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Inventor(s)	Gregersen; Colin S. et al.

Dynamic compression implant

Abstract

A dynamic compression implant may be insertable into a bone, and may have a distal member with distal bone-engaging threads, a proximal member that slidably engages the distal member, and a tension member with a proximal end coupled to the proximal member, and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member. The bone screw may further have an interpositional member, formed separately from the proximal member and the distal member, that cooperates with the proximal member and the distal member to form a torque transmission feature that transmits torque between the proximal member and the distal member. The dynamic compression implant may be a bone screw, intramedullary implant, or other implant that applies compression across two bone portions.

Inventors: **Gregersen; Colin S. (Salt Lake City, UT), Fallin; T. Wade (Hyde Park, UT), Saltzman; Charles L. (Salt Lake City, UT), Hagman; Chase (Salt Lake City, UT)**

Applicant: **University of Utah Research Foundation** (Salt Lake City, UT)

Family ID: **1000008749746**

Assignee: **University of Utah Research Foundation (Salt Lake City, UT)**

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Primary Examiner: Chang; Olivia C

Attorney, Agent or Firm: Maywood IP Law

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims the benefit of U.S. Provisional Application No. 63/714,601, entitled DYNAMIC COMPRESSION IMPLANT, filed on Oct. 31, 2024. This application is also a continuation-in-part of U.S. patent application Ser. No. 18/375,482, entitled CANNULATED CONTINUOUS COMPRESSION SCREW, filed on Sep. 30, 2023, which claims the benefit of U.S. Provisional Application No. 63/534,817, entitled CANNULATED CONTINUOUS COMPRESSION SCREW, filed on Aug. 26, 2023. All of the foregoing are incorporated by reference as though set forth herein in their entirety.

TECHNICAL FIELD
(1) The present disclosure relates to bone fixation devices, systems, and methods. More specifically, the present disclosure relates to dynamic compression implants such as bone screws and intramedullary implants that can apply compressive force to surrounding bone.
BACKGROUND

(2) Surgical procedures involving fixation of bone portions with bone screws and fasteners can fail or become loose over time due to bending loads, multi-axial forces, and/or off-axis loading scenarios that may be applied to the bone screws during the healing process. Existing bone screws and fasteners and intramedullary implants may not provide sufficient fixation and strength to overcome these bending loads, multi-axial forces, and/or off-axis loading scenarios.
(3) Further, it has been observed that healing of fractures, fusion of bone portions, and other forms of osteogenesis are facilitated by pressure applied across the bone interface. Existing bone fixation systems often provide pressure when initially applied, but then this pressure subsides over time due to subsidence, resorption, motion of the bone portions involved, loosening of the fastener, and/or other factors.
(4) Accordingly, bone fixation devices, systems, and methods with improved fixation, strength, and bone loading characteristics would be desirable.
SUMMARY
(5) The various bone fixation devices, systems, and methods of the present disclosure have been developed in response to the present state of the art, and in particular, in response to the problems and needs in the art that have not yet been fully solved by currently available bone fixation devices, systems, and methods. In some embodiments, the bone fixation devices, systems, and methods of the present disclosure may provide improved bone fixation and stabilization between two or more bone portions and/or implants.
(6) According to one embodiment, a dynamic compression implant may be insertable into a bone. The dynamic compression implant may have a distal member with distal bone-engaging threads, a proximal member configured to slidably engage the distal member, and a tension member with a proximal end coupled to the proximal member, and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member. The bone screw may further have an interpositional member, formed separately from the proximal member and the distal member, configured to cooperate with the proximal member and the distal member to form a torque transmission feature that transmits torque between the proximal member and the distal member.
(7) For a dynamic compression implant according to any preceding paragraph, a first longitudinal axis of the interpositional member may be oriented transverse to a second longitudinal axis of the dynamic compression implant.
(8) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a first proximal aperture, the distal member may have a first distal aperture, and the interpositional member may extend through the first proximal aperture and the first distal aperture to keep the first proximal aperture and the first distal aperture at the same rotational position about the second longitudinal axis.
(9) For a dynamic compression implant according to any preceding paragraph, the proximal member may further have a second proximal aperture, the distal member may further have a second distal aperture, and the interpositional member may further extend through the second proximal aperture and the second distal aperture to keep the second proximal aperture and the second distal aperture at the same rotational position about the second longitudinal axis.
(10) For a dynamic compression implant according to any preceding paragraph, the interpositional member may further cooperate with the proximal member and the distal member to form a length limiting mechanism that prevents motion of the distal member away from the proximal member beyond a maximum length of the dynamic compression implant.
(11) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a proximal shank and a head that is wider than the proximal shank.
(12) For a dynamic compression implant according to any preceding paragraph, the proximal member may have proximal bone-engaging threads.

(13) For a dynamic compression implant according to any preceding paragraph, the proximal member may have an aperture configured to receive a cross-fixation fastener.
(14) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a coupling interface configured to mate with a pre-stretch driver to enable the pre-stretch driver to urge the distal member to move distally relative to the proximal member.
(15) According to one embodiment, a dynamic compression implant may be insertable into a bone, and may have a distal member with distal bone-engaging threads, a proximal member configured to slidably engage the distal member, and a tension member with a proximal end coupled to the proximal member, and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member. The dynamic compression implant may further have an interpositional member, formed separately from the proximal member and the distal member, configured to cooperate with the proximal member and the distal member to form a length limiting mechanism that prevents motion of the distal member distally away from the proximal member beyond a maximum length of the dynamic compression implant.
(16) For a dynamic compression implant according to any preceding paragraph, the length limiting mechanism may further prevent motion of the distal member proximally toward the proximal member below a minimum length of the dynamic compression implant.
(17) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a first proximal aperture, the distal member may have a first distal aperture, and the interpositional member may extend through the first proximal aperture and the first distal aperture.
(18) For a dynamic compression implant according to any preceding paragraph, the first proximal aperture may have a first length along a longitudinal axis of the dynamic compression implant, the first distal aperture may have a second length along the longitudinal axis, and the interpositional member may have a width along the longitudinal axis. The width may be close to the first length such that the interpositional member has a close sliding fit within the first proximal aperture. The width may be less than the second length. A difference between the width and the second length may be equivalent to a difference between the maximum length and the minimum length.
(19) For a dynamic compression implant according to any preceding paragraph, a first longitudinal axis of the interpositional member may be oriented transverse to a second longitudinal axis of the dynamic compression implant.
(20) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a proximal shank and a head that is wider than the proximal shank.
(21) For a dynamic compression implant according to any preceding paragraph, the proximal member may have proximal bone-engaging threads.
(22) For a dynamic compression implant according to any preceding paragraph, the proximal member may have an aperture configured to receive a cross-fixation fastener.
(23) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a coupling interface configured to mate with a pre-stretch driver to enable the pre-stretch driver to urge the distal member to move distally relative to the proximal member.
(24) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a proximal engagement surface defining a smooth interior bore, the distal member may have a distal engagement surface that faces outward, and the proximal engagement surface and the distal engagement surface may be sized to form a close sliding fit with each other to define a bending transmission feature.
(25) According to one embodiment, a dynamic fixation system may include a dynamic compression implant insertable into a cavity of a bone. The dynamic compression implant may define a second longitudinal axis may have a distal member with a distal exterior surface configured to directly

engage the bone surrounding the cavity, and a proximal member configured to slidably engage the distal member. The proximal member may have a proximal exterior surface configured to directly engage the bone surrounding the cavity. The dynamic compression implant may further have an interpositional member, formed separately from the proximal member and the distal member and defining a first longitudinal axis. The interpositional member may be fixed with respect to the second longitudinal axis. The dynamic compression implant may further have a tension member with a proximal end coupled to the interpositional member, and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member.

(26) For a dynamic compression implant according to any preceding paragraph, the proximal member may have a bore configured to receive the distal member. The dynamic fixation system may further have a pre-stretch driver configured to retain the proximal member, and engage the distal member from within the bore to urge the distal member to move distally.

(27) For a dynamic compression implant according to any preceding paragraph, one of the proximal member and the distal member may have bone-engaging threads, and the distal member and the proximal member may both be shaped to engage bone surrounding an intramedullary canal.

(28) For a dynamic compression implant according to any preceding paragraph, the dynamic fixation system may further have a cross-fixation fastener. One of the proximal member and the distal member may have an aperture extending transversely to a longitudinal axis of the dynamic compression implant. The aperture may be configured to receive the cross-fixation fastener.

