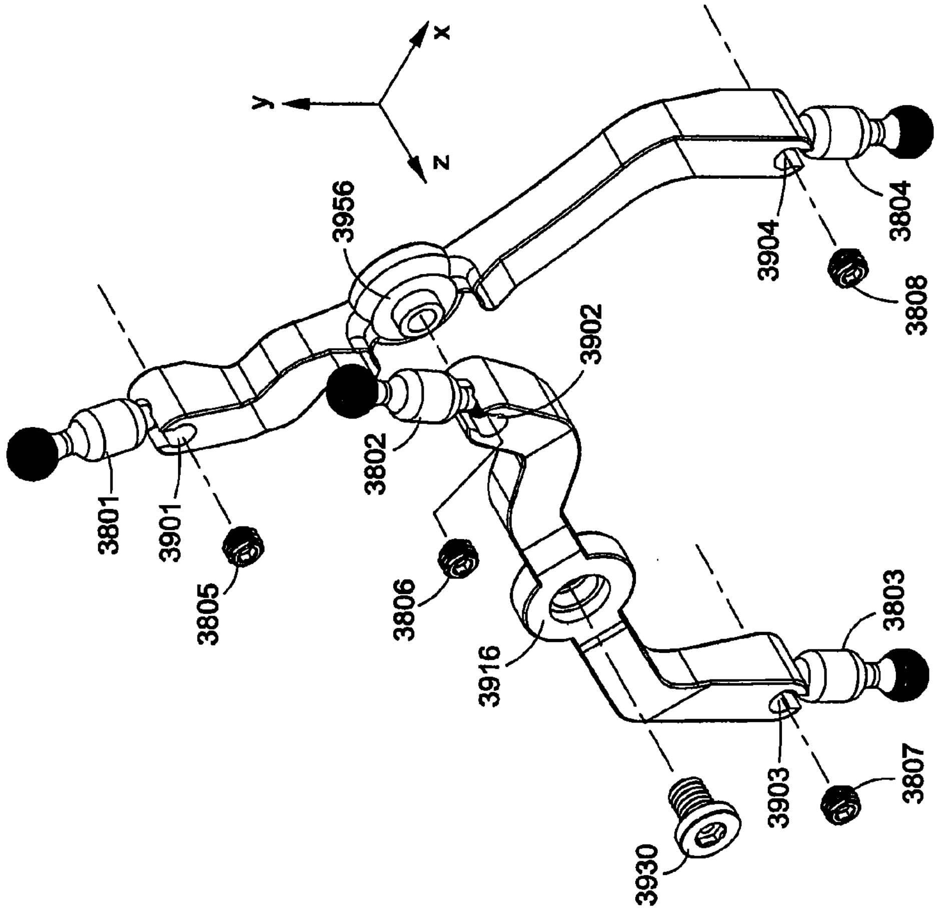


FIG. 37B


x
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3956
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FIG. 39

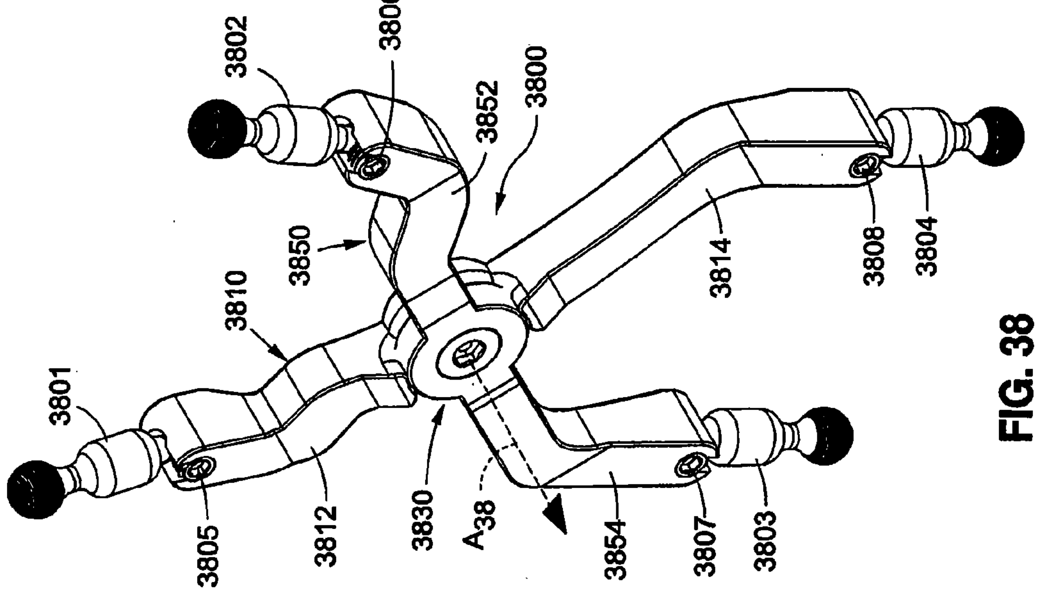
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FIG. 38

