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Huebner et al.

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(54) **SYSTEM FOR FUSING JOINTS**

(56) **References Cited**

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(73) Assignee: **Acumed LLC**, Hillsboro, OR (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1101 days.

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(21) Appl. No.: **11/329,368**

The Herbert™ Bone Screws for Small Bone Fractures, Fracture Management, 97-1152-01 12.5MI printed in U.S.A. © 1992 Zimmer, Inc.

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Related U.S. Application Data

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(63) Continuation of application No. 10/162,397, filed on Jun. 3, 2002, now Pat. No. 6,984,235, which is a

(Continued)

(57) **ABSTRACT**

A method of fusing a joint between two bones, comprising boring a hole through one of the bones across the joint therebetween and into the other bone, placing the leading end of a screw into the hole, where the screw has a threaded region having a pitch that is larger toward a leading end of the screw and smaller toward a trailing end of the screw, and driving the screw into the bone until the threaded region spans the joint.

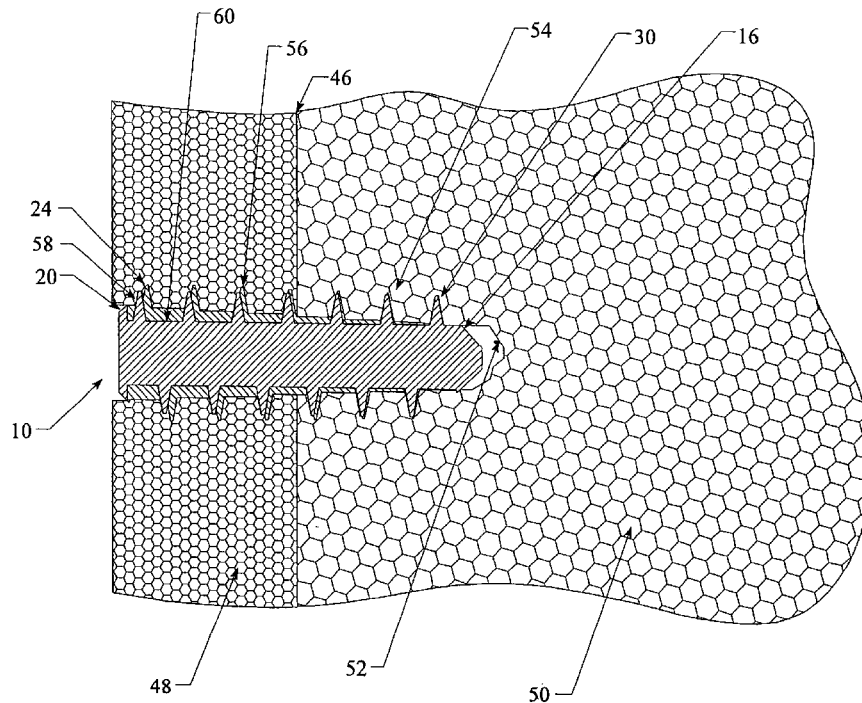
(51) **Int. Cl.**
A61B 17/84 (2006.01)

(52) **U.S. Cl.** 606/317; 606/105

(58) **Field of Classification Search** 606/317, 606/105

See application file for complete search history.

18 Claims, 13 Drawing Sheets



Related U.S. Application Data

- (63) continuation of application No. 09/483,076, filed on Jan. 14, 2000, now abandoned, which is a continuation-in-part of application No. 09/305,841, filed on May 5, 1999, now Pat. No. 6,017,347, which is a continuation-in-part of application No. 09/157,783, filed on Sep. 21, 1998, now Pat. No. 6,120,505, which is a continuation-in-part of application No. 08/457,624, filed on Jun. 1, 1995, now Pat. No. 5,810,825, said application No. 09/483,076 is a continuation-in-part of application No. 09/375,306, filed on Aug. 16, 1999, now Pat. No. 6,299,615, which is a continuation-in-part of application No. 09/019,135, filed on Feb. 5, 1998, now Pat. No. 5,976,134, which is a continuation-in-part of application No. 08/847,820, filed on Apr. 28, 1997, now abandoned, which is a continuation-in-part of application No. 08/587,210, filed on Jan. 11, 1996, now Pat. No. 5,624,440, said application No. 09/483,076 is a continuation-in-part of application No. 08/622,368, filed on Mar. 26, 1996, now Pat. No. 5,665,087, and a continuation-in-part of application No. 09/318,437, filed on May 25, 1999, now Pat. No. 6,162,224, and a continuation-in-part of application No. 09/318,669, filed on May 25, 1999, now Pat. No. 6,171,309, said application No. 09/318,437 is a continuation-in-part of application No. 08/636,326, filed on Apr. 22, 1996, now Pat. No. 5,662,649, said application No. 09/483,076 is a continuation-in-part of application No. 08/715,017, filed on Sep. 17, 1996, now Pat. No. 5,658,283, and a continuation-in-part of application No. 08/759,075, filed on Dec. 2, 1996, now Pat. No. 5,697,934, and a continuation-in-part of application No. 29/063,695, filed on Dec. 13, 1996, now Pat. No. Des. 404,128, and a continuation-in-part of application No. 08/773,968, filed on Dec. 26, 1996, now Pat. No. 5,702,472, and a continuation-in-part of application No. 09/034,046, filed on Mar. 3, 1998, now Pat. No. 5,964,768, which is a continuation-in-part of application No. 08/781,471, filed on Jan. 10, 1997, now Pat. No. 5,871,486, said application No. 09/483,076 is a continuation-in-part of application No. 08/792,988, filed on Feb. 3, 1997, now Pat. No. 5,868,789, said application No. 09/483,076 is a continuation-in-part of application No. 08/986,717, filed on Dec. 8, 1997, now Pat. No. 5,994,721, and a continuation-in-part of application No. 09/093,415, filed on Jun. 8, 1998, now Pat. No. 6,001,099, and a continuation-in-part of application No. 09/216,316, filed on Dec. 18, 1998, now Pat. No. 6,030,162, and a continuation-in-part of application No. 09/263,141, filed on Mar. 5, 1999, now Pat. No. 6,077,271.

- (60) Provisional application No. 60/077,168, filed on Mar. 6, 1998.

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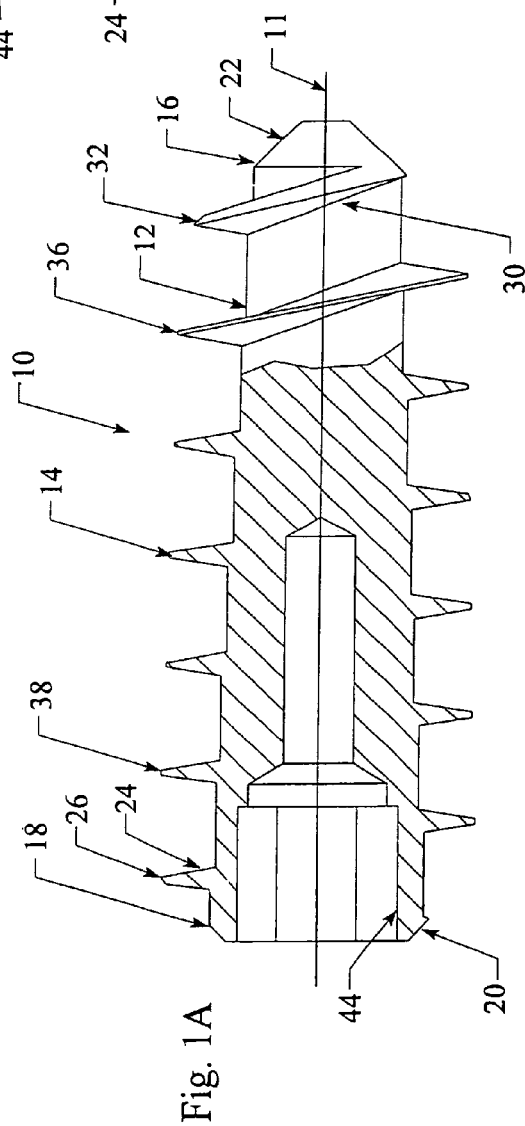
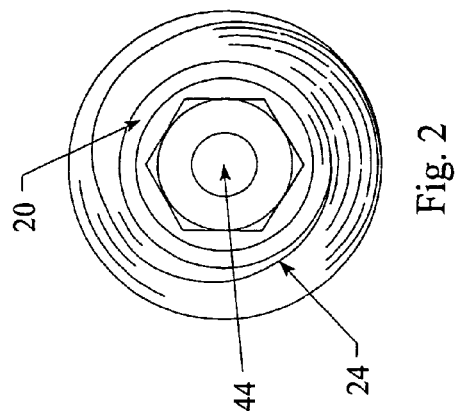
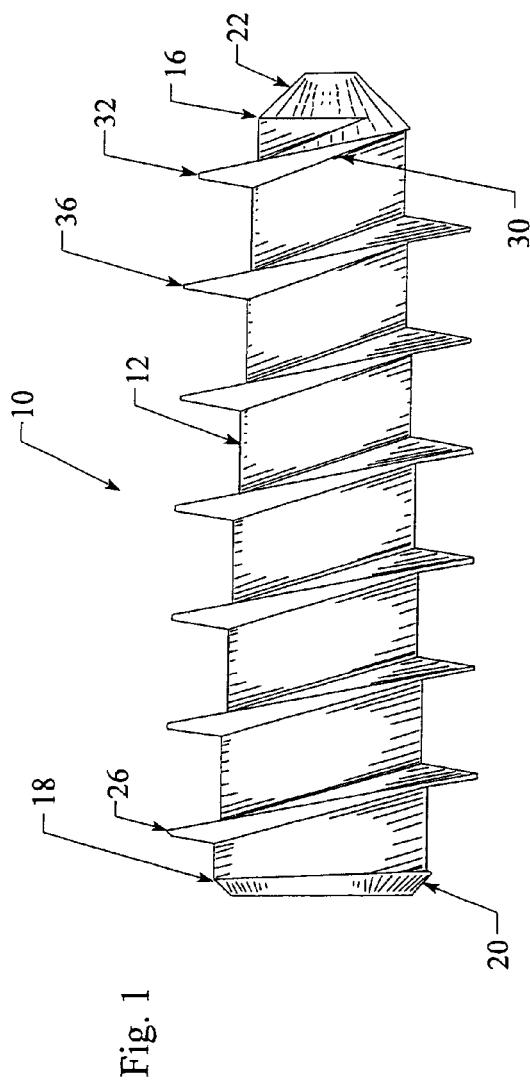
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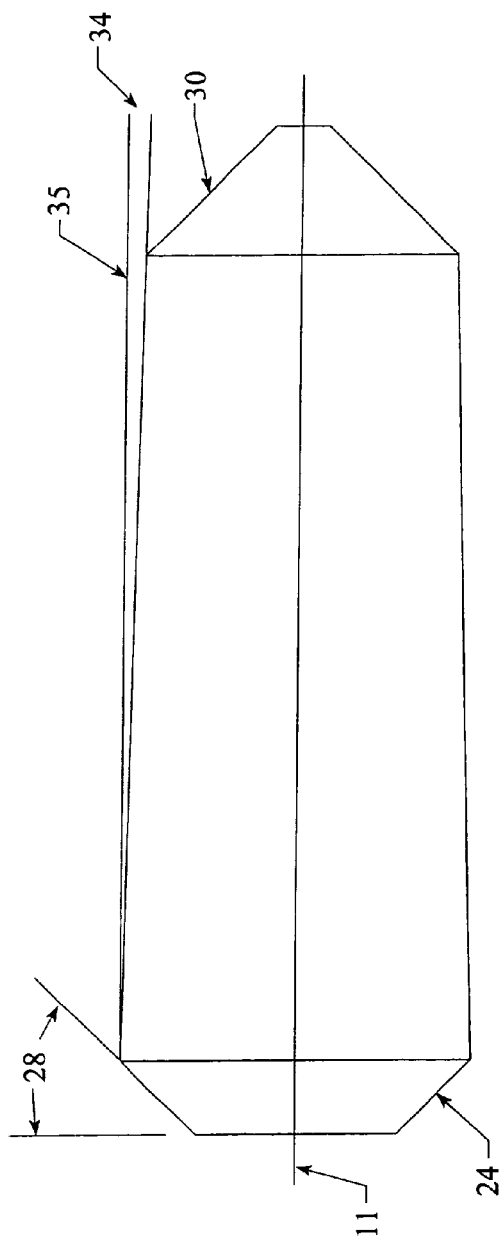