(29) For a dynamic compression implant according to any preceding paragraph, the aperture may have a proximal aperture on the proximal member, proximal to the proximal end of the tension member. The cross-fixation fastener may be a proximal cross-fixation fastener. The dynamic fixation system may further have a distal cross-fixation fastener. The distal member may have a distal aperture extending transversely to the longitudinal axis, distal to the distal end of the tension member. The distal aperture may be configured to receive the distal cross-fixation fastener.

(30) For a dynamic compression implant according to any preceding paragraph, the distal aperture may be nonparallel to the proximal aperture.

(31) According to one embodiment, a driver system may be provided for inserting either of a headed variable-length bone screw, and a headless variable-length bone screw, into a bone. The driver system may have a headed engagement sleeve with a first non-threaded coupling interface, a headless engagement sleeve with a threaded coupling interface, and a first drive shaft comprising a torque output feature. In a headed drive configuration, the first drive shaft may extend through the headed engagement sleeve, the first non-threaded coupling interface may mate with a second non-threaded coupling interface on the headed variable-length bone screw, and the torque output feature may engage a driver engagement feature of the headed variable-length bone screw. In a headless drive configuration, the first drive shaft may extend through the headless engagement sleeve, the threaded coupling interface may mate with proximal bone-engaging threads of the headless variable-length bone screw, and the torque output feature may engage a driver engagement feature of the headless variable-length bone screw.

(32) For a driver system of any preceding paragraph, each of the headed variable-length bone screw and the headless variable-length bone screw may have a distal member comprising distal bone-engaging threads, a proximal member configured to slidably engage the distal member, and a tension member with a proximal end coupled to the proximal member, and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member. The second non-threaded coupling interface may be on the proximal member of the headed variable-length bone screw. The proximal bone-engaging threads may be on the proximal member of the headless variable-length bone screw. The first non-threaded coupling

interface may mate with the second non-threaded coupling interface in a manner that permits the headed engagement sleeve to urge the proximal member of the headed variable-length bone screw proximally, thus allowing the driver system to pre-stretch the headed variable-length bone screw as the first drive shaft urges the distal member of the headed variable-length bone screw to move distally. The threaded coupling interface may mate with the proximal bone-engaging threads in a manner that permits the headless engagement sleeve to urge the proximal member of the headless variable-length bone screw proximally, thus allowing the driver system to pre-stretch the headless variable-length bone screw as the first drive shaft urges the distal member of the headless variable-length bone screw to move distally.
(33) For a driver system of any preceding paragraph, the first drive shaft may have a knob that is rotatable with the first drive shaft within the headed engagement sleeve, to urge the torque output feature to move distally relative to the headed engagement sleeve, and with the first drive shaft within the headless engagement sleeve, to urge the torque output feature to move distally relative to the headless engagement sleeve.
(34) For a driver system of any preceding paragraph, the driver assembly may further have a second drive shaft configured to engage the headless engagement sleeve and to engage the headless variable-length bone screw to disconnect the headless variable-length bone screw from the headless engagement sleeve.
(35) For a driver system of any preceding paragraph, the headed variable-length bone screw may have a groove, and the first non-threaded coupling interface may have a tab configured to flex to enable engagement of the tabs with the groove.
(36) For a driver system of any preceding paragraph, the groove may be on an interior surface of the headed variable-length bone screw, the tab may be configured to flex inward to move into engagement with the groove, and the first drive shaft, when positioned within the headed engagement sleeve, may impede inward flexure of the tab to impede disengagement of the tab from the groove.
(37) These and other features and advantages of the present disclosure will become more fully apparent from the following description and appended claims or may be learned by the practice of the devices, systems, and methods set forth hereinafter.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Exemplary embodiments of the present disclosure will become more fully apparent from the following description taken in conjunction with the accompanying drawings. Understanding that these drawings depict only exemplary embodiments and are, therefore, not to be considered limiting of the scope of the present disclosure, the exemplary embodiments of the present disclosure will be described with additional specificity and detail through use of the accompanying drawings in which:
(2) FIGS. **1**A, **1**B, **1**C, and **1**D are perspective, side elevation, front elevation, and rear elevation views, respectively, of a bone screw according to one embodiment.
(3) FIG. **2** is an exploded, perspective view of the bone screw of FIG. **1**.
(4) FIGS. **3**A, **3**B, **3**C, and **3**D are side elevation, section views of the bone screw, the proximal member, the distal member, and the tension member, respectively, of FIG. **1**.
(5) FIG. **4** is a front elevation, section view of the bone screw of FIG. **1**.
(6) FIG. **5** is another front elevation, section view of the bone screw of FIG. **1**.
(7) FIGS. **6**A and **6**B are side elevation, section views of the bone screw of FIG. **1**, upon initial insertion into bone, and upon further insertion to tension the bone screw, respectively.
(8) FIG. **7** is a flowchart depicting a method of inserting a bone screw into bone, according to one

embodiment.
(9) FIG. **8** is a flowchart depicting a method of inserting a bone screw into bone along a guide wire, according to one embodiment.
(10) FIG. **9**A is a diagram depicting stress versus strain for an exemplary superelastic material.
(11) FIG. **9**B is a diagram depicting changes in insertion torque and screw length during screw insertion.
(12) FIG. **10**A is a diagram depicting changes in screw compression during screw insertion.
(13) FIG. **10**B is a diagram depicting changes in screw decompression during relative shortening between bone portions.
(14) FIGS. **11**A, **11**B, **11**C, and **11**D are perspective, side elevation, front elevation, and rear elevation views, respectively, of a bone screw according to another embodiment.
(15) FIG. **12** is an exploded, perspective view of the bone screw of FIG. **11**.
(16) FIGS. **13**A, **13**B, **13**C, and **13**D are side elevation, section views of the bone screw, the proximal member, the distal member, and the tension member, respectively, of FIG. **11**.
(17) FIG. **14** is a front elevation, section view of the bone screw of FIG. **11**.
(18) FIG. **15** is another front elevation, section view of the bone screw of FIG. **11**.
(19) FIGS. **16**A and **16**B are side elevation, section views of the bone screw of FIG. **11**, upon initial insertion into bone, and upon further insertion to tension the bone screw, respectively.
(20) FIG. **17** is a flowchart depicting a method of inserting a bone screw into bone, according to another embodiment.
(21) FIG. **18** is a side elevation view of a bone screw according to yet another embodiment.
(22) FIG. **19**A is a perspective view of a bone screw according to one embodiment.
(23) FIG. **19**B is a side elevation view of the bone screw shown in FIG. **19**A in a shortened state.
(24) FIG. **19**C is a side elevation view of the bone screw shown in FIG. **19**A in a lengthened state.
(25) FIG. **20** is an exploded perspective view of the bone screw shown in FIG. **19**A with a guidewire.
(26) FIGS. **21**A, **21**B, **21**C, and **21**D are side elevation, section views of the bone screw, a proximal member, a distal member, and a tension member, respectively, of the bone screw shown in FIG. **19**A.
(27) FIG. **22** is a side elevation, section view of the nut shown in FIG. **20**.
(28) FIG. **23** is a front elevation, section view of the bone screw shown in FIG. **19**A, taken along the section lines shown in FIG. **19**B.
(29) FIG. **24**A is a side elevation view of a head of a bone screw according to one embodiment.
(30) FIG. **24**B is a side elevation view of a head of a bone screw according to another embodiment.
(31) FIG. **24**C is a side elevation view of a head of a bone screw according to yet another embodiment.
(32) FIG. **25**A is a perspective view of a bone screw according to one embodiment.
(33) FIG. **25**B is a side elevation view of the bone screw shown in FIG. **25**A in a shortened state.
(34) FIG. **25**C is a side elevation view of the bone screw shown in FIG. **25**A in a lengthened state.
(35) FIG. **26** is an exploded perspective view of the bone screw shown in FIG. **25**A with a guidewire.
(36) FIGS. **27**A, **27**B, **27**C, and **27**D are side elevation, section views of the bone screw in a first plane, the bone screw in a second plane orthogonal to the first plane, a support ring and a distal member, and a tension member and a nut, respectively, of FIG. **25**A.
(37) FIG. **28** is a side elevation, section view of the nut shown in FIG. **26**.
(38) FIG. **29** is a side elevation, section view of the support ring shown in FIG. **26**.
(39) FIG. **30** is a side elevation, section view of the proximal member shown in FIG. **26**.
(40) FIG. **31** is a perspective view of a bone screw and a pre-stretch driver according to one embodiment.
(41) FIG. **32** is an exploded perspective view of the bone screw and the pre-stretch driver shown in

