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(54) **BONE FASTENER AND INSTRUMENT FOR INSERTION THEREOF**

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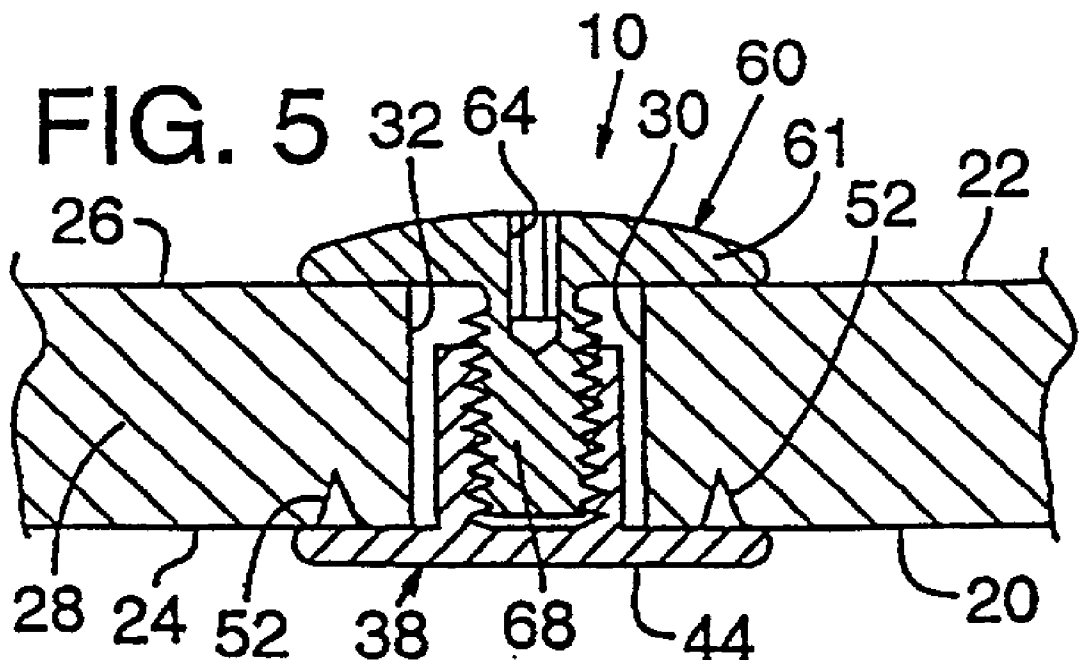
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(57) **ABSTRACT**

A bone member fastener for closing a craniotomy includes a cap and a base interconnected by a narrow cylindrical collar. The cap has an externally threaded stud that screws into an internally threaded bore of the collar, thereby allowing the cap and base to be brought into clamping engagement against the internal and external faces of a bone plate and surrounding bone. In a particularly disclosed embodiment, the base of the fastener is placed below a craniotomy hole with the collar projecting into the hole, and the stud of the cap is screwed into the bore of the base from above the hole to clamp a bone flap against the surrounding cranium. This device provides a method of quickly and securely replacing a bone cover into a craniotomy. The distance between the cap and base can be selected by how far the threaded stud of the cap is advanced into the internally threaded collar. The fastener is therefore adaptable for use in several regions of the skull having various thicknesses. An insertion tool with a long handle permits safe and convenient placement of the base between the brain and the internal face of the bone plate. Some disclosed embodiments of the fastener have a cap and base that conform to the curved surface of the skull, for example by having an arcuate shape or flexible members that conform to the curvature of the bone plate and surrounding cranial bone as the fastener is tightened.