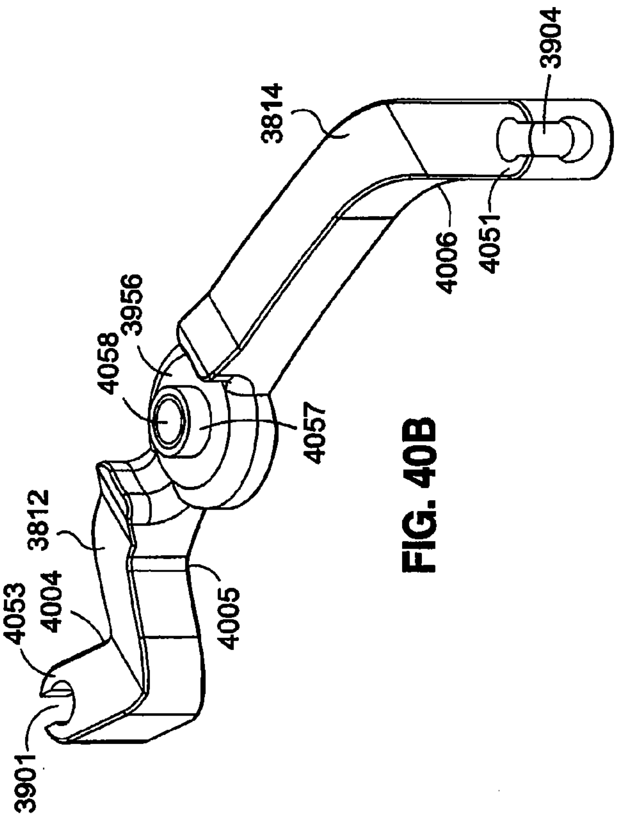

FIG. 40B

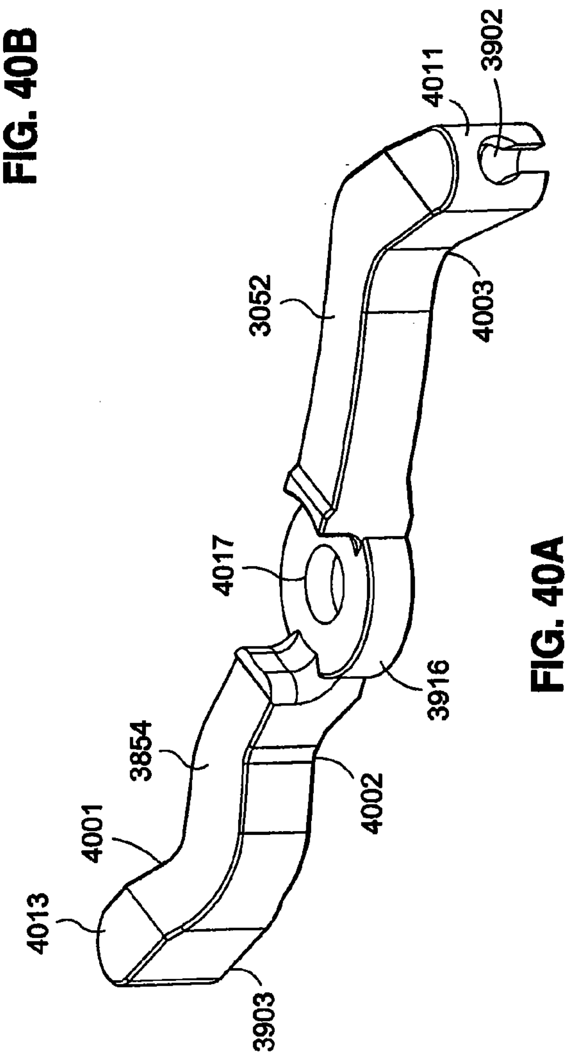

FIG. 40A

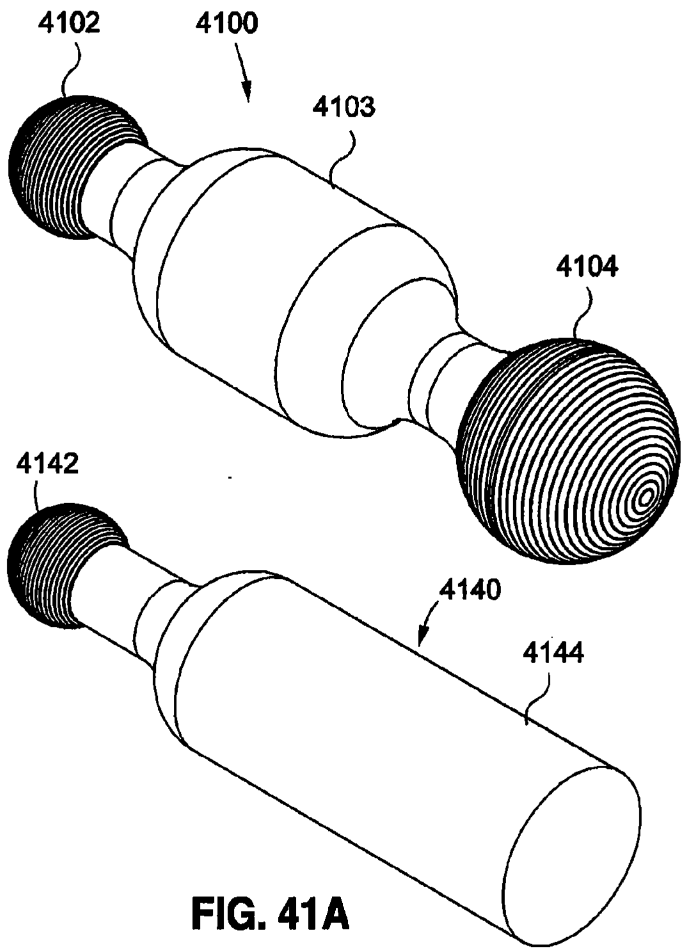

FIG. 41A

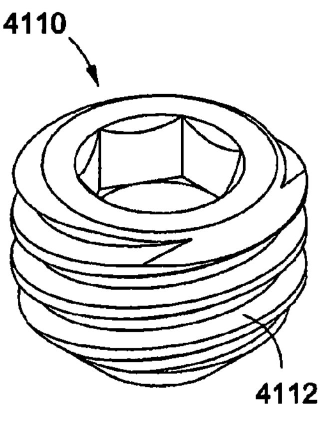