Fig. 3

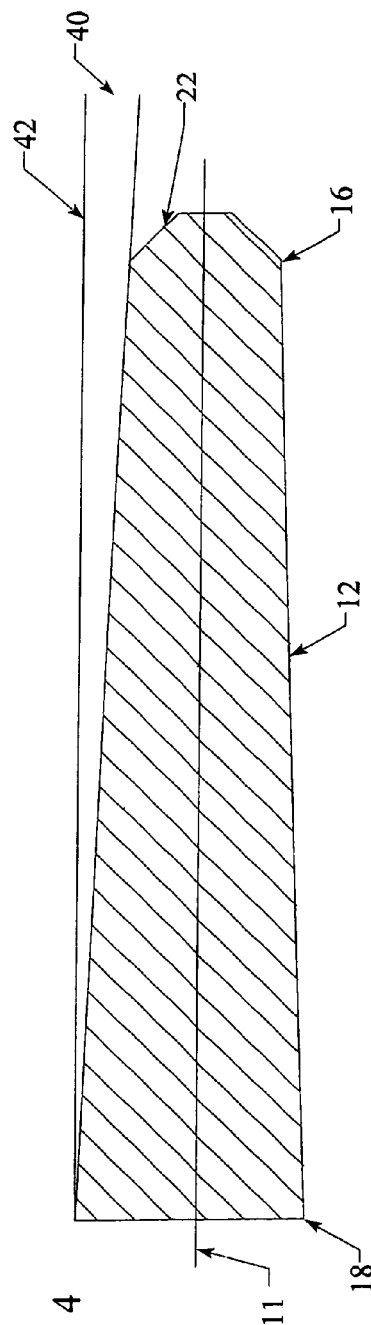


Fig. 4

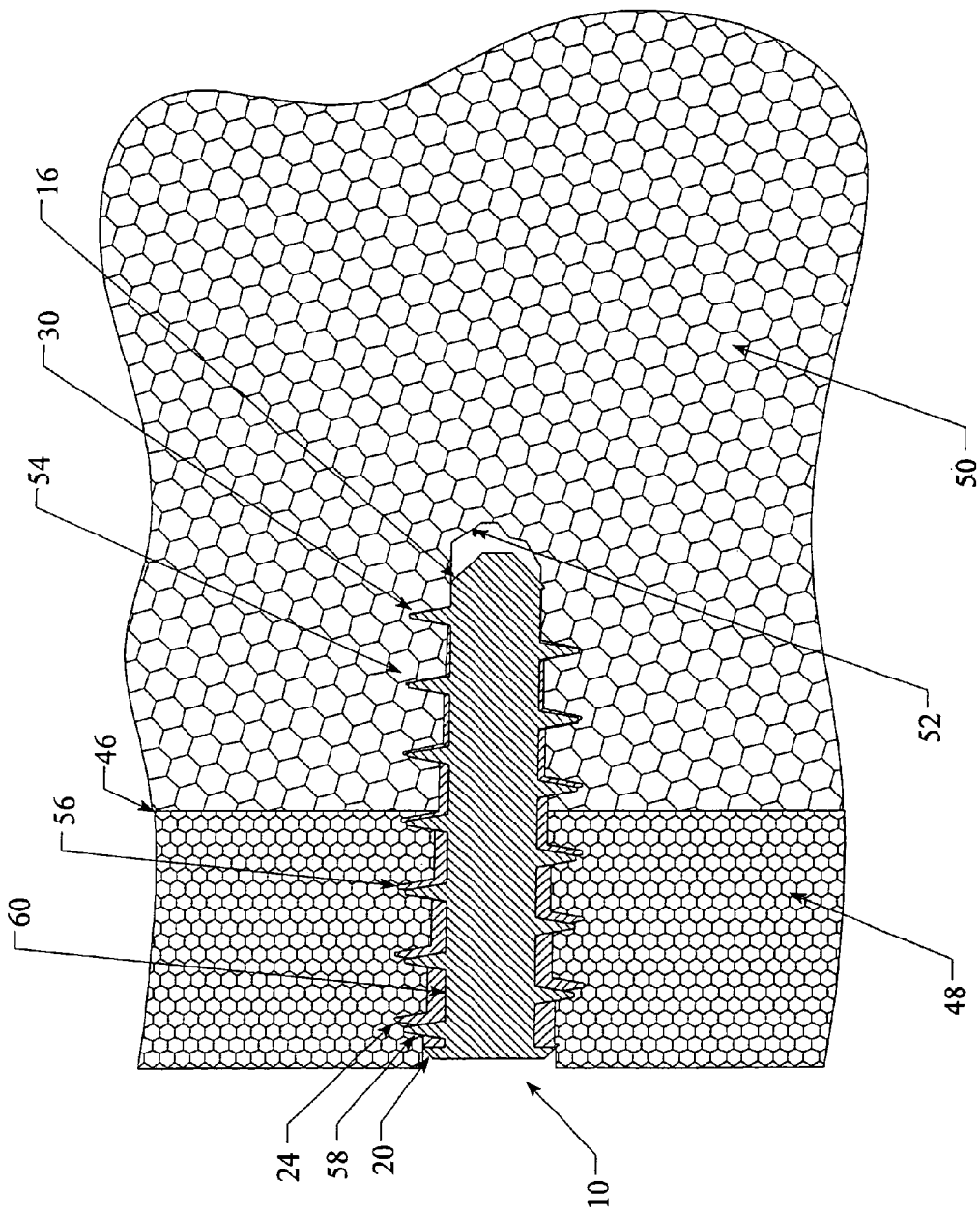
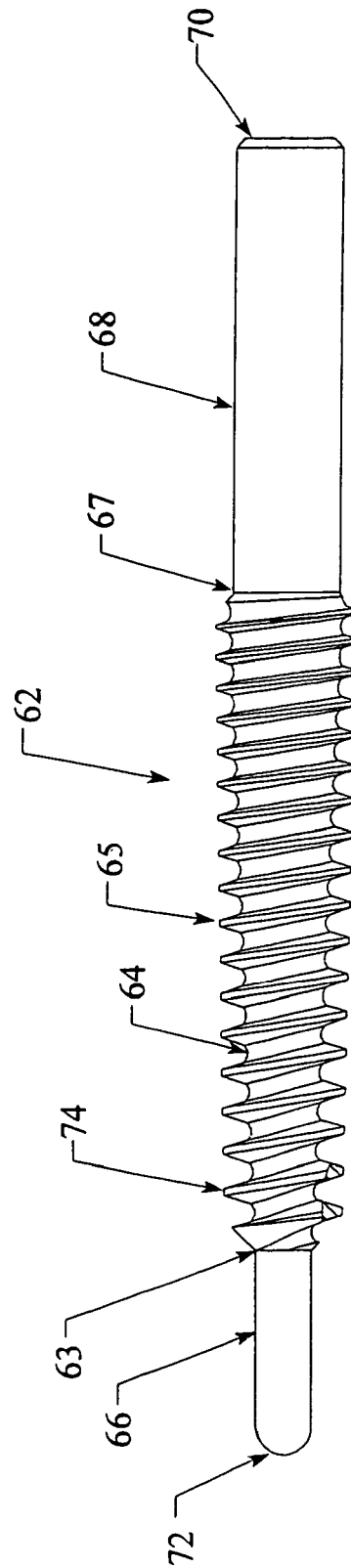


