US006955677B2

(12) **United States Patent**
Dahners

(10) **Patent No.: US 6,955,677 B2**
(45) **Date of Patent: Oct. 18, 2005**

(54) **MULTI-ANGULAR FASTENING APPARATUS AND METHOD FOR SURGICAL BONE SCREW/PLATE SYSTEMS**

(75) Inventor: **Laurence E. Dahners**, Chapel Hill, NC (US)

(73) Assignee: **The University of North Carolina at Chapel Hill**, Chapel Hill, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 256 days.

(21) Appl. No.: **10/271,635**

(22) Filed: **Oct. 15, 2002**

(65) **Prior Publication Data**

US 2004/0073218 A1 Apr. 15, 2004

(51) **Int. Cl.**[7] **A61B 17/56**
(52) **U.S. Cl.** **606/69**
(58) **Field of Search** 606/69, 70, 71, 606/72, 73, 60, 61, 62

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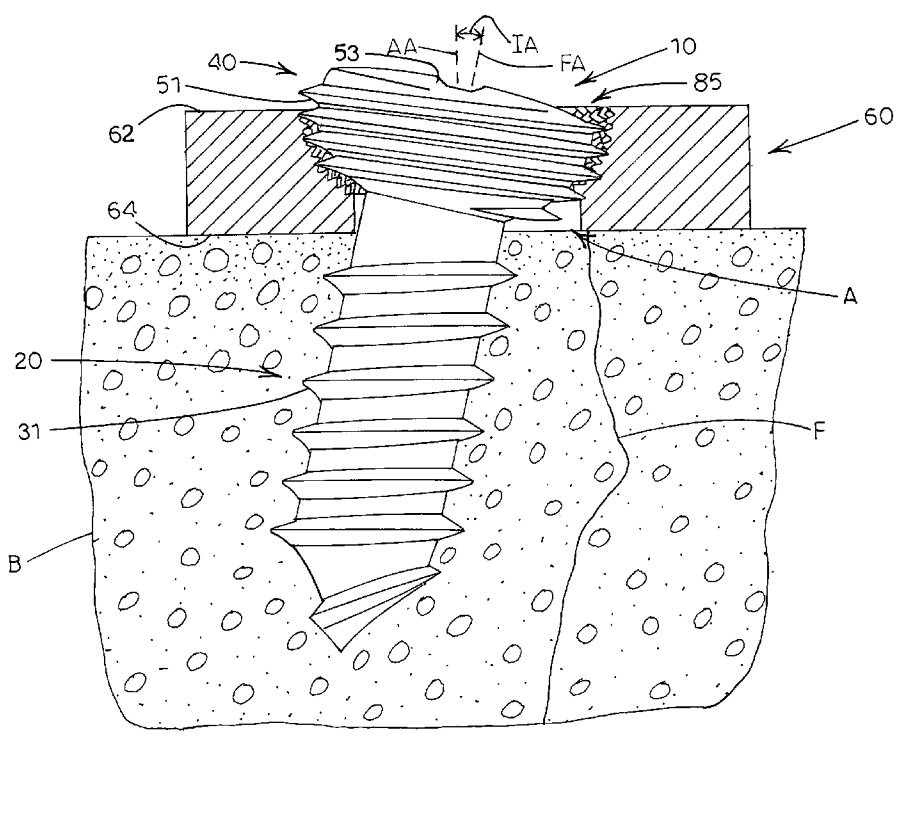
Primary Examiner—Pedro Philogene
(74) *Attorney, Agent, or Firm*—Jenkins, Wilson & Taylor, P.A.

(57) **ABSTRACT**

A fastening apparatus includes a fastener and a fastener receiving member. The apparatus enables the fastener to be affixed to the fastener receiving member at a variable insertion angle selected by the user. The fastener includes an elongate section and an adjoining head section. Both the elongate section and the head section are threaded. The fastener receiving member includes one or more apertures through which one or more corresponding fasteners can be inserted. Each aperture includes a contact region formed or disposed on an inside surface defining the aperture. The contact region includes a porous matrix of protrusions or fiber metal having a density and strength sufficient to render contact region tappable by the thread of the head section of the fastener. The thread on the head section is driven into the contact region at the selected insertion angle. As a result, the thread of the head section taps into the material of the contact region such that the fastener is affixed to the fastener receiving member and maintained at the insertion angle.