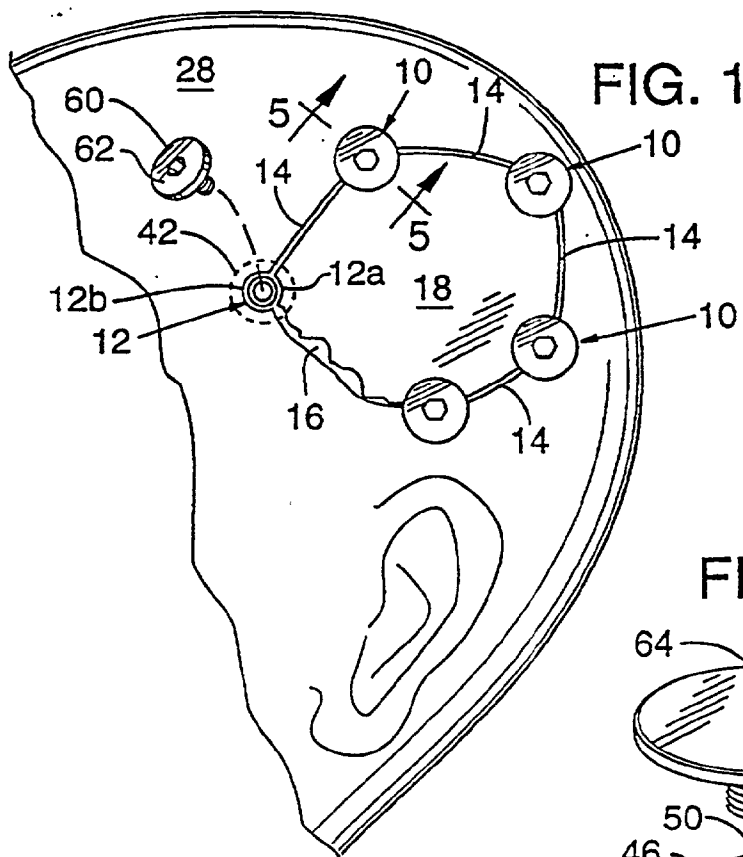


FIG. 2

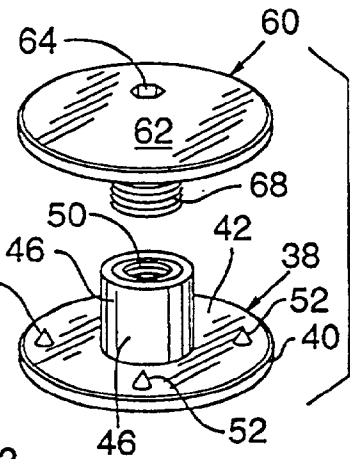


FIG. 3

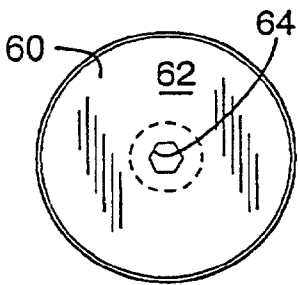


FIG. 4

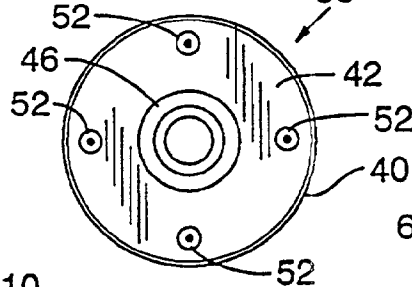


FIG. 5

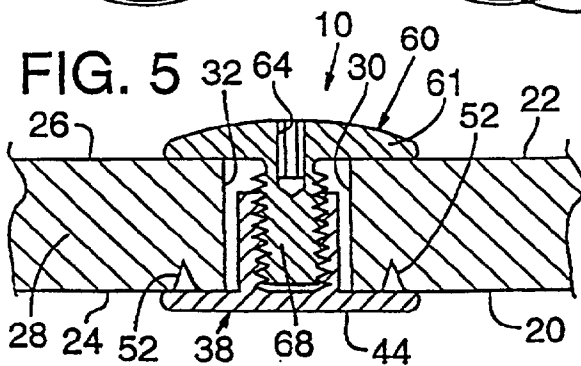
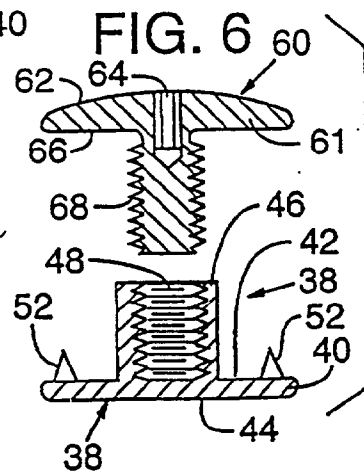
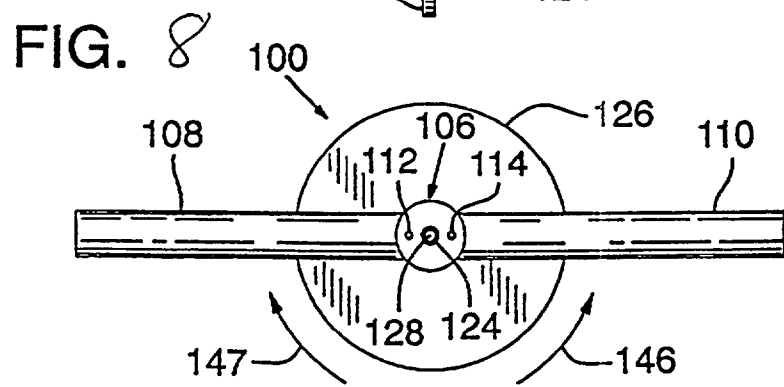
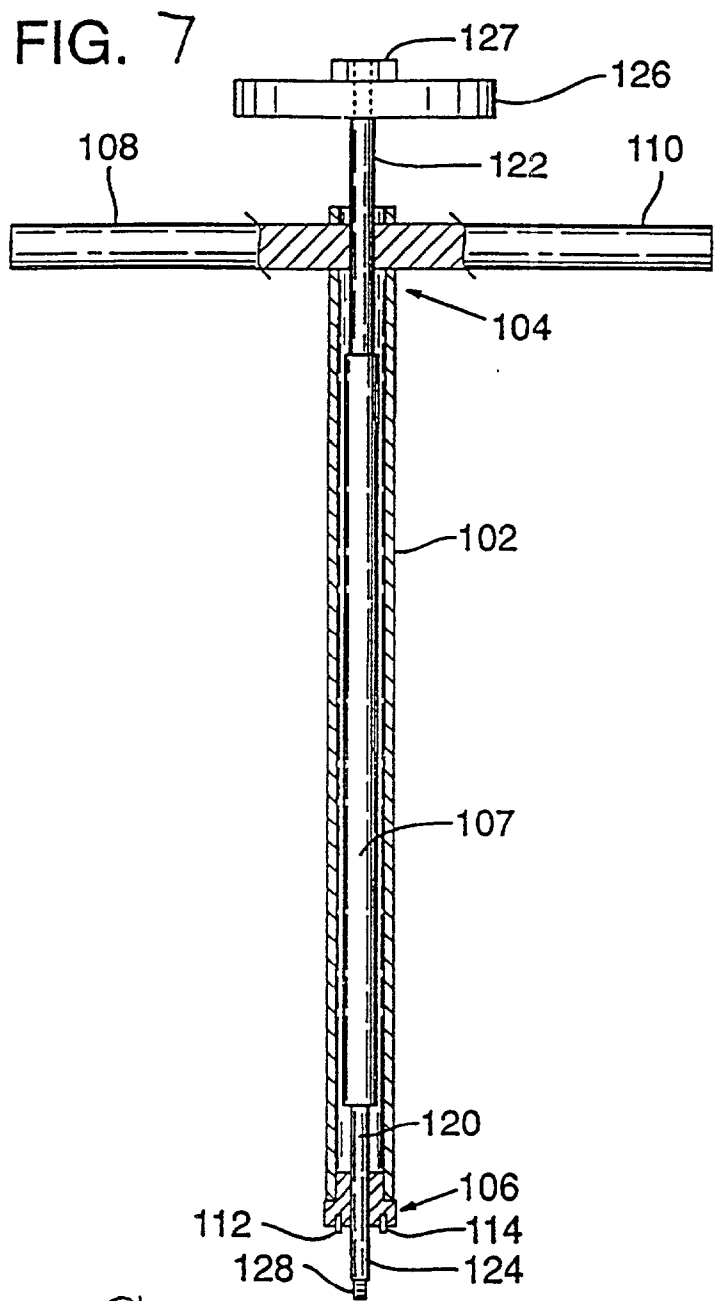


FIG. 6





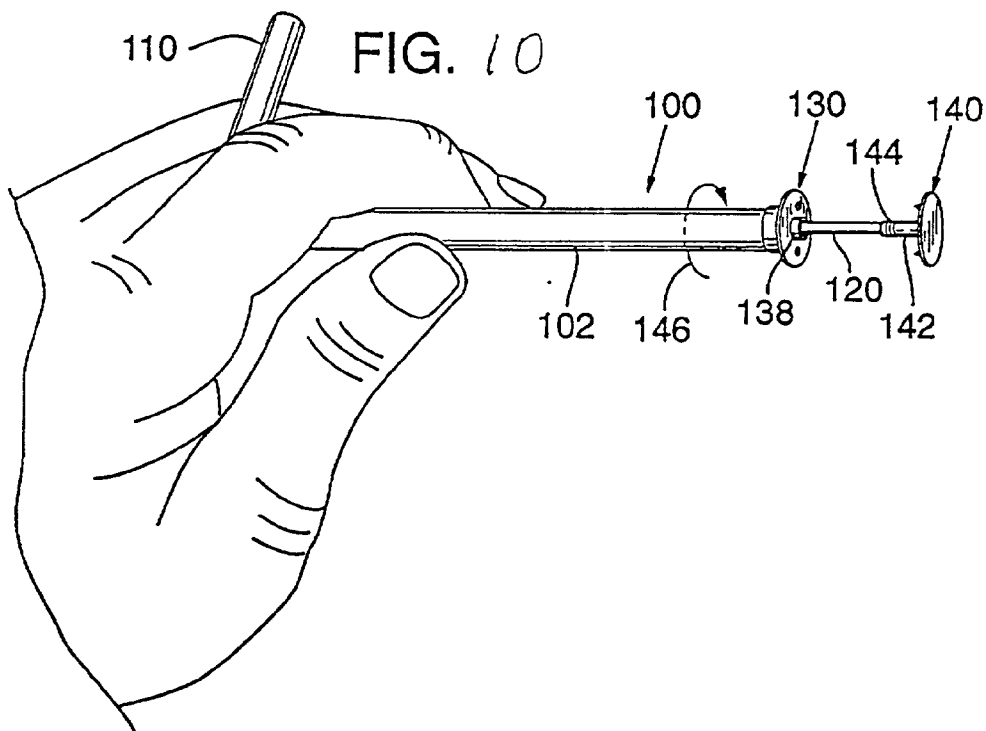
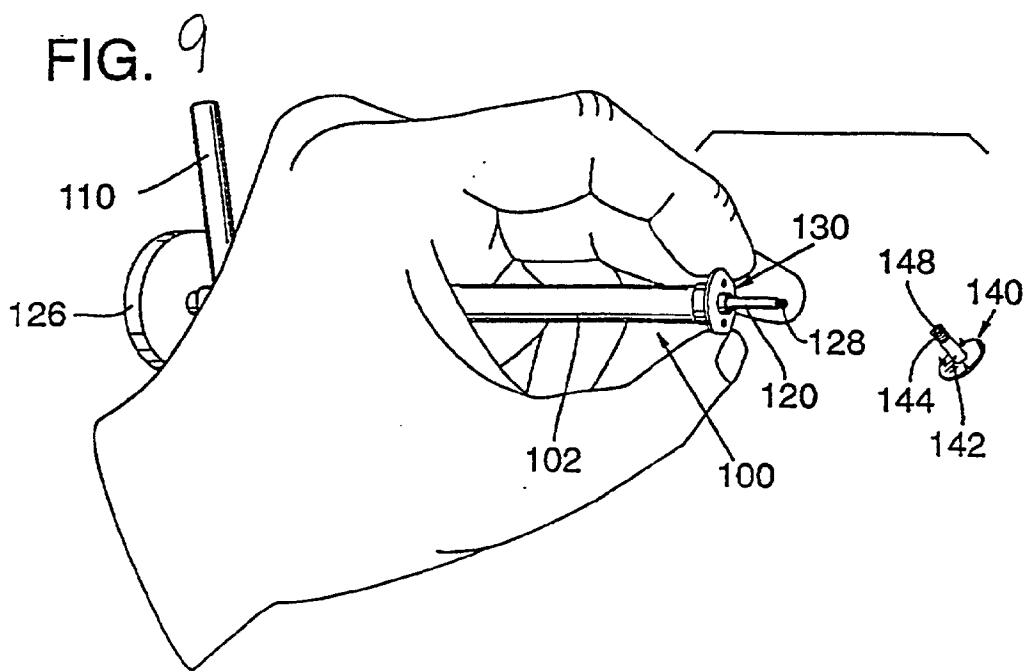