Fig. 5

Fig. 6



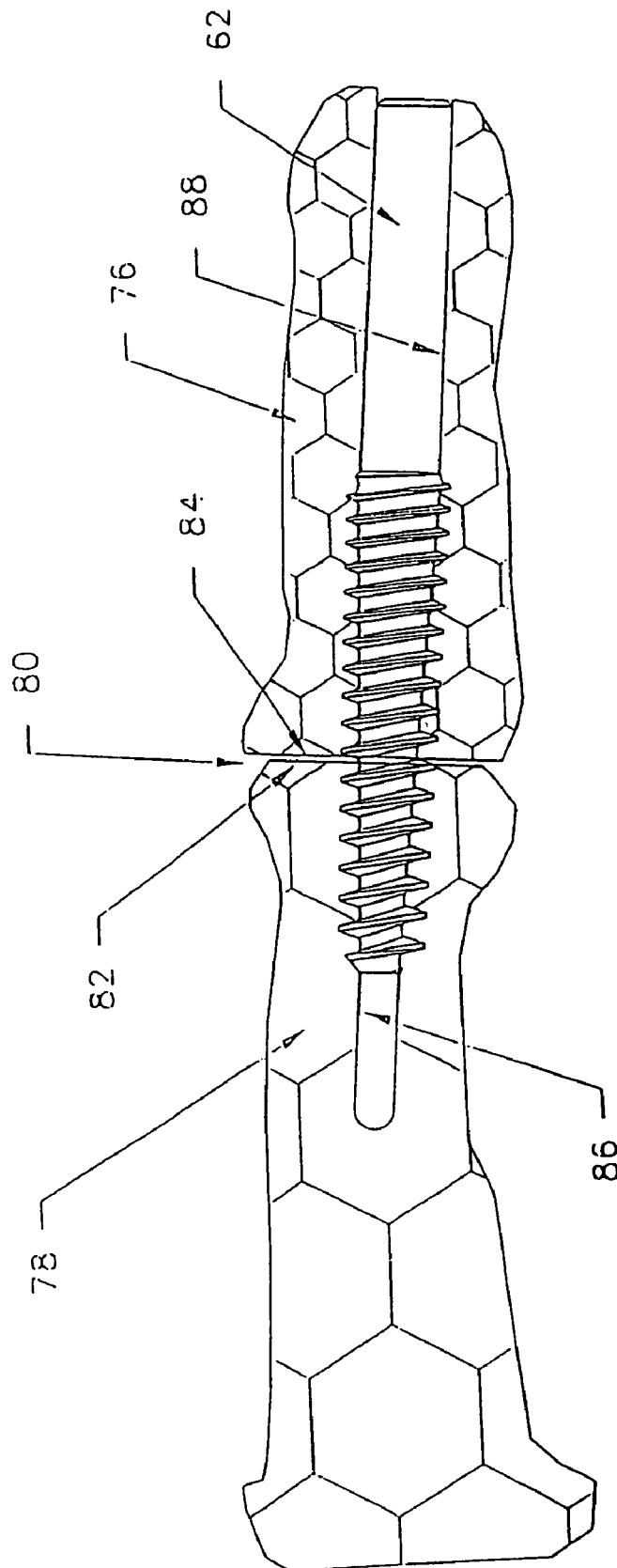
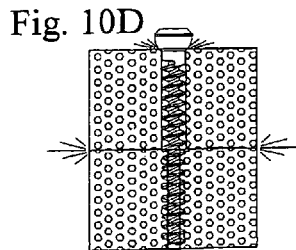
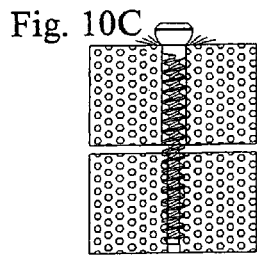
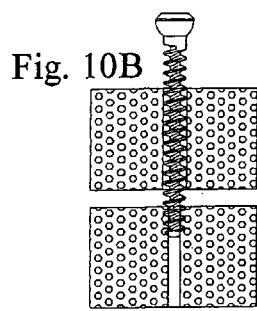
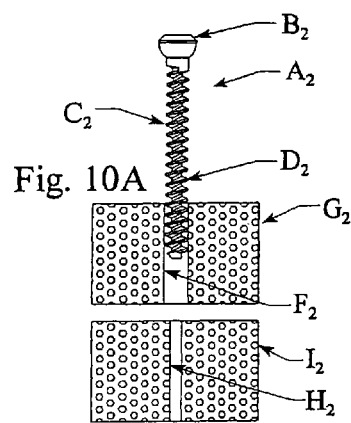
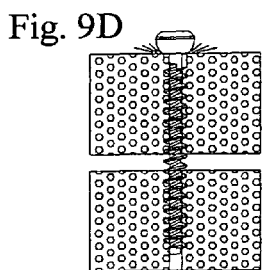
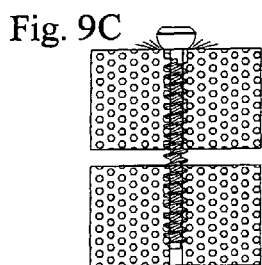
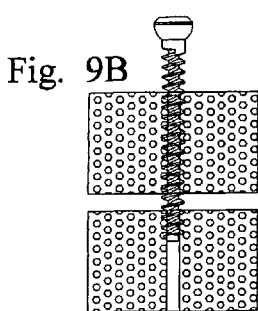
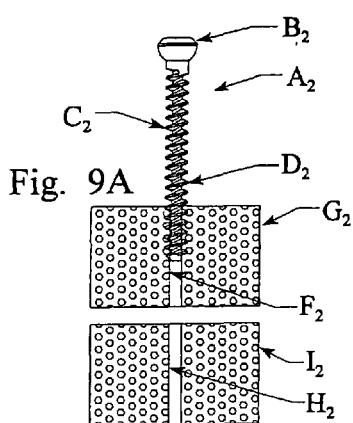
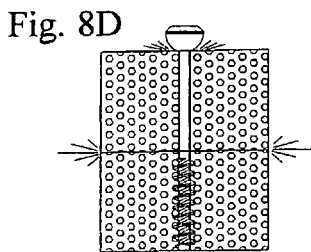
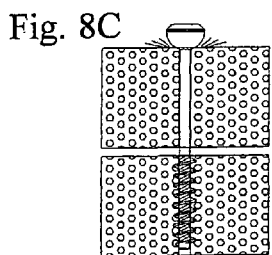
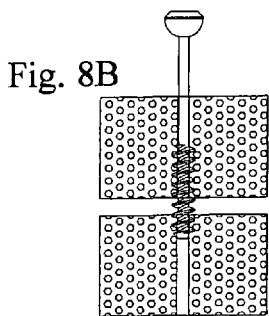
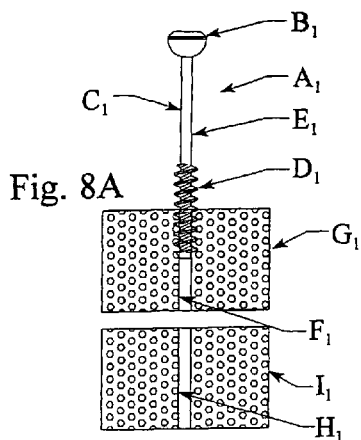
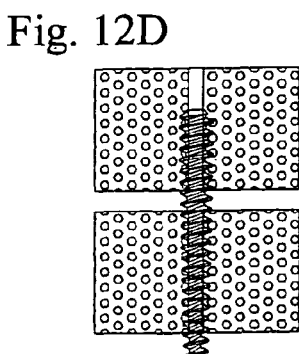
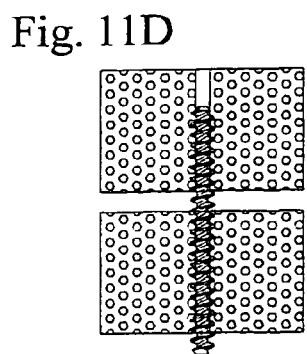
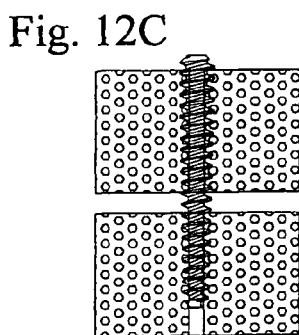
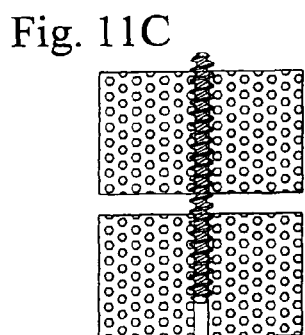
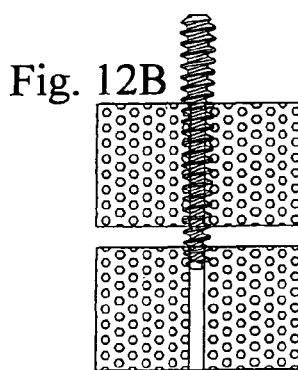
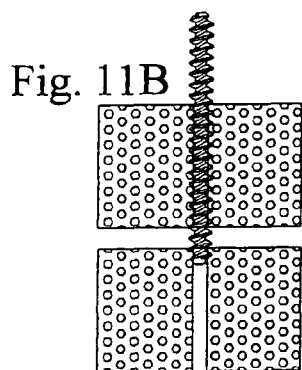
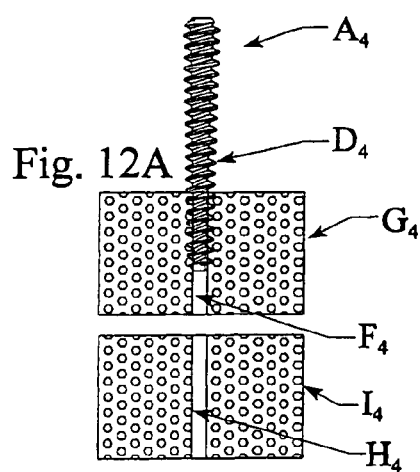
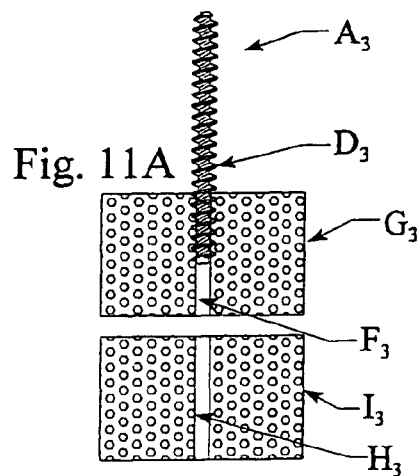
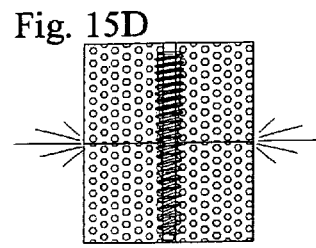
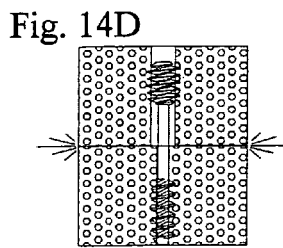
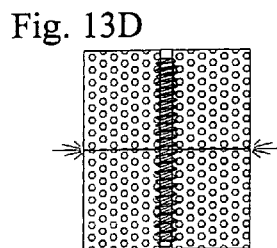
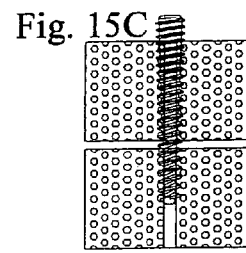
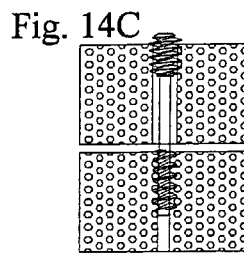
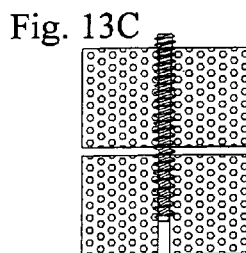
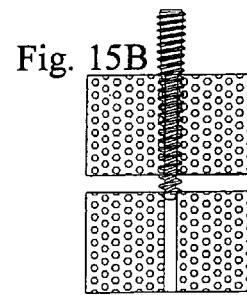
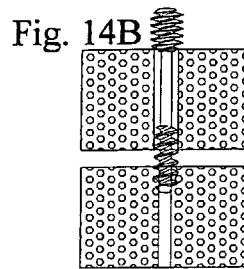
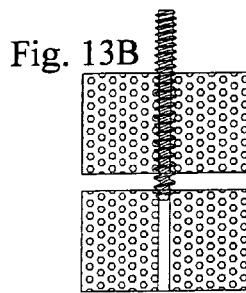
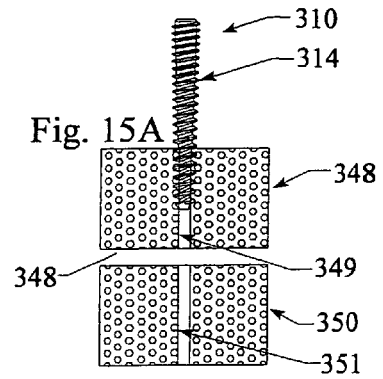
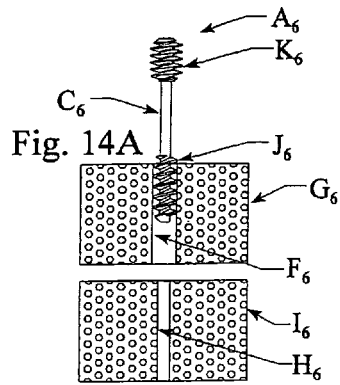
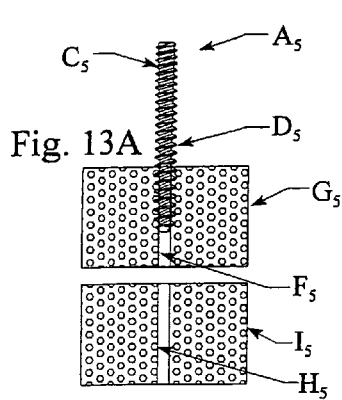
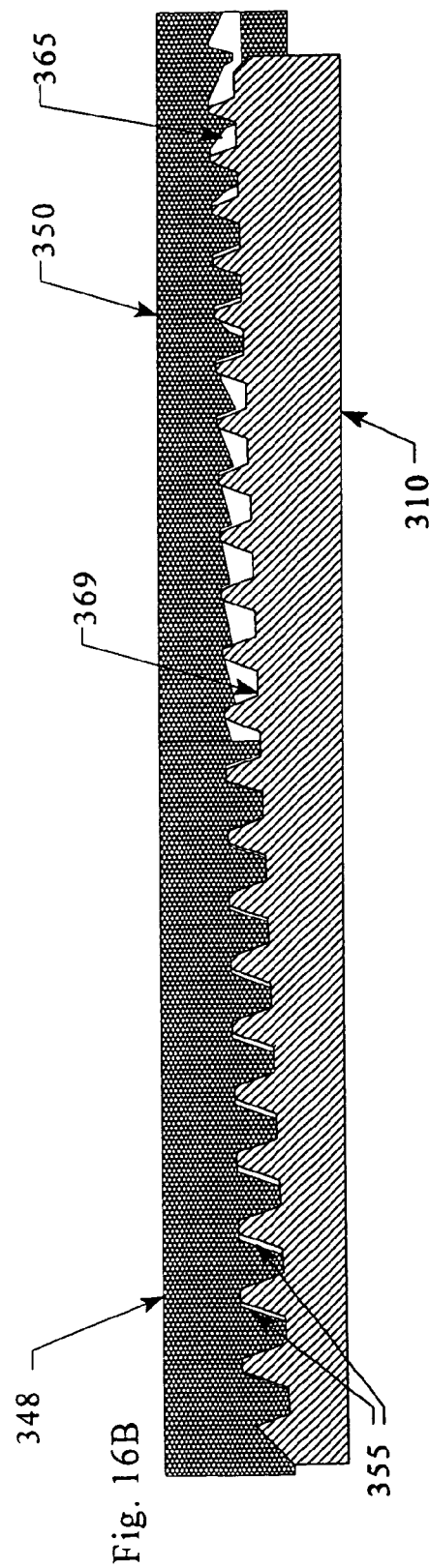
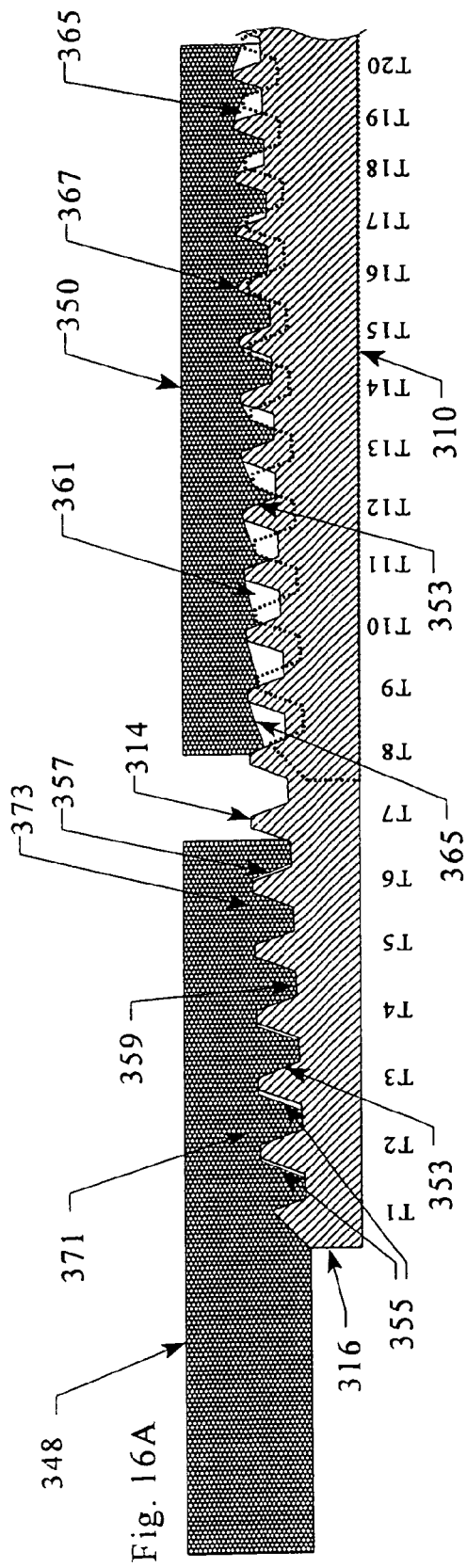