FIG. 41B

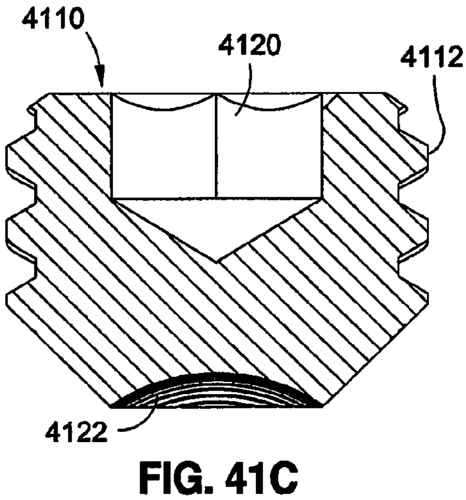

FIG. 41C

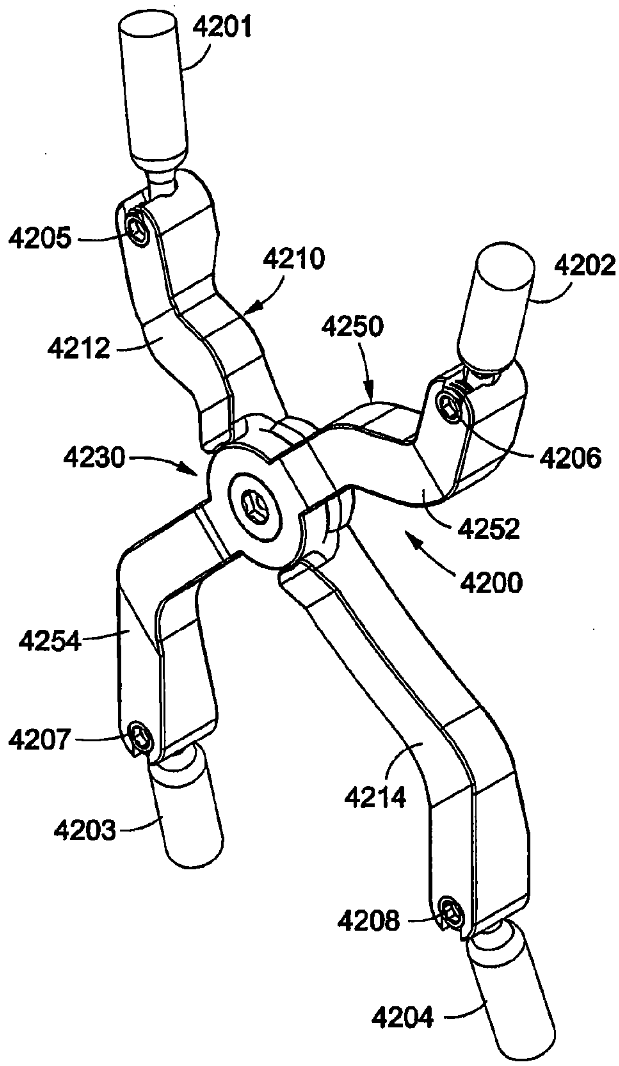
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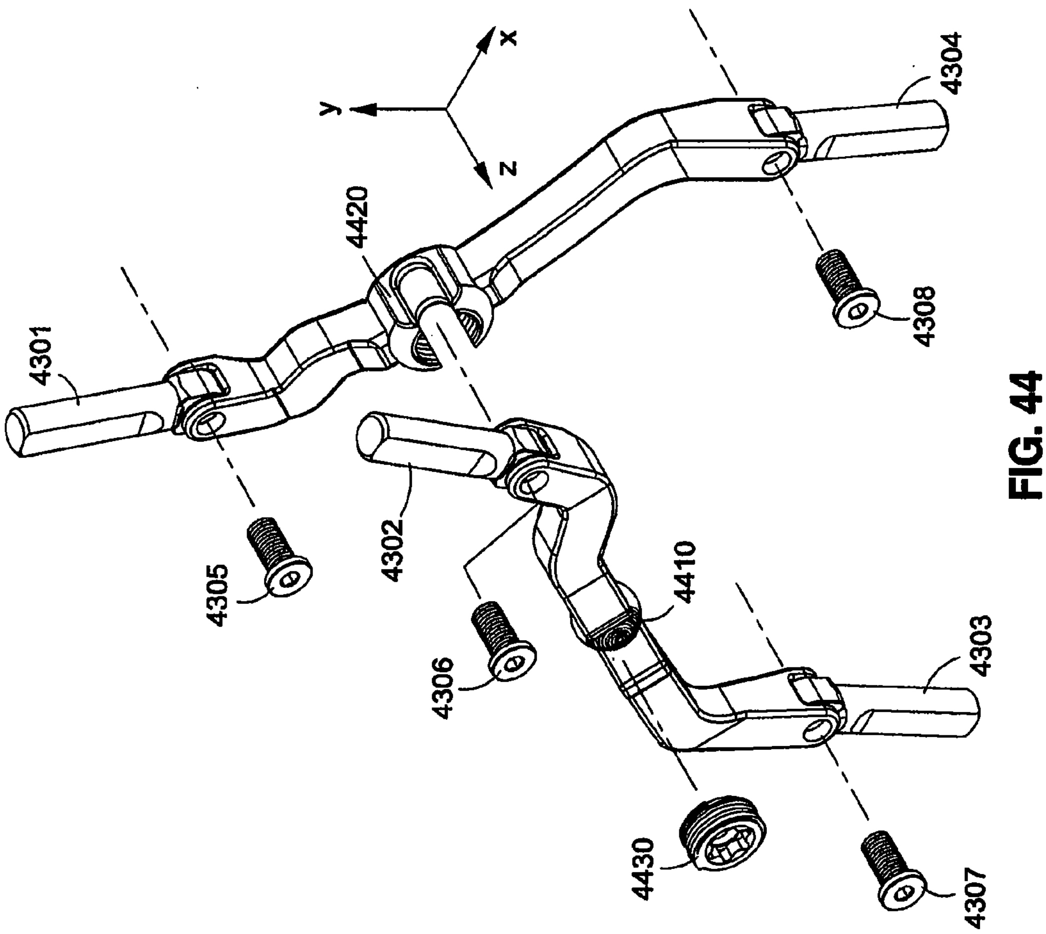
FIG. 42