FIG. 11

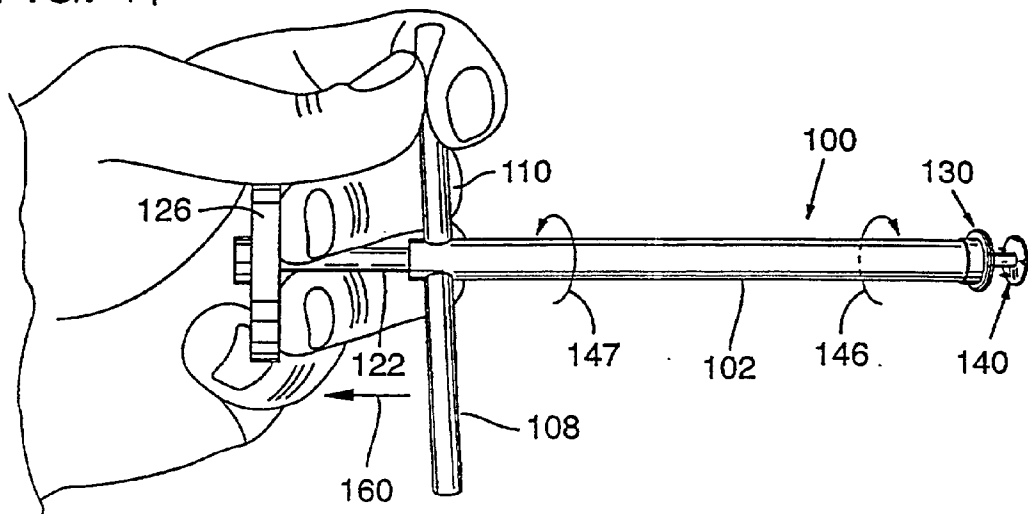
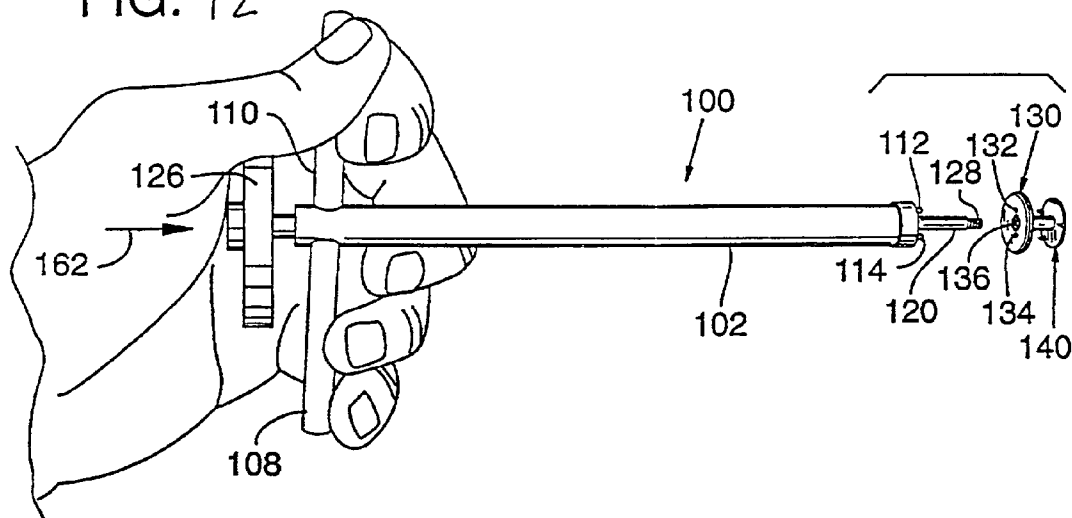
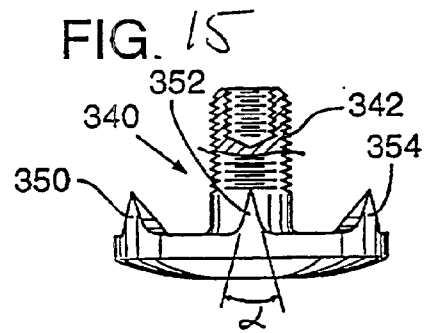
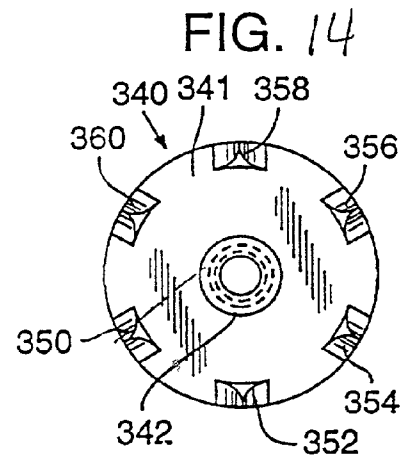
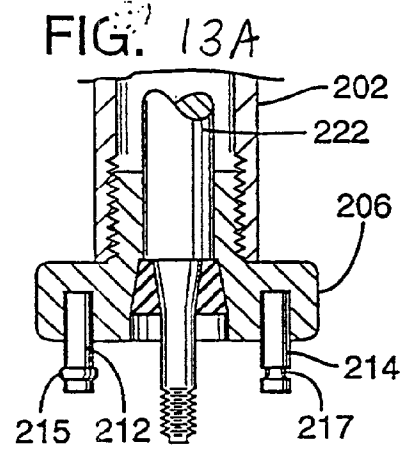
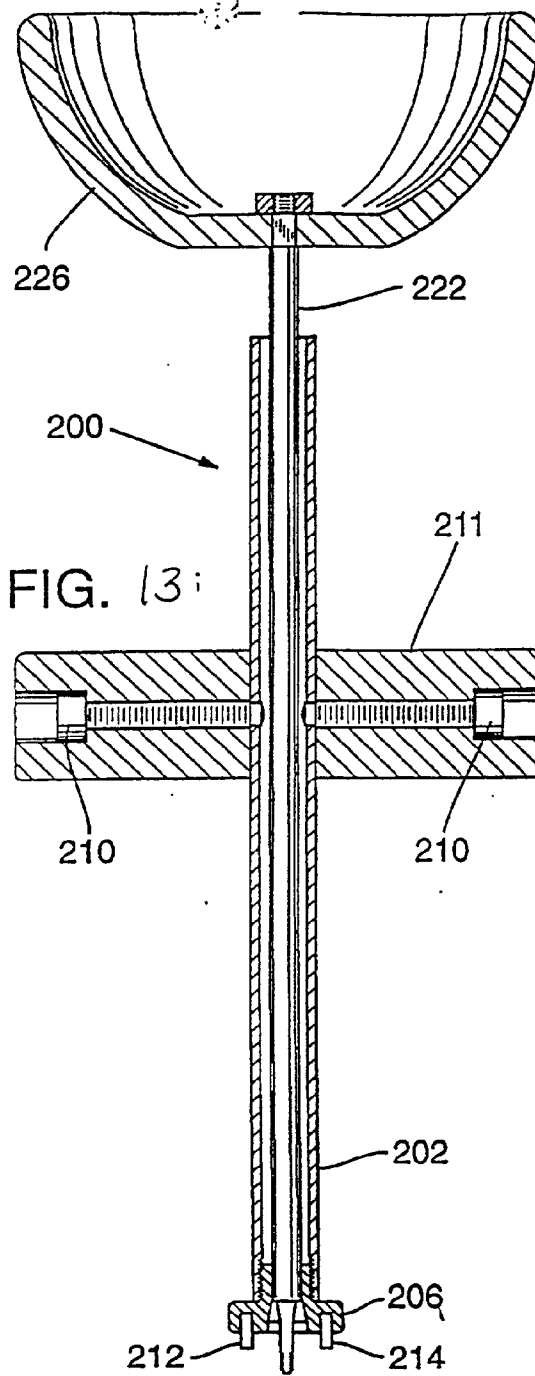
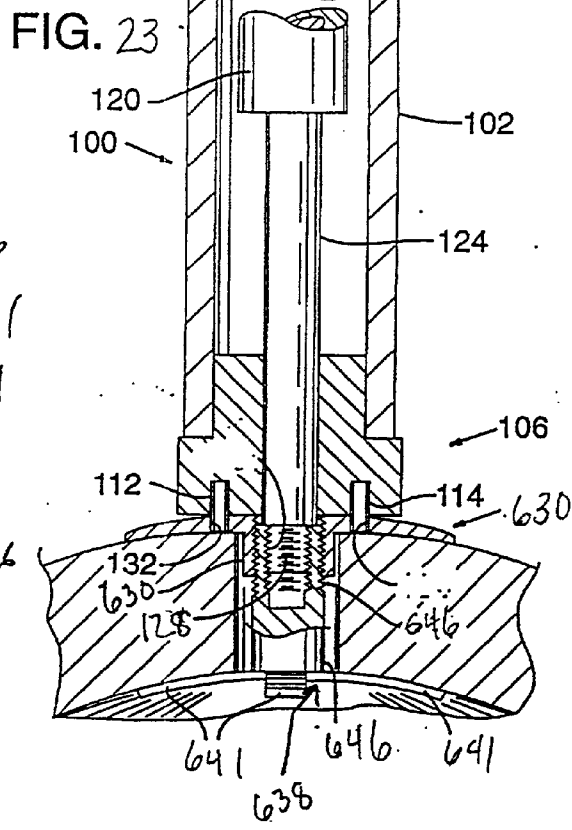
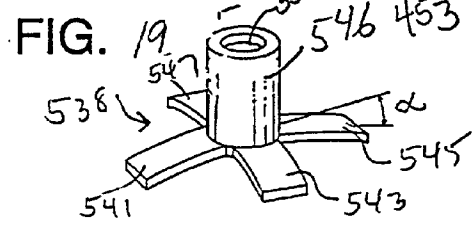
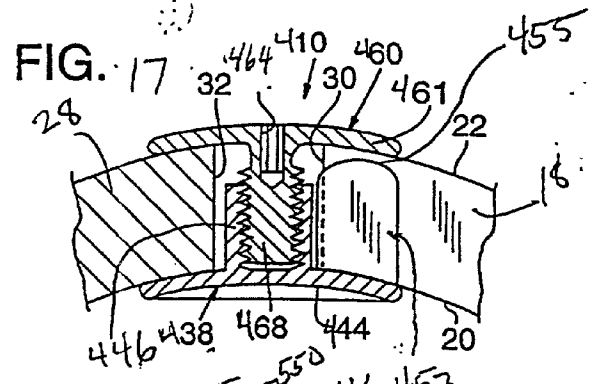
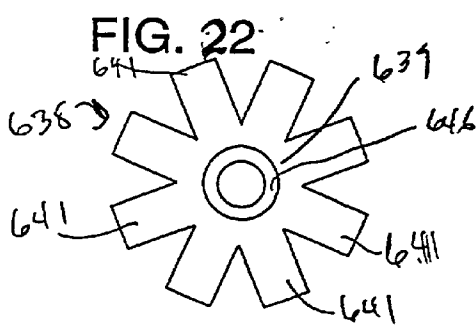
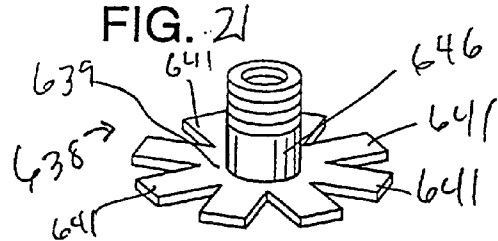
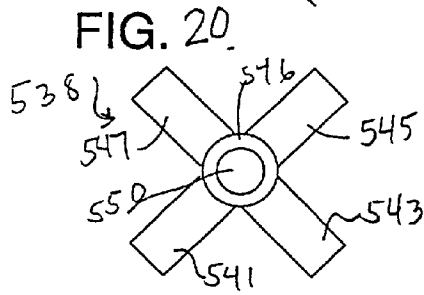
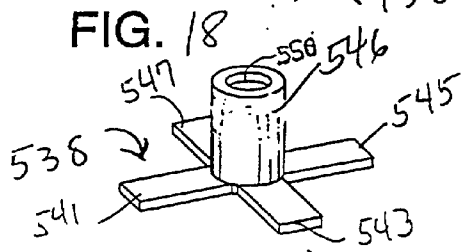
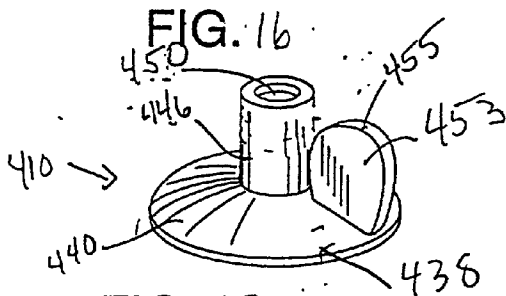