FIG. **31**.
(42) FIG. **33** is a side elevation, section view of the bone screw and the pre-stretch driver shown in FIG. **31**.
(43) FIGS. **34**A and **34**B are side elevation, section views of the bone screw and the pre-stretch driver shown in FIG. **31** in unstretched and stretched state, respectively.
(44) FIGS. **35**A and **35**B are exploded perspective views of the proximal end of the bone screw and the distal end of a sleeve of the pre-stretch driver shown in FIG. **31**.
(45) FIG. **36** is a side elevation, section view of the proximal member shown in FIG. **31**.
(46) FIG. **37** is a flowchart depicting a method of inserting a variable-length bone screw into bone, according to one embodiment.
(47) FIG. **38** is a diagram depicting stress versus strain behavior of a tension member according to one embodiment.
(48) FIG. **39** is a diagram depicting stress versus strain behavior of exemplary superelastic material at two different temperatures.
(49) FIG. **40** is a flowchart depicting a method of inserting a variable-length bone screw into bone, according to one embodiment.
(50) FIG. **41** is a perspective view of a bone screw according to one embodiment.
(51) FIG. **42** is an exploded perspective view of the bone screw shown in FIG. **41** with a guidewire.
(52) FIG. **43** is a front elevation, section view of the bone screw shown in FIG. **41**.
(53) FIG. **44** is an enlarged view of a proximal portion of the bone screw shown in FIG. **43**.
(54) FIG. **45** is a front elevation, section view of a proximal nut, tension member, and distal nut.
(55) FIG. **46**A is a front elevation, section of a proximal member, according to one embodiment.
(56) FIG. **46**B is a front elevation, section of a proximal member, according to one embodiment.
(57) FIG. **47** is an exploded perspective view of a pre-stretch driver and the bone screw shown in FIG. **41**.
(58) FIG. **48** is an exploded perspective view of a pre-stretch driver and a bone screw, according to one embodiment.
(59) FIG. **49** is a side elevation, section view of the bone screw and the pre-stretch driver shown in FIG. **47**.
(60) FIG. **50** is a side elevation, section view of the bone screw and the pre-stretch driver shown in FIG. **48**.
(61) FIG. **51** is an exploded, perspective view of an embodiment of an intramedullary implant.
(62) FIG. **52** is a perspective view of the intramedullary implant shown in FIG. **51** in a fully assembled state.
(63) FIG. **53** is a front elevation, section view of a proximal nut, tension member, and distal nut.
(64) FIG. **54** is a front elevation, section view of a proximal member.
(65) FIG. **55** is a front elevation, section view of a distal member.
(66) FIG. **56** is a front elevation, section view of the intramedullary implant shown in FIG. **52**, at a first length.
(67) FIG. **57** is a front elevation, section view of the intramedullary implant shown in FIG. **52**, at a second length.
(68) FIG. **58** is an exploded, perspective view of the intramedullary implant shown in FIG. **51**, proximal cross screws, distal cross screws, and a pre-stretch driver.
(69) FIG. **59** an exploded, perspective view of the pre-stretch driver shown in FIG. **58**.
(70) FIG. **60** is an exploded, perspective view of another embodiment of an intramedullary implant.
(71) FIG. **61** is a perspective view of the intramedullary implant shown in FIG. **60** in a fully assembled state.
(72) FIG. **62** is a front elevation, section view of the intramedullary implant shown in FIG. **60**.
(73) FIG. **63** is an exploded, perspective view of another embodiment of an intramedullary implant.
(74) FIG. **64** is a perspective view of the intramedullary implant shown in FIG. **63** in a fully

assembled state.
(75) FIG. **65** is a front elevation, section view of the intramedullary implant shown in FIG. **63**.
(76) It is to be understood that the drawings are for purposes of illustrating the concepts of the present disclosure and may not be drawn to scale. Furthermore, the drawings illustrate exemplary embodiments and do not represent limitations to the scope of the present disclosure.

DETAILED DESCRIPTION

(77) Exemplary embodiments of the present disclosure will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. It will be readily understood that the components of the present disclosure, as generally described and illustrated in the drawings, could be arranged, and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the implants, systems, and methods, as represented in the drawings, is not intended to limit the scope of the present disclosure, but is merely representative of exemplary embodiments of the present disclosure.
(78) The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. While the various aspects of the embodiments are presented in the drawings, the drawings are not necessarily drawn to scale unless specifically indicated.
(79) The following examples have been included to provide guidance to one of ordinary skill in the art for practicing representative embodiments of the presently disclosed subject matter. In light of the present disclosure and the general level of skill in the art, those of skill in the art can appreciate that the following examples are intended to be exemplary only and that numerous changes, modifications, and alterations can be employed without departing from the scope of the presently disclosed subject matter.
(80) Fixation of bone portions with bone screws may be utilized in a variety of surgical procedures including, but not limited to trauma fixation, arthrodesis, osteotomies, etc. For example, trauma fixation procedures may be needed when high-energy events cause bones to break and fragment. Bone screws may be utilized to secure the bone fragments in a correct anatomic alignment while the bone heals. Arthrodesis procedures can treat degenerative bone joints, which may cause pain and loss of joint function, by removing degraded articular cartilage from a bone joint and then holding the bone joint in compression with bone screws while the bones fuse together across the joint. Osteotomy procedures can realign a bone to a more favorable position, by first cutting the bone and then using bone screws to hold the cut bone portions in a new desired alignment while the bone heals.
(81) Example applications/procedures that may utilize any of the fixation devices described or contemplated herein, in any configuration and with any of the features described herein, may include, but are not limited to: trauma procedures (e.g., fracture fixation, etc.), post-traumatic reconstruction (pelvic or joint fusions), spine procedures (e.g., SI fusion, facet fixation, etc.), joint reconstruction procedures (total hip arthroplasty, total knee arthroplasty), sports related procedures, extremity procedures, cranio-maxillo-facial procedures, rib plating procedures, veterinary procedures, bone plating procedures (e.g., femur plates, humerus plates, tibial plates, etc.), intramedullary nail fixation procedures, amputee connection procedures, sarcoma procedures, shoulder/glenoid fixation, small bone fixation, correction, or fusion (e.g., foot/ankle, hand/wrist, etc.), joint fusions, osteotomies, procedures involving osteoporotic or compromised bone, etc.
(82) The following disclosure presents various bone fixation devices, systems, and methods for utilization in bone and other tissues as implantable devices (e.g., orthopedic implants, spine implants, sports medicine implants, trauma implants, reconstruction implants, extremity implants, veterinary implants, etc.). It will be understood that any feature of any bone fixation assembly described or contemplated herein may be combined with any other bone fixation assembly that is described or contemplated herein without departing from the spirit or scope of the present