x
y
z
4304
4420
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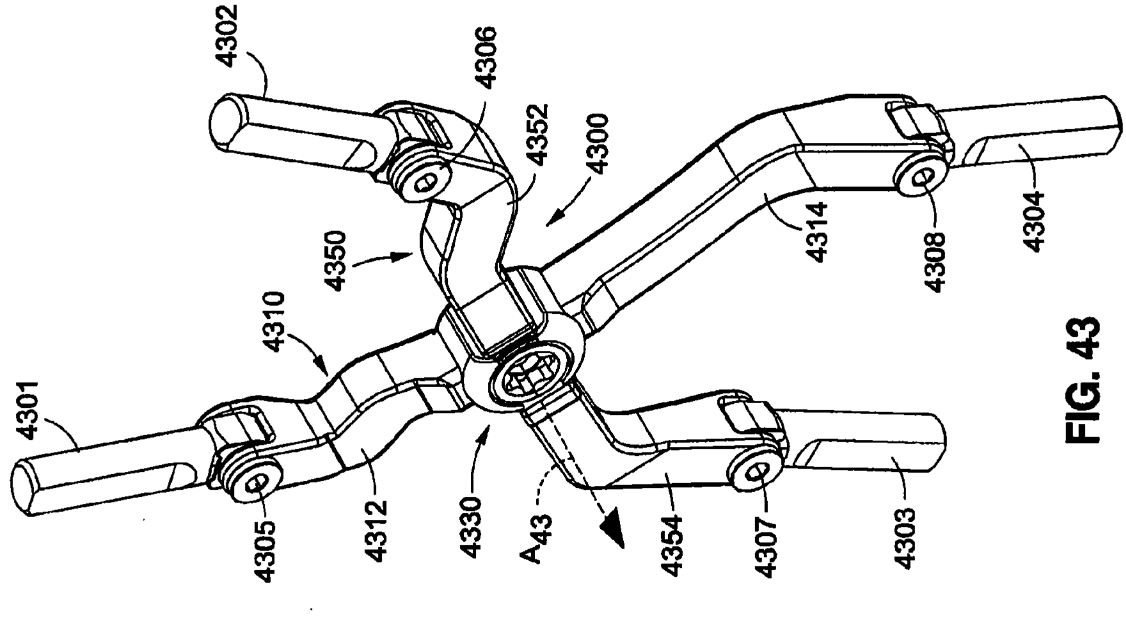
4410
4306
4303
4430
4307

FIG. 44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4330
A_{43}
4354
4307
4303