76 Claims, 9 Drawing Sheets



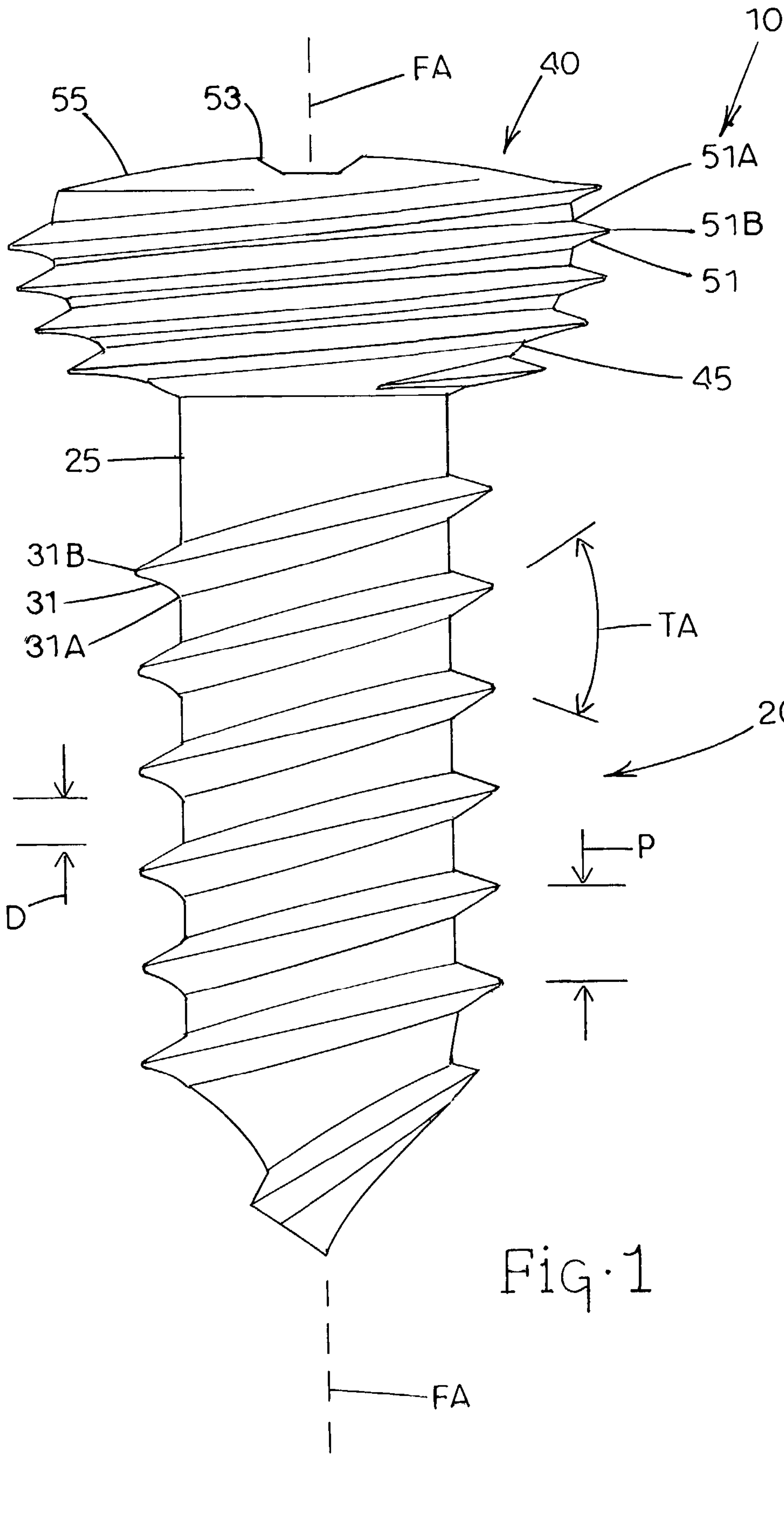


Fig. 1

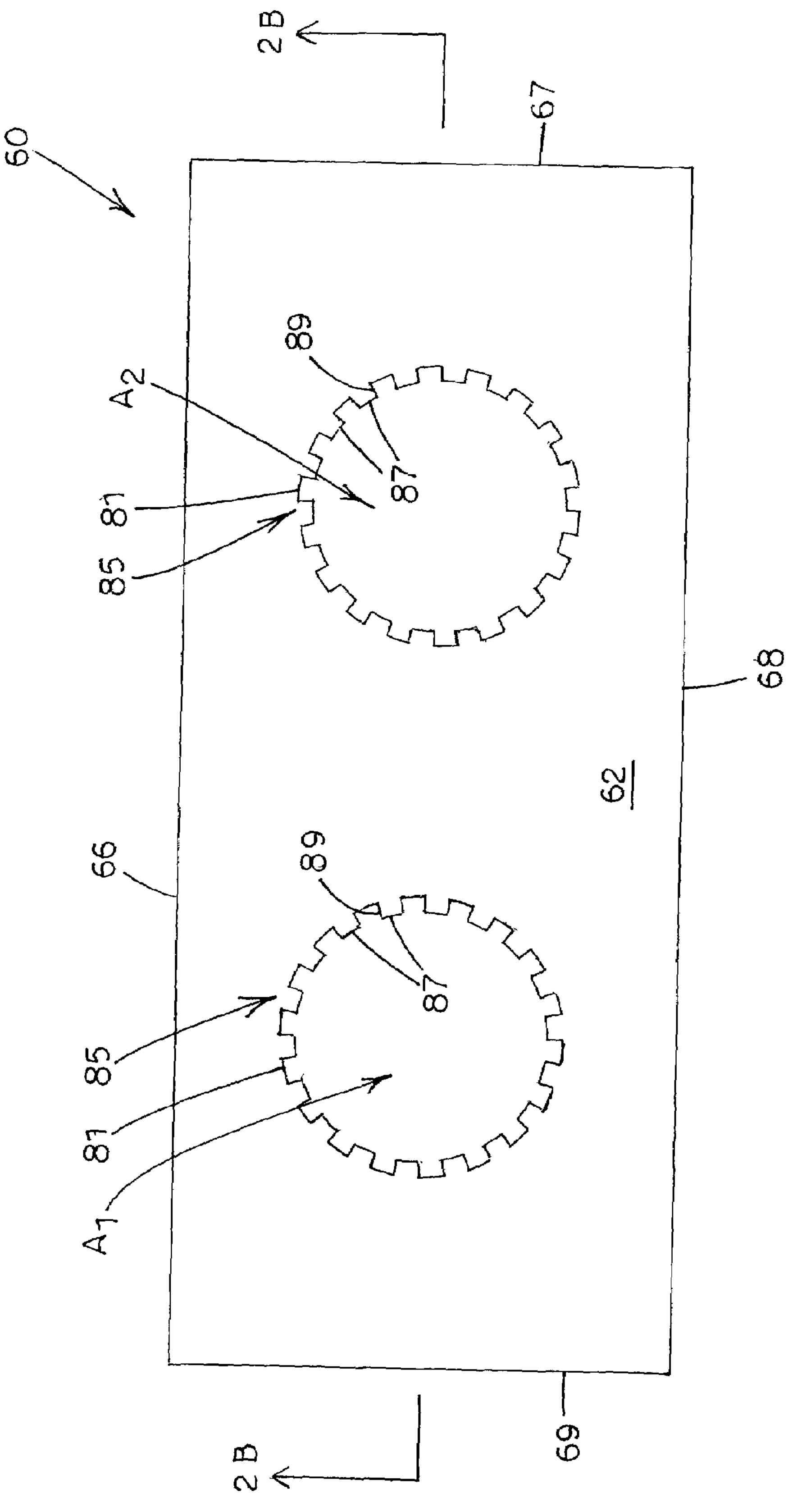


FIG. 2A

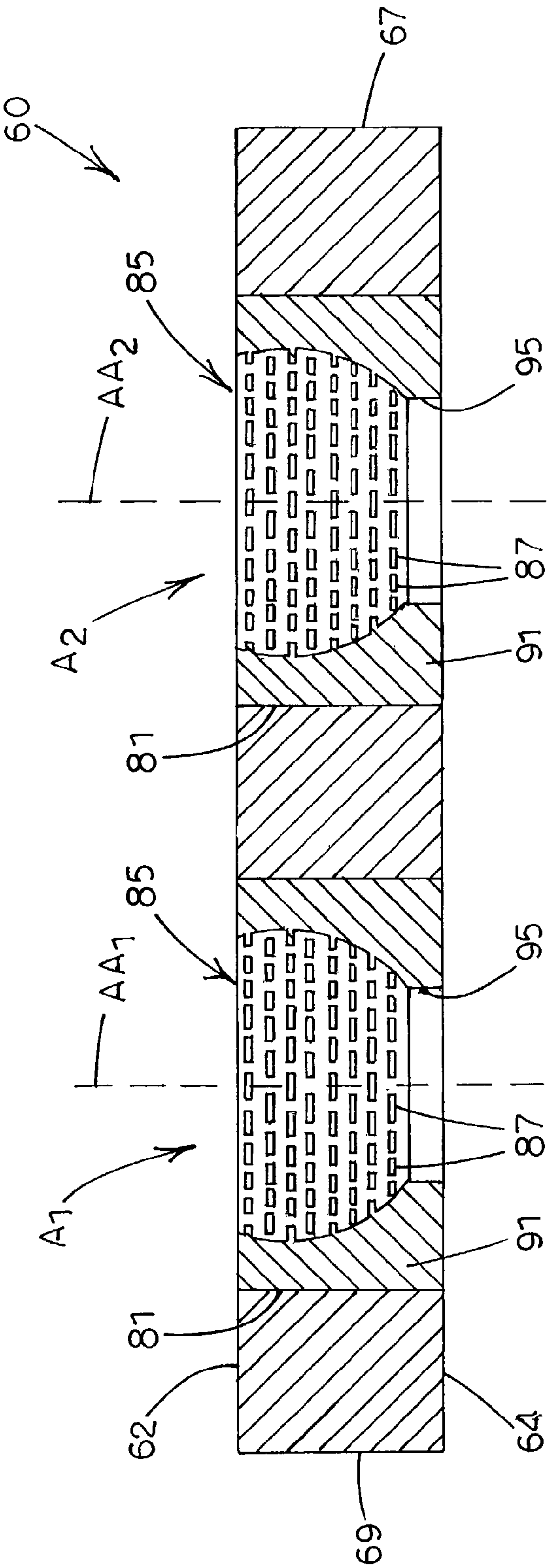


FIG. 2B

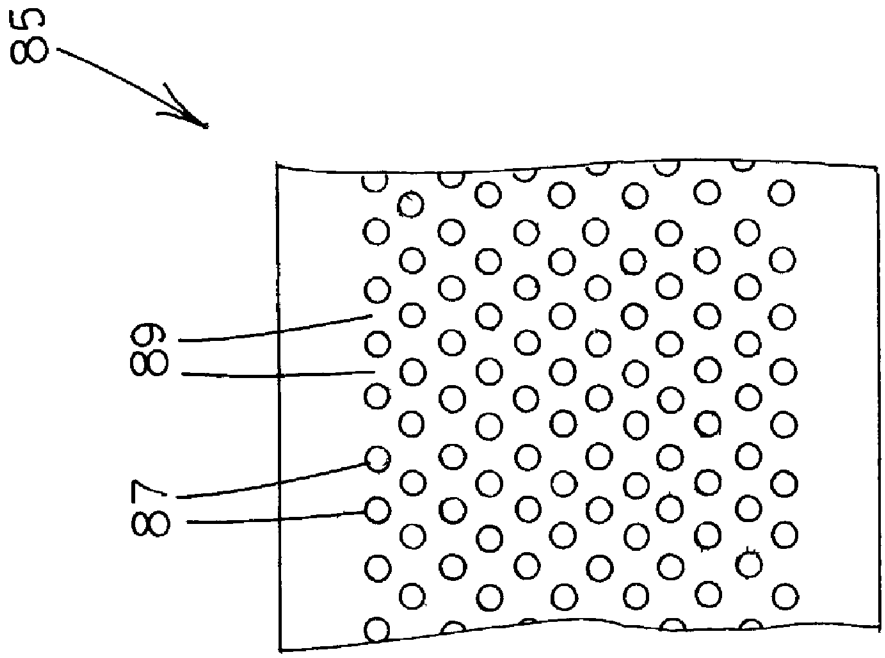


Fig.2D

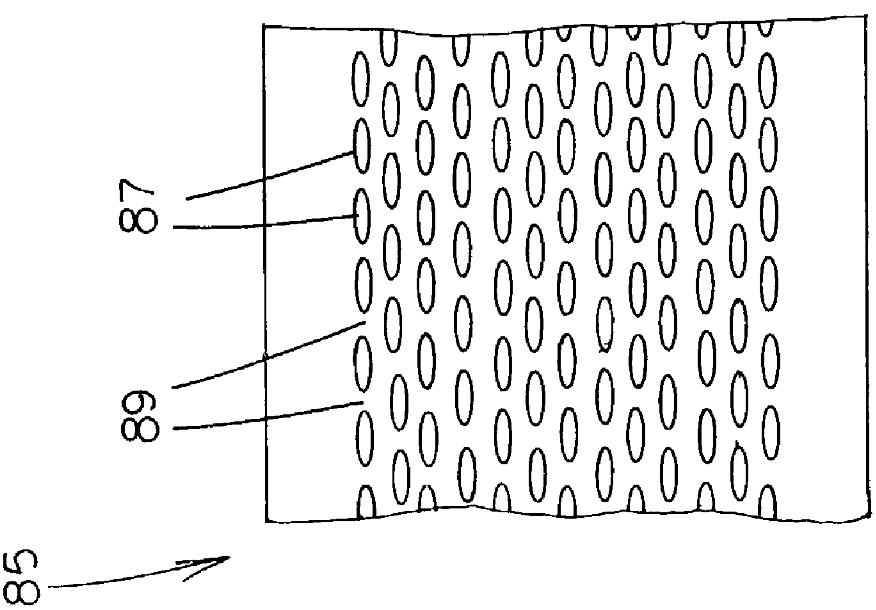


Fig.2C

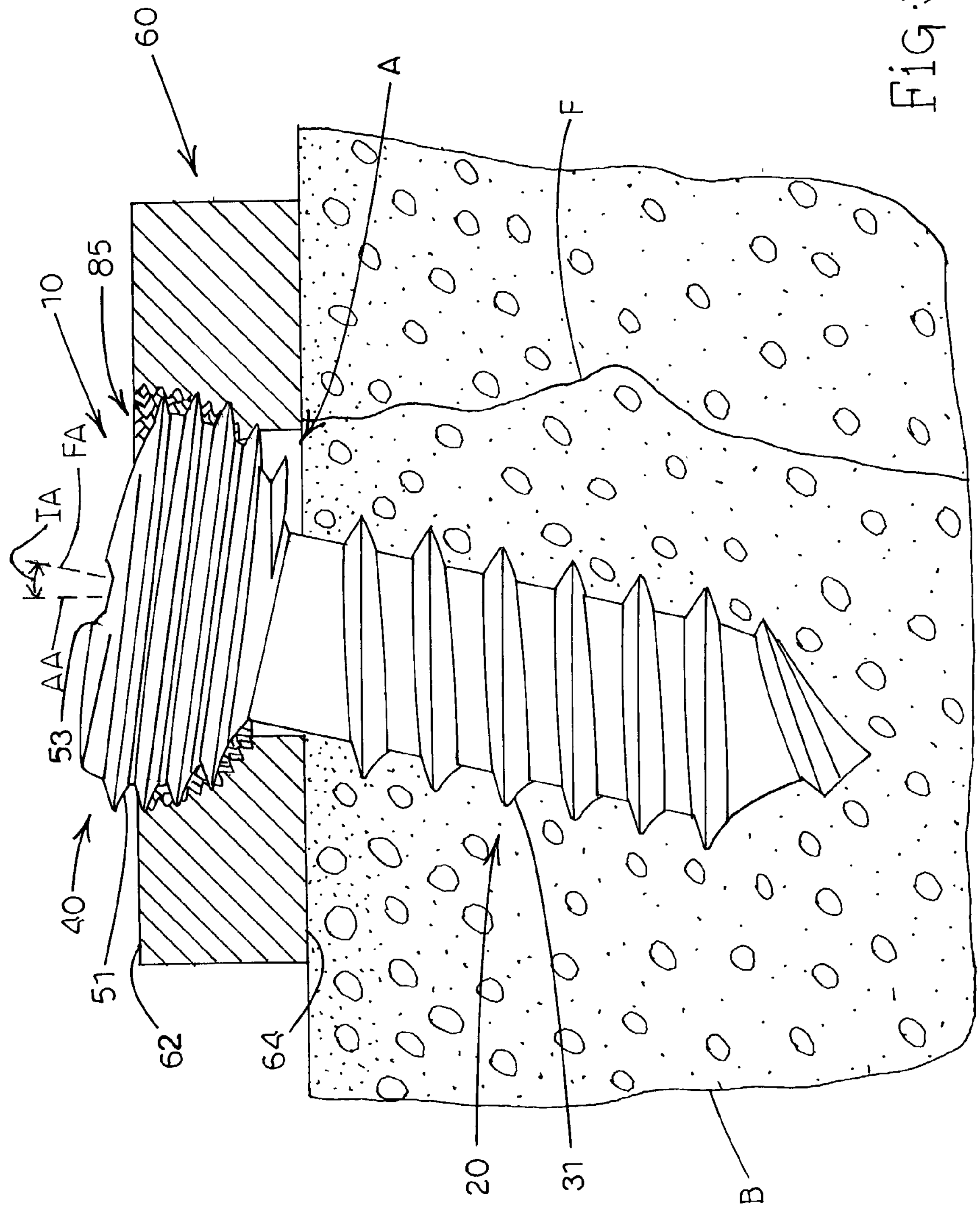


Fig. 3

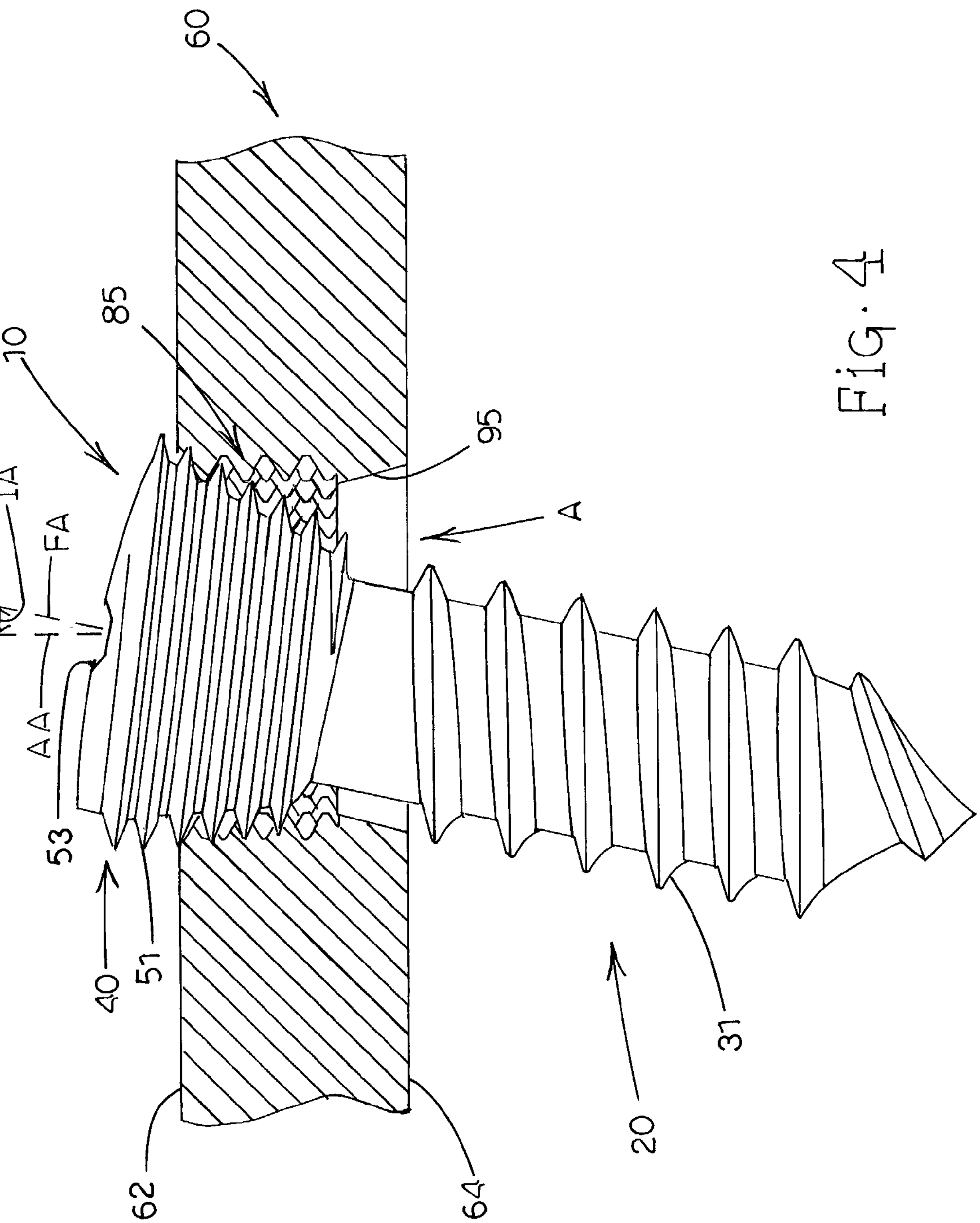


Fig. 4

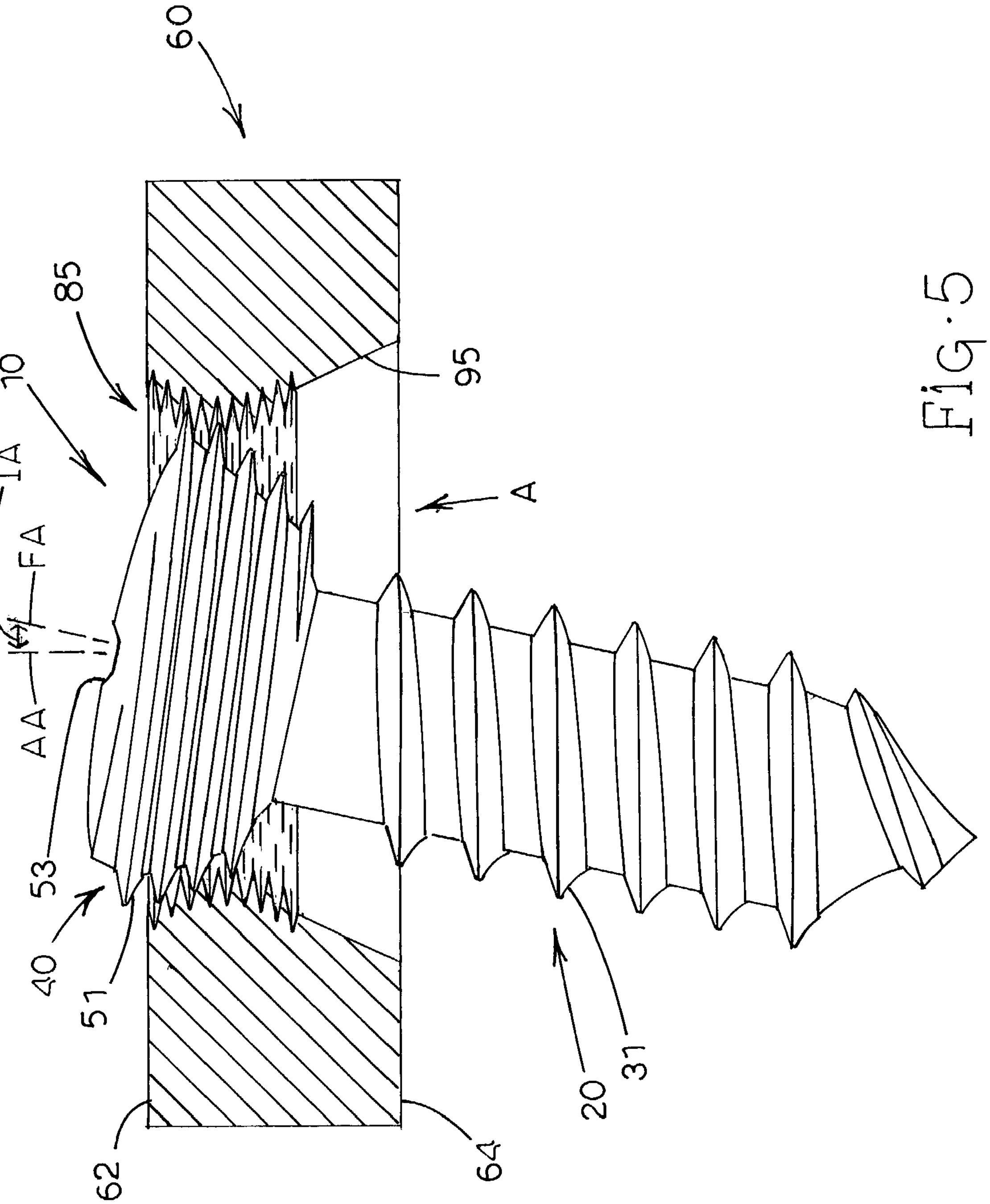


FIG. 5

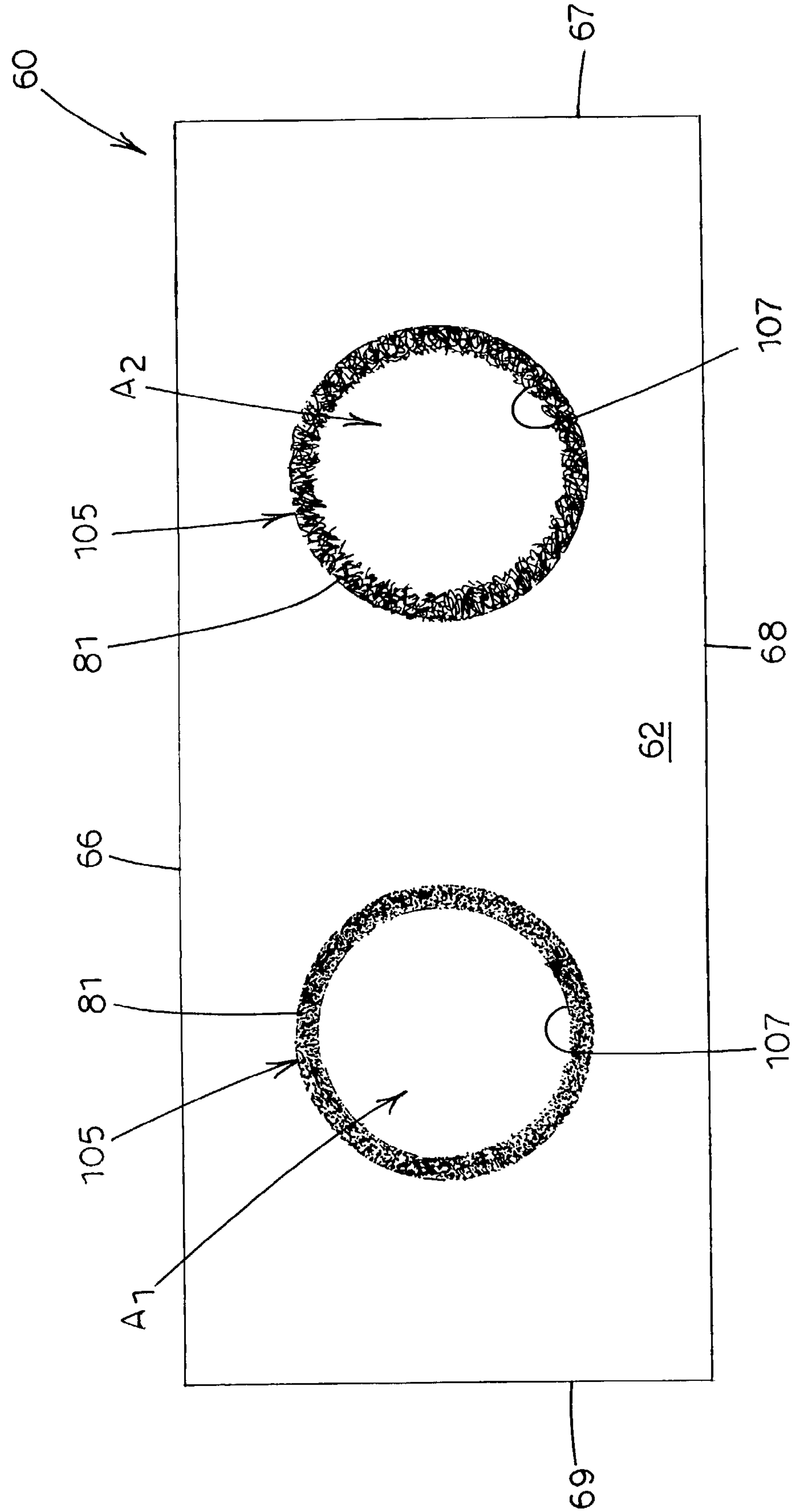


FIG. 6

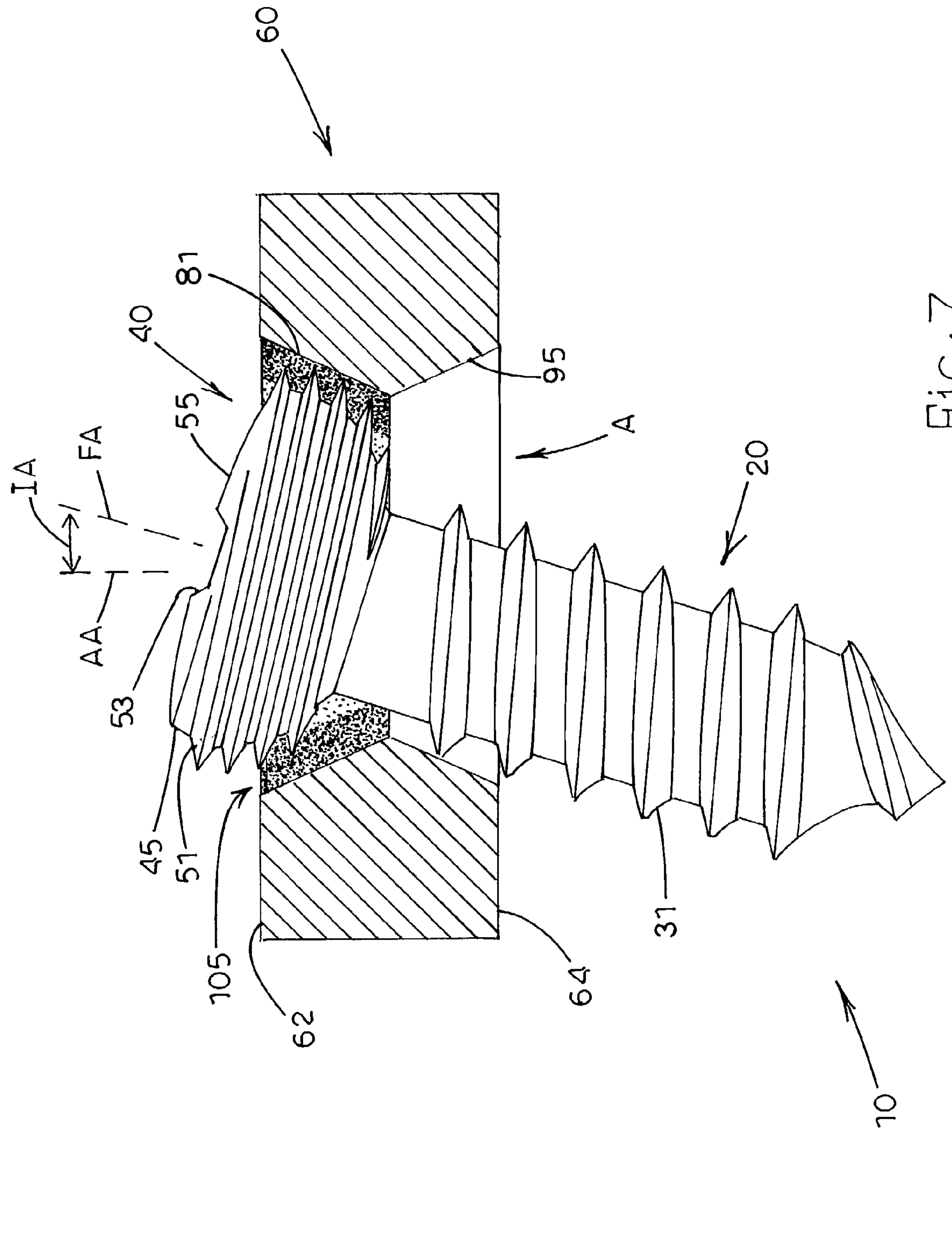


FIG. 7

MULTI-ANGULAR FASTENING APPARATUS AND METHOD FOR SURGICAL BONE SCREW/PLATE SYSTEMS

TECHNICAL FIELD

The present invention relates generally to the design of fasteners and components to which fasteners are affixed. A specific application of the present invention relates to the design and use of bone screw/plate systems in the course of orthopaedic surgical procedures.

BACKGROUND ART

A variety of techniques exist in the field of orthopaedic surgery for treating bone fractures. Many known techniques utilize bone screws and bone fixation plates. Typically, the plate is used to stabilize the site of a bone fracture, and one or more bone screws are inserted through apertures of the plate and threaded into the bone material so as to secure the plate to the bone material. It is also known that bone screw/plate systems can be improved by machining a thread onto the head of the bone screw, in addition to the thread normally machined onto the main shaft of the screw. In connection with the use of threaded-head screws, the apertures of the plate are threaded to matingly receive the threads of the screw head. Thus, as the screw is inserted into an aperture of the plate and threaded into the bone material, the head of the screw likewise is threaded into the aperture. As a result, the screw becomes rigidly affixed to the plate, in effect locking to the plate rather than simply bearing against the plate. Examples of threaded-head bone screws and threaded-aperture bone plates are disclosed in U.S. Pat. No. 5,709,686 to Talus et al.; U.S. Pat. No. 6,206,881 to Frigg et al.; and U.S. Pat. No. 6,306,140 to Siddiqui.