disclosure.
(83) According to some embodiments, a bone screw **100** may be provided. The bone screw may have a longitudinal axis **102**, a proximal member **104**, a distal member **106**, and a tension member **108**. The bone screw **100** will be shown and described in connection with FIGS. **1**A through **5**. FIGS. **1**A, **1**B, **1**C, and **1**D are perspective, side elevation, front elevation, and rear elevation views, respectively, of the bone screw **100**. FIG. **2** is an exploded, perspective view of the bone screw **100**. FIGS. **3**A, **3**B, **3**C, and **3**D are side elevation, section views of the bone screw **100**, the proximal member **104**, the distal member **106**, and the tension member **108**, respectively. FIG. **4** is a front elevation, section view of the bone screw **100**. FIG. **5** is another front elevation, section view of the bone screw **100**.
(84) As shown, the longitudinal axis **102** of the bone screw **100** may be an axis extending along the geometric center and/or axis of radial symmetry of the bone screw **100**, along the longest length of the bone screw **100**. The terms "proximal" and "distal" are generally used with reference to displacement along the longitudinal axis **102**, although they are sometimes used as adjectives to connect features to a proximal or distal member, such as the proximal member **104** and the distal member **106**.
(85) The proximal member **104** may have a proximal shank **110** at a distal end of the proximal member **104**, a head **112** at a proximal end of the proximal member **104**, and a proximal interior surface **114** that cooperates with an interior surface **115** of the proximal member **104** to define a proximal portion **132** of a variable-length cavity **130**. The head **112** may have a width **126** (i.e., greatest dimension perpendicular to the longitudinal axis **102**) greater than a width **128** of the proximal shank **110**. Thus, upon insertion into the bone, the head **112** may protrude transverse to the longitudinal axis **102** to engage the cortex of the bone into which the bone screw **100** is driven, as will be shown subsequently. The proximal interior surface **114** and the interior surface **115** may face inwardly, toward the longitudinal axis **102**. The head **112** may have a driver engagement feature **230** that receives torque from a driver (not shown). For example, the driver engagement feature **230** may be a socket with a radially symmetrical pattern that receives a boss, with a matching shape, on the distal end of the driver. The driver engagement feature **230** may be a hexagonal socket as shown.
(86) The distal member **106** may have a distal shank **120** at a proximal end of the distal member **106**, bone-engaging threads **122** at a distal end of the distal member **106**, and a distal interior surface **124** defining a distal portion **134** of the variable-length cavity **130**. The bone-engaging threads **122** may be designed to engage bone, and may be shaped to function optimally upon insertion into a pilot hole previously formed in the bone. In the alternative, the bone-engaging threads **122** may be self-tapping, and may enable the bone screw **100** to form its own pilot hole in the bone into which it is inserted.
(87) The tension member **108** may have a proximal end **140**, a distal end **142**, and a shank **144**, extending along the longitudinal axis **102**, that connects the proximal end **140** to the distal end **142**. The proximal end **140** may have proximal threads **146** that facilitate coupling of the tension member **108** to the proximal member **104** via threaded engagement with interior threads **147** within the proximal member **104**. The distal end **142** may have a distal flange **148** that facilitates coupling of the tension member **108** to the distal member **106** via abutment of the distal flange **148** on a corresponding surface **149** of the distal member **106**, distal to the bone-engaging threads **122**. The distal end **142** may further have a distal tip **150** that is sufficiently sharp for bone penetration. The distal tip **150** may have one or more features, such as channels or grooves, that help remove bone cuttings from in front of the distal tip **150**. Additionally or alternatively, the distal tip **150** may have a slot **152** that facilitates rotation of the tension member **108** with a driver such as a flat-head screwdriver.
(88) As shown more clearly in FIGS. **2** and **3**A, the bone screw **100** may be assembled by, first, inserting the proximal end **140** of the tension member **108** along the proximal direction, through

the open distal end of the distal member **106**, until the distal flange **148** of the distal end **142** of the tension member **108** rests against the corresponding surface **149** of the distal member **106**. Then, the distal shank **120** of the distal member **106** and the proximal end **140** of the tension member **108** may be inserted into the proximal portion **132** of the variable-length cavity **130**, within the proximal member **104**. The tension member **108** may be rotated relative to the proximal member **104** and the distal member **106** (for example, by rotating the distal tip **150** of the tension member **108** with a flat-head screwdriver or other driver) such that the proximal threads **146** of the proximal end **140** of the tension member **108** engage the interior threads **147** of the proximal member **104**.
(89) This may result in the configuration shown in FIG. **3**A, in which the tension member **108** resides generally within the variable-length cavity **130**, which is defined by the proximal member **104** and the distal member **106**. The variable-length cavity **130** may include a proximal portion **132** within the proximal member **104**, and a distal portion **134** within the distal member **106**. Part of the distal portion **134** may also reside within the proximal member **104**, as the distal shank **120** is within the proximal portion **132** of the variable-length cavity **130**.
(90) The bone screw **100** may be used for a variety of purposes, including but not limited to fracture fixation, joint arthrodesis, and implant fixation. In some implementations, the bone screw **100** may be inserted through one bone portion or implant, and into a separate bone portion in which the bone-engaging threads **122** are anchored. As mentioned previously, in some embodiments, the bone screw **100** may be inserted into a pilot hole previously formed in the bone. In alternative embodiments, the bone screw **100** may be driven against the bone to form and tap its own hole.
(91) In either case, the bone screw **100** may be rotated (for example, via a driver) such that the bone-engaging threads **122** draw the bone screw **100** to advance until the head **112** rests against the exterior surface of the proximal bone portion or implant. Then, the bone screw **100** may be further advanced such that the distal member **106** is urged distally, by virtue of the action of the bone-engaging threads **122**, relative to the proximal member **104**. The tension member **108** may be dimensioned such that the shank **144** of the tension member **108** elongates in response to this force, permitting the distal member **106** to move distally while the proximal member **104** remains generally in place.
(92) The tension on the shank **144** may cause the tension member **108** to exert compressive force. drawing the distal member **106** back proximally relative to the proximal member **104**. This compressive force may act across the junction between the bone portions (or in the case of implant fixation, between the bone and the implant), and may beneficially facilitate osteointegration, fracture healing, lasting fracture fixation, and/or the like.
(93) This further advancement of the distal member **106** may continue until the bone screw **100** has reached its desired length. The length may be selected such that the tension member **108** continues to exert compressive force, even after some of the strain in the tension member **108** has relaxed, for example due to bone subsidence, patient motion, and/or other factors.
(94) In some embodiments, the proximal member **104** and the distal member **106** may be formed of relatively high-strength biocompatible materials such as titanium and/or titanium alloys. The tension member **108** may advantageously be formed of a biocompatible superelastic material such as Nitinol. The superelastic material may beneficially undergo considerable strain while exerting a generally constant compressive force on the proximal member **104** and the distal member **106**. Thus, the tension member **108** may maintain compression even after some relaxation in strain has occurred.
(95) The bone screw **100** will likely be under considerable stress as it is driven into the bone and/or as the patient goes about his or her activities with the bone screw **100** in place. In a larger screw (such as most wood screws), these stresses may not be of concern. However, the bone screw **100** may desirably be relatively small in diameter—for example, from 3.5 mm to 7.0 mm, measured at the diameter of the proximal shank **110** of the proximal member **104**. The bone screw **100** may thus have a number of features that help distribute, shift, and/or otherwise manage stresses in the

proximal member **104**, the distal member **106**, and/or the tension member **108** to avoid failure (for example, breakage or plastic deformation) of the proximal member **104**, the distal member **106**, and/or the tension member **108**. Notably, hollow screws of this size that lack such stress distribution features may be likely to fail during insertion and/or during healing.

(96) More specifically, the bone screw **100** may have a torque transmission feature, a length limiting mechanism, a bending transmission feature, and deliberately selected exterior diameter. Each of these features may help to control some aspect of the stresses experienced by the proximal member **104**, the distal member **106**, and/or the tension member **108**, as will be described below.

(97) The bone screw **100** may have a torque transmission feature that transmits torque from the proximal member **104** to the distal member **106**. The torque transmission feature may be configured to control stresses in the proximal member **104** and the distal member **106** incident to application of torque as the bone screw **100** is driven into the bone. It has been observed that torque transmission features with torque transmission surfaces oriented circumferentially, or nearly circumferentially, can be subject to high hoop stresses as these surfaces, as can the surfaces to which they transmit torque. Conventional polyhedral interfaces (such as a hexagonal hole and driver) are thus subject to high stresses during torque transmission. Similarly, an interface in which one or more flats on a cylindrical member are placed within a hole having one or more matching flats, would also be subject to high stress.

(98) Accordingly, the torque transmission feature employed by the bone screw **100** may have a design in which the torque transmission surface(s) are angled significantly from the circumferential direction. This angle may be greater than 20°, greater than 30°, greater than 40°, greater than 50°, greater than 60°, greater than 70°, or even greater than 80°. In some embodiments, the angle may be 90°. Further, in other embodiments, this angle may be even greater than 90°. Although large angles may be beneficial for hoop stress reduction, in some embodiments, sufficient hoop stress reduction may be obtained with torque transmission surfaces that are angled such that they are oriented closer to the radial direction than the circumferential direction.

(99) As embodied in FIGS. **1**A through **5**, and shown most clearly in FIG. **4**, the torque transmission feature of the bone screw **100** may be a spline **200**. The spline **200** may include an outer spline component **202** formed on the proximal interior surface **114** of the proximal member **104**, and an inner spline component **206** formed on the distal shank **120** of the distal member **106**. The outer spline component **202** may mesh with the inner spline component **206** such that the outer spline component **202** transmits torque to the inner spline component **206**. Thus, as the proximal member **104** is rotated by the surgeon (for example, via a driver engaging the head **112**), the distal member **106** may also rotate, driving the bone-engaging threads **122** into the bone.