FIG. 12







## BONE FASTENER AND INSTRUMENT FOR INSERTION THEREOF

### CROSS REFERENCE TO RELATED CASES

[0001] This case claims priority from U.S. patent application Ser. No. 08/635,410 filed Apr. 26, 1996, which claims priority from U.S. Provisional Patent Application Serial No. 60/011,647 filed Feb. 14, 1996, and U.S. Provisional Patent Application Serial No. 60/014,048 filed on Mar. 25, 1996.

### BACKGROUND OF THE INVENTION

#### [0002] 1. Field of the Invention

[0003] This invention relates to a fastener for securing a bone plate to surrounding bone, for example when replacing a portion of the cranial vault removed during a craniotomy for a neurosurgical procedure. The invention also relates to an instrument for securing two threaded members to each other. The instrument may be used during neurosurgical procedures, or as a mechanical tool in many other contexts.

#### [0004] 2. General Discussion of the Background

[0005] A craniotomy is a surgical procedure in which a portion of the cranial vault is removed or folded back in a flap to permit surgical access to the cranial contents (such as the brain). To perform the craniotomy, several burr holes are drilled through the skull. The number and position of these holes varies depending on the shape of bone to be removed. For example, three burr holes are drilled at corner points if a triangular bone flap is desired. The burr holes are then connected by osteotomy cuts, for example using a Gigli flexible saw which is passed internally between the burr holes. The saw is then oscillated back and forth to cut the skull along a line of separation (defined by the connecting osteotomies) connecting adjoining burr holes. The bone cover is subsequently lifted off the underlying dura mater to expose the brain. The bone cover may either be completely removed from the surgical site, or folded back in a flap along an uncut edge of the flap.

[0006] After completion of the operation, the bone cover must again be fixed in its original position to protect the underlying brain. Conventional craniotomy closure requires that holes be drilled in the bone plate and surrounding cranium along the osteotomy lines, and stainless steel wire or silk sutures are then passed through the holes to retain the plate in place. Unfortunately, drilling the holes is time consuming and potentially dangerous, because of the risk of introducing infection. The sutures are also unstable and prone to breakage. Suture instability or breakage can lead to dangerous movements of the cranial plate against the brain, with pathologic sequelae similar to a depressed skull fracture. The sutures closing the osteotomy lines are not aesthetically pleasing, because they can leave irregularities in the overlying surface of the face or scalp. This irregularity is particularly unsightly if the surface of the bone plate is not held substantially co-planar with the surrounding bone.

[0007] Various fixtures have previously been proposed for securing the bone cover to the surrounding cranium. U.S. Pat. No. 5,201,737 discloses a flexible plate having a plurality of vanes with holes for receiving bone screws. The plate is placed over a cranial burr hole and adjoining osteotomy lines to provide external fixation of the bone cover to the surrounding cranium.

[0008] Other external bone plates are shown in U.S. Pat. Nos. 4,651,724; 4,923,471; 5,139,497 and 5,372,498. All of these plates are designed for external application to fractured bones, and require placement of a plurality of screws through the plates. As with the plate in U.S. Pat. No. 5,201,737 discussed above, placement of multiple screws through the plates is time consuming, predisposes to catastrophic infection, and is difficult to remove once in place.

[0009] A variety of fixation devices are also known for fusing fractured bones. An example of such a device is U.S. Pat. No. 2,511,051, in which an externally threaded stud screws into an internally threaded shank. Movement of the stud into the shank is guided by an hexagonal wrench that is inserted through the shank into a countersunk receptacle on the tip of the threaded stud.

[0010] U.S. Pat. No. 3,875,936 shows an attachment for replacing a trochanteric head to the femur by providing a barbed shear washer between the femur and trochanteric head. U.S. Pat. No. 5,098,433 uses a winged compression bolt for fusing fractured bones. U.S. Pat. Nos. 5,196,016 and 5,433,719 disclose fixation pins or screws for retaining bone fragments against one another.

[0011] In spite of the use of a variety of fasteners in orthopedic and neurosurgical procedures, improved techniques are still being sought to secure a cranial cover to the surrounding cranium following a craniotomy. Improved methods and devices for securing the fasteners to the skull are also disclosed.

[0012] Accordingly, it is an object of the present invention to provide a fastener that is especially suitable for closure of craniotomies.

[0013] Yet another object is to provide such a fastener that can be quickly and efficiently installed, and which is capable of easy removal in the event that subsequent intracranial access is required for another neurosurgical procedure.

[0014] Yet another object of the invention is to provide such a fastener that avoids the aesthetic drawbacks of prior fasteners, such as large indentations in skin overlying the craniotomy.

[0015] It is another object of the invention to provide such a fastener, and an instrument for manipulating the fastener, that allows it to be easily inserted and removed, yet which provides a potentially permanent and reliable fixation of the cranial cover, thereby avoiding the potentially catastrophic neurological consequences that can result from dislodgement or depression of the cranial cover.

[0016] Finally, it is an object of the invention to provide an instrument that is useful for engaging first and second members to each other, particularly when the engagement must occur on opposite surfaces, and one of the surfaces is not easily accessible.

### SUMMARY OF THE INVENTION

[0017] These and other objects are achieved by the bone cover fastener of the present invention, which has internal and external fastening members. At least one of the fastening members has a conforming surface that conforms to a curved surface, such as the inside surface of the cranial vault. In other embodiments, both the internal and external fastening members have conforming surfaces, such that a



surface of the internal fastener conforms to the internal surface of the cranium, while the external fastener also has a surface that conforms to the external surface of the cranium.

**[0018]** In one embodiment, there is a connector on the internal fastening member and a connector on the external fastening member, and the connectors cooperatively hold the internal and external fastening members in a fixed relationship that fixes the bone cover in a defect from which the bone plate has been removed. The conforming surface may be a curved surface of the internal fastening member that seats against the inner face of the cranium. In particularly disclosed embodiments, the internal and external fastening members are curved plates that respectively conform to the internal and external curvature of the skull. Alternatively, the conforming surface may be provided by flexible struts that deform into a curved configuration as the fastener is tightened.

**[0019]** In other embodiments, a tab is provided on one of the fastening members to prevent relative rotation between the fastening member and the cranium. In particular, the tab is a relatively flat member that extends away from the internal fastening member a sufficient distance to be retained between the bone plate and the remaining cranium. The tab is sufficiently thin that it fits within the gap between the bone plate and surrounding cranium. When the external fastening member is rotated relative to the internal fastening members to interconnect threaded connectors, rotation of the internal fastening member is opposed by the tab which is retained within the gap formed by the cranial osteotomy incision.

**[0020]** One of the connectors may be an elongated, externally threaded stud that projects from the first fastening member, while the second connector may be an elongated internally threaded collar that projects from the second fastening member. The stud is rotationally threaded into the collar, with the collar extending between the fastening members. The collar fits through the burr hole of a craniotomy incision, and each fastening member is wider than the collar and the burr hole to provide clamping surfaces above and below the burr hole that engage the internal and external surfaces of the bone cover and surrounding cranium. Screwing the threaded stud into the internally threaded collar brings the opposing fastening members closer together, and tightens them against the internal and external surfaces of the bone cover and surrounding cranium. The fastening members overlap margins of the burr hole and adjoining osteotomy lines to securely fix the bone cover to the surrounding bone.