The use of threaded-head screws and threaded-aperture plates provides certain advantages. It is known that some types of small bone fragments tend to change position relative to the plate over time. This deleterious condition can result from the "toggling" of the screws affixed to the plate. However, when multiple screws are rigidly fixed to the plate by mating the respective threads of the screw heads with the threads of the corresponding plate apertures, the screws do not toggle in the plate. The locking action provided by the threaded-head screw in combination with the threaded-aperture plate prevents motion between the bone fragment and the plate as well as premature loosening of the screws.

Although the use of threaded-head screws has provided improvements in orthopaedic surgical techniques, there remains the disadvantage that currently available screw/plate systems are unidirectional. That is, the thread formed on the inside surface of the aperture of the plate is structurally fixed at a constant helical angle with respect to the central axis passing through the center point of the aperture. Hence, the head of a conventional threaded-head screw can only be rigidly affixed to the plate by mating its thread with that of the aperture, such that the bone screw is always inserted and threaded in one direction, e.g., perpendicularly or coaxially with respect to the plate.

It would therefore be advantageous to provide a screw/plate system that allows the surgeon to choose the angle at which the screw is inserted through, and rigidly affixed in, an aperture of the plate. Such an improvement would enable the surgeon to direct the bone screw toward bone fragments that are not situated directly beneath the aperture of the plate, and would also provide flexibility in the placement of the plate in relation to the bone fracture. The ability to choose the angle at which the screw is threaded into the bone material would allow the surgeon to better tailor the application of the screw/plate system to the specific nature of the bone fracture suffered by the individual orthopaedic patient, and additionally allow the surgeon to adjust his or her application strategy as necessary after the surgical site has been accessed but prior to insertion of the screw into the bone material. Additionally, in situations where a screw is intended for coaxial insertion into an aperture, the improvement would allow a secure fit between the screw and aperture even if the screw is unintentionally inserted in non-coaxial relation to the aperture.

DISCLOSURE OF THE INVENTION

The present invention in broad terms provides a plate or other component suitable for affixation by a fastener. The plate has one or more apertures through which one or more corresponding fasteners can be inserted. Notably absent from these apertures are any forms of permanent internal thread structures as found in the prior art and which, as indicated above, are a limitation in applications such as the treatment of bone trauma. Each aperture is bounded by a region structured to enable the fastener, and particularly a threaded head portion of the fastener, to be tapped into the material constituting the region. By providing this tappable region, the fastener can be inserted at any desired angle in relation to the aperture, thereby providing significant flexibility in practice. While it is contemplated that the invention can be applied in a wide range of fastening and fixation techniques, particular advantage is found in the field of orthopaedic surgery. Embodiments of the invention can be practiced in any surgical procedure that conventionally involves the use of bone screw/plate systems. Examples include the treatment of general bone trauma, stabilization of metaphyseal fractures, treatment of osteoporotic bones, bone fusion, joint prosthesis, spinal alignment or correction, and the like.

According to one embodiment of the present invention, a surgical plate adapted for fixation with a bone screw is provided. The plate comprises first and second opposing major surfaces, and an inside surface extending between the first and second major surfaces. The inside surface defines an aperture that is generally coaxially disposed about an aperture axis. A non-threaded tappable contact region is disposed on the inside surface. The tappable contact region has a minimum inside diameter that is large enough to permit a bone screw to pass therethrough at an insertion angle defined between a longitudinal axis of the fastener and the aperture axis. The tappable contact region is adapted for being tapped by an external thread of the bone screw to affix the bone screw to the tappable contact region at the insertion angle.

According to one aspect of this embodiment, the tappable contact region is formed in the inside surface of the fastener receiving member. According to another aspect, the tappable contact region comprises an insert that is fitted to the inside surface.

According to a further aspect of this embodiment, the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface, and a plurality of interstices between the protrusions. According to a yet further aspect, the tappable contact region comprises a porous fiber metal matrix.

According to another embodiment of the present invention, a fastening apparatus adapted for multi-angular insertion is provided. The fastening apparatus comprises a fastener and a fastener receiving member. The fastener comprises an elongate section and an adjoining head section disposed along a fastener axis. The elongate section comprises a first thread and the head section comprises a second thread. The fastener receiving member comprises first and second opposing major surfaces, and an inside surface extending between the first and second major surfaces. The inside surface defines an aperture generally coaxially disposed about an aperture axis. A tappable contact region is disposed on the inside surface. The tappable contact region has a minimum inside diameter that is large enough to permit the elongate section to pass therethrough at an insertion angle defined between the fastener axis and the aperture axis. The tappable contact region is adapted for being tapped by the second thread of the head section to affix the head section to the tappable contact region at the insertion angle.

The present invention also provides a method for affixing a fastener to a fastener receiving member at a desired orientation. A fastener is provided that comprises an elongate section and an adjoining head section disposed along a fastener axis. The elongate section comprises a first thread and the head section comprises a second thread. A fastener receiving member is provided that comprises first and second opposing major surfaces and an inside surface extending between the first and second major surfaces. The inside surface defines an aperture generally coaxially disposed about an aperture axis. A tappable contact region is disposed on the inside surface. An insertion angle, defined between the fastener axis and the aperture axis, is selected as the angle at which the fastener is to be inserted in relation to the fastener receiving member. The elongate section of the fastener is inserted through the aperture until the second thread of the head section contacts the tappable contact region. The fastener is tapped into the receiving member such that the fastener is oriented at the selected insertion angle. This is accomplished by threading the second thread of the head section into the tappable contact region while the fastener is oriented at the selected insertion angle.

According to one aspect of this method, one of the major surfaces of the receiving member is placed against bone material. The first thread of the elongate section of the fastener is threaded into the bone material so as to anchor the fastener to the bone material. This procedure is useful in a number of applications, such as the stabilization and healing of bone fractures. As the first thread of the elongate section is threaded into the bone material, the second thread of the head section eventually contacts the tappable contact region of the fastener receiving member. Further threading of the first thread into the bone material causes the second thread of the head section to be threaded into the tappable contact region of the receiving member.

It is therefore an object of the present invention to provide a plate or other fastener receiving member that enables a threaded fastener to be affixed thereto at a desired angle selected from a range of available angles.

It is another object of the present invention to provide such fastener receiving member with an aperture that does not require a pre-tapped, fixed-position thread structure with which a threaded fastener is to be interfaced.

It is yet another object of the present invention to provide a surgical bone screw/plate system comprising a fastener having a threaded head portion and a fastener receiving member having an aperture lined with a region into which the threaded head portion can be tapped, such that the threaded head portion can be rigidly affixed to the fastener receiving member at an arbitrary angle selected by the user.

Some of the objects of the invention having been stated hereinabove, and which are addressed in whole or in part by the present invention, other objects will become evident as the description proceeds when taken in connection with the accompanying drawings as best described hereinbelow.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an elevation view of a fastener provided in accordance with the present invention;

FIG. **2**A is a top plan view of a fastener receiving member provided in accordance with the present invention;

FIG. **2**B is a vertical cross-sectional side view of the fastener receiving member illustrated in FIG. **2**A taken along cut-away line **2**B—**2**B in FIG. **2**A;

FIG. **2**C is a plan view of a section of a contact region provided with the fastener receiving member in accordance with one embodiment of the present invention;

FIG. **2**D is a plan view of a section of a contact region in accordance with another embodiment of the present invention;

FIG. **3** is a partially cut away and vertical cross-sectional view illustrating an application of the present invention in which the fastener is affixed to the fastener receiving member and anchored to an object such as bone material at a desired insertion angle;

FIG. **4** is a partially cut away and vertical cross-sectional view of a fastener and fastener receiving member according to an alternative embodiment of the present invention;

FIG. **5** is a partially cut away and vertical cross-sectional view of a fastener and fastener receiving member according to another alternative embodiment of the present invention;

FIG. **6** is a top plan view of a fastener receiving member provided with an alternative contact region provided in accordance with the present invention; and

FIG. **7** is a partially cut away and vertical cross-sectional view illustrating the fastener affixed to the fastener receiving member illustrated in FIG. **6**.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. **1**, one example of a threaded-head fastener, generally designated **10**, is illustrated in accordance with the present invention. Fastener **10** can be constructed from any material appropriate for withstanding compressive, tensile, torque, or other forces encountered during and after application of fastener **10** to a target site. In the context of orthopaedic surgery, fastener **10** is preferably constructed from a biocompatible metal or metal alloy such as stainless steel, titanium, chromium, or alloys thereof. As is appreciated by persons skilled in the art, fastener **10** could also be constructed from a suitable ceramic material or a polymeric material such as a resorbable polymer, or could be coated with a polymeric film. Fastener **10** comprises an elongate section, generally designated **20**, and an adjoining head section, generally designated **40**, both of which are generally arranged along a longitudinal fastener axis FA. Elongate section **20** comprises a shaft having a first outer surface **25** coaxially disposed in relation to fastener axis FA. Preferably, first outer surface **25** is cylindrical. Elongate section **20** is machined to form a first thread **31** thereon. First thread **31** has a root **31**A adjoining first outer surface **25** from which first thread **31** extends generally radially outwardly to terminate at a crest **31**B. First thread **31** winds around first outer surface **25** or a length thereof in a generally helical fashion.

In the illustrated example, first thread **31** has a conical or "V" cross-sectional profile and thus tapers from first outer surface **25** to its crest **31**B.

In a preferred implementation of the invention in which fastener **10** is utilized as a bone screw for anchoring to bone material B such as a bone fragment, the illustrated "V" profile of first thread **31** is advantageous in that renders fastener **10** self-tapping. The invention, however, is not limited to any particular design for first thread **31**. For instance, the profile of first thread **31** could be rectilinear or square, with its crest **31**B being a generally flat surface. Alternatively, the profile of first thread **31** could be trapezoidal (i.e., an "Acme" thread). The degree of sharpness or flatness of crest **31**B is not limited, and crest **31**B could be rounded. Moreover, the invention is not limited to any particular diameter of first outer surface **25**, diameter of crest **31**B, thread angle TA between the side walls of adjacent thread passes, or thread pitch P (i.e., the axial distance between the crest portions of adjacent thread passes, or the reciprocal of the number of thread passes per inch). Additionally, first thread **31** could be a multiple-threaded or multi-start design, in which two or more individual threads are cut beside each other. First thread **31** could also constitute one or more single threads formed on different axial sections of shaft. Also, pitch P of first thread **31** could be such that adjacent thread passes are separated from each other by an axial distance D over which only first outer surface **25** of shaft exists. Finally, the "hand" or "sense" associated with the turning of first thread **31** about fastener axis FA may or may not follow the standard right-hand rule.