(100) As further shown in FIG. **4**, the outer spline component **202** may have torque transmitting surfaces **203** that are on the leading sides of outer teeth **204** as the proximal member **104** rotates about the longitudinal axis **102**, along the direction of rotation R. The outer teeth **204** may extend along part of the length of the proximal portion **132** of the variable-length cavity **130**, parallel to the longitudinal axis **102**. The outer teeth **204** may be separated from each other by outer grooves **205** that also extend parallel to the longitudinal axis **102**.

(101) The outer spline component **202** is shown with ten of the outer teeth **204**; however, those of skill in the art will recognize that any number of teeth may be present. In some embodiments, only a single tooth may be present. The presence of multiple teeth may help to spread the loads induced by torque transmission across additional surfaces, and to multiple sectorial portions of the proximal member **104** and the distal member **106**.

(102) The inner spline component **206** may have torque receiving surfaces **207** that are on the trailing surfaces of inner teeth **209** as the distal member **106** rotates about the longitudinal axis **102**, along the direction of rotation R. The inner teeth **209** may extend along part of the length of the distal portion **134** of the variable-length cavity **130**, parallel to the longitudinal axis **102**. The inner teeth **209** may be separated from each other by inner grooves **208** that also extend parallel to the

longitudinal axis **102**.
(103) The number of inner grooves **208** on the inner spline component **206** may be equal to the number of outer teeth **204** on the outer spline component **202**. In FIG. **4**, there are ten of the outer teeth **204** that reside within ten of the inner grooves **208**. Similarly, there are ten of the inner teeth **209** that reside within ten of the outer grooves **205**. Thus, the outer spline component **202** meshes with the inner spline component **206**. As indicated previously, more or fewer teeth or grooves may be present in either component. The number of teeth in one component may be equal to the number of grooves in the other. but this is not necessarily the case—in some embodiments, unequal numbers of teeth and/or grooves may be present between inner and outer spline components.
(104) The torque transmitting surfaces **203** of the outer spline component **202** may advantageously be angularly displaced from the circumferential direction C by an angle Φ, shown in FIG. **4**. The line L represents one of the torque transmitting surfaces **203** of the outer spline component **202**. As set forth above, the angle Φ may be significant so as to reduce hoop stresses in the proximal member **104** and/or the distal member **106**. In some embodiments, the angle Φ may be greater than an angle θ between the line L and the radial direction R. Thus, the angle Φ may be greater than 45°.
(105) The spline **200** represents only one of multiple different types of torque transmission features that may be used within the scope of the present disclosure. Various other torque transmission features, including but not limited to polyhedral and curvilinear shapes, may be used. A polyhedral torque transmission feature may include star shapes, rectangles, and/or other shapes with torque transmission surfaces that are angularly displaced from the circumferential direction. Curvilinear torque transmission features may likewise have such angled torque transmission surfaces, and may include curvilinear and/or rectilinear segments. In some embodiments, a more organically-shaped rounded spline may be used. In other embodiments, an ovoid, elliptical, or other curvilinear torque transmission feature may be present.
(106) The bone screw **100** may also have a length limiting mechanism **210** that helps to control the elongation of the bone screw **100**. Unlimited elongation of the bone screw **100** may cause the tension member **108** to fail in tension, as the loads experienced by the tension member **108** (static and/or fatigue loading) may cause the tension member **108** to break or plastically deform. In some embodiments, the length limiting mechanism **210** may operate to limit the displacement of the distal member **106** relative to the proximal member **104** such that the stress on the tension member **108** remains within its superelastic zone, as will be shown and described hereafter. Further, in some embodiments, the bone screw **100** may be designed for infinite life. Thus, the length limiting mechanism **210** may be designed to limit displacement of the distal member **106** relative to the proximal member **104** such that the strength limits of the tension member **108** are not exceeded.
(107) As shown, the length limiting mechanism **210** may include a proximal stop feature on the proximal member **104** and a distal stop feature on the distal member **106**. The proximal stop feature and the distal stop feature may come into contact with each other when the maximum length of the bone screw **100** is reached, preventing further distal motion of the distal member **106** relative to the proximal member **104**. The proximal stop feature and the distal stop feature may each take many forms. One or more than one of each of the proximal stop feature and the distal stop feature may be present in a bone screw according to the present disclosure.
(108) As shown in FIGS. **3**A, **3**B, and **5**, the proximal member **104** may have multiple proximal stop features, each of which is a protrusion **212** on the proximal interior surface **114**. Each protrusion **212** may protrude inwardly (i.e., toward the longitudinal axis **102** and the distal member **106**, nested within the proximal portion **132** of the variable-length cavity **130**) from the remainder of the proximal interior surface **114**. Each protrusion **212** may be formed, for example, through the use of apertures **214** formed in the exterior surface of the proximal member **104**. In some embodiments, the apertures **214** may be formed as blind holes that are separated from the proximal portion **132** of the variable-length cavity **130** by relatively thin walls. After the distal shank **120** of the distal member **106** has been inserted into the proximal portion **132** of the variable-length cavity

130, pins or other projecting members may be inserted into the apertures **214** and pressed inwardly to flex the thin walls inward, thus forming each protrusion **212**.

(109) The distal member **106** may have a single distal stop feature that contacts all of the protrusions **212**. As shown in FIGS. **3**A, **3**C, and **5**, the distal stop feature of the distal member **106** may be a shoulder **216** that defines one end of a relief **218** formed on the distal shank **120** of the distal member **106**. Specifically, the relief **218** may be formed as a smaller-diameter section of the distal shank **120**, on an extension of the distal shank **120** that extends proximally from the inner spline component **206**. The relief **218** may be proximate a proximal end of the distal shank **120** and may define the shoulder **216**.

(110) After full insertion of the distal shank **120** into the proximal portion **132** of the variable-length cavity **130**, the relief **218** may be aligned with the apertures **214** of the proximal member **104**. Thus, when the protrusions **212** are formed as described above, the protrusions **212** may extend inwardly into the relief **218**. The protrusions **212** may protrude sufficiently into the relief **218** such that the shoulder **216** is unable to move distally beyond the protrusions **212**. Thus, abutment of the shoulder **216** against the protrusions **212** may limit the extent to which the distal member **106** is able to move distally relative to the proximal member **104**.

(111) When the distal shank **120** is fully inserted into the proximal portion **132** of the variable-length cavity **130** (such that the distal shank **120**, in its entirety, is received within the proximal portion **132**), the protrusions **212** may reside near the distal end of the relief **218**. Thus, the length of the relief **218** may define the extent to which the distal member **106** is able to move distally relative to the proximal member **104**.

(112) Advantageously, the length limiting mechanism **210** may be displaced proximally of the spline **200**. Thus, the length limiting mechanism **210** may operate without interfering with operation of the spline **200**, and without requiring added complexity in the torque transmission feature of the bone screw **100**.

(113) A “length limiting mechanism” may include any of a wide variety of devices that can limit the elongation of a bone screw. Similarly, a “proximal motion stop” and a “distal motion stop” may each include any feature that can physically interfere with such elongation. Thus, proximal and distal motion stops may include any known combination of protruding elements, including but not limited to flanges, bumps, tabs, detents, shoulders, and the like. Such elements may protrude inwardly, outwardly, and/or in a circumferential direction.

(114) The bone screw **100** may also have a bending transmission feature **220** that helps to transfer bending loads between the proximal member **104** and the distal member **106** at a location displaced from where such loading is applied. For example, if the bone screw **100** is inserted through a first bone portion such that the bone-engaging threads **122** anchor in a second bone portion, motion (or attempted motion) of the user may urge the second bone portion to move relative to the first bone portion. This force may be in shear (i.e., urging relative motion parallel to the interface or fracture between the first and second bone portions), tension (urging relative motion perpendicular to the interface or fracture), bending (urging relative motion along an axis offset from the longitudinal axis **102** of the bone screw **100**), and/or torsion (urging rotation of the second bone portion relative to the first bone portion about the longitudinal axis **102** of the bone screw **100**).

(115) These forces may result in a bending moment on the bone screw **100** and may be greatest at the interface between the first and second bone portions. The bending transmission feature **220** may advantageously be displaced proximally or distally from this interface and may thus distribute some of these forces away from the interface. Further, the bending transmission feature **220** may transfer some bending load from the distal member **106** to the proximal member **104**. The distal member **106** may have the smaller cross-sectional shape proximate the interface between the first and second bone portions and may thus be subject to higher bending stress. Accordingly, shifting some of this bending stress to the proximal member **104** may increase the overall bending load that can be tolerated by the bone screw **100**.