**[0021]** In a disclosed embodiment, one of the fastening members is a base which includes a disc having a flat inner face and a flat outer face. A plurality of raised barbs extend from the inner face of the base to provide frictional engagement between the disc and bone. The other fastening member is a cap with an outer face that may be flat or convex, and a recess is provided in the outer face for engaging a drive member that rotates the cap. An externally threaded stud projects from an inner face of the base and an internally threaded collar projects from an inner face of the cap. The stud is approximately as long as the collar. The stud may be screwed partially or entirely into the collar, depending on the thickness of the bone cover. Hence the fastener has the versatility to be used in different locations of the skull, where bone thickness varies.

**[0022]** The fastener is used in a method for fixing a bone plate, such as a cranial cover, in a bone defect, such as a craniotomy opening. The bone plate has opposing internal and external surfaces that are to be held in position substantially co-planar with internal and external surfaces of surrounding bone. The method provides the steps of placing the base and cap of the fastening member on opposing internal and external surfaces of the bone plate, with the collar projecting into the hole, and a portion of the base and a portion of the cap overlapping the border of the junction between the bone plate and surrounding bone. The base and cap are then rotated into threaded engagement with one another, until the cap and base tightly engage opposing surfaces of the bone plate and surrounding bone to clamp the bone plate in place. In particularly preferred embodiments, the fastener is placed through a craniotomy burr hole, with the cap and base covering and closing the burr hole.

**[0023]** In yet another embodiment of the invention, a fastening instrument is provided to secure first and second members to each other. The instrument includes a sleeve, a shaft or rod that slides within the sleeve, an attachment mechanism on the sleeve for engaging the first member to the instrument, and an engagement structure on the shaft that engages the second member and pulls it into engagement with the first member. In more particular embodiments, the sleeve includes a handle extending out from the sleeve, and the rod includes a handle that allows the rod to be rotated and reciprocated relative to the sleeve. There is a threaded tip on the rod that engages an internally threaded collar of the first member to screw the first and second member to be moved into engagement with each other.

**[0024]** In a more particular embodiment, the instrument includes a sleeve that has a handle (such as a rod or disc) extending from the sleeve. A rod slides within the sleeve, and has a threaded tip at a distal end of the rod, and a handle (such as a disc or curved hand grip) near a proximal end of the rod. The handle extends perpendicularly to the rod, and allows an operator to both rotate the rod and move the rod axially within the sleeve. A distal tip of the sleeve that surrounds the threaded rod has a plurality of locking members or prongs that extend from the tip of the sleeve and fit into complementary receptacles on one of the fasteners to lock the fastener to the tip of the sleeve, for example by frictional engagement of the prongs to one of the fasteners.

**[0025]** The instrument is designed to engage two threaded fasteners to each other. The fastener includes a cap and a base, and a receptacle in the cap that engages the prongs on the sleeve to lock the cap to the sleeve. The cap also includes an opening through which the rod can slide. The base of the fastener includes a post having both internal and external threads, and the threaded tip of the rod has threads that are complementary to the internal threads of the post. The cap has a collar with internal threads that are complementary to the external threads on the post.

**[0026]** The fasteners are attached to each other by first engaging the fastener cap to the sleeve of the base by introducing the prongs into the receptacles on the cap. The rod is then extended through the cap, and the base secured to the rod by threading the threaded tip of the rod into the internally threaded post of the base. The sleeve is then axially advanced over the rod until the external threads of the base post abut the internal threads of the cap collar. The

rod and sleeve are then rotated relative to each other (for example by rotating the shaft) to screw the externally threaded tip of the post on the base into the internally threaded collar of the cap. The threaded rod tip is then unscrewed from the internally threaded post of the base. The connected fasteners may then be disengaged from the instrument, for example by pulling the instrument away from the fasteners to disengage the locking member from the fasteners. Alternatively, axial movement of the rod towards the fasteners brings the threaded rod tip into abutment against the internal threads of the post, and pushes the fasteners off the locking members to disengage the fasteners from the instrument.

[0027] The instrument of the present invention can be used with many different types of fasteners, in many situations where two fasteners must be secured to each other in a difficult to reach location. The instrument is particularly useful when the fasteners are to be secured to opposite faces of a barrier that inhibits access to both faces of the barrier. One particular fastener with which the instrument can be used is the bone cover fastener of the present invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a schematic view of a portion of the human skull in which a craniotomy has been performed, and fasteners of the present invention have been placed to secure the cranial cover to surrounding cranium.

[0029] FIG. 2 is an enlarged, perspective view of one of the fasteners of the present invention, wherein the cap and base are disengaged.

[0030] FIG. 3 is a top view of the cap of the fastener of FIG. 2.

[0031] FIG. 4 is a top view of the base of the fastener of FIG. 2.

[0032] FIG. 5 is a cross-sectional view taken along section line 5-5 of FIG. 1.

[0033] FIG. 6 is a cross-sectional view of the fastener shown in FIG. 2.

[0034] FIG. 7 is a cross-sectional view of a fastening instrument suitable for engaging another embodiment of the fasteners to one another.

[0035] FIG. 8 is an end elevational view of the fastening instrument of FIG. 7.

[0036] FIG. 9 is a view of a fastener instrument, showing the fastener cap secured to the instrument.

[0037] FIG. 10 is a view similar to FIG. 9, but showing both the fastener cap and base secured to the instrument.

[0038] FIG. 11 is a view showing how the instrument is manipulated to rotate the fastener base relative to the fastener cap to secure the base and cap to each other.

[0039] FIG. 12 is a view showing the instrument disengaged from the assembled fastener.

[0040] FIG. 13 is a side elevational view showing another embodiment of the fastening instrument, in which the sleeve handle is a disc and the rod handle is a curved handgrip.

[0041] FIG. 13A is an enlarged view of the tip of the instrument shown in FIG. 13.

[0042] FIG. 14 is a top plan view of another embodiment of the base, showing distribution of the barbs around the inner face of the base.

[0043] FIG. 15 is a side elevational view of the base shown in FIG. 14, illustrating the profile of the barbs.

[0044] FIG. 16 is a perspective view of the base of another embodiment of the fastener, in which an inner face of the base is convex and an outer face (not shown) of the base is concave.

[0045] FIG. 17 is a cross-sectional view of the assembled fastener extending through a craniotomy burr hole and retaining a bone plate in place within a cranial defect.

[0046] FIG. 18 is a perspective view of yet another embodiment of the base having flexible struts.

[0047] FIG. 19 is a view of the base shown in FIG. 18, but wherein the struts have flexed to conform to an interior curve of an internal face of a bone plate.

[0048] FIG. 20 is a top view of the base shown in FIG. 18.

[0049] FIG. 21 is a view of another embodiment of the base which includes multiple struts.

[0050] FIG. 22 is a top view of the base shown in FIG. 21.

[0051] FIG. 23 is a cross-sectional view of the fastener shown in FIGS. 21 and 22, illustrating the fastening instrument that is used to assemble the fastener in the bone plate.

#### DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0052] The present invention includes fasteners for securing two table-like or curved plate structures to each other. The invention also includes a positioning instrument that is particularly useful for positioning the fasteners in a surgical wound, and a fastening instrument for securing the fasteners to each other. This detailed description will describe several embodiments of the fasteners, as well as an instrument that can engage the fasteners to each other. The instrument can be used to secure many different types of fasteners to each other, but is shown in connection with the neurosurgical fasteners for purposes of illustration.

[0053] A clamp 10 is shown in the drawings for closing a craniotomy (FIG. 1), which is a particular type of table-like structure. As is known in the art, a craniotomy is performed by incising pericranium and muscle with cutting diathermy in the line of an intended bone flap. An incision is not made interiorly where a pedicle of pericranium or temporalis muscle is often left uncut to allow some blood supply to the bone and overlying tissue to remain intact. Alternatively, the pericranium and muscle may be detached completely from the intended bone flap.

[0054] The craniotomy is performed by making a series of burr holes 12 through the cranium about six or seven centimeters apart with a conventional trephine. The underlying dura mater is separated from the bone covering the osteotomy site ("the bone cover") using a periosteal elevator. Osteotomies 14 between the burr holes 12 are then made using a Gigli flexible saw that is passed between adjacent burr holes and moved back and forth to make the osteotomies from the internal to the external surfaces of the cranium. The base of the flap, as illustrated in FIG. 1, is not

made with a saw. A bone forceps (such as a de Vilbiss forceps) is used to cut between burr holes until the bridge breaks at base **16** when the flap is elevated.

[0055] After placement of the burr holes and performance of the osteotomies, a bone plate **18** is separated from the surrounding cranium along a line of separation formed by osteotomies **14**. Each burr hole **12** has a plate portion **12a** and a complementary cranial portion **12b** which together form the completed hole **12**. Trephines come in graduated sizes, for example between 0.5 and 2 inches (13-51 mm) diameter, for drilling burr holes of sizes varying across this usual range.

[0056] The bone plate **18** may be completely removed if osteotomies connect all of the burr holes **12**. However, it is often preferred to leave an intact edge of the craniotomy (such as **16**) to preserve the blood supply to the bone (as shown in FIG. 1). In either case, the bone plate or flap is referred to as the cranial cover.