With continuing reference to FIG. **1**, head section **40** comprises a second outer surface **45** coaxially disposed in relation to fastener axis FA. In the example illustrated in FIG. **1**, the shape of head section **40**, i.e., the cross-sectional profile of second outer surface **45**, is substantially hemispherical or parabolic. It will be understood, however, that head section **40** can have other types of rounded shapes, and its profile can be either convex or concave. Moreover, the shape of head section **40** can be substantially frusto-conical as shown in FIGS. **4** and **5**. In addition, the shape of head section **40** can be a composite form, such as a converging/diverging or "trumpet-shaped" profile. Head section **40** is machined to form a second thread **51** thereon. Second thread **51**, has a root adjoining second outer surface **45** from which second thread **51** extends generally radially outwardly to terminate at a crest **51**B. Second thread **51** winds around second outer surface **45** in a generally helical fashion. To facilitate the turning of fastener **10** by the user thereof, a recess **53** is formed in a top surface **55** of head section **40** for the insertion of an appropriate tool such as a screwdriver, key, or wrench. The shape of recess **53** can be a single or cross-shaped slot, a square, a hexagon, a star, or the like.

In the illustrated example, second thread **51** has a conical or "V" profile and thus tapers from second outer surface **45** to crest **51**B. The "V" profile of second thread **51** is preferred because it facilitates the self-tapping of head section **40** into a plate or other fastener receiving member **60** (see, e.g., FIGS. **2**A and **2**B), in accordance with the invention and as described below. However, like first thread **31** of elongate section **20**, the invention is not limited to any particular design for second thread **51**. Thus, no limitations are made with regard to the profile or shape of first thread **31**, the degree of sharpness or flatness of its crest **31**B, the outer diameter of any portion of second outer surface **45** or crest **31**B (although the average diameter of head section **40** is greater than that of elongate section **20**), the thread angle TA, the thread pitch P, the number and locations of the threads constituting second thread **51**, or the turning direction of second thread **51** with respect to fastener axis FA.

In an alternative embodiment, elongate section **20** is not threaded, and fastener **10** takes the form of a peg or a pin. This alternative embodiment may be preferred in certain procedures where, for instance, the main object is to prevent tilting of a bone segment, as well as other procedures where there is no concern of fastener **10** pulling out from the bone and hence no need for elongate section **20** to be threaded. In these implementations, head section **40** is threaded, and thus the advantages and benefits of the present invention as described herein apply.

Turning to FIGS. **2**A–**2**D, a fastener receiving member, generally designated **60**, is illustrated in accordance with the present invention. In the illustrated example, fastener receiving member **60** is provided in the form of a mounting plate, such as a bone plate for use in orthopaedic surgical procedures. Fastener receiving member **60** can be constructed from any material appropriate for withstanding compressive, tensile, torque, or other forces encountered during and after application of fastener **10** to fastener receiving member **60** at a target site. In the context of orthopaedic surgery, fastener receiving member **60** is preferably constructed from a biocompatible metal or metal alloy such as stainless steel, titanium, cobalt, chromium, tungsten, tantalum, molybdenum, gold, and alloys thereof. Alternatively, fastener receiving member **60** can be constructed from a suitable ceramic or polymeric material. The polymeric material may be reinforced with glass, carbon, or metal fibers.

Fastener receiving member **60** comprises a first major outer surface **62**, an opposing second major outer surface **64**, and outer lateral edges **66**, **67**, **68** and **69** at the perimeter. In orthopaedic applications, second outer surface **64** can in some cases be used for contact with bone material B (see FIG. **3**), while in other cases actual contact is unnecessary or undesirable. While in the illustrated example first and second outer surfaces **62** and **64** are planar, it will be understood that the cross-section of fastener receiving member **60** or certain portions thereof can have a contoured profile. For instance, in some types of orthopaedic applications, minimum contact between fastener receiving member **60** and the target bone material B might be desired. In such a case, second outer surface **64** or a portion thereof can be convex.

One or more apertures, generally designated A (e.g., apertures A_1 and A_2 shown in FIGS. **2**A and **2**B), are formed through the thickness of fastener receiving member **60** for receiving one or more elongate sections **20** of corresponding fasteners **10** therethrough. Each aperture A is defined by an inside surface **81** cut through the thickness of fastener receiving member **60**. Each aperture A is generally transversely oriented in relation to first and second outer surfaces **62** and **64**, and thus is generally coaxially disposed about a central aperture axis AA (e.g., aperture axis AA_1 or AA_2 shown in FIG. 2B) directed through the thickness of fastener receiving member **60**. The precise number and arrangement of such apertures A can depend on the intended use for fastener receiving member **60**. It will be understood, however, that the invention contemplates procedures in which a multi-apertured fastener receiving member **60** is employed in connection with a single fastener **10**, with one aperture A of such fastener receiving member **60** being selected by the user for interfacing with the single fastener **10**.

As indicated above, the invention departs from the conventional use of a thread formed on inside surface **81** of aperture A for mating with the thread of a screw head. That is, apertures A of fastener receiving member **60** do not contain a permanent helical thread structure of fixed orientation. Instead, a tappable contact region, generally designated **85**, is disposed on each inside surface **81** of fastener receiving member **60**. The term "tappable" is used herein to denote that contact region **85** is structured such that it can be tapped by second thread **51** of head section **40** of fastener **10** in response to forceful insertion and rotation of head section **40** into the material of contact region **85**. As described below in connection with FIG. **3**, this enables the user to manipulate second thread **51** of head section **40** to form, in effect, a custom internal thread in contact region **85** sufficient to maintain fastener **10** at an arbitrary orientation in relation to receiving member **60** selected by the user. In FIG. **3**, this orientation is represented by an insertion angle IA, defined between fastener axis FA and aperture axis AA. In accordance with the invention, insertion angle IA can range from 0 to 90 degrees wherein at 0 degrees fastener axis FA coincides with aperture axis AA. Due to the relative positions of aperture A, second outer surface **64** and fastener **10**, insertion angle IA in practice will be less than 90 degrees.

In the embodiment illustrated in FIGS. **2A–2D**, the tappable property is realized by structuring contact region **85** as a matrix of protrusions **87** and interstices **89** between protrusions **87**. Protrusions **87** can be provided in any protruding form, such as pegs, bristles or tines. Protrusions **87** are based on inside surface **81** and extend generally radially inwardly into the open space of apertures A. Protrusions **87** can be formed directly from inside surface **81** and the region of fastener receiving member **60** circumscribing aperture A. Alternatively, as shown in FIG. **2B**, protrusions **87** can be formed on a substrate **91** (see FIG. **2B**) that is thereafter fitted to inside surface **81** as an insert, such as by press-fitting or binding. The material selected for protrusions **87** can be any material suitable for tapping by fastener **10**. Non-limiting examples include stainless steel, titanium, cobalt, chromium, tungsten, tantalum, molybdenum, gold, and alloys thereof, as well as suitable polymers.

It will be noted that the density of protrusions **87** over the area of inside surface **81**, and the size of individual protrusions **87**, are not limited by the invention, so long as the matrix formed on inside surface **81** renders contact region **85** tappable. Accordingly, the matrix of protrusions **87** can appear as a bristle board or a porous surface. The characteristic cross-sectional dimension of each protrusion **87** (e.g., diameter, width, or the like) can range from approximately 1 micron to approximately 25 mm, although the invention is not limited to this range. The density of protrusions **87** over the area of inside surface **81** from which they protrude can range from approximately 5 to approximately 65%, although the invention is not limited to this range. Protrusions **87** can be formed by any suitable means, such as growing protrusions **87** by material deposition, forming protrusions **87** by coating, welding protrusions **87** to inside surface **81**, or forming ridges or grooves and subsequently cutting transversely through the ridges to discretize the ridges into protrusions **87**.

It will be further noted that in the embodiment illustrated in FIGS. **2A** and **2B**, each protrusion **87** has a generally rectilinear cross-section. The invention, however, encompasses within its scope any cross-section suitable for realizing the tappable property of contact region **85**. Hence, as another example, FIG. **2C** illustrates an area of contact region **85** in which protrusions **87** are generally elliptical in cross-section. As a further example, FIG. **2D** illustrates an area of contact region in which protrusions **87** are generally circular in cross-section. In addition, depending on the density and size of protrusions **87** and the pattern defined by the matrix, protrusions **87** may or may not be deformable as necessary to realize the tappable property of contact region **85**.

As seen from the perspective of FIG. **2B**, the resultant profile of contact region **85** is illustrated in one embodiment as being rounded to accommodate the rounded profile of head section **40** of fastener **10**. The term "resultant" is meant to denote that the profile can be defined by the inside surface **81** itself with each protrusion **87** having a substantially uniform length, or alternatively, the profile can be defined by protrusions **87** of varying lengths. The invention, however, is not limited to any specific profile for contact region **85**. In addition, in some embodiments of the invention, contact region **85** is not formed over the entire axial length of inside surface **81**. Thus, in FIG. **2B**, contact region **85** terminates at a lower section **95** of inside surface **81** (or substrate **91**) proximate to second outer surface **64** of fastener receiving member **60**.