FIG. 43

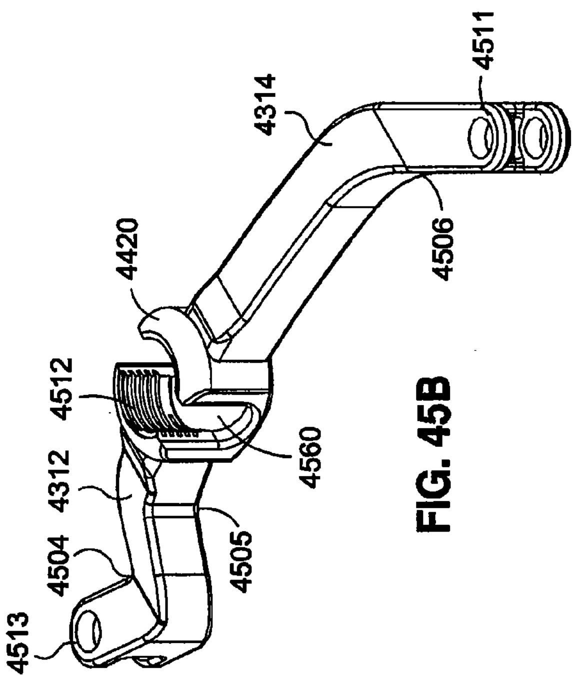

FIG. 45B

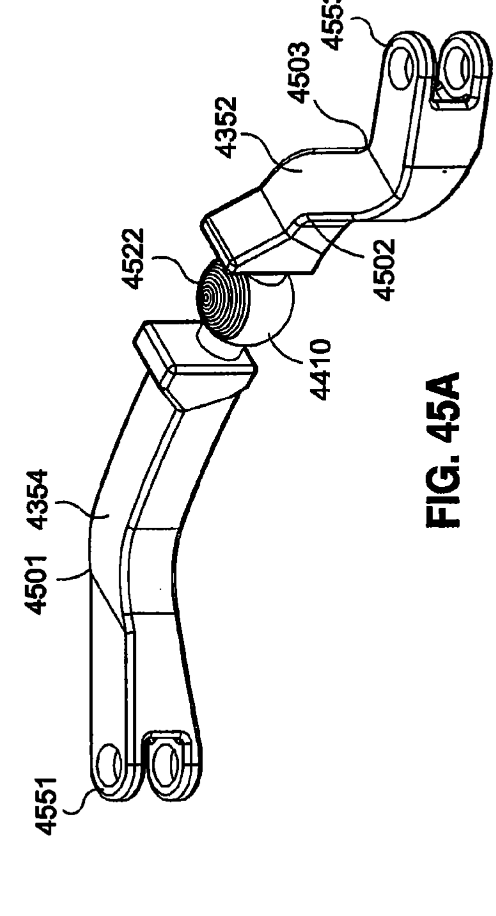

FIG. 45A

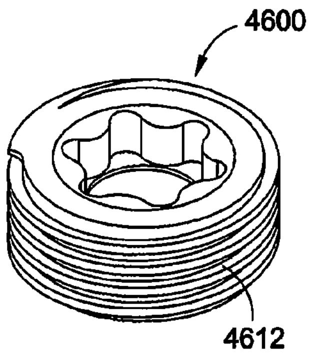

FIG. 46A

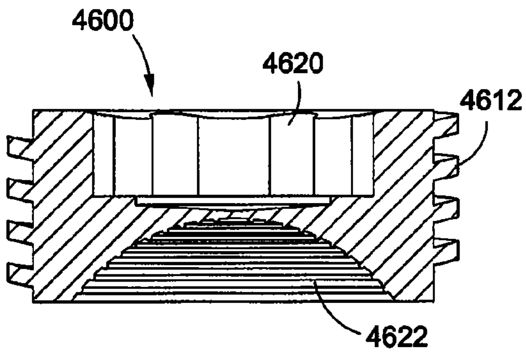

FIG. 46B

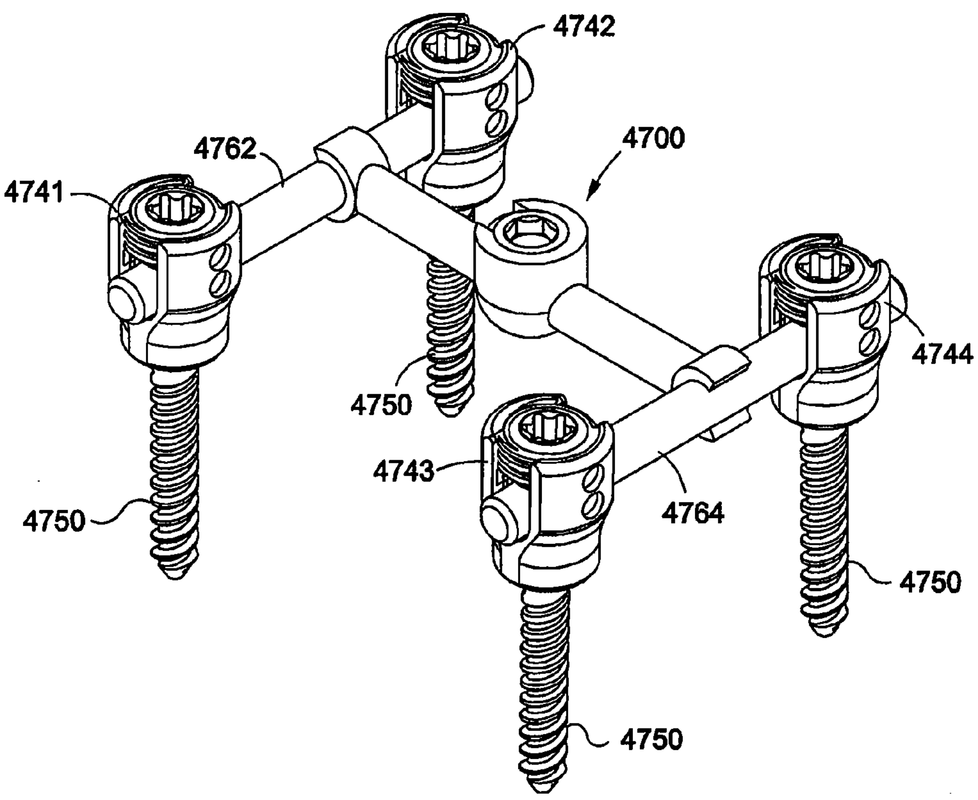

FIG. 47

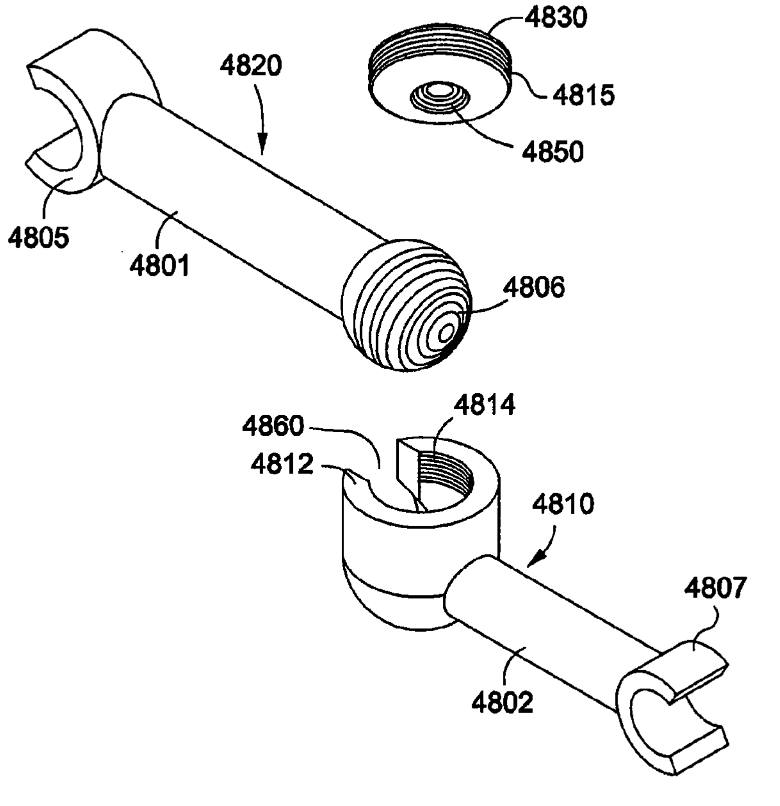
4820
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FIG. 48