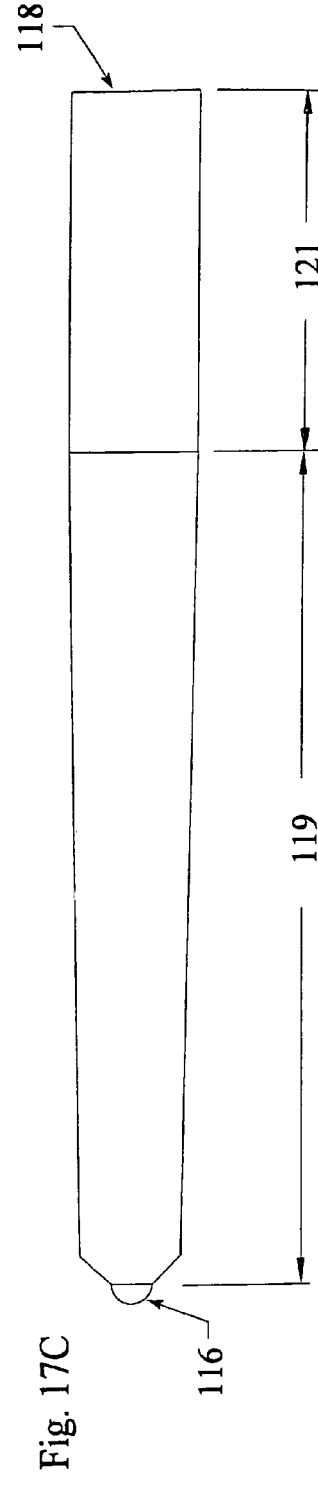
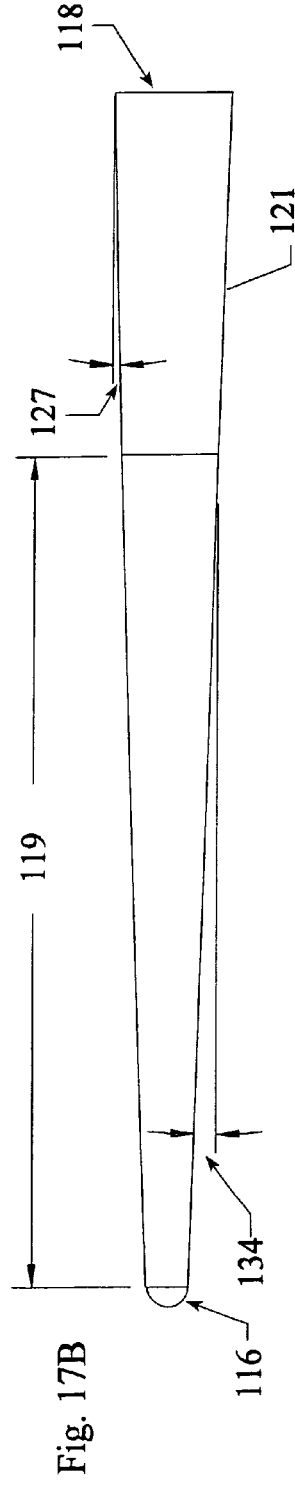
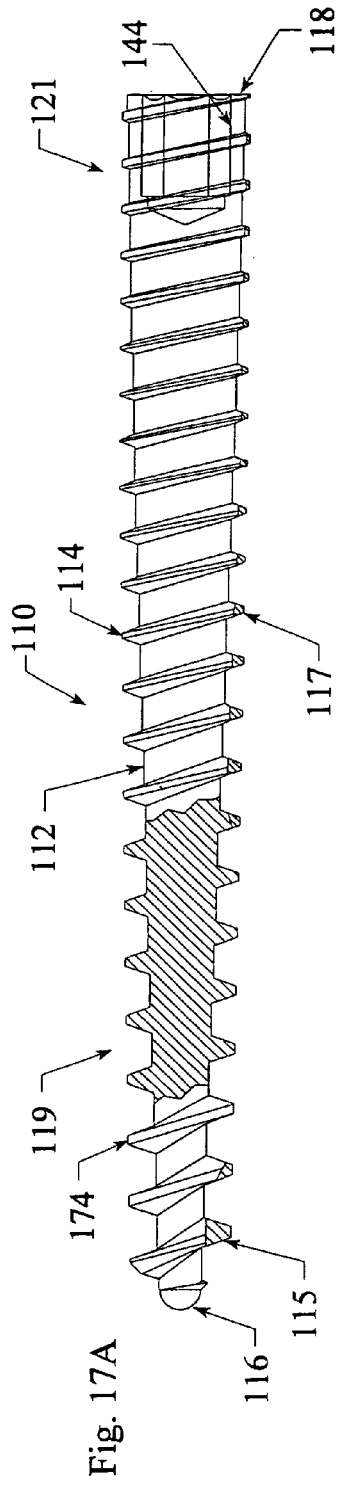
FIG. 7

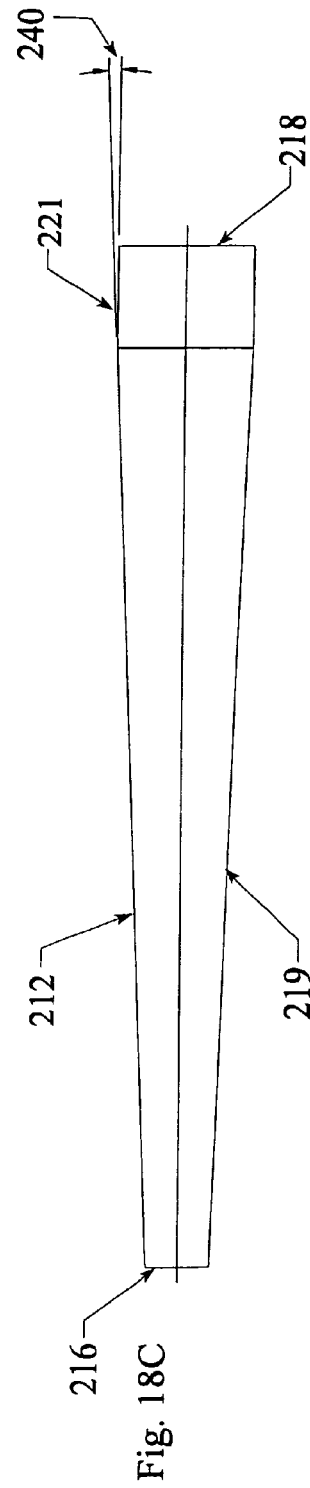
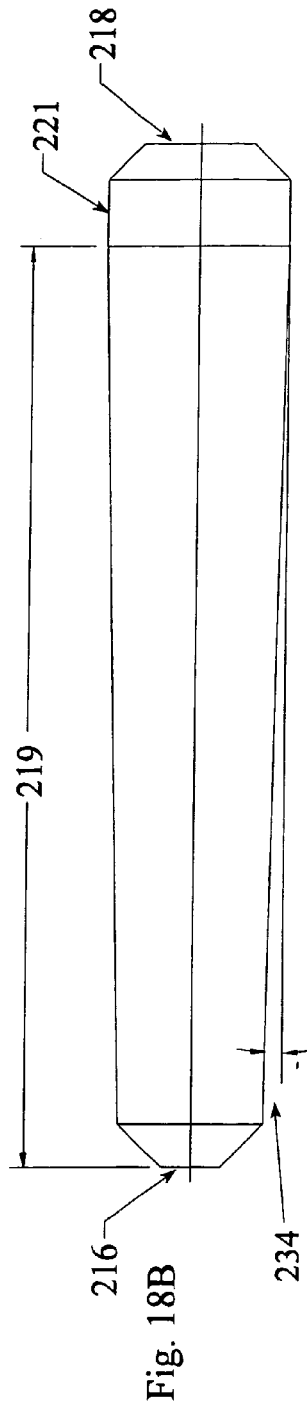
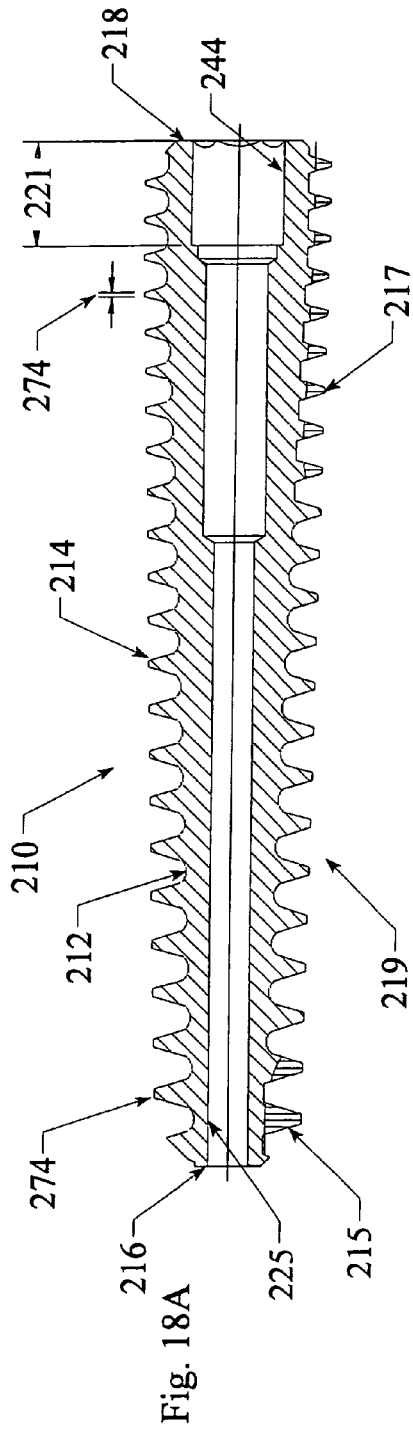












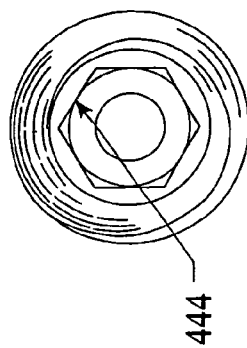
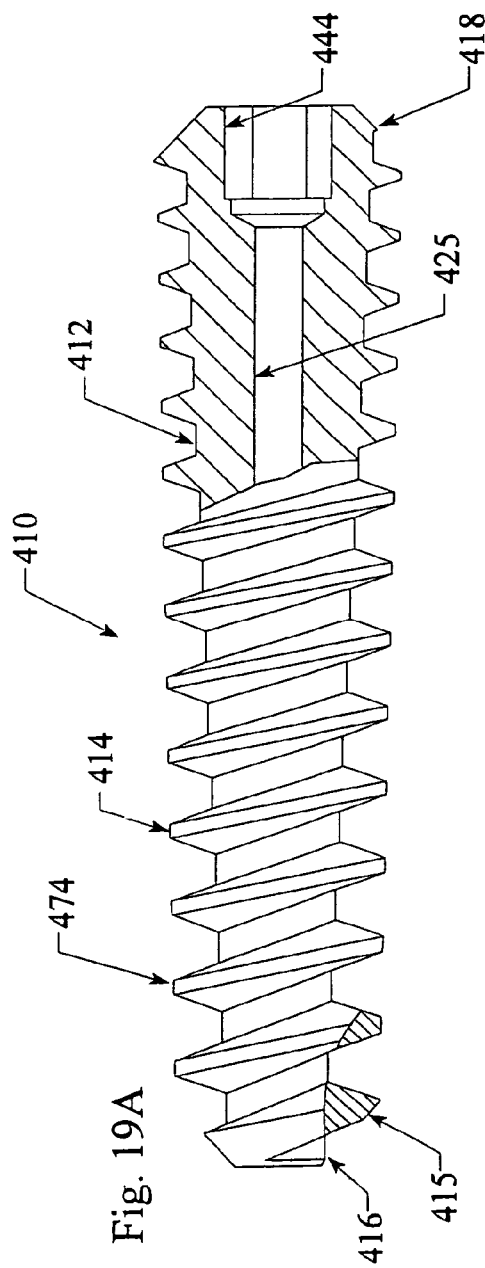
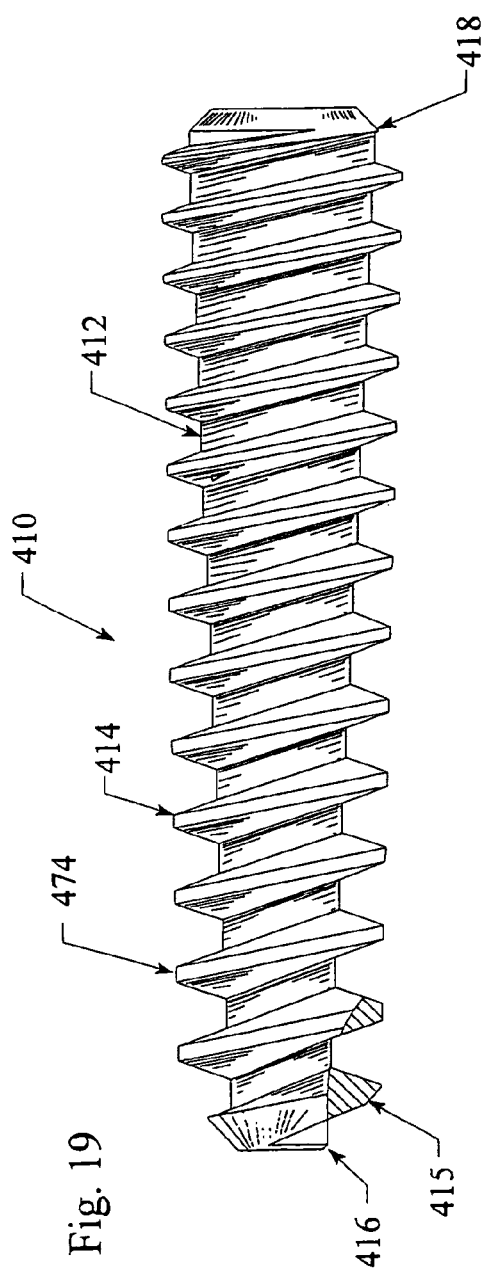