[0057] After the neurosurgical procedure is performed, the bone defect must be repaired by placing the cranial cover **18** back in the defect with opposing internal surface **20** and external surface **22** (FIG. 5) substantially co-planar or aligned with the internal surface **24** and external surface **26** of surrounding cranium **28** (FIG. 5). A transverse face **30** of bone cover **18** must also be fixed in apposition with a transverse face **32** of cranium **28**, along a border of junction defined by the osteotomy **14** between bone cover **18** and surrounding cranial bone **28**.

#### Structure of the Fastener

[0058] In one embodiment, the fastener **10** is a one-piece member that includes a base **38** (FIGS. 2, 4-6) formed by a solid disc **40** having a flat inner face **42** and a flat outer face **44**. Inner face **42** circumscribes an elongated, cylindrical collar **46** projecting outwardly from the center of inner face **42**. An internally threaded bore **48** extends longitudinally through collar **46**, but does not extend through disc **40**. Hence bore **48** in this embodiment communicates only with a round opening **50** at the top of collar **46**, and does not extend through disc **40**, which has a flat, solid, lower face **44**. In other embodiments, bore **48** may extend through the base.

[0059] A plurality of raised, conical or pyramidal barbs **52** are integral with and extend upwardly from inner face **42** of disc **40**. As best shown in FIG. 4, four barbs **52** are located on face **42**, equally spaced around disc **40**, and inwardly spaced from the perimeter of the disc. Barbs **52** taper to sharp tips **54** for engaging bone against which the barbs are placed, and into which the barbs may be embedded by pushing the barbs against the bone. The cancellous nature of the skull bone makes it particularly suitable for embedment of the barbs therein.

[0060] A cap **60** fastens to base **38** to form a fastener that secures bone cover **18** in place, and occludes the burr holes. Cap **60** is a solid disc **61** (FIGS. 5-6) with a convex outer face **62** that is smooth except for a recess **64** for engaging a complementary drive member (not shown) that rotates cap **60**. The illustrated recess **64** is hexagonal, and designed to receive the tip of a surgical instrument resembling an Allen wrench. However, an elongated kerf could alternatively be scored in the surface **62** for receiving the tip of an instrument resembling a screw driver.

[0061] Cap **60** has a flat, annular inner face **66** from which an externally threaded stud **68** projects for inter-engagement with internally threaded bore **48** of collar **46**. Stud **68** projects from the center of face **66**, and the external threads are helical and machined to complement and screw into the internal helical threads of collar **46**. Hence the collar resembles a nut into which the cap threads like a bolt. Stud **68** preferably has a length (extending perpendicularly away from face **66** along a longitudinal axis of fastener **10**) that is approximately as long as threaded bore **48** of collar **46**. The greatest width of cap **60** (as measured by the diameter of disc **61**) and the greatest width of base **38** (as measured by the diameter of disc **40**) are each wider than the outer diameter of cylindrical collar **46**. The outer diameter of cylindrical collar **46** is less than the diameter of burr holes **12**, but the diameters of discs **40** and **61** are greater than the diameter of burr holes **12**. Cap **60** and base **38** each have a longitudinal axis of symmetry, such that the fastener when assembled is symmetric.

#### Method of Use to Close Craniotomy

[0062] The fastener **10** is used in a method of replacing a bone plate, such as cranial cover **18**, following a craniotomy. As already described, the craniotomy is performed by providing a plurality of craniotomy holes, such as burr holes **12**, through the skull. The burr holes are subsequently connected by osteotomies **14** to create a separation border for the cranial bone cover (which may be a plate that is removed or a flap that is folded back along one edge). The craniotomy opening therefore includes a portion **12a** of burr hole **12** formed in cranial cover **18**, and a complementary portion **12b** of the hole formed in surrounding cranial bone **28**.

[0063] Bone cover **18** has internal face **20** and external face **22** that are respectively placed in substantially coplanar relationship with internal face **24** and external face **26** of the surrounding cranial bone **28** when a craniotomy is closed. Opposing transverse faces **30**, **32** of the bone cover and surrounding bone appose along the separation border when the bone cover is in place. Faces **30**, **32** are substantially parallel to each other when in apposition.

[0064] In the method of the present invention, the bone cover **18** is folded back along a base **16**, or completely removed as a plate, to expose the underlying dura mater and brain. Following the intracranial procedure, and prior to replacing the bone flap into its original orientation within the craniotomy opening, base **38** is placed below each burr hole **12** with the inner face **42** of base **38** against the internal surface **24** of cranium **28**, such that one or more of barbs **52** engage the internal face **24**. Base **38** overlaps the margins of hole **12** and the separation border between the cranial cover and surrounding bone (as shown in FIG. 1). Collar **46** projects upwardly into or through the portion **12b** of the hole, but preferably does not extend out of the external surface. Cranial cover **18** is then replaced into the craniotomy opening, for example, by folding the bone flap along base **16** back down into the craniotomy opening.

[0065] Once cranial cover **18** is restored to its original position in the craniotomy opening, complementary portions **12a**, **12b** now reform hole **12**. Collar **46** is centered in hole **12**, with barbs **52** engaging the internal faces **20** and **24** of cover **18** and cranium **28** (FIG. 5). Cap **60** is then positioned over the reformed hole **12**, with externally threaded stud **68**

above opening **50**. Stud **68** is introduced into collar **46** through opening **50**, and a drive member (such as a surgical instrument resembling an Allen wrench) is inserted into hexagonal recess **64** to rotate cap **60** and advance stud **68** into threaded bore **48**. Continued rotation of cap **60** diminishes the distance between base **38** and cap **60**, to tighten inner faces **42**, **66** of the base and cap against the internal and external surfaces of the cranium and cranial cover. The cap and base are thereby brought together in frictional engagement against opposing faces of the cranial cover **18** and surrounding bone **28**, thereby clamping the cranial cover and surrounding bone to each other. Barbs **52** of base **38** anchor the base to both the cranial cover and surrounding bone, preventing rotation of the base while the cap is screwed into the collar. The base is attached to the bone as barbs **52** become progressively advanced into the bone by tightening of the fastener.

[0066] The fastener is used to clamp the cranial cover to the surrounding bone at one or more of the burr holes, and preferably all of the burr holes as shown in FIG. 1. A base **38** is therefore positioned below each burr hole **12** with collar **46** projecting up into the hole prior to replacement of cranial cover **18**. A cap **60** is then screwed into each internally threaded collar until the cap and base clamp the bone cover **18** and surrounding cranium securely to each other. The cap and base are in a fixed relationship determined by the degree of advancement of the externally threaded stud **68** into the internally threaded collar **46**, so that movement of the bone plate is substantially prevented. The bone plate and surrounding bone are held firmly in place with respect to each other, which avoids inadvertent depression of the cranial cover (with attendant catastrophic neurological consequences).

[0067] The smooth, convex top outer face **62** of cap **60** diminishes the aesthetic problem of visible indentations on the skull or face overlying the craniotomy burr holes. The closed base **44** tightly engages the internal surfaces of the cranial cover and surrounding cranium, providing ideal occlusion of the hole, to help avoid infection or trauma. The fastener also clamps the cranial cover in place quickly, thereby diminishing the period of time the brain must be exposed, and also reduces medical expenses associated with prolonged time in the operating room. The fastener is also easily removed, for example, by inserting an instrument into recess **64** of cap **60** and rotating the cap off of the fastener, to allow the bone flap to be subsequently removed if a follow-up neurosurgical procedure is required.

[0068] The fastener **10** is made of any biocompatible material, including stainless steel, titanium alloy, polyglycolic acid, silicone rubber, teflon or nylon. Titanium is a particularly preferred material. The biocompatibility of these and other materials can be enhanced by functionalization of the surface of the fasteners. Plasma gas discharge and corona treatment with reactive groups introduced on polymeric surfaces have been described as ways to modify biomaterial surfaces. See Lee et al., *Biomaterials* 12:443, 1991 and Lee et al., *J Colloid Interface Sci.* 151:563, 1992.

[0069] The fastener **10** may be made in many different sizes. For purposes of illustration, the diameter of the stud **68** can be 7 mm (the same diameter as cylindrical bore **48**); the external diameter of collar **46** may be 8 mm; the diameter of disc **61** can be 20 mm; the diameter of disc **40** may be 20

mm. In one preferred embodiment, stud **68** is 6 mm long, which is the same length as collar **46** and its internal bore **48**.

[0070] The fastener of the present invention is adjustable for use in repairing craniotomies through bone of varying thickness. The pterion (in the temporo-parietal region) for example, is quite thin and may require a fastener with a 3 mm stud and collar, with advancement of the cap and base toward each other until the stud **68** has been completely advanced into collar **46** and face **66** of disc **61** abuts against collar **46**. The 3 mm stud and collar, however, would also allow the fastener to clamp bones up to 6 mm thick (if the stud is only initially advanced into the collar). The parietal or frontal bone, however, may be 10-20 mm thick. A fastener with a 6 mm long stud **68** (and a 6 mm long internally threaded collar) can clamp bones together varying in thickness from 6 mm to 12 mm. A longer stud and collar (for example the stud and collar each 12 mm long) could clamp together bones from about 12 mm thick (when the fastener is fully tightened) to 24 mm thick (when the cap and base are initially engaged but before more rotation of the cap into the base occurs).