(116) As shown in FIGS. **3**A, **3**B, and **3**C, the bending transmission feature **220** may include a proximal engagement surface **222** on the proximal member **104** and a distal engagement surface **226** on the distal member **106**. In the embodiment of FIGS. **3**A, **3**B, and **3**C, the distal engagement surface **226** may be an outwardly-facing surface proximal to the shoulder **216**, at the proximal end of the distal shank **120**. The proximal engagement surface **222** may be located on a proximal portion of the interior surface **115**, which faces inwardly, and faces the distal engagement surface **226**.

(117) The distal engagement surface **226** may be sized such that it has a diameter near that of the proximal engagement surface **222**. Advantageously, the distal engagement surface **226** may be slightly smaller than the proximal engagement surface **222** such that the distal engagement surface **226** can be received within the proximal engagement surface **222** with clearance during assembly of the proximal member **104** and the distal member **106**. This clearance may be relatively small so that, in response to slight bending of the bone screw **100**, the distal engagement surface **226** abuts the proximal engagement surface **222** to transmit some of the bending load from the distal member **106** to the proximal member **104**.

(118) For example, a bending load on the bone screw **100** may urge the distal member **106** to shift such that its axis is no longer colinear with the axis of the proximal member **104**. This motion of the distal member **106** may cause the distal shank **120** of the distal member **106** to move toward one side of the interior surface **115**. Abutment of the distal engagement surface **226** with the proximal engagement surface **222** may limit this bending such that the material near the maximum bending stress (for example, near the interface between bone portions) is not stressed at a level that would cause it to plastically deform or break.

(119) The bending transmission feature **220** is only one of many possible structures that may be used to transmit bending loads away from the site of maximum stress. Notably, the bone screw **100** may include other features that may also act as bending transmission features, in addition to or in the alternative to the proximal engagement surface **222** and the distal engagement surface **226**. Any surfaces of the proximal member **104** and the distal member **106** that abut each other in response to application of bending load on the bone screw **100** may be considered bending transmission features. In particular, the entire length of the distal shank **120** (with the exception of the relief **218**) proximal to the inner spline component **206**, and the corresponding inwardly facing regions of the interior surface **115** of the proximal member **104**, may also act as bending transmission features, as they may abut each other and transmit bending loads from the distal member **106** to the proximal member **104** as the bone screw **100** is loaded in bending.

(120) Further, the phrase “bending transmission feature” includes any combination of surfaces. however shaped, that abut each other to transmit such loading. By way of example and not limitation, such surfaces may have cylindrical, splined, polygonal, irregular, and/or other cross-sectional shapes. Such surfaces may be parallel to the longitudinal axis **102**, or in alternative embodiments, may be angled nonparallel to the longitudinal axis **102**. Thus, bending transmission features need not be linear extrusions, but may instead have conical, semispherical, or other shapes with variation toward and/or away from the longitudinal axis **102**.

(121) The bone screw **100** may further have other features and/or dimensions that help provide the bone screw **100** with enhanced strength and/or rigidity over prior art variable-length screws. For example, many known screws have a shank that is only as large as the minor diameter of the screw threads. Such a design has the benefit of simple preparation, as the corresponding pilot hole may be formed with a drill bit (not shown) with a constant diameter. By contrast, the bone-engaging threads **122** of the bone screw **100** may be dimensioned such that portions of the bone screw **100** proximal to the bone-engaging threads **122** (excluding the head **112**) are larger than the minor diameter of the bone-engaging threads **122**.

(122) Specifically, as shown in FIG. **3**C, the bone-engaging threads **122** may have a minor diameter **242**, a major diameter **244**, and a pitch **246**. The distal shank **120** may have an exterior diameter

248, adjacent to the bone-engaging threads **122**, that is larger than the minor diameter **242** of the bone-engaging threads **122**. This may provide the distal shank **120**, and in particular, the portion of the distal shank **120** adjacent to the bone-engaging threads **122**, with added bending strength over that which would be present in bone screws with shanks that are limited in size to the minor diameter of the screw threads.

(123) The distal shank **120** may also have an exterior diameter **250**, displaced proximally of the bone-engaging threads **122**, and also proximal to the inner spline component **206**. The exterior diameter **250** may also be larger than the minor diameter **242** of the bone-engaging threads **122**. In some embodiments. the exterior diameter **248** and/or the exterior diameter **250** may be equal to and/or larger than the major diameter **244**. In yet other embodiments, the exterior diameter **248** and/or the exterior diameter **250** may be the equal in size, larger, or smaller than the average of the minor diameter **242** and the major diameter **244** of the bone-engaging threads **122**.

(124) As a result of these deliberate dimensioning decisions, the weakest cross-section of the bone screw **100**, as to bending, may be displaced from the location of maximum bending stress. More precisely, maximum bending stress may be experienced at the interface between the items being secured together by the bone screw **100** (for example, between two bone fragments or portions to be secured together). A screw (not shown) with distal threading with a minor diameter equal to the outer diameter of the shank of the screw may have a weakest cross section, as to bending, displaced significantly proximally of the screw threads. Thus, the location of maximum stress may unfortunately align with the part of the screw that is most susceptible to bending, which may be near the center of the screw.

(125) Conversely, the bone screw **100** may have a weakest cross section, as to bending, that is distal to the center of the screw, and thus likely displaced distally of the location of maximum bending stress. For example, the weakest cross section of the bone screw **100**, as to bending, may be immediately proximal to the bone-engaging threads **122**. This location may be displaced distally from the interface between bone portions when the bone screw **100** is fully inserted because the bone-engaging threads **122** may advantageously be driven fully into the distal bone portion or fragment, and then driven further to cause elongation of the bone screw **100**, as will be described hereafter.

(126) Further, as shown in FIG. **3**B, the proximal shank **110** may have an exterior diameter **252** that is also larger than the minor diameter **242** of the bone-engaging threads **122**. Thus, not only the distal member **106**, but also the proximal member **104**, may have enhanced strength and/or rigidity. As further shown in FIG. **3**A, the exterior diameter **252** may be as large as the major diameter **244** of the bone-engaging threads **122**, providing the bone screw **100** with yet more additional strength and/or rigidity. In alternative embodiments, the exterior diameter **252** may be larger than the minor diameter **242** but smaller than the major diameter **244** of the bone-engaging threads **122**.

(127) The exterior diameter **252** may conform to standard or otherwise known sizes for orthopedic screws. This may facilitate use of the bone screw **100** in place of conventional screws for a wide variety of orthopedic applications. In some embodiments, the exterior diameter **252** may be within the range of 1 mm to 10 mm. Yet more specifically, the exterior diameter **252** may be within the range of 2 mm to 8 mm. Still more specifically, the exterior diameter **252** may be within the range of 3.5 mm to 7 mm. In some embodiments, the exterior diameter **252** may be within the range of 4 mm to 6 mm. Yet more specifically, the exterior diameter **252** may be about 5 mm. FIGS. **1**A through **5** are shown to scale for the particular embodiment of the bone screw **100**; hence, other dimensions of the bone screw **100** may be derived from these possible values of the exterior diameter **252**.

(128) The bone screw **100** may be applied to bone and/or implant structures in a wide variety of ways. In some embodiments, a pilot hole may first be formed in the bone in which the bone-engaging threads **122** are to be engaged. A stepped pilot drill bit (not shown) may advantageously be used for this purpose. The stepped pilot drill bit may have a distal portion with a smaller

diameter and a proximal portion with a larger diameter. The distal portion may have a length and position that corresponds to the location of the bone-engaging threads **122** when the bone screw **100** has been fully inserted and/or when the bone-engaging threads **122** have reached their final position in the bone.

(129) FIGS. **6**A and **6**B are side elevation, section views of the bone screw **100** of FIG. **1**, upon initial insertion into bone, and upon further insertion to tension the bone screw, respectively. As shown, the bone screw **100** may be used, in this particular implementation, to secure a first bone portion **160** to a second bone portion **162**. The first bone portion **160** and the second bone portion **162** may be fragments of a single fractured bone, or they may be previously separate bone structures that are to be brought together and fused and/or otherwise secured to each other.