Fig. 20

Fig. 21A

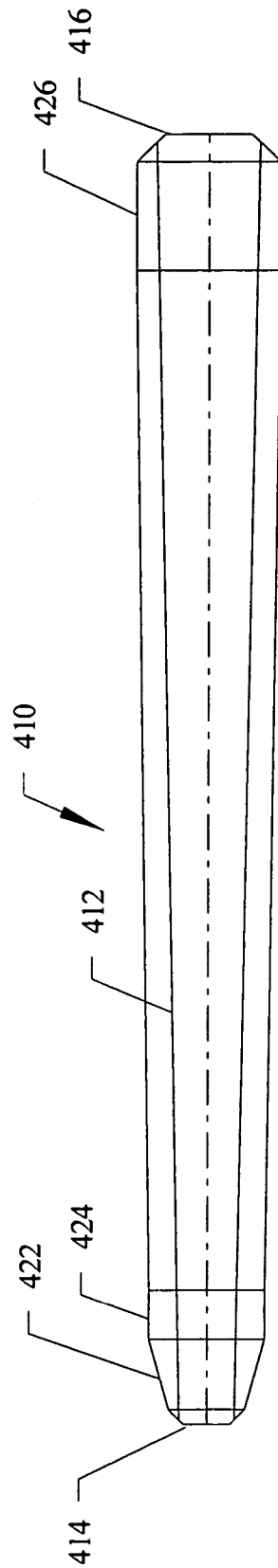
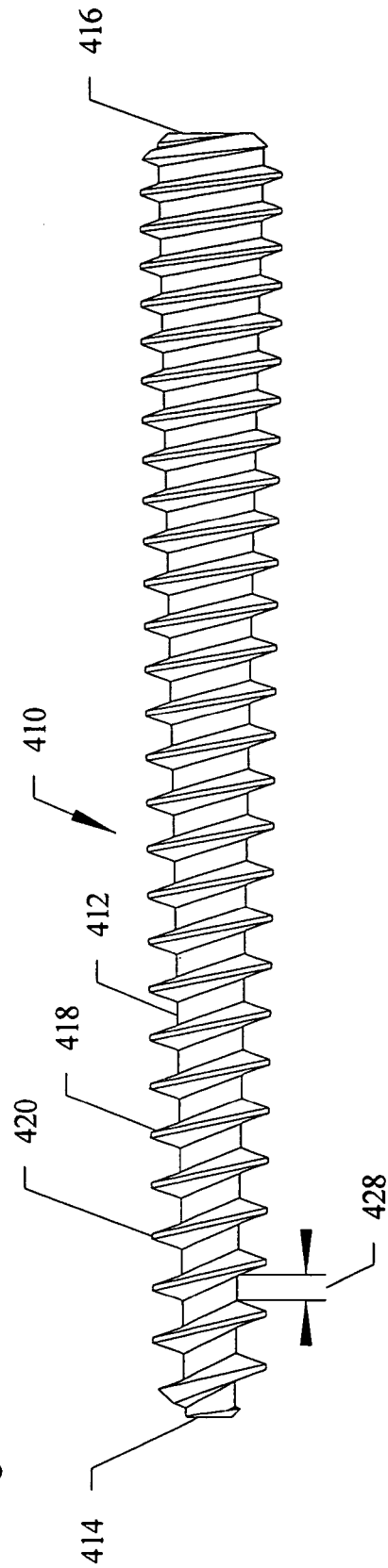


Fig. 21B



1

SYSTEM FOR FUSING JOINTS**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 10/162,397, filed Jun. 3, 2002, issued as U.S. Pat. No. 6,984,235 on Jan. 10, 2005.

U.S. patent application Ser. No. 10/162,397, in turn, is a continuation of U.S. patent application Ser. No. 09/483,076, filed Jan. 14, 2000, now abandoned.

U.S. patent application Ser. No. 09/483,076, in turn, is a continuation-in-part of U.S. patent application Ser. No. 09/305,841, filed May 5, 1999, issued as U.S. Pat. No. 6,017,347 on Jan. 25, 2000, which is a continuation-in-part of U.S. patent application Ser. No. 09/157,783, filed Sep. 21, 1998, issued as U.S. Pat. No. 6,120,505 on Sep. 19, 2000, which is a continuation-in-part of U.S. patent application Ser. No. 08/457,624, filed Jun. 1, 1995, issued as U.S. Pat. No. 5,810,825 on Sep. 22, 1998.

U.S. patent application Ser. No. 09/483,076 also is a continuation-in-part of U.S. patent application Ser. No. 09/375,306, filed Aug. 16, 1999, issued as U.S. Pat. No. 6,299,615 on Oct. 9, 2001, which is a continuation-in-part of U.S. patent application Ser. No. 09/019,135, filed Feb. 5, 1998, issued as U.S. Pat. No. 5,976,134 on Nov. 2, 1999, which is a continuation-in-part of U.S. patent application Ser. No. 08/847,820, filed Apr. 28, 1997, now abandoned, which is a continuation-in-part of U.S. patent application Ser. No. 08/587,210, filed Jan. 11, 1996, now issued as U.S. Pat. No. 5,624,440 on Apr. 29, 1997, and also a continuation-in-part of U.S. patent application Ser. No. 08/622,368, filed Mar. 26, 1996, now issued as U.S. Pat. No. 5,665,087 on Sep. 9, 1997, and a continuation-in-part of U.S. patent application Ser. No. 09/318,437, filed May 25, 1999, issued as U.S. Pat. No. 6,162,224 on Dec. 19, 2000, and U.S. patent application Ser. No. 09/318,669, filed May 25, 1999, issued as U.S. Pat. No. 6,171,309 on Jan. 9, 2001. The '224 and '309 patents are continuations-in-part of U.S. patent application Ser. No. 08/636,326, filed Apr. 22, 1996, now issued as U.S. Pat. No. 5,662,649 on Sep. 2, 1997.

U.S. patent application Ser. No. 09/483,076 also is a continuation-in-part of U.S. patent application Ser. No. 08/715,017, filed Sep. 17, 1996, now issued as U.S. Pat. No. 5,658,283 on Aug. 19, 1997, and a continuation-in-part of U.S. patent application Ser. No. 08/759,075, filed Dec. 2, 1996, now issued as U.S. Pat. No. 5,697,934 on Dec. 16, 1997, and also a continuation-in-part of U.S. Design patent application Ser. No. 29/063,695, filed Dec. 13, 1996, now U.S. Pat. No. D.404,128 and a continuation-in-part of U.S. patent application Ser. No. 08/773,968, filed Dec. 26, 1996, now issued as U.S. Pat. No. 5,702,472 on Dec. 30, 1997, and also a continuation-in-part of U.S. patent application Ser. No. 09/034,046, filed Mar. 3, 1998, issued as U.S. Pat. No. 5,964,768 on Oct. 12, 1999, which is a continuation-in-part of U.S. patent application Ser. No. 08/781,471, filed Jan. 10, 1997 now U.S. Pat. No. 5,871,486, and also a continuation-in-part of U.S. patent application Ser. No. 08/792,988, filed Feb. 3, 1997 now U.S. Pat. No. 5,868,789.

U.S. patent application Ser. No. 09/483,076 also is a continuation-in-part of Ser. No. 09/157,783, filed Sep. 21, 1998, which is a continuation-in-part of U.S. patent application Ser. No. 08/457,624, filed Jun. 1, 1995, now issued as U.S. Pat. No. 5,810,825 on Sep. 22, 1998.

U.S. patent application Ser. No. 09/483,076 also is a continuation-in-part of U.S. patent application Ser. No. 08/986,717, filed Dec. 8, 1997, issued as U.S. Pat. No. 5,994,721 on Aug. 31, 1999, and also a continuation-in-part of U.S. patent

2

application Ser. No. 09/093,415, filed Jun. 8, 1998, issued as U.S. Pat. No. 6,001,099 on Dec. 14, 1999.

U.S. patent application Ser. No. 09/483,076 also is a continuation-in-part of U.S. patent application Ser. No. 09/216,316, filed Dec. 18, 1998, issued as U.S. Pat. No. 6,030,162 on Feb. 29, 2000, and U.S. patent application Ser. No. 09/263,141, filed Mar. 5, 1999, issued as U.S. Pat. No. 6,077,271 on Jun. 20, 2000, which claims priority from U.S. Provisional Patent Application Ser. No. 60/077,168, filed Mar. 6, 1998, now expired.

All of the above patents and patent applications are hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to a bone screw for drawing together bone fragments separated by a fracture and more particularly to such a screw which draws the bone fragments together as a result of different-pitched threads on the screw.

BACKGROUND OF THE INVENTION

In healing bone fractures it is desirable to compress the fractures so that the fractured surfaces are pressed against one another. In the prior art, bone screws have been used to draw the fractured surfaces together and thereby optimize the healing process.

A number of prior art bone screws have been constructed in a fashion resembling wood screws. For example, some prior art bone screws include a threaded distal portion and a head with a relatively long unthreaded shank disposed between the head and the distal portion. A drill is used to create a bore through the fracture and the screw is threaded into the remote bone fragment with the head of the screw compressing the near fragment tightly against the remote bone fragment.

Other bone screws are threaded along the length thereof, thus requiring a first drill bit to create a bore in both bone fragments extending across the fracture and a second bit to drill a larger bore in the near bone fragment so that the screw threads do not engage the near bone fragment. Thereafter, the screw is tightened in the same manner as described above in connection with the screw having an unthreaded shank, thereby compressing the fragments together.

The operation of two prior art headed lag screws is illustrated in FIGS. 8A-10D. The operation of a lag screw A₁ with a head B₁ and a shank C₁ is shown in FIG. 8A-D. Shank C₁ of screw A₁ includes threads D₁ at the distal end and an unthreaded region E₁ proximal to head B₁. The pitch of threads D₁ is constant. FIG. 8A shows screw A₁ partially engaged in a bore F₁ in a near bone fragment G₁. The diameter of bore F₁ is less than the diameter of threads D₁ and therefore the threads engage the walls of the bore as the screw is twisted in. FIG. 8B shows screw A₁ as it starts threading into a bore H₁ in a remote bone fragment I₁. At this point threads D₁ are engaged in both bores and moving forward at the same speed in both fragments so no compression between the fragments is achieved. Head B₁ has reached the top of fragment G₁ in FIG. 8C, as indicated schematically by the radiating "force" lines. Since threads D₁ are no longer engaged in fragment G₁, screw A₁ rotates freely in the fragment without being drawn forward therein. Subsequent rotation of screw A₁ draws fragment I₁, further up the screw. Because head B₁ prevents fragment G₁ from moving further up screw A₁, fragment I₁ is drawn up against fragment G₁ and compression between the

fragments is achieved as shown in FIG. 8D, with the head pulling down on the near fragment and the threads pulling up on the remote fragment.

The importance of the unthreaded region of screw A_1 is illustrated in FIGS. 9A-d. A lag screw A_2 including a head B_2 and a shank C_2 is shown partially engaged in a bore F_2 in a near fragment G_2 in FIG. 9A. Shank C_2 includes threads D_2 running the entire length with no unthreaded region such as E_1 on screw A_1 . Rotating screw A_2 causes it to be drawn through fragment G_2 and pass into a bore H_2 in a remote fragment I_2 , as shown in FIG. 9B. Further rotation of screw A_2 brings head B_2 down against the upper surface of fragment G_2 . See FIG. 9C. At this point, threads D_2 are still engaged in bore F_2 of fragment G_2 and the interaction of the head on the surface of fragment G_2 impedes the further rotation of screw A_2 . To have additional rotation, head B_2 would have to be drawn down into fragment G_2 or the portion of threads D_2 in fragment G_2 would have to strip out. Therefore a fully threaded screw, such as screw A_2 , would not be preferred for use in the fragment and bore configuration of FIGS. 9A-D.

The proper bore configuration for using screw A_2 is illustrated in FIGS. 10A-D. As shown in FIG. 10A, bore F_2 in fragment G_2 is enlarged to allow threads D_2 of screw A_2 to pass freely through the bore. Screw A_2 therefore slips into bore F_2 until it reaches fragment I_2 . At that point, threads D_2 engage the walls of bore H_2 and draw screw A_2 down into fragment I_2 . See FIGS. 10B-C. When head B_2 reaches the upper surface of fragment G_2 , further rotation causes fragment I_2 to be drawn up into contact with fragment G_2 as shown in FIGS. 10C-D. No binding occurs between head B_2 and threads D_2 in the near fragment because of the large bore in fragment G_2 , and the screw functions as intended to draw the two fragments together.

FIGS. 11A-12D illustrate the effect of substituting headless screws in the place of lag screws A_1 and A_2 . FIG. 11A, in particular, shows a headless screw A_3 partially installed in a bore F_3 in a near fragment G_3 . Screw A_3 includes threads D_3 extending along its entire length. The pitch of threads D_3 is constant. FIG. 11B shows screw A_3 extending through fragment G_3 and just entering a bore H_3 in a remote fragment I_3 . FIG. 11C shows screw A_3 advanced further into fragment I_3 . Since the pitch of threads D_3 is constant, screw A_3 moves forward in fragments G_3 and I_3 by the same amount with each rotation. As shown in FIG. 11D, screw A_3 will pass through both fragments without altering their relative spacing or compressing them together. Thus, a headless screw such as screw A_3 will not work to draw the fragments together in the same way as lag screws A_1 and A_2 .

A variation of screw A_3 is shown at A_4 in FIG. 12A. Screw A_4 includes threads D_4 of constant pitch extending along its entire length and differs from screw A_3 in that it tapers from a smaller outside diameter at the leading end to a larger outside diameter at the trailing end. Screw A_4 is shown because it incorporates tapering, which is one of the features of the present invention, however, it is unknown whether such a screw is found in the prior art. Screw A_4 is shown partially installed in a bore F_4 in a near fragment G_4 in FIG. 12A. As screw A_4 is rotated, it moves through fragment G_4 and into a bore H_4 in a remote fragment I_4 , as shown in FIG. 12B. Subsequent rotation simply carries screw A_4 further into and through fragment I_4 without any effect on the spacing between the fragments. See FIGS. 12C-D. With a constant pitch thread, such as found on thread D_4 , the taper does not facilitate compression. Taper may, however, make a screw easier to start in a small pilot hole or even without a pilot hole.

The threaded portion of many wood screws follows this general format, tapering to a sharp point, to allow installation without a pilot hole.