[0071] Other variations of the disclosed fastener are possible. The internally helically threaded collar, for example, may depend from the cap while the externally helically threaded stud may project from the base. The cap and base may assume many shapes other than circular, and may for example be square or triangular. Bone plates other than in the skull may be secured to surrounding bone, for example a relatively flat top bone such as the trapezium, mandible, maxilla, or bones of the orbit. The convex face of cap **60** may also be flat, particularly in areas of the skull (such as the temporal bone) with relatively flat external surfaces.

[0072] The fastener may also be used to fix adjacent members together, even where the members are curved. However, the embodiment of the fastener shown in FIGS. 16-23 is preferred for curved surfaces, and will be subsequently described.

#### Fastening Instrument

[0073] An instrument **100** for securing fastener members to each other is shown in FIGS. 7-12 to include an elongated tubular sleeve **102** (see especially FIG. 7) having a proximal end **104** (nearer the surgeon or other user) and a distal end **106** (farther away from the surgeon or other user). Two tubular handle members **108**, **110** extend diametrically away from each other, perpendicular to the axis of sleeve **102**. Distal end **106** has two small posts **112**, **114** (FIGS. 7 and 8) projecting 1-3 mm (for example 2-3 mm) away from the flat surface **116** of distal end **106**. Posts **112**, **114** are spaced approximately 180° from each other, and serve as prongs that fasten the fastener to the instrument.

[0074] An elongated rod **120** (FIG. 7) slides within sleeve **102**. A tubular guide member **107** may be placed in the sleeve **102** to fill empty space and inhibit relative transverse movement between the sleeve **102** and rod **120** that freely slides axially in the sleeve. Rod **120** includes a proximal end **122** and a distal end **124**. A disc **126** is fixed to the proximal end **122** of rod **120** by hex nut **127**, and extends perpendicularly to the longitudinal axis of rod **120**. Disc **126** provides a handle on the instrument that can be grasped by a user to reciprocate or rotate rod **120** within sleeve **102**.

[0075] The distal end 124 of rod 120 has an externally threaded, cylindrical, reduced diameter externally threaded tip 128. In one embodiment, sleeve 102 is approximately 14 cm long, with the span of arms 108, 110 being approximately 9 cm. Rod 120 is longer than sleeve 102, with a total length of approximately 16 mm from tip 128 to disc 126. The disc 126 is a solid, cylindrical disc having a diameter of approximately 3½ cm. Dimensions of the instrument may vary.

[0076] Instrument 100 is used to engage a first and second fastener to each other. In this disclosed embodiment, the first fastener is a cap 130, which is in the shape of a disc. Two openings 132, 134 through the disk are complementary to the size and location of posts 112, 114 on sleeve 102. Hence openings 132, 134 provide receptacles into which posts 112, 114 can be inserted and snugly received to secure or lock cap 130 to instrument 100, for example by frictional engagement between the posts 112, 114 and the receptacles in the cap 130.

[0077] A central opening 136 is provided through the center of the cap, along the axis of rotation of cap 130. Central opening 136 has a diameter only slightly greater than the diameter of rod 120, such that the rod can slide through and be guided by the walls of central opening 136. An internally threaded collar 138 (having helical internal threads) projects downwardly from cap 130 around central opening 136, and the central opening 136 communicates with and can extend through the collar 138.

[0078] The second fastener member is a base 140 which has the shape of a plate or disc with a central stud 142 projecting upwardly therefrom. Stud 142 is provided with external helical threads 144 that are complementary with the helical internal threads of collar 138, such that collar 138 can be rotated to thread cap 130 onto base 140.

[0079] Three sharp projections 150, 152, 154 extend upwardly from the disc of base 140 to help lock the base against a bearing surface. These projections 150-154 are located at the periphery of base 140, and are equally spaced about 60° from one another (such that all of the projections are on one-half of the base, preferably all within 120° of each other). The projections are substantially triangular, and each has a sharp apex that is suitable for embedment in a bearing surface (such as the internal surface of the skull).

[0080] Use of the instrument 100 to rotate the cap and base relative to one another, for engaging them to each other, is demonstrated in FIGS. 9-12. FIG. 9 shows the first step, in which rod 120 is inserted through opening 136 of cap 130 until locking posts 112, 114 are inserted into openings 132, 134 and cap 130 is secured in place on end 106 of sleeve 102. The frictional engagement between locking posts 112, 114 and the receptacles formed by openings 132, 134 holds cap 130 on end 106.

[0081] As shown in FIG. 10, base 140 is then attached to rod 120 by inserting threaded tip 128 (FIG. 9) into internally threaded stud 142 of base 140 (while the base is secured in place against an inner face of the bone plate). Rod 120 is then rotated in the direction of arrow 146 (FIGS. 8 and 10) to screw threaded tip 128 into internally threaded stud 142 of the base. Rod 120 is rotated by turning disc 126 until base 140 is tightly secured on the tip. The step of threading base 140 onto tip 128 is preferably performed with rod 120 fully extended (as shown in FIG. 10) by exerting axial pressure against disc 126.

[0082] Rod 120 is then axially retracted relative to sleeve 102 (or sleeve 102 is advanced relative to rod 120) (FIG. 11) to introduce external helical threads 144 on the stud 142 into the internal helical threads in 138 of cap 130. With the rod in the fully retracted position, sleeve 102 is rotated by turning handle 110 in the rotational direction shown by arrow 146 (FIG. 11). Base 140 will remain stationary, because barbed projections 150-154 on the base engage bone, and inhibit rotation of the base. Hence rotation of sleeve 102 in the direction shown by arrow 146 screws internally threaded collar 138 on to externally threaded stud 142.

[0083] After collar 138 has been fully screwed on to base 140, disc handle 126 is then rotated in the direction of arrow 147 (the opposite direction of arrow 146) to unscrew threaded tip 128 of the shaft 120 from the internal threads of stud 142. When tip 128 is fully unscrewed from stud 142 and collar 138, the tip is axially retracted from opening 136 to fully disengage the instrument 100 from the fastener. When used in a surgical procedure, the instrument may then be withdrawn from the surgical wound, leaving the fastener firmly in place engaging the opposing faces of the bone plate and surrounding bone.

[0084] The fastening instrument 100 can also be used in non-surgical applications, for example securing a fastener to opposing faces of a work piece such as a wall or adjacent pieces of wood. Variations of the method of using the instrument can also be used, in both surgical and non-surgical applications. For example, the base 140 can be rotated to screw it on to threaded tip 128 instead of rotating threaded tip 128 to screw it into the base. Only relative rotation between the base and sleeve is needed. Similarly, the base collar can be screwed into the cap collar by providing relative rotation between the cap and base, without necessarily rotating the cap by turning the sleeve 102. The rod can instead be rotated (in a direction 147) to screw the base into the cap by relative rotation between the base and cap.

[0085] The relationships of the various parts of the instrument to the fastener are shown in the drawings, with particular reference to FIG. 11, wherein rod 120 has been axially retracted and cap 130 rotated relative to base 140 to attach the cap and base by threaded engagement of the helical threads. Base disc 140 has a lesser diameter than cap 130. In the disclosed embodiment, base disc 140 has a diameter of about 11 mm, while cap 130 has a diameter of about 13 mm. Stud 142 has a height of about 9 mm, while the height of collar 138 is about 4 mm. The smaller diameter of base disc 140 helps the base fit better against the interior face of the cranial vault, which has a steeper curvature than the curvature of the outer cranial cover.

[0086] The barbs 150, 152 and 154 are all within a 120° sector of base disc 140. This allows the barbs to be placed on the intact portion of the skull bone, without being embedded into the removable portion of the cranial cover. Hence the cranial cover can be removed when desired by disengaging the cap and base, without disengaging the barbs from the bone of the plate that is to be removed.

#### Alternative Embodiment of Fastener Instrument

[0087] Another embodiment of the fastener instrument is shown in FIGS. 13-13A, and is designated instrument 200.

This instrument is similar to instrument **100** shown in FIGS. 7-12, hence like parts have been given like reference numerals plus **100** to denote the similar parts, beginning with instrument **200**. This embodiment differs, however, in that the rod handle **226** is not a disc, but is instead a handle grip with an arcuate frusto-hemispherical outer face. Alternatively, the handle **226** may be hemispherical or spherical in shape. The advantage of this shape is that it presents an arcuate side surface that can be easily grasped by the hand, with the fingers directed somewhat inwardly (toward the longitudinal axis of the instrument **200**). Handle **226** provides a secure handgrip that is also easily rotated during use of the instrument.

[**0088**] The sleeve handle **210** also differs from the perpendicular rods **108**, **110** that served as the sleeve handle in instrument **100**. The sleeve handle is instead a disc that circumscribes the sleeve **202** and extends perpendicularly outwardly therefrom. The circumferential face **211** of disc **210** is serrated or otherwise roughened to increase frictional engagement between face **211** and the hand of a surgeon or other user of the instrument. Improved frictional engagement between the handle and hand is particularly helpful, for example, in surgical procedures during which blood or other body fluids may moisten the handle and make it slippery.