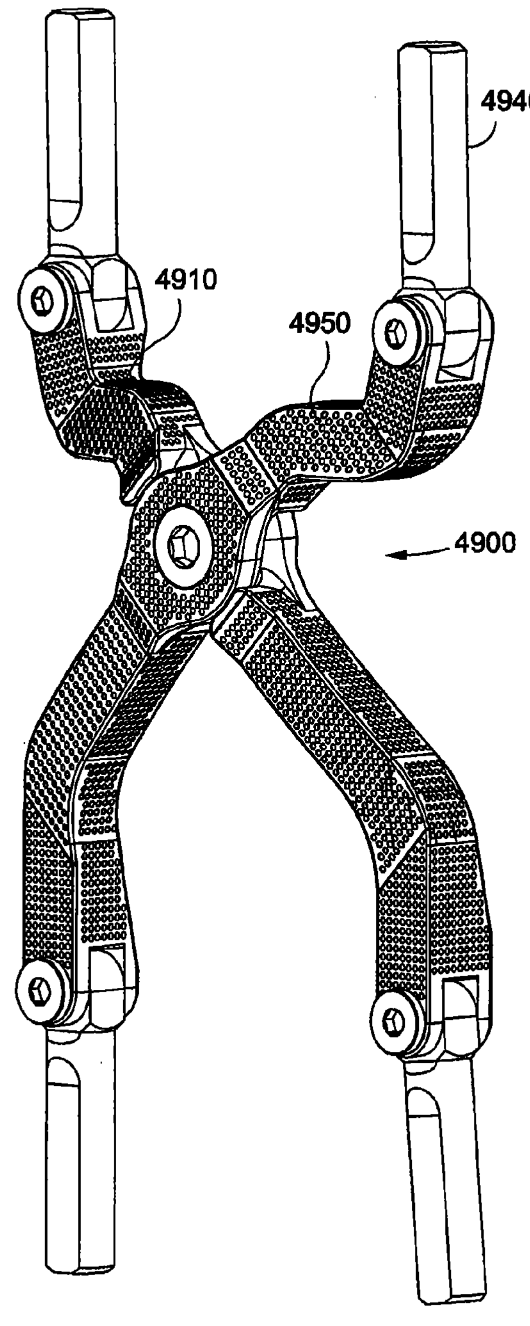

FIG. 49A

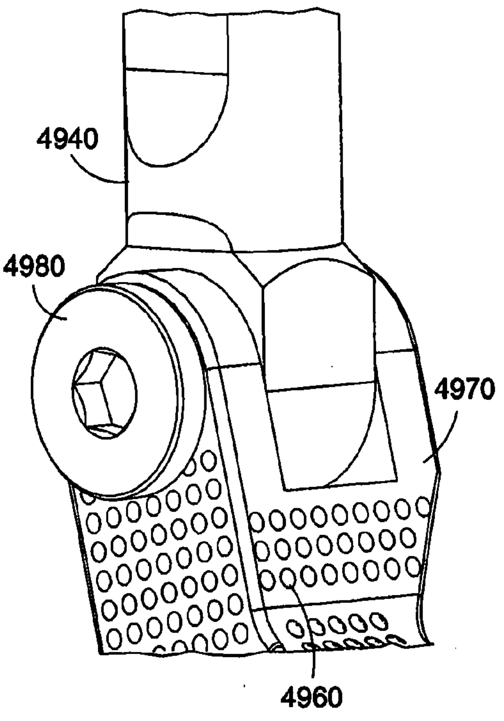

FIG. 49B

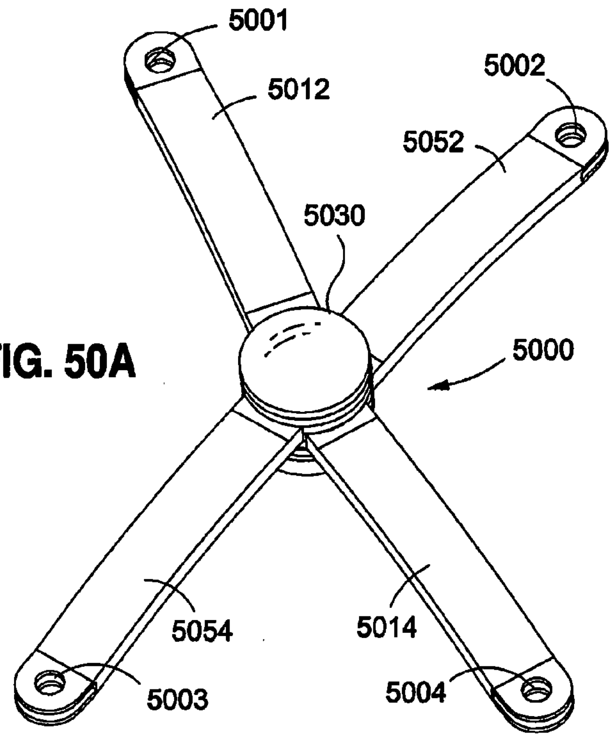