It can be seen from the above discussion that a headless screw of constant pitch does not achieve the desired compressive effect between the two fragments as will a lag screw with a head. It is, however, possible to draw two fragments together with a headless screw if it has varying pitch. FIG. 13A shows a headless screw A_5 with threads D_5 formed along its entire length. Such a screw is shown in U.S. Pat. No. 146,023 to Russell. The pitch of threads D_5 varies from a maximum at the leading end to a minimum at the trailing end. It is expected that such a screw moves forward upon rotation in a fragment according to the approximate average pitch of the threads engaged in the fragment. Screw A_5 is shown in FIG. 13A with the leading threads engaged in a bore F_5 in a near fragment G_5 . Rotation of screw A_5 causes it to move forward into and through fragment G_5 and into a bore H_5 in a remote fragment I_5 , as shown in FIG. 13B. Additional rotation after the leading threads engage fragment I_5 causes the two fragments to be drawn together. See FIGS. 13C-D. This is because the average pitch of the threads in fragment I_5 is greater than the average pitch of threads in fragment G_5 . Since the screw moves forward in each fragment with each 360° rotation by an amount roughly equal to the average pitch of the threads in that fragment, each rotation will move the screw forward further in fragment I_5 than in fragment G_5 . This effect will gradually draw the fragments together as the screw moves forward. Depending on the initial spacing between the fragments, they can make contact either before or after the trailing end of the screw has entered fragment G_5 . Screw A_5 , in contrast to constant pitch screws such as screws A_1 and A_2 , can be used to separate fragments G_5 and I_5 by simply reversing the rotation.

One drawback of a screw such as shown in Russell is the stripping or reaming of the female threads created in the bore by the leading threads as the trailing threads follow. Because the pitch changes along the length of the screw, no thread exactly follows the thread directly in front of it. Rather, each thread tends to cut its own new path which only partially overlaps the path of the thread ahead of it. Thus, the trailing threads tend to ream out the female threads in the bore made by the leading threads. This effect reduces the grip of the trailing threads and therefore the overall compressive force available to urge the fragments together.

FIG. 14A shows a headless screw A_6 , such as disclosed in U.S. Pat. No. 4,175,555 to Herbert, that offers one solution to the problem of reaming of threads. As noted in the Herbert patent, bone screws having heads suffer from several disadvantages including concentrated loads beneath the screw head and the protrusion of the screw head itself after the screw is installed. Several other shortcomings of the standard type of bone screw are detailed in the Herbert patent.

Screw A_6 , as per Herbert, includes a shank C_6 with leading threads J_6 at the leading end, trailing threads K_6 at the trailing end and an unthreaded region E_6 separating the leading and trailing threads. Threads J_6 and K_6 each have fixed pitch, but leading threads J_6 have a larger pitch and smaller outside diameter than trailing threads K_6 . FIG. 14A shows leading threads J_6 of screw A_6 installed in a bore F_6 of a near fragment G_6 . Threads J_6 do not engage the walls of bore F_6 , the bore having been bored large enough to allow leading threads J_6 to pass freely. As the screw moves forward, the leading threads engage a bore H_6 in a remote fragment I_6 . See FIG. 14B. The diameter of bore H_6 is adapted so that leading threads J_6 engage the walls. Meanwhile, at the trailing end of the screw,

5

trailing threads K_6 start to engage the walls of bore F_6 , which has been bored to an appropriate diameter therefor.

As soon as trailing threads K_6 are engaged in bore F_6 and leading threads J_6 are engaged in bore H_6 , the two fragments start drawing together. See FIG. 14C. Further rotation of screw A_6 completes the process of moving the two fragments together as shown in FIG. 14D. Screw A_6 operates on the same general principle as screw A_5 , except that the average pitch of the threads in the remote and near fragments is simply the pitch of the leading and trailing threads, respectively. For instance, if the pitch of the leading threads is 0.2 inches and the pitch of the trailing threads is 0.1 inches, each rotation of screw A_6 will move it 0.2 inches further into fragment H_6 , but only 0.1 inches further into fragment I_6 , thus moving the fragments 0.1 inches closer together.

The Herbert screw overcomes at least one of the drawbacks of the Russell screw, the reaming of female threads by subsequent threads on the screw, but at the same time suffers from a number of other disadvantages. In the Herbert screw, the leading threads have a smaller diameter than the trailing threads. This is necessary to permit the leading threads to pass through the relatively large bore in the near bone fragment and engage the smaller bore in the remote bone fragment. The larger trailing threads then engage the larger bore in the near bone fragment. As a result of this arrangement, any stripping of the threads cut into the bones during installation of the screw occurs in the remote bone. If the stripping occurred in the bore in the near bone fragment, a screw having a head thereon could still be used to compress the fracture even though the near bore was stripped; however, when stripping occurs in the bore in the remote bone, a standard screw with the head thereon cannot be used and another bore must be drilled.

Further, the Herbert screw must be correctly positioned, i.e., it is imperative that the fracture intersect the unthreaded central portion of the Herbert bone screw when the same is installed. Thus, the Herbert screw is not suitable for treating fractures that are very near the surface of the bone where the hole is to be drilled. In addition, because the Herbert screw is not threaded entirely along the length thereof, the purchase obtained by the screw in the bone is not as good as with a screw threaded along the entire length. Also, two bores of different sizes must be drilled to install the Herbert screw rather than a single bore.

Yet another problem with the Herbert screw is the stripping that can occur if additional tightening occurs after the screw has drawn the bone fragments together. While the bone fragments are being drawn together, trailing threads K_6 all follow a single path through the near fragment. Similarly, leading threads J_6 all follow a single path through the remote fragment. When, however, the bone fragments make contact, the two sets of threads can no longer move independently. Further rotation of the Herbert screw after contact between the fragments can cause the leading threads to strip out as they attempt to move forward through the distal bone fragment faster than the trailing threads will allow. See *The Herbert Bone Screw and Its Applications in Foot Surgery, The Journal of Foot and Ankle Surgery*, No. 33, Vol 4, 1994, pages 346-354 at page 346, which reports on a study that found compression of 10 kg. after only two complete turns of the trailing threads engaged in the near bone fragment. Each subsequent revolution lead to a decrease in compressive force. Thus, care must be taken not to over-tighten the Herbert screw.

In addition to drawing two bone fragments together to repair fractures, it is sometimes desirable to draw together two bones for fusing the same together in connection with arthrodesis of the interphalangeal joints. This procedure is

6

sometimes indicated with symptoms of pain or instability in the finger joints. The purpose is to immobilize and draw together adjacent bones across a joint to cause them to fuse together thereby preventing further movement at the joint.

In one prior art procedure for immobilizing the distal interphalangeal joint (DIP), axial bores are drilled in the articular surfaces of the distal and proximal phalanges. The bore in the distal bone is sufficiently large to receive without threading a screw which is inserted therein via an incision in the tip of the finger. The screw threadably engages the bore in the proximal bone and when the screw head is tightened against the distal end of the distal bone, the two bones are compressed together. After several weeks, the bones fuse together. A second procedure to remove the screw must be performed because the head of the screw will cause discomfort in the finger pad if the screw is not removed.

This procedure is undesirable because it requires two separate surgeries. Katzman, et al., *Use of a Herbert Screw for Interphalangeal Joint Arthrodesis, Clinical Orthopedics and Related Research*, No. 296 pages 127-132 (November 1993), describes use of the screw disclosed in the Herbert patent in procedures for interphalangeal joint arthrodesis.

Many of the above-discussed disadvantages associated with using a Herbert screw to compress a fracture are also present when the Herbert screw is used for interphalangeal joint arthrodesis.

It would be desirable to provide a headless bone screw which overcomes the disadvantages associated with the Herbert bone screw, as well as other prior art bone screws.

SUMMARY OF THE INVENTION

A bone screw for drawing together bone fragments separated by a fracture includes a root portion having a leading end and a trailing end. The leading end has a smaller diameter than the trailing end. A screw thread is formed on the root portion between the leading and trailing ends and has a pitch which varies along the length thereof, having a larger pitch near the leading end and a smaller pitch near the trailing end. The thread is adapted to thread in the cancellous material of the respective bone fragments to be joined by the screw. Means are provided on the trailing end of the root portion to accommodate a tool for driving the screw. The present invention also contemplates a method for drawing together bone fragments separated by a fracture.

The foregoing and other objects, features and advantages of the invention will become more readily apparent from the following detailed description of a preferred embodiment which proceeds with reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an enlarged side elevation view of a bone screw constructed in accordance with the present invention;

FIG. 1A is a view of the screw of FIG. 1 shown partially in cross section;

FIG. 2 is an end view of the bone screw of FIG. 1;

FIG. 3 is a drawing illustrating the outside diameter of the screw;

FIG. 4 is a drawing illustrating the diameter of the root portion of the screw;

FIG. 5 is a cross-sectional view of a bone screw constructed in accordance with the present invention installed in a bone to draw a fracture together;

FIG. 6 is a side elevation view of a bone screw constructed in accordance with the present invention which may be used for interphalangeal joint arthrodesis;

FIG. 7 is a view of the bone screw of FIG. 5 installed in a distal interphalangeal joint with the bones forming the joint as shown in cross-section;

FIGS. 8A-14D show the operation of various screws to compress two bone fragments together;

FIGS. 15A-D show the operation of a screw constructed according to an alternative embodiment of the present invention to compress two bone fragments together;

FIGS. 16A-B are detailed views of the screw shown in FIGS. 15C and 15D, respectively;

FIG. 17A is a side elevation view of a bone screw constructed according to an alternative embodiment of the present invention;

FIG. 17B is a representation of the side profile of a root portion of the screw of FIG. 17A;

FIG. 17C is a representation of the outside diameter of the screw of FIG. 7A;

FIG. 18A is a side elevation view of a bone screw constructed according to a fourth embodiment of the present invention;

FIG. 18B is a representation of the side profile of a root portion of the screw of FIG. 18A;

FIG. 18C is a representation of the outside diameter of the screw of FIG. 8A;

FIG. 19 is an enlarged side elevation view of a bone screw constructed in accordance with an alternative embodiment of the present invention;

FIG. 19A is a view of the screw of FIG. 19 shown partially in cross section;

FIG. 20 is an end view of the bone screw of FIG. 19;

FIG. 21a illustrates the outside diameter and root profile of an alternative embodiment of the present invention; and

FIG. 21b is an elevational view of the screw of FIG. 21a.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Indicated generally at 10 in FIGS. 1 and 1A is a bone screw constructed in accordance with the present invention. Bone screw 10 is centered on a longitudinal axis 11. The length of screw 10 as measured along axis 11 is 0.394 inches in the present embodiment of the invention. The bone screw includes a root portion 12 having a continuous screw thread 14 formed thereon.

Root portion 12 includes a leading end 16 and a trailing end 18. As can best be seen in FIG. 4, the diameter of leading end 16 is less than the diameter of trailing end 18. Also in FIG. 4, it can be seen that root portion 12 tapers between trailing end 18 and leading end 16. A 45° bevel 20, in FIGS. 1 and 1A, is formed on trailing end 18. In the present embodiment of the invention, trailing end 18 has a diameter of approximately 0.092 inches. A frusto-conical nose portion 22 is formed on leading end 16 of root portion 12.

Screw thread 14 extends continuously between nose portion 22 and bevel 20. As can be seen in FIGS. 2 and 3, a trailing thread 24 has a crest height, i.e., the distance between axis 11 and a crest 26 of trailing thread 24, which varies so as to form a substantially 45° angle, illustrated as angle 28 in FIG. 3, between the outside diameter of crest 24 and axis 11.

A similarly tapering leading thread 30 also has a crest 32 which varies in height over a first partial turn of screw thread 14 so as to form an angle of substantially 45° with axis 11 as illustrated in FIG. 3.

The crest of screw thread 14 between trailing and leading threads 24, 30 respectively, varies in height along the length of thread 14. In the present embodiment of the invention, the outside diameter defined by the crest of thread 14 between the

leading and trailing threads forms an angle 34, in FIG. 3, of approximately 1.43° with respect to an axis 35 extending from the radially outermost portion of thread 14 parallel to axis 11. In the present embodiment of the invention, the diameter of the radially outermost portion of thread 14 is approximately 0.138 inches.

The pitch of thread 14, i.e., the distance from one point on the thread to the corresponding point on an adjacent thread measured parallel to axis 11, decreases between the leading and trailing ends of the screw. The term pitch is also sometimes used to refer to the number of threads per unit length, i.e., 20 threads per inch. This alternative definition is simply the inverse of the definition chosen for use in this application. The distinction is important to remember for proper understanding of the subsequent description because the screw of the present invention relies on varying pitch to achieve its function.

In the embodiment of the invention shown in FIGS. 1 and 1A, the distance between the uppermost portion of crest 32 and a corresponding crest portion 36 is 0.04964 inches. The distance between the uppermost portion of crest 26 and a corresponding crest portion 38 is 0.04748 inches. In the present embodiment of the invention, the pitch change per revolution is approximately 0.00036 inches.

The pitch depth, i.e., the distance between the crest and the radially outer surface of root portion 12 similarly varies along the length of the screw. In the present embodiment of the invention, the pitch depth where leading thread 30 joins the remainder of screw thread 14 is approximately 0.0302 inches. The pitch depth where trailing thread 24 joins the remainder of thread 14 is approximately 0.0240 inches.

The decrease in pitch depth between the leading end and trailing end of the screw can be seen by comparing FIG. 3 and FIG. 4 wherein root portion 12 tapers more sharply from the trailing to the leading end of the screw than does the change in crest height as shown in FIG. 3. In the present embodiment of the invention, the outside diameter of root portion 12 between leading and trailing ends, 16, 18, respectively, forms an angle 40, in FIG. 4, of approximately 2.5° with respect to an axis 42 extending from the radially outermost portion of trailing end 18 parallel to axis 11.