(130) As shown, the first bone portion **160** and the second bone portion **162** may initially be separated from each other by an interface **164**, at which a gap exists between the first bone portion **160** and the second bone portion **162**. The first bone portion **160** may be nearer the surgeon and may have an exterior cortex **166**.

(131) The bone screw **100** may first be inserted into the pilot hole. In order to reach the position shown in FIG. **6**A, torque may be applied to the head **112** of the bone screw **100** such that the bone-engaging threads **122** engage the second bone portion **162**. Torque may continue to be applied until the head **112** seats on the exterior cortex **166** of the first bone portion **160** as shown.

(132) With the head **112** seated against the exterior cortex **166**, further torque may be applied to the bone screw **100** in order to drive the bone-engaging threads **122** further into the second bone portion **162** and draw the second bone portion **162** toward the first bone portion **160**, closing the gap at the interface **164**. Leaving the bone screw **100** in this configuration may hold the second bone portion **162** and the first bone portion **160** together for a period of time, but once stress is applied to the first bone portion **160** and the second bone portion **162**, or once bone proximate the interface **164** begins to subside, a gap may form again at the interface **164**.

(133) Thus, further torque may be applied to the bone screw **100** to cause the bone screw **100** to elongate, applying compression between the first bone portion **160** and the second bone portion **162** even after such motion and/or subsidence occurs. More specifically, elongation of the bone screw **100** may occur as the shank **144** of the tension member **108** elongates, resulting in the configuration shown in FIG. **6**B. The tension member **108**, in turn, may pull the distal member **106** back toward the proximal member **104**, compressing the second bone portion **162** against the first bone portion **160**. Such compression may continue as long as the tension member **108** is elongated. Use of a superelastic material to form the tension member **108** may help provide a continuous level of compression between the first bone portion **160** and the second bone portion **162** as the bone screw **100** shortens, rather than providing a high level of compression at maximum elongation, followed by lesser compression as the bone screw **100** is permitted to shorten due to motion of the first bone portion **160** and the second bone portion **162**, or due to subsidence.

(134) As discussed previously, the length of the bone screw **100**, and therefore the compression applied by the tension member **108** and the compression applied by the tension member **108**, may be limited by the operation of the length limiting mechanism **210**. Thus, as the bone screw **100** reaches the length shown in FIG. **6**B, the protrusions **212** of the proximal member **104** may abut the shoulder **216** of the distal member **106** to prevent further elongation of the bone screw **100**. This limitation may help to ensure that the tension member **108** does fail in tension and does not apply excessive compression across the interface **164**.

(135) The configuration of the bone screw **100** may help control the manner in which torque is applied to the bone screw **100** to insert and then elongate the bone screw **100**. A threshold torque may be required to cause the bone screw **100** to elongate; this threshold torque may generally be higher than the level of torque required to drive the bone screw **100** into the first bone portion **160** and the second bone portion **162**, up until the head **112** contacts the exterior cortex **166** of the first bone portion **160**.

(136) FIG. **7** is a flowchart depicting a method **300** of inserting the bone screw **100** into bone, according to one embodiment. As shown, the method **300** may commence with a step **310** in which an insertion torque is applied to the bone screw **100**. As mentioned above, this insertion torque may be less than the threshold torque required to cause elongation of the bone screw **100**. The step **310** may continue until the head **112** seats against the exterior cortex **166**.
(137) The method **300** may then proceed to a step **320** in which further torque is applied, at a level equal to the threshold torque required to elongate the bone screw **100**, until the bone screw **100** is fully elongated. Use of a superelastic, material (such as Nitinol) in the tension member **108** may cause the threshold torque to remain generally constant as the bone screw **100** elongates. This is distinct from conventional materials, which may require an increasing level of tension (and therefore increasing torque) as strain in the material increases.
(138) Once the bone screw **100** has elongated fully, the method **300** may proceed to a step **330** in which an insertion torque is again applied at a higher level than the threshold torque as the bone screw **100** is further tightened in the first bone portion **160** and the second bone portion **162**. This tightening may not further elongate the bone screw **100**, which may be at its maximum length. However it may, for example, seat the head **112** deeper in the exterior cortex **166** and apply additional compression across the interface **164** between the first bone portion **160** and the second bone portion **162**.
(139) The bone screw **100** may not be designed for insertion along a guide wire. Full assembly of the bone screw **100** prior to insertion may interfere with use of a guide wire, as the tension member **108** may occupy the variable-length cavity **130** that would otherwise receive the guide wire. However, in alternative embodiments, a bone screw may be designed for insertion along a guide wire and subsequent assembly, and elongation, in-situ. One such embodiment will be shown and described subsequently in connection with FIGS. **11** through **17**.
(140) FIG. **8** is a flowchart depicting a method **400** of inserting a bone screw, such as the bone screw **100** of FIGS. **1**A through **5**, into bone according to one embodiment. The method **400** assumes that the bone screw **100** is used to secure two bone portions (for example, two fragments of a single bone to be repaired, or two bones to be locked together); similar methods may be envisioned for use of the bone screw **100** to secure an implant to bone.
(141) As shown, the method **400** may commence with a step **410** in which a bone hole is formed in the first and second bone portions. As mentioned previously, this may be done with a stepped pilot drill bit (not shown) that forms a smaller hole in the second bone portion **162**, and a larger hole in the first bone portion **160**. In alternative embodiments, the bone screw **100** may be self-tapping, and the step **410** may be omitted.
(142) The method **400** may proceed to a step **420** in which the bone screw **100**, in a fully-assembled state (including the tension member **108**), is inserted into the holes formed in the first bone portion and in the second bone portion **162**. This may be done without using a guide wire. Insertion of the bone screw **100** may be carried out by rotating the bone screw **100** with a driver (not shown) until the head **112** of the bone screw **100** abuts the exterior cortex **166** of the first bone portion **160** (the proximal bone portion).
(143) In a step **430**, the bone screw **100** may be further advanced, causing the bone screw **100** to extend from a first length to a second length. The first length may be the base (unelongated) length of the bone screw **100**, as shown in FIG. **6**A. The second length may be the fully extended length of the bone screw **100**, as shown in FIG. **6**B. In the alternative, the second length may less than the maximum length of the bone screw **100**. Elongation of the bone screw **100** pursuant to the step **430** may be carried out by further rotating the bone screw **100** with the driver such that the distal member **106** moves distally relative to the proximal member **104**. This rotation may be carried out until the bone screw **100** has reached the second length.
(144) After performance of the step **430**, the tension member **108** may be under tension, and may exert compressive force urging the distal member **106** to move proximally back toward the

proximal member **104**. This compressive force may be propagated to the interface **164** between the first bone portion **160** and the second bone portion **162** to accelerate healing and/or fusion.
(145) Those of skill in the art will recognize that the method **300** of FIG. **7** and the method **400** of FIG. **8** may be performed with other extendable bone screws besides the bone screw **100** of FIGS. **1**A through **5**. Further, the bone screw **100** may be used in connection with surgical methods besides the method **300** and the method **400**.
(146) Returning to the bone screw **100** of FIGS. **1**A through **5**, as mentioned previously, the tension member **108** may be formed of a superelastic material such as Nitinol. The manner in which this affects performance of the bone screw **100** will be further shown and described in connection with FIG. **9**A.
(147) FIG. **9**A is a diagram **500** depicting stress versus strain for an exemplary superelastic material. The diagram **500** is idealized and is only meant to indicate general properties of superelastic materials.
(148) As shown, the diagram **500** may have a strain curve **510**, showing stress versus strain under increasing stress, and a recovery curve **520**, showing stress versus strain as stress is reduced. The strain curve **510** may have a horizontal portion **530**, showing that the material will undergo steadily increasing strain as an upper plateau stress is applied. The strain range represented by horizontal portion **530** is referred to herein as superelastic strain. The strain at the left end of horizontal portion **530** represents the beginning of the transition of the superelastic material from a first crystal structure phase such as austenite to a second crystal structure phase such as martensite. The right end of horizontal portion **530** represents the complete transformation to the second crystal structure phase, and this represents the limit of superelastic strain. The span between the left and right ends of horizontal portion **530** is referred to herein as the superelastic zone. This upper plateau stress may be the stress experienced by the tension member **108** as the threshold level of torque is applied. The horizontal portion **530** may be generally horizontal, showing that application of torque at the threshold level (rather than at an increasing level) will cause the tension member **108** to continue to elongate.
(149) The recovery curve **520** may also have a horizontal portion **540**, showing that the material will undergo a steadily reducing strain, while a constant level of stress is maintained. This shows the performance of the bone screw **100** as the bone screw **100** is permitted to shorten again, due to shifting of the first bone portion **160** and the second bone portion **162** and/or subsidence of the first bone portion **160** and/or the second bone portion **162**. The strain level experienced by the tension member **108** may equate to the compressive force applied by the bone screw **100**, urging the first bone portion **160** and the second bone portion **162** together. The length and horizontal orientation of the horizontal portion **540** indicate how relatively steady compression at the lower plateau stress level may be maintained even as considerable shortening of the bone screw **100** occurs. Thus, the bone screw **100** may maintain compression to help the first bone portion **160** and the second bone portion **162** to heal and/or fuse, even while the bone screw **100** is shorter than its maximum length at the time of surgery.
(150) FIG. **9**B is a diagram **600** depicting changes in insertion torque and screw length during screw insertion. A torque curve **610** depicts the torque needed to advance the bone screw **100**. A length curve **620** shows the length of the bone screw **100**. The torque curve **610** may rise gradually and then level off at the threshold torque one the bone screw **100** has been fully inserted and begins to elongate. A horizontal portion **630** of the torque curve **610** may indicate how the insertion torque remains relatively constant during elongation of the bone screw **100**. In the length curve, this elongation is shown by a flat portion **640** with a constant upward slope. Prior to application of the threshold torque, and after the bone screw **100** reaches its maximum length, the length curve **620** is horizontal, reflecting a lack of change in length of the bone screw **100**.
(151) FIG. **10**A is a diagram **700** depicting changes in screw compression during insertion of the bone screw **100**, as in FIG. **9**B. The torque curve **610** is compared with a torque curve **710** for