FIG. 50A

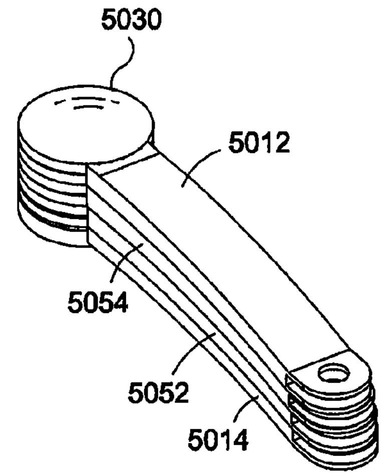

FIG. 50B

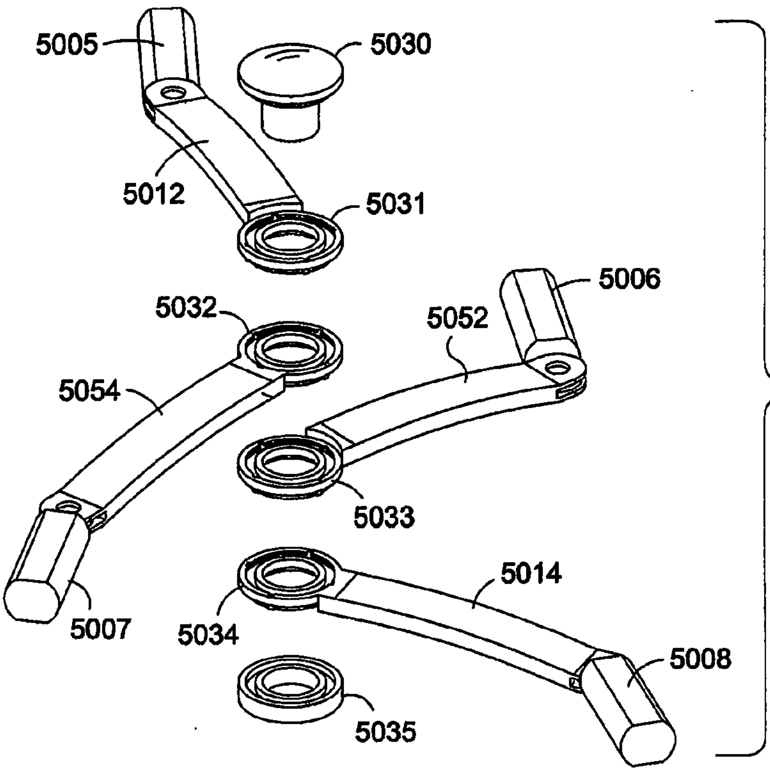

FIG. 50C