While the profile of lower section **95** in FIG. **2A** is cylindrical, other profiles for lower section **95** are suitable in accordance with the invention. The respective profiles for contact region **85** and any exposed portion of inside surface **81** such as lower section **95** will be dictated in part by the shape of head section **40** of fastener **10**, and also by the need to affix fastener **10** over a wide range of available insertion angles IA in relation to receiving member **60** and/or the bone material B or other object in which fastener **10** is to be anchored. Thus, in FIG. **4**, a fastener **10** with a conical head section **40** is employed in connection with a receiving member **60** having a contact region **85** of cylindrical profile and a lower section **95** that tapers from second outer surface **64** to contact region **85**. As another example, in FIG. **5**, a fastener **10** with a rounded head section **40** is employed in connection with a receiving member **60** having a contact region **85** of converging/diverging or trumpet-shaped profile and a lower section **95** of tapering profile. It will be noted for all embodiments that the minimum inside diameter of contact region **85** should be large enough to provide clearance for elongate section **20** and its first thread **31** to pass through aperture A. As one example, the minimum inside diameter can range from approximately 0.5 to approximately 10 mm. In non-orthopaedic applications, the minimum inside diameter can be greater than 10 mm.

Referring now to FIGS. **6** and **7**, an alternative embodiment of a tappable contact region, generally designated **105**, is illustrated. In this embodiment, tappable contact region **105** takes the form of a matrix or mesh of fiber metal **107** that lines inside surface **81** of each aperture A of fastener receiving member **60**. As understood by persons skilled in the art, fiber metal consists of a porous or interstitial aggregate of metal or metal alloy wires or fibers. The characteristic cross-sectional dimension of each fiber (e.g., diameter, width, or the like) can range from approximately 1 micron to approximately 25 mm. The porosity of the matrix can range from approximately 40 to approximately 90%. The fibers are often interlocked and kinked in any number of different patterns, and often has the appearance of steel wool. The aggregate can be formed by a variety of techniques. As one example, the fibers can be molded and sintered so as create metallurgical bonds between the fibers and a base surface. The composition of the fibers of contact region **105** can be any biocompatible material that provides contact region **105** with mechanical strength and deformability suitable for being tapped by fastener **10** in accordance with the invention. Non-limiting examples include stainless steel, titanium, cobalt, chromium, tungsten, tantalum, molybdenum, gold, and alloys thereof.

An example of a method for affixing fastener **10** to fastener receiving member **60** will now be described by referring back to FIG. **3**, with the understanding that the method can likewise be described in association with the other embodiments illustrated in FIGS. **4–7**. It will be further understood that while the present example is given in the context of an orthopaedic surgical procedure, the invention is not so limited. That is, the fastener/receiver system provided by the invention can be applied to any procedure, surgical or non-surgical, in which a threaded fastener is to be tapped into an object and which would benefit by the ability to rigidly orient such fastener at a desired angle in relation to a mounting structure such as fastener receiving member **60**.

Turning now to FIG. **3**, the surgeon accesses the surgical site of interest, which can be, for example, an internal site at which a bone fracture F is located and requires stabilization to ensure proper healing. The surgeon mounts fastener receiving member **60** against bone material B at a desired location thereof in relation to the bone fracture F. A suitable alignment or mounting tool (not shown) can be employed to retain receiving member **60** in the desired position prior to complete affixation of fastener **10**. The surgeon then selects an insertion angle IA, defined hereinabove, as the direction along which fastener **10** is to be inserted through a selected aperture A of receiving member **60** and subsequently driven into a target section of bone material B. If receiving member **60** includes more than one aperture A, the surgeon also selects the specific aperture A to be used. After selecting insertion angle IA and aperture A, the surgeon inserts elongate section **20** of fastener **10** through aperture A until the tip of elongate section **20** contacts bone material B beneath aperture A. In some cases, at this point a hole might be drilled or tapped into bone material B along insertion angle IA to facilitate the initial tapping by fastener **10**. The surgeon then inserts an appropriate driving tool (not shown) into recess **53** of head section **40** of fastener **10**, and manipulates the driving tool to rotate fastener **10** while forcefully bearing fastener **10** against bone material B. This causes first thread **31** of elongate section **20** to tap into bone material B and anchor fastener **10** to bone material B. As elongate section **20** is driven further through aperture A and into bone material B, head section **40** eventually encounters contact region **85** of aperture A. Due to the intervening presence of contact region **85**, the continued driving of fastener **10** into bone material B at this stage causes second thread **51** of head section **40** to tap into contact region **85**, thereby rigidly affixing fastener **10** to receiving member **60** at the desired insertion angle IA.

The manner by which head section **40** of fastener **10** is affixed to aperture A of receiving member **60** depends on whether contact region **85** illustrated in FIGS. **2A–3** or contact region **105** illustrated in FIGS. **6** and **7** is provided. In the use of contact region **85**, second thread **51** of head section **40** is driven through a series of available interstices **89** (see, e.g., FIGS. **2C** and **2D**) and between a series of protrusions **87** adjacent to these interstices **89**. The driving of second thread **51** causes this series of protrusions **87** to contact second thread **51** and maintain fastener **10** at the desired insertion angle IA. As described hereinabove, protrusions **87** contacting second thread **51** may or may not deform or otherwise move in response to the driving of second thread **51** into contact region **85**. On the other hand, in the use of contact region **105**, the metal fibers will deflect in response to the driving of second thread **51** and envelop second thread **51**. The mechanical strength of the fibers contacting or proximate to second thread **51** is sufficient to maintain fastener **10** at the desired insertion angle IA. Some of the fibers may be cut in response to the driving of second thread **51** into contact region **105**. With the use of either contact region **85** or contact region **105**, the driving of second thread **51** through aperture A in effect forms a custom internal thread in contact region **85** or **105** that is complimentary to the orientation and structure of second thread **51** and turns in relation to fastener axis FA.

Depending on the nature of the procedure being executed, the surgeon can affix additional fasteners **10** to additional apertures A of receiving member **60**, either at the same insertion angle IA as the illustrated fastener **10** or at different angles. It will be noted that, depending on the number of fasteners **10** utilized and how far each is threaded into its corresponding aperture A, the mechanical strength of the interface between each corresponding second thread **51** and contact region **85** or **105** can be made sufficient to cause compression of receiving member **60** against bone material B if desired by the surgeon.

As an alternative to the embodiments specifically illustrated in FIGS. **1–7**, the interface between second thread **51** of head section **40** and contact region **85** or **105** of aperture A could be reversed. That is, head section **40** of fastener **10** could be provided with contact region **85** or **105**, and aperture A of fastener receiving member **60** could be provided with second thread **51**. This alternative embodiment likewise enables fastener **10** to be rigidly secured non-coaxially to aperture A.

It will be understood that various details of the invention may be changed without departing from the scope of the invention. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation, as the invention is defined by the claims as set forth hereinafter.

What is claimed is:

1. A surgical plate adapted for fixation with a bone screw, comprising first and second opposing major surfaces, an inside surface extending between the first and second major surfaces and defining an aperture generally coaxially disposed about an aperture axis, and a non-rotatable, non-threaded tappable contact region disposed on the inside surface of the aperture, the tappable contact region having an inside diameter large enough to permit a bone screw to pass therethrough at a variable insertion angle defined between the longitudinal axis of the bone screw and the aperture axis, and the tappable contact region is formed so as to allow for being tapped by an external thread of the bone screw to rigidly affix the bone screw to the tappable contact region at a selected one of a plurality of different insertion angles that can be selectively formed between the axis of the bone screw and the aperture axis.

2. The surgical plate according to claim **1** wherein the first and second major surfaces are disposed generally transversely in relation to the aperture axis.

3. The surgical plate according to claim **1** comprising a plurality of inside surfaces, each inside surface defining a respective aperture generally coaxially disposed about a respective aperture axis, and a plurality of tappable contact regions respectively disposed on the inside surfaces.

4. The surgical plate according to claim **1** wherein the tappable contact region has a substantially cylindrical vertical profile.

5. The surgical plate according to claim **1** wherein the tappable contact region has a rounded vertical profile.

6. The surgical plate according to claim **1** wherein the tappable contact region has a substantially hemispherical vertical profile.

7. The surgical plate according to claim 1 wherein the tappable contact region has a substantially frusto-conical vertical profile.

8. The surgical plate according to claim 1 wherein the tappable contact region has a converging/diverging vertical profile.

9. The surgical plate according to claim 1 wherein the tappable contact region is formed in the inside surface of the aperture.

10. The surgical plate according to claim 1 wherein the tappable contact region comprises an insert fitted to the inside surface.

11. The surgical plate according to claim 1 wherein the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface and a plurality of interstices between the protrusions.

12. The surgical plate according to claim 11 wherein the protrusions are constructed from a metal-containing material.

13. The surgical plate according to claim 11 wherein the protrusions are constructed from a polymeric material.

14. The surgical plate according to claim 11 wherein the protrusions have substantially polygonal cross-sections.

15. The surgical plate according to claim 11 wherein the protrusions have substantially rounded cross-sections.

16. The surgical plate according to claim 1 wherein the tappable contact region comprises a porous fiber metal matrix.

17. The surgical plate according to claim 16 wherein the fiber metal matrix comprises a plurality of titanium-containing fibers.

18. The surgical plate according to claim 1 wherein the minimum inside diameter of the tappable contact region ranges from approximately 0.5 to approximately 10 mm.

19. The surgical plate according to claim 1 wherein the minimum inside diameter of the tappable contact region is greater than 10 mm.

20. The surgical plate according to claim 1 wherein the insertion angle ranges from approximately 0 to approximately 90 degrees.