[**0089**] The friction engaging posts **212**, **214** have also been elongated to 2-3 mm (for example 3 mm) to provide prongs that more securely hold the fastener cap on the instrument. The receptacle holes have been correspondingly elongated, and tightly engage the posts **212**, **214** to selectively hold the instrument and fastener together. FIG. 13A also shows an alternative embodiment of the posts or prongs in which a circular coil spring or O-ring **215** (shown in place on post **212**) is seated in an annular indentation (shown as **217**) on each post. The coil spring is somewhat resilient, such that the spring is slightly compressed as posts **212**, **214** are introduced into the receptacles of the cap. These compression springs provide improved engagement of the posts to the cap, such that the cap is even less likely to be dislodged from the instrument during use. Secure engagement of the cap to the instrument is important to allow the instrument to be manipulated, if desired, with one hand.

[**0090**] Another embodiment of the fastener base is shown in FIGS. 14 and 15. The base **340** is shown with six barbs **350**, **352**, **354**, **356**, **358** and **360** distributed equally around the periphery of and extending from the inner face **341** of base **340**. The barbs have a sharp profile, for example the apex of the barb forms and angle  $\alpha$  that is about 30 degrees or less (FIG. 15). Each barb extends 2-3 mm in height above the surface of inner face **341**. This height has been found to allow the barbs to enter bone (such as a bone plate) to a depth that provides particularly superior engagement between the fastener base and bone plate. Distribution of the barbs around the base (instead of placing the barbs in only a sector of the base, for example a 60° or 120° sector) allows the barbs to engage the bone plate even if the base rotates slightly from its original position of placement.

#### Alternative Fastener Embodiments

[**0091**] Other embodiments of the fastener are contemplated as part of the present invention, and shown in FIGS. 16-23. A specific embodiment of the fastener **410**, for example, is shown in FIGS. 16 and 17. That embodiment is

similar to the fastener embodiment of FIGS. 5 and 6, except that the cap and base are curved to conform to the shape of the external and internal surface of the cranial vault. The range of curvatures of the human skull may range, for example, from a radius of curvature of 65-105 mm, and the radius of curvature of the cap and base can extend across this same range.

[**0092**] Fastener **410** includes a base **438** and a cap **460** made of polyethylene, and each having a surface with a radius of curvature of 84 mm that fits against the skull. The base (which is illustrated in isolation in FIG. 16) has a member **438** which is capable of conforming to the shape of a curved surface against which the member seats. In the disclosed embodiment of FIGS. 16-17, member **438** has a curved upper surface **440** which has a shape defined by a portion of a sphere. The curvature of surface **440** is substantially the same as a curvature of the internal surface of the bone plate **18** and surrounding bone **28** that form the internal face of the cranial vault. Bottom surface **444** of member **438** is also curved (and preferably parallel to curved surface **440**) so that both the top and bottom surface of the base member **440** mimic the curve of the surrounding cranium. This curvature of the base helps member **438** fit against the internal face of the cranial vault, and avoids damage to surrounding dura mater that can occur when a flat plate fastener base does not conform well to the curvature of the skull.

[**0093**] In the disclosed embodiment, top member **461** of cap **460** is also curved to conform to the external curvature of the skull, such that cap **460** fits unobtrusively against the external surface of the skull. The curved cap is less obtrusive than a flat plate, and creates less of a post-surgical cosmetic defect in the overlying scalp. The curved plate creates less of a pucker in the overlying tissue.

[**0094**] Another feature of the fastener **410** is that it does not require barbs extending up from the base member **438** into bone to prevent relative rotation between base **410** and the bone against which the base seats. Instead, base **438** includes an upwardly extending tab **453** that extends into the osteotomy incision **14** between burr holes to oppose rotation of base **438** as cap **460** is screwed into it. Tab **453** is a projection that extends a sufficient distance from base **438** to be retained within the osteotomy incision. For example, the tab extends about at least one half the height of collar **446**, or to a height the same height as the collar, or even slightly higher than the collar (as shown in FIG. 17). The range of tab heights, for example, may be 0.5 to 11.5 mm. Tab **453** is preferably a thin plate-like member that is substantially flat (with a thickness no greater than the osteotomy incision), for example, about 1-2 mm thick, or 1 mm thick, and extends radially from collar **446** substantially the entire radial width of base **438**, and has a top that is not sufficiently sharp to penetrate bone. The illustrated tab **453** has a curved, blunt top **455**.

[**0095**] Assembly of fastener **410** is illustrated in FIG. 17, which is similar to FIG. 5, and wherein like parts have been given like reference numerals plus **400**, and the fastener **410** is positioned in a burr hole within an osteotomy separation. Base **438** can be positioned against the internal surface of bones **18**, **28** such that the curved member **438** conforms to the shape of the skull, and tab **453** projects up into the osteotomy separation between bone plate **18** and surround-

ing bone 28. Base 438 can be placed in this position, for example, using the instrument shown in FIGS. 7-10 or FIGS. 13-13A.

[0096] Once the base 438 is appropriately positioned, cap 460 is then placed above the base, and externally threaded stud 468 is threaded into internally threaded collar 446 by rotating cap 460. Rotation of base 438 does not occur as cap 460 is rotated, because tab 453 is retained within the osteotomy incision and abuts against either the bone plate 18 or surrounding bone 28. Stud 468 is rotated into collar 446 until cap 460 and base 438 are appropriately tightened against the bone.

[0097] In an alternative embodiment of FIG. 16, the tab 453 can extend from collar 446 instead of surface 440. The base includes both surface 440 and collar 446.

[0098] Another embodiment of the fastener is shown in FIGS. 18-20, which show a strut embodiment of the base. The base 538 is made of four flexible strut members 541, 543, 545 and 547 that cooperatively form an "X" shaped base. Each strut is a thin, rectangular extension that is made of plastic (such as high density polyethylene) or other flexible material, and which can be flexed within about 2-15°, preferably at least 2°, of its resting position (as shown by  $\alpha$  in FIG. 19) without breaking, and in the disclosed example flexes about 5°. Internally threaded collar 546 (having threaded bore 550 shown in FIG. 18) projects upwardly from the intersection of the struts, and is connected to a cap having an externally threaded stud (similar to the cap 460 shown in FIG. 17). As the cap is rotated relative to base 538, and base 538 tightens against the internal surface of bone plate 18 and surrounding bone 28, the flexible struts are bowed to conform to the curvature of the internal surface of the cranial vault.

[0099] Yet another embodiment of the strut base 638 is shown in FIGS. 21 and 22, wherein there are multiple thin flexible struts 641 extending from a central solid portion 639. Collar 646 projects upwardly from base 638. Collar 646 is externally threaded to accept an internally threaded cap, and is also internally threaded to accept the externally threaded tip of the insertion instrument. The thin struts 641 are approximately 1 mm thick, and may, for example, be 5-10 mm long.

[0100] FIG. 23 shows the base of FIGS. 21 and 22 wherein the flexible struts 641 of the base are bowed to conform to the curvature of the internal skull as the curved cap 630 is tightened by screwing internally threaded cap 630 on to externally threaded collar 646. The fastening instrument 102 is also shown attached to the fastener, with threaded tip 128 screwed into the internal threads of collar 646 to hold base 638 against the internal surface of the cranium while curved cap 630 is rotated to screw internally threaded cap 630 on to externally threaded collar 646.

[0101] The flexible struts of the base provide more flexibility than a solid member. The struts are preferably made of a high density polyethylene. In the disclosed embodiment, each strut does not occupy more than about a 20-30° sector of the base. The disclosed struts are rectangular in shape, but they can alternatively taper, flare, or assume other shapes that sufficiently reduce the solid areas of the base to increase the flexibility of the base such that it conforms to the curvature of the skull when the fastener is tightened to such an extent that the bone in the skull is not fractured or damaged. For example, the modulus of flexibility of the base (or each individual strut) is 300,000 to 700,000 psi.

[0102] The fastener instrument of the present invention is preferably made of a metallic material that is suitable for sterile use in surgical procedures. Titanium or stainless steel are examples of such materials, particularly for the embodiments that do not flex. The fastener or instrument may also be made of a durable plastic material. Plastic is a particularly preferred material for embodiments of the invention that use flexible struts (such as the embodiments of FIGS. 18-23). The invention also includes a fastener, positioning instrument, and fastening instrument that has been sterilized, for example in an autoclave, or by irradiation (e.g. irradiation with ultraviolet radiation), or by chemical sterilization (e.g. with disinfectants or anti-microbials).

[0103] As used in this specification, the term "conforms to a curved member" does not require identical curvature of the conforming member and the surface to which it conforms. Substantial conformity of the members is all that is required, and that includes surfaces between flat planes and curves that precisely conforms to the curved member against which the conforming member slats.

[0104] Having illustrated and described the principles of the invention in several preferred embodiments, it should be apparent to those skilled in the art that the invention can be modified in arrangement and detail without departing from such principles.

What is claimed is:

1. A fastener for holding adjacent members together, the fastener comprising:

first and second fastening members, wherein at least one of the fastening members has a conforming surface that conforms to a curved member;

a first connector on the first fastening member; and

a second connector on the second fastening member for connecting with the first connector, and holding the first and second fastening members in a fixed relationship that holds the adjacent members together;

wherein the adjacent members are bone plates.

\* \* \* \* \*