A hex socket 44 is formed on the trailing end of screw 10 to accommodate a driver as will be hereinafter further explained in connection with a description of the procedure in which the screw is used to draw opposing fragments of a fractured bone together.

An alternative embodiment of the screw of the present invention is shown generally at 410 in FIGS. 19 and 19A. Screw 410 includes a root portion 412 on which is formed a thread 414. Thread 414 extends from a leading end 416 to a trailing end 418 and includes a land 474. The pitch of thread 414 at the leading end is 0.055 inches and the pitch at the trailing end is 0.035 inches. The land varies from 0.010 inches to 0.004 inches over the same range. Thread 414 includes a cutting flute 415 near the leading end to facilitate the cutting of female threads as the screw is installed. Both the outside diameter of thread 414 and root 412 taper from a smaller value at the leading end to a larger value at the trailing end. See FIGS. 21-22. The root diameter tapers from 0.062 inches to 0.122 inches, while the outside diameter tapers from 0.130 inches to 0.156 inches. The length of screw 410 is 0.689 inches.

Screw 410 also includes an axial bore 425 which extends from the leading end to the trailing end. Bore 425 is adapted to receive a stiff guide wire, not shown, which facilitates

installation of screw 410. A hex socket 444 is formed at the trailing end to allow the screw to be driven by an hex wrench. See FIG. 20.

Turning now to FIG. 5, illustrated therein is a fracture 46 which separates adjacent bone fragments 48, 50. Screw 10 is illustrated installed in a bore 52 which extends through bone fragments 48, 50 across fracture 46.

In installing screw 10, a surgeon first drills bore 52 across bone fragments 48, 50 as shown. The bit may be a conventional cylindrical bone bit or may comprise a bit having a slight taper from the leading to the trailing end thereof. Thereafter, the surgeon inserts a tool (not shown) having a hex driver extending therefrom which is connectable to hex socket 44 for screwing screw 10 into bore 52. Bore 52 is of a size to just receive leading end 16 of screw 10. As soon as nose portion 22 is received within the bore, torque is applied using the tool inserted into hex socket 44 thereby causing leading thread 30 to cut into the bone adjacent bore 52.

In the view of FIG. 5, screw 10 is hatched to show the path cut by leading thread 30 after screw 10 is installed in the position illustrated in FIG. 5. The path of thread 30 is depicted using hatching, like hatching 54, 56, 58 which indicates the position of the path cut by leading thread 30 relative to succeeding threads of the screw. Hatching 60 depicts the actual position of the thread on screw 10 and root 12. Hatching 54, 60 are not used in FIG. 5 to depict different structure, which is unitary as illustrated in FIG. 1, but to depict relative positions of the path cut by leading thread 30 in the actual position of subsequent threads in the installed screw.

Because of the decreasing pitch along the length of the screw, each successive thread received in the path cut by thread 30 exerts pressure against the right side (as viewed in FIG. 5) of the path cut by thread 30 thereby tending to compress the bone along the length of the screw. As can be seen in FIG. 5, by the time the screw is fully installed, trailing thread 24 compresses a substantial amount of bone when it is received in the path cut by thread 30. This tends to draw bone fragments 48, 50 tightly together across fracture 46 thereby promoting healing of the fracture.

As can be appreciated from the view of FIG. 5, the thread taper is important for two reasons. First, each succeeding portion of the thread is spaced further radially outwardly as a result of the taper and therefore the outer portion of each thread (that portion closely adjacent the crest) cuts into new bone which was not cut by the preceding thread. This provides a much better purchase than would a thread having a continuously varying pitch with constant diameter. In such a configuration, each succeeding thread cuts additional bone within the generally cylindrical volume defined by the outside diameter of the threads. The outer portion of each thread (that portion closely adjacent the crest) therefore cuts into bone uncut by the preceding thread.

The tapered root is also advantageous in that the radially outer surface of the root, i.e., that portion between adjacent threads, is tightly urged against uncut bone defining the wall of bore 52. It is desirable to maximize the surface area of screw 10 urged against adjacent bone, rather than a space cut by a thread, to increase purchase of the screw.

The details of the operation of the screw of the present invention, as currently understood, may be better appreciated by examination of FIGS. 15A-D and FIGS. 16A-B and the following description. FIGS. 15A-D illustrate the operation of a screw 310 to draw together and join bone fragments 348 and 350. FIG. 15A shows screw 310 partially installed in a bore 349 in bone fragment 348. Screw 310 is shown just entering a bore 351 in bone fragment 350 in FIG. 15B. Subsequent

rotation of screw 310 starts the process of drawing the bone fragments together as shown in FIGS. 15C-D.

FIG. 16A shows the interaction of a thread 314 in bores 349 and 351 when screw 310 is positioned therein as shown in FIG. 15C. In FIG. 16A a leading end 316 of screw 310 is engaged in bore 349. Each revolution of the thread 314 is labelled for reference in the subsequent discussion, from thread T1 at the leading end to thread T23 at the trailing end.

As the screw moves through bone fragments 348 and 350, thread 314 will cut a mating female thread 353. However, because the pitch of thread 314 changes along the length of the screw, female thread 353 will not precisely match thread 314 of screw 310 along its entire length. In particular, since subsequent threads will not track in the same path as the preceding threads, a pattern of leading gaps 355 and trailing gaps 357 will evolve between female thread 353 and screw thread 314 as the screw moves forward in the bores.

The screw will move forward in the bone fragment with rotation at a rate that is a function of the competing forces from all of the threads engaged in the bore. The rate will correspond to an effective pitch of the threads in the bore and will be equal to the pitch of the screw at an effective pitch point 359 along the portion of the screw engaged in the fragment. As more of the screw enters the bore, the effective pitch point will move back along the screw and further into the bone fragment. Once the screw extends completely through the bone fragment, the location of the effective pitch point will stabilize at a relatively constant location in the bone fragment, simply moving back along the screw at the rate the screw moves forward in the bore. The threads ahead of the effective pitch point, which will be referred to as the pulling threads 371, will have greater pitch than the effective pitch. Similarly, the threads behind the effective pitch point, or dragging threads 373, will have a pitch that is smaller than the effective pitch. In FIG. 16A the pulling threads in fragment 348 are T₁-T₄ and the dragging threads are T₅ and T₆.

Each rotation of the screw will move it forward in fragment 348 by an amount corresponding to the present value of the effective pitch. In FIG. 16A the effective pitch will be equal to the pitch of thread 314 between threads T₄ and T₅. Starting at the leading end, thread T₁ will always be cutting a new thread path in the fragment, so no gap will form around it. Thread T₂, however, will attempt to follow the track of thread T₁ in fragment 348, which would carry it forward by an amount equal to the pitch between thread T₁ and T₂. Since, however, the screw will only move forward by the effective pitch, i.e., the pitch between threads T₄ and T₅, thread T₂ can only move forward by the same amount. This causes thread T₂ to pull back against the surrounding bone and creates a leading gap in front that thread. Similarly, thread T₃ will attempt to move into the position of thread T₂, but will be held back from moving as far forward as its pitch would indicate, thus creating a leading gap as thread T₃ is pulled back against the surrounding bone. Behind the effective pitch point, thread T₆ will attempt to move into the prior position of thread T₅, but will be dragged forward somewhat, leaving a trailing gap.

The pattern of leading and trailing gaps created by screw 310 in bone fragment 350 is also shown in FIG. 16A. Bone fragment 350 includes leading gaps 361 and trailing gaps 363 similar to those found in bone fragment 348. However, because more of the screw has moved through bone fragment 350, the gaps have evolved to a greater extent. The earlier position of screw 310 in fragment 350 is shown in dotted lines in FIG. 16A to illustrate the evolution of the threads as the screw moves forward.

In the earlier position of screw 310, the effective pitch point falls at approximately thread T₈. With the screw positioned as

11

shown, the effective pitch point is at approximately thread T_{16} , the screw having completed approximately 8 revolutions between the two positions. The current and prior screw positions are aligned at effective pitch point 367 in fragment 350 based on the assumption that thread 314 will track through this point uniformly. The evolution of the position of threads behind and ahead of the effective pitch point can thus be seen by comparing the prior position with the current position.

Leading gaps 361 have a sloping upper surface 365, which is a result of the gradual expansion of the outside diameter of thread 314 toward the trailing end of the screw. Upper surface 365 represents a line from the prior position of the thread to the position as shown. As thread 314 at a given point in the bone fragment is held back, it simultaneously expands in diameter. This effect prevents thread 314 from completely reaming out the female thread in the bone fragment, as discussed above. Without the taper, sloping upper surface 365 would be flat and as soon as the width of the gap grew to equal the spacing between the threads, there would be no purchase left for subsequent threads along a portion of the bore.

Once the leading end of screw 310 has passed through bone fragment 351 the effective pitch point remains at a relatively constant position along the bore for the remainder of the screw. If the pitch change per revolution is dP and the effective pitch points are separated by N threads, then the bone fragments will be drawn together by a distance N times dP for every revolution of the screw. In screw 310, $dP=0.0008$ inches and the effective pitch points are separated by approximately 11 threads, therefore the gap between the bone fragments will close by about 0.009 inches per revolution.

It is thought that the effective pitch point will be somewhat behind the geometric middle of the portion of the screw engaged in the bore as shown in FIG. 16A. Because bone becomes less dense near the center in the cancellous portion, the threads nearer to the surface in the cortex are expected to have greater effect. Also, the threads nearer the surface are of larger diameter because of the taper in the outside diameter of the thread.

The other factor tending to cause the pitch point to be closer to the surface of the bone relates to balancing the amount of bone displaced as the leading and trailing gaps are formed. As shown in FIG. 16A, the pulling threads 371, which have pitch greater than the effective pitch, are held back from moving as far forward with each rotation as their pitch would indicate. Likewise, dragging threads 373 are drawn forward faster than their pitch would dictate. This effect creates leading gaps 355 in front of pulling threads 371 as they pull against the surrounding bone. Similarly, trailing gaps 357 form behind dragging threads 373 as they are dragged forward through the surrounding bone.

Since the leading and trailing gaps are formed in opposition to one another, it is reasonable to assume that they will evolve at a relatively balanced rate. Combining this assumption with the fact that the effective pitch point is constantly moving forward in the bone fragment as the screw enters, suggests that the effective pitch point will be behind the geometric middle of the portion of the screw in the bone fragment. Because the effective pitch point is moving forward in the bone fragment by approximately one-half the pitch change per revolution, the dragging threads will be dragged forward by approximately an extra one-half the pitch change per revolution for each revolution of the screw. The fact that the effective pitch point is moving forward means that the pulling threads are not held back as much as would be the case if the effective pitch point remained constant. If the movement of the two thread regions through the bone are balanced, then the effective pitch point will not move forward in the

12

bone fragment as rapidly as would otherwise be expected and the effective pitch point will lie behind the geometric middle.

FIG. 16B shows how the pattern of gaps changes once the two bone fragments have been drawn together. After the bone fragments meet, the pattern of gaps starts to evolve toward that found in a single fragment. In particular, gaps form or increase on the leading side of all of the pulling threads ahead of an effective combined pitch point 369, and on the trailing side of all the dragging threads behind the effective combined pitch point. Near the joint between the fragments, the gaps will generally transition from leading to trailing and vice versa, because the dragging threads in fragment 348 near the joint are converted to pulling threads after the joint closes. The pulling threads in fragment 350 likewise become dragging threads after the fragments meet.

Rotation of screw 310 after the bone fragments have come together tends to increase the pressure in the joint between them. Additional rotation can be used to set the depth of the screw as desired. Since the outside diameter of the thread tapers, as described above, the screw can be driven in until the trailing end is below the surface of the bone without danger of stripping the female thread formed by the preceding threads, even if the bone fragments first meet with the trailing end protruding substantially. This is because subsequent threads expand and cut into some new bone even as they partially ream the female threads left by preceding threads on the screw. This is in contrast to the Herbert screw, where, as discussed above, additional tightening after the fragments have come together can strip out the threads in the distal fragment and reduce compression. Since it is important in the preferred application of the present invention to have the trailing end of the screw below the surface of the bone, this is an important feature and advantage over prior art screws.

The tolerance in the screw of the present invention to further tightening after the fragments have come together is also important because it simplifies the installation process by eliminating the danger of over-tightening that must be guarded against when using the Herbert screw.

Turning now to FIG. 6, indicated generally at 62 is a second embodiment of a bone screw constructed in accordance with the present invention. Bone screw 62 is sized and constructed for use in connection with interphalangeal joint arthrodesis. Screw 62 includes a tapered root 64 having a thread 65 formed thereon from a leading end 63 to a trailing end 67, a substantially cylindrical leading extension 66 joined to the leading end and a substantially cylindrical trailing extension 68 joined to the trailing end. The diameter of leading extension 66 is slightly larger than root 64 at leading end 63, while the diameter of trailing extension 68 is slightly smaller than root 64 at trailing end 67. The trailing extension 68 includes a hex socket (not visible), like hex socket 44 in FIG. 1A, formed on an end surface 70 thereof. Leading extension 66 includes a tapered nose 72 formed on the forward end thereof. In the present embodiment of the invention, screw 62 is 1.259 inches in length with the threaded portion being 0.630 inches long and the diameter of leading extension 66 being 0.05 inches. The trailing extension diameter is 0.100 inches. As is the case with the previously described embodiment, the pitch of thread 65 decreases between the leading and trailing ends. In the embodiment of FIG. 6, a land 74 is formed in the crest of thread 65 and decreases in width between the leading and trailing ends of the screw.