21. A fastening apparatus adapted for multi-angular insertion, comprising:

(a) a fastener comprising an elongate section and an adjoining head section disposed along a fastener axis, the head section comprising a thread; and

(b) a fastener receiving member comprising first and second opposing major surfaces, an inside surface extending between the first and second major surfaces and defining an aperture generally coaxially disposed about an aperture axis, and a non-rotatable tappable contact region disposed on the inside surface of the aperture, the tappable contact region having an inside diameter large enough to permit the elongate section of the fastener to pass therethrough at a variable insertion angle defined between the fastener axis and the aperture axis, and the tappable contact region is formed so as to allow for being tapped by the thread of the head section to rigidly affix the head section to the tappable contact region at a selected one of a plurality of different angles that can be selectively formed between the axis of the fastener and the aperture axis.

22. The apparatus according to claim 21 wherein the fastener is a surgical bone screw.

23. The apparatus according to claim 21 wherein the elongate section comprises a thread.

24. The apparatus according to claim 23 wherein the elongate section comprises a first outer surface, and the thread of the elongate section extends along a length of the first outer surface in generally helical relation to the fastener axis.

25. The apparatus according to claim 24 wherein the head section comprises a second outer surface, and the thread of the head section extends along a length of the second outer surface in generally helical relation to the fastener axis.

26. The apparatus according to claim 23 wherein the head section has a rounded vertical profile.

27. The apparatus according to claim 23 wherein the head section has a substantially hemispherical vertical profile.

28. The apparatus according to claim 23 wherein the head section has a substantially frusto-conical vertical profile.

29. The apparatus according to claim 23 wherein the head section has a converging/diverging vertical profile.

30. The apparatus according to claim 21 wherein the first and second major surfaces of the fastener receiving member define a surgical plate.

31. The apparatus according to claim 21 wherein the tappable contact region is formed in the inside surface of the fastener receiving member.

32. The apparatus according to claim 21 wherein the tappable contact region comprises an insert fitted to the inside surface.

33. The apparatus according to claim 21 wherein the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface and a plurality of interstices between the protrusions.

34. The apparatus according to claim 33 wherein the protrusions are constructed from a metal-containing material.

35. The apparatus according to claim 33 wherein the protrusions comprise a polymeric material.

36. The apparatus according to claim 21 wherein the tappable contact region comprises a porous fiber metal matrix.

37. The apparatus according to claim 36 wherein the fiber metal matrix comprises a plurality of titanium-containing fibers.

38. The apparatus according to claim 21 wherein the insertion angle ranges from approximately 0 to approximately 90 degrees.

39. A method for affixing a fastener to a fastener receiving member at a desired orientation, comprising the steps of:

(a) providing a fastener comprising an elongate section and an adjoining head section disposed along a fastener axis, the head section comprising a thread;

(b) providing a fastener receiving member comprising first and second opposing major surfaces, an inside surface extending between the first and second major surfaces and defining an aperture generally coaxially disposed about an aperture axis, and a non-rotatable tappable contact region disposed on the inside surface of the aperture, the tappable contact region having an inside diameter large enough to permit the elongate section of the fastener to pass therethrough at a variable insertion angle defined between the fastener axis and the aperture axis, and the contact region is formed so as to allow for being tapped by the thread of the head section to rigidly affix the head section to the tappable contact region at a selected one of a plurality of different angles that can be selectively formed between the axis of the fastener and the apertur axis;

(c) selecting one of the plurality of different insertion angles at which the fastener is to be inserted in relation to the fastener receiving member;

(d) inserting the elongate section through the aperture until the thread of the head section contacts the non-rotatable tappable contact region; and

(e) tapping the fastener into the receiving member such that the fastener is rigidly oriented at the selected insertion angle by threading the thread of the head section into the non-rotatable tappable contact region while the fastener is oriented at the selected insertion angle.

40. The method according to claim **39** comprising the steps of placing one of the major surfaces of the receiving member against bone material, and inserting the elongate section of the fastener into the bone material.

41. The method according to claim **40** wherein the elongate section is threaded, and inserting the elongate section into the bone material comprises threading the elongate section into the bone material.

42. The method according to claim **41** wherein threading of the elongate section further into the bone material causes threading of the thread of the head section into the tappable contact region of the receiving member.

43. The method according to claim **39** wherein the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface and a plurality of interstices between the protrusions, and tapping the fastener comprises driving the thread of the head section through a series of the interstices and into contact with a series of the protrusions.

44. The method according to claim **43** wherein driving the thread of the head section into contact with the series of protrusions deforms at least some of the protrusions.

45. The method according to claim **39** wherein the tappable contact region comprises a porous fiber metal matrix, and the step of tapping the fastener comprises driving the thread of the head section into the matrix to create a screw path in the matrix.

46. The method according to claim **45** wherein driving the thread of the head section into the matrix cut, deforms, or deflects fibers of the matrix.

47. A surgical plate adapted for fixation with a bone screw, comprising first and second opposing major surfaces, an inside surface extending between the first and second major surfaces and defining an aperture generally coaxially disposed about an aperture axis, and a non-threaded tappable contact region disposed on the inside surface, wherein the tappable contact region has a minimum inside diameter large enough to permit a bone screw to pass therethrough at an insertion angle defined between a longitudinal axis of the bone screw and the aperture axis, and the tappable contact region is adapted for being tapped by an external thread of the bone screw to affix the bone screw to the tappable contact region at the insertion angle and wherein the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface and a plurality of interstices between the protrusions.

48. The surgical plate according to claim **47** wherein the protrusions are constructed from a metal-containing material.

49. The surgical plate according to claim **47** wherein the protrusions are constructed from a polymeric material.

50. The surgical plate according to claim **47** wherein the protrusions have substantially polygonal cross-sections.

51. The surgical plate according to claim **47** wherein the protrusions have substantially rounded cross-sections.

52. The surgical plate according to claim **47** wherein the tappable contact region comprises a porous fiber metal matrix.

53. The surgical plate according to claim **52** wherein the fiber metal matrix comprises a plurality of titanium-containing fibers.

54. A fastening apparatus adapted for multi-angular insertion, comprising:

(a) a fastener comprising an elongate section and an adjoining head section disposed along a fastener axis, the head section comprising a thread, said fastener comprising a surgical bone screw; and

(b) a fastener receiving member comprising first and second opposing major surfaces, an inside surface extending between the first and second major surfaces and defining an aperture generally coaxially disposed about an aperture axis, and a tappable contact region disposed on the inside surface, wherein the tappable contact region has a minimum inside diameter large enough to permit the elongate section to pass therethrough at an insertion angle defined between the fastener axis and the aperture axis, and the tappable contact region is adapted for being tapped by the thread of the head section to affix the head section to the tappable contact region at the insertion angle.

55. The apparatus according to claim **54** wherein the elongate section comprises a thread.

56. The apparatus according to claim **55** wherein the elongate section comprises a first outer surface, and the thread of the elongate section extends along a length of the first outer surface in generally helical relation to the fastener axis.

57. The apparatus according to claim **56** wherein the head section comprises a second outer surface, and the thread of the head section extends along a length of the second outer surface in generally helical relation to the fastener axis.

58. The apparatus according to claim **54** wherein the head section has a rounded vertical profile.

59. The apparatus according to claim **54** wherein the head section has a substantially hemispherical vertical profile.

60. The apparatus according to claim **54** wherein the head section has a substantially frusto-conical vertical profile.

61. The apparatus according to claim **54** wherein the head section has a converging/diverging vertical profile.

62. The apparatus according to claim **54** wherein the first and second major surfaces of the fastener receiving member define a surgical plate.

63. The apparatus according to claim **54** wherein the tappable contact region is formed in the inside surface of the fastener receiving member.

64. The apparatus according to claim **54** wherein the tappable contact region comprises an insert fitted to the inside surface.

65. The apparatus according to claim **54** wherein the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface and a plurality of interstices between the protrusions.

66. The apparatus according to claim **65** wherein the protrusions are constructed from a metal-containing material.

67. The apparatus according to claim **65** wherein the protrusions comprise a polymeric material.

68. The apparatus according to claim **54** wherein the tappable contact region comprises a porous fiber metal matrix.

69. The apparatus according to claim **68** wherein the fiber metal matrix comprises a plurality of titanium-containing fibers.

70. The apparatus according to claim **54** wherein the insertion angle ranges from approximately 0 to approximately 90 degrees.

71. A method for affixing a fastener to a fastener receiving member at a desired orientation, comprising the steps of:

(a) providing a fastener comprising a threaded elongate section and an adjoining head section disposed along a fastener axis, the head section comprising a thread;

(b) providing a fastener receiving member comprising first and second opposing major surfaces, an inside surface extending between the first and second major surfaces and defining an aperture generally coaxially disposed about an aperture axis, and a tappable contact region disposed on the inside surface;

(c) selecting an insertion angle at which the fastener is to be inserted in relation to the fastener receiving member, wherein the insertion angle is defined between the fastener axis and the aperture axis;

(d) inserting the elongate section through the aperture until the thread of the head section contacts the tappable contact region;

(e) tapping the fastener into the receiving member such that the fastener is oriented at the selected insertion angle by threading the thread of the head section into the tappable contact region while the fastener is oriented at the selected insertion angle; and

(f) comprising the step of placing one of the major surfaces of the receiving member against bone material, and inserting the elongate section of the fastener into the bone material by threading the elongate section into the bone material.

72. The method according to claim **71** wherein threading of the elongate section further into the bone material causes threading of the thread of the head section into the tappable contact region of the receiving member.

73. The method according to claim **71** wherein the tappable contact region comprises a plurality of protrusions extending generally radially inwardly from the inside surface and a plurality of interstices between the protrusions, and tapping the fastener comprises driving the thread of the head section through a series of the interstices and into contact with a series of the protrusions.

74. The method according to claim **73** wherein driving the thread of the head section into contact with the series of protrusions deforms at least some of the protrusions.

75. The method according to claim **71** wherein the tappable contact region comprises a porous fiber metal matrix, and the step of tapping the fastener comprises driving the thread of the head section into the matrix to create a screw path in the matrix.

76. The method according to claim **75** wherein driving the thread of the head section into the matrix cut, deforms, or deflects fibers of the matrix.

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