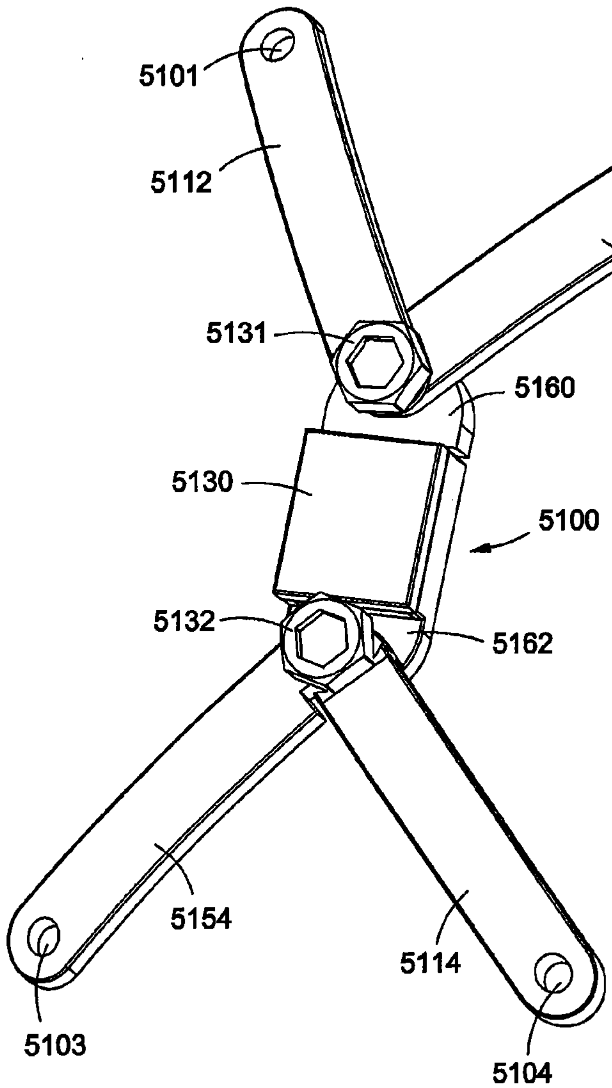

FIG. 51A

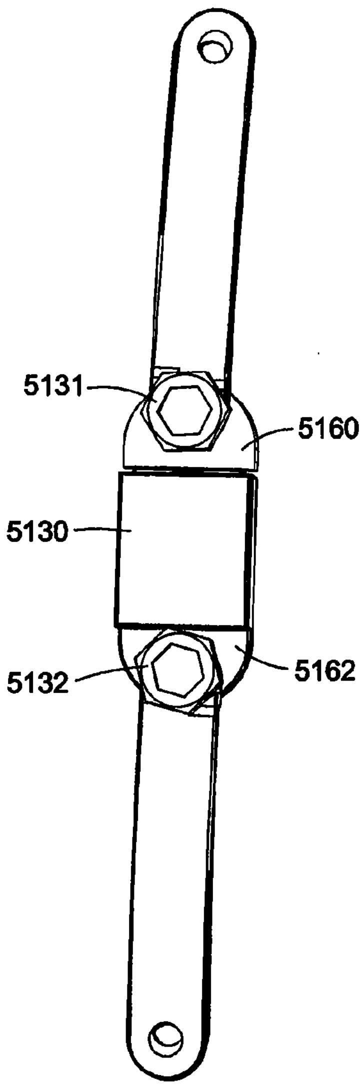

FIG. 51B

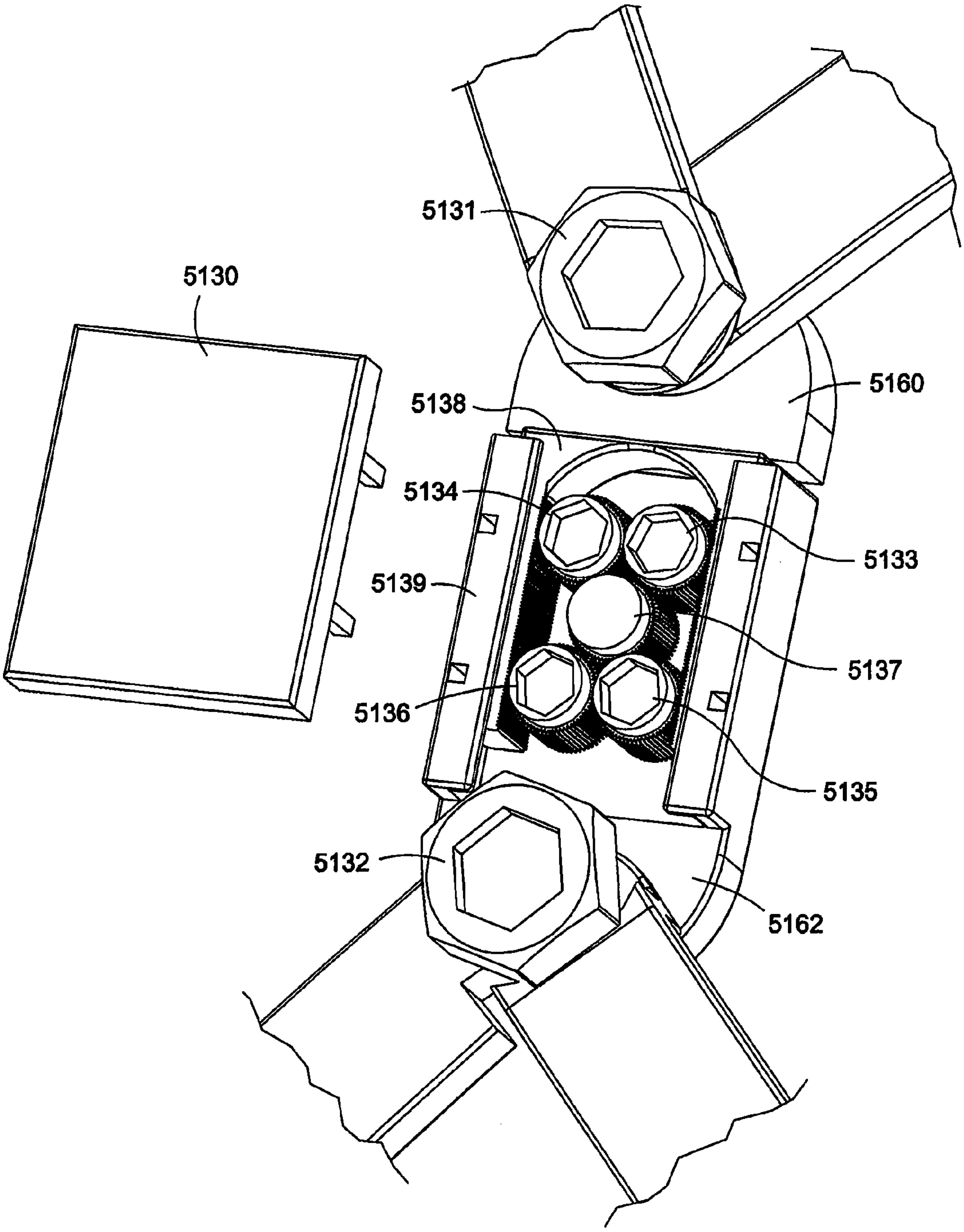

FIG. 51C