Turning now to FIG. 7, a distal phalanx 76 comprises the outermost bone of one of the four fingers. A proximal phalanx 78 is adjacent thereto with a distal interphalangeal (DIP) joint 80 being formed therebetween.

13

The joint includes a pair of articular surfaces **82, 84** which have been flattened in accordance with a known technique for immobilizing DIP joint **80**. Bores **86, 88** are drilled into each of phalanges **76, 78** from articular surfaces **82, 84**, respectively. Thereafter the bones are repositioned as shown in FIG. 7 and screw **62** is driven into the distal end of the bore in phalanx **76** until the screw is positioned as shown in FIG. 7.

Screw **62** thus compresses across joint **80** even though it has a relatively small diameter, which is critical in DIP joint arthrodesis because of the small diameter of the bones involved. Screw **62** also has sufficient length, due to the leading and trailing extensions **66, 68**, to provide stability while the bones are fusing. Because the screw is entirely received within the bones, i.e., there is no protrusion from the screw, it can remain implanted and thus a second procedure to remove the bone is not necessary.

A third embodiment of a screw constructed according to the present invention is shown generally at **110** in FIG. 17A. Screw **110** includes a root portion **112** on which is formed a continuous screw thread **114** and associated land **174**. Screw **110** includes a leading end **116** and a trailing end **118**. Leading cutting flutes **115** are formed in thread **114** near leading end **116** to help the thread self tap into the bone. A series of trailing cutting flutes **117** are formed in thread **114** along the sides of the screw toward the trailing end. Trailing cutting flutes **117** facilitate installation and removal of the screw by helping to cut a thread path in the bone. Screw **110** may be formed with two sets of trailing cutting flutes, one oriented to cut female threads upon insertion and another oriented to cut female threads upon removal of the screw, thus easing both installation and extraction. A hex socket **144** is formed in the trailing end of screw **110** to receive a drive tool.

Screw **110** is formed with a variable pitch portion **119** and a constant pitch portion **121**. Variable pitch portion **119** extends from leading end **116** back toward trailing end **118** for about 70 percent of the length of the screw. The length of the screw is 0.961 inches. Screw **110** does not include a bevel at the trailing end as formed on screw **10** and shown at **20** in FIG. 1A. The bevel was eliminated in screw **110** to provide additional structural support around hex socket **144** which is used for driving the screw.

Variable pitch portion **119** of screw **110** is formed according to the previously described construction of screw **10**. In particular, the pitch of thread **114** is largest at leading end **116** and decreases over variable pitch portion **119** back toward trailing end **118**. The pitch starts at 0.050 inches and decreases to 0.0365 inches at the trailing end of the variable pitch portion. As shown in FIG. 17B, root portion **112** tapers outward from leading end toward trailing end over variable pitch portion **119** with an angle **140** of 1.93° relative to the longitudinal axis of the screw. The diameter of the root portion is 0.032 inches at the leading end and 0.091 inches at the trailing end. The outside diameter of thread increases over the same region at an angle **134** of 1.0°. See FIG. 17C. The outside diameter of the thread at the leading end is 0.077 inches and 0.1 inches at the trailing end.

The construction of constant pitch portion **121** is considerably different from that of variable pitch portion **119**. The pitch and outside diameter of thread **114** are constant over the section of the screw forming constant pitch portion **121**. Root portion **112** continues to taper outward relative to the axis of the screw but at a lesser angle **127** of 1.57° over the constant pitch portion. The width of land **174**, i.e., the flat at the crest of the thread, which decreases from the leading end over the variable pitch portion, increases over the length of the constant pitch portion toward the trailing end. Land **174** starts at the leading end at 0.008 inches and decreases to 0.002 inches

14

at the end of the variable pitch region. Land **174** starts to increase again moving back over the constant pitch portion, reaching a value of 0.006-0.007 inches at the trailing end.

The constant pitch portion at the rear of screw **110** allows construction of a longer screw without the commensurate increase in diameter that would occur by extending the structure of the variable pitch portion. This is important where the screw is to be used in small bones that cannot accept a larger bore, but which require a longer screw. A longer screw may be required to reach deeper fractures or for use in fusing two bones together. Screw **110** is particularly suitable for use in distal interphalangeal fusions in the hand as described above.

A fourth embodiment of a screw constructed according to the present invention is shown at **210** in FIG. 18A. Screw **210** is generally similar to screw **110** of FIG. 17A, and includes a root portion **212**, a thread **214**, a leading end **216** and a trailing end **218**. Screw **210** also includes a variable pitch portion **219** and a constant pitch portion **221**. See FIG. 18B. The diameter of root portion **212** tapers at an angle **240** of 2.29° from 0.050 inches at the leading end to 0.106 inches at the trailing end. The outside diameter of thread **214** tapers at an angle **234** of 1.2° from 0.110 inches to 0.140 inches over the same range. The overall length of screw **210** is 0.787 inches.

The principal difference between screws **110** and **210** is found in the constant pitch portions. In screw **210**, neither the root portion nor the outside diameter of the thread is tapered in the constant pitch region. See FIG. 18B-C. Screw **210** is designed, like screw **110**, to have additional length without additional thickness. If additional length is desired, it is possible to form screw **210**, or screw **110**, with leading and/or trailing extensions such as found on screw **62** in FIG. 6.

Thread **214** on screw **210** includes a land **274**. Land **274** starts at a maximum of 0.007 inches at the leading end and decreases to 0.003 inches at the trailing end. In contrast to screw **110**, land **274** does not increase over the constant pitch portion. Thread **214** also includes leading cutting flutes **215** and trailing cutting flutes **217** to facilitate installation and removal.

Screw **210** also varies from screw **110** in that it includes an axial bore **225**. Axial bore **225** permits screw **210** to be guided into the bone on a stiff wire to facilitate positioning and prevent the screw from wandering off axis as it is driven in.

A screw according to the present invention particularly adapted for use in ankle fusions is shown generally at **410** in FIGS. 21a-b. Screw **410** includes a root portion **412** that tapers at a constant rate from a leading end **414** to a trailing end **416**. In the preferred embodiment the root has a length of 2.383-inches and tapers from a radius of 0.184-inches near the trailing end to a radius of 0.098-inches near the leading end.

A screw thread **418** is formed on root portion **412** and extends from the leading end to the trailing end thereof. Thread **418** has a thread crest **420** at its radial outermost edge. As with the previously described embodiments, the thread is terminated at the leading end and trailing end with a 45-degree taper. Thread **418** has a pitch measured between consecutive thread crests which varies between a larger value near the leading end to a smaller value near the trailing end. Preferably, the pitch changes uniformly between the ends from a value of 0.097-inches at the leading end to a value of 0.066-inches at the trailing end.

In contrast to the previously described screws, screw **410** has a guide taper **422** at the leading end of the root portion. The guide taper has a taper angle of approximately 15-degrees and serves to help maintain the leading end of the screw centered in the pilot hole in the bone in which it is installed.

15

The guide taper extends along the root portion back from the 45-degree taper for a distance of 0.129-inches.

Screw **410** has a region **424** of constant outside diameter that extends back from the guide taper for a length of 0.090-inches with a diameter of 0.205-inches. A second region **426** of constant diameter is disposed adjacent the trailing end of the screw with a diameter of 0.256-inches for a length of 0.197-inches. Provision of regions **424** and **426** allows screw **410** to have a long length while reducing the amount of taper that would otherwise be required. It is important to maintain the radius as large as possible near the lead end to obtain adequate grip in this region. This is particularly important in the preferred application for screw **410** of ankle fusions because the amount of screw **410** engaged in the tibia may be limited. It is likewise important not to make the radius at the trailing end any larger than necessary to minimize the size of the hole required. The region of constant diameter at the trailing end is also important because it provides a region for gripping the screw during manufacture. Between the regions of constant diameter is a central region **428** in which the pitch and diameter of the screw change together. The central region has a length of 1.870-inches in the preferred embodiment.

A significant difference between screw **410** and the previously described embodiment lies in the formation of the threads. In particular, in the previously described embodiments, the screw thread is cut with a tool with a flat face and outwardly sloping sides. In the previous embodiments, the width of the face determines the spacing between the threads on the root portion, which was therefore constant along the length of the screw. By pulling the tool back from the axis of the screw and adjusting the pitch properly, the thread can be cut with a varying pitch and depth. However, with each pass of the tool along the screw, the tool follows the same longitudinal path in the thread but simply cuts closer to the root portion. The land at the crest is also increased near the leading end to allow for additional pitch gain near the leading end while maintaining a decreasing outside radius.

In screw **410**, in contrast, the longitudinal position of the tool along the root portion is changed from pass to pass as the screw is being turned. In particular, in one pass down the screw thread, the tool follows a first path. In a subsequent pass the tool is shifted longitudinally along the screw slightly at the same depth to increase the width of the inter-thread distance **428** on the root toward the leading end. Cutting the thread in this fashion allows a sharper thread to be produced while still obtaining the desired outside diameter taper and pitch variation. Sharper thread is beneficial because it leaves a smaller track in the bone which leaves more bone for subsequent threads to grip and makes the screw easier to drive in during installation. As with previously described embodiments, it is important that the radius and depth of the threads near the leading end be sufficient to provide a grip on the bone which is comparable to the grip of the threads near the trailing end of the screw.

Screw **410** could be manufactured in a variety of lengths to accommodate different size patients. Moreover, for shorter screws, the region of constant outside diameter near the leading end may be eliminated without unduly compromising the grip of the leading threads. Shorter screws will typically taper at a greater angle.

In the actual fusion, a hole is drilled up from the heel through the calcaneus and talus and into the distal end of the tibia. The screw is then driven into the hole to draw the three bones together. With time, the pressure generated by the screw leads to fusion of the bones. The present screw is advantageous for this operation because it can be mounted sub-surface since it does not have a head. Furthermore, the

16

screw offers excellent grip and controllable compression when compared with standard lag screws.

Although not shown in FIGS. **21a-b**, screw **410** preferably is cannulated to provide improved stability during installation.

The length, number of threads, pitch, pitch change per revolution and the various diameters are not critical to the present invention and can be varied without departing from the spirit of the invention. Such parameters are chosen to suit the particular use to which the screw is applied.

While the invention has been disclosed in its preferred form, the specific embodiments thereof as disclosed and illustrated herein are not to be considered in a limiting sense because numerous variations are possible. Applicant regards the subject matter of his invention to include all novel and non-obvious combinations and subcombinations of the various elements, features, functions, and/or properties disclosed herein. No single feature, function, element, or property of the disclosed embodiments is essential. The following claims define certain combinations and subcombinations which are regarded as novel and non-obvious. Other combinations and subcombinations of features, functions, elements, and/or properties may be claimed through amendment of the present claims or presentation of new claims in this or a related application. Such claims, whether they are broader, narrower, or equal in scope to the original claims, also are regarded as included within the subject matter of applicant's invention.

We claim:

1. A method of compressing a bone, comprising:
boring a hole through a first bone fragment, across a fracture, and into a second bone fragment;
placing a leading end of a screw into the hole, where the screw includes a substantially continuous thread having a pitch that is larger toward the leading end of the screw and smaller toward a trailing end of the screw, and where respective portions of the thread having the pitch that is larger and smaller follow distinct parts of a same helical path; and
driving the screw into the hole such that the thread spans the fracture.
2. The method of claim 1, wherein the leading end is unthreaded.
3. The method of claim 1, wherein the trailing end is unthreaded.
4. The method of claim 1, wherein the thread has a depth that is greater near the leading end of the screw and smaller toward the trailing end of the screw.
5. The method of claim 1, wherein the thread has an outside diameter that tapers over at least a first few revolutions of the thread.
6. The method of claim 1, wherein the thread has a region of constant diameter toward the trailing end of the screw.
7. The method of claim 1, wherein the pitch is approximately fifty-percent larger toward the leading end than toward the trailing end.
8. The method of claim 1, wherein the outside diameter of the thread has a conical truncation at the leading end of the screw.
9. The method of claim 1, wherein the thread has a land, and wherein the land is larger near the leading end than near the trailing end.
10. A method of compressing a bone, comprising:
boring a hole through a first bone fragment, across a fracture, and into a second bone fragment;
placing a leading end of a screw into the hole, where the screw includes a substantially continuous thread having

17

a pitch that is larger toward the leading end of the screw and smaller toward a trailing end of the screw; and

driving the screw into the hole such that the thread spans the fracture and such that respective portions of the thread having the pitch that is larger and the pitch that is smaller each engage bone.

11. The method of claim 10, wherein the leading end is unthreaded.

12. The method of claim 10, wherein the trailing end is unthreaded.

13. The method of claim 10, wherein the thread has a depth that is greater near the leading end of the screw and smaller toward the trailing end of the screw.

18

14. The method of claim 10, wherein the thread has an outside diameter that tapers over at least a first few revolutions of the thread.

15. The method of claim 10, wherein the thread has a region of constant diameter toward the trailing end of the screw.

16. The method of claim 10, wherein the pitch is approximately fifty-percent larger toward the leading end than toward the trailing end.

17. The method of claim 10, wherein the outside diameter of the thread has a conical truncation at the leading end of the screw.

18. The method of claim 10, wherein the thread has a land, and wherein the land is larger near the leading end than near the trailing end.

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