"Prior Art #1," which is a standard bone screw that does not elongate, and a torque curve **720** for "Prior Art #2," which is a bone screw with elongation provided by a more conventional coil spring that is not formed of a superelastic material.

(152) As shown, the torque curve **710** has a constant slope, which is relatively steep, reflecting the fact that a conventional bone screw does not elongate significantly. The insertion depth of the screw is thus limited by the excessively high torque required to deepen insertion of the screw, and the correspondingly high tension applied to the screw (and compression applied across the interface **164**). Excessive torque may cause the screw to fail during insertion, and excessive compression may cause the bone to fail. Accordingly, insertion depth is limited, and any subsidence or motion in the first bone portion **160** and/or the second bone portion **162** may be expected to negate compression across the interface **164**.

(153) The torque curve **720** also has a constant slope, which is less steep than that of the torque curve **710**. This reflects the elongation provided by the coil or other conventional spring, which provides greater elongation than a conventional screw, but still requires increasing torque to obtain greater insertion depth. Again, any relative motion and/or subsidence in the first bone portion **160** and/or the second bone portion **162** may reduce the elongation in the spring, causing the compression applied across the interface between bone portions to decrease in proportion to the slope of the torque curve **720**. This concept will be further illustrated in FIG. **10**B.

(154) FIG. **10**B is a diagram **800** depicting changes in screw decompression during relative shortening between bone portions. A decompression curve **810** is shown for the bone screw **100**, as well as a decompression curve **820** for Prior Art #1 and a decompression curve **830** for Prior Art #2. The decompression curve **820** and the decompression curve **830** illustrate how compression applied across the interface **164** between the first bone portion **160** and the second bone portion **162** decreases in response to shortening of the bone screw. The decompression curve **810** may have a horizonal portion **840**.

(155) With the conventional bone screw, only a minimal amount of strain in the screw needs to be relieved before all compression across the interface **164** is lost. With the bone screw with a conventional spring, relief of strain reduces the compression across the interface **164** in relation to the slope of the decompression curve **830**, which may be the inverse of the slope of the torque curve **720** of the diagram **700**. Accordingly, the only way to maintain an optimal level of compression across the interface **164** (for example, a level of compression close to the "Threshold Compression" of FIG. **10**B) with this screw is to apply excessive compression at the time of surgery, so that strain relief only reduces the compression applied by the screw down from the excessive compression level to the healthy compression level. As mentioned previously, application of excessive compression (i.e., by applying high torque to the screw) can result in failure of the screw and/or the surrounding bone.

(156) By contrast, the decompression curve **810** illustrates how a broad range of strain relief in the bone screw **100** can occur without significantly changing the level of compression applied across the interface **164**. The bone screw **100** need not be torqued excessively in order to accomplish this. Rather, the bone screw **100** may advantageously be inserted only far enough to remain in the horizonal portion **840** of the decompression curve **810**. In some embodiments, the horizonal portion **840** may extend across a length of 0 to 5 mm. More precisely, the horizonal portion **840** may extend across a length of 1 to 4 mm. Still more precisely, the horizonal portion **840** may extend across a length of 1.5 to 3 mm. Yet more precisely, the horizonal portion **840** may extend across a length of 2 mm.

(157) This concept may apply across all of FIGS. **9**A, **9**B, **10**A, and **10**B. For example, with reference to FIG. **9**A, the tension member **108** of the bone screw **100** may be tensioned only enough that the stress and strain experienced by the tension member **108** remains in the horizontal portion **530** of the strain curve **510**. This limit may be provided by the length limiting mechanism **210**, which may limit elongation of the tension member **108** during insertion of the bone screw **100**

to keep stress in the tension member **108** from moving beyond (i.e., to the right of) the horizontal portion **530**. Relief of stress in the tension member **108** may thus only traverse the horizontal portion **540** of the recovery curve **520**. This is reflected in FIG. **9**B, in which further torque applied to the bone screw **100** after the bone screw **100** has traversed the horizontal portion **630** of the torque curve **610**, may not cause further elongation of the bone screw **100**. All of this may be transparent to the surgeon, who can simply drive the screw in a generally conventional manner.
(158) The bone screw **100** of FIGS. **1**A through **5** is only one of many embodiments of the present disclosure. Those of skill in the art will recognize that many variations could be conceived. For example, in some embodiments, the bone-engaging threads **122** may be adapted for the type of bone being penetrated. This may entail use of more or fewer bone-engaging threads **122**, or bone-engaging threads **122** with different shapes and/or sizes, than those depicted in FIGS. **1**A through **5**. In other embodiments, the proximal member **104** and the distal member **106** may be reconfigured such that the proximal member (not shown) has a distal end that resides within the proximal end of the distal member (not shown). Further, as set forth above, a wide variety of torque transmission features, length limiting mechanisms, bending transmission features, driver engagement features, and/or the like may be used, in addition to or in place of those of the bone screw **100**.
(159) In some embodiments, it may be desirable to use a variable-length bone screw in conjunction with a guide wire, as will be set forth in the method **1300** of FIG. **17**. FIGS. **11**A through **15** show a bone screw **1100** that is configured to facilitate use with a guide wire.
(160) The bone screw **1100** may have a longitudinal axis **102**, a proximal member **1104**, a distal member **1106**, and a tension member **1108**. FIGS. **11**A, **11**B, **11**C, and **11**D are perspective, side elevation, front elevation, and rear elevation views, respectively, of the bone screw **1100**. FIG. **12** is an exploded. perspective view of the bone screw **1100**. FIGS. **13**A, **13**B, **13**C, and **13**D are side elevation, section views of the bone screw **1100**, the proximal member **1104**, the distal member **1106**, and the tension member **1108**, respectively. FIG. **14** is a front elevation, section view of the bone screw **1100**. FIG. **15** is another front elevation, section view of the bone screw **1100**. Various parts of the bone screw **1100** may be identical or similar to their counterparts on the bone screw **100**; they will not be described again here. All statements made regarding the bone screw **100** apply to the bone screw **1100**, unless they would be contradicted by the differences between the two.
(161) The bone screw **1100** may be configured to allow the tension member **1108** to be inserted into the proximal member **1104** and the distal member **1106** after the remainder of the bone screw **1100** (i.e., the proximal member **1104** and the distal member **1106**) have been assembled together and inserted into the bone. The tension member **1108** may be designed to be inserted into and coupled to the proximal member **1104** and the distal member **1106** after the proximal member **1104** and the distal member **1106** have been implanted in the bone.
(162) Specifically, like the tension member **108** of the bone screw **100** of FIGS. **1**A through **5**, the tension member **1108** may have a proximal end **1140**, a distal end **1142**, and a shank **1144**, extending along the longitudinal axis **102**, that connects the proximal end **1140** to the distal end **1142**. However, in place of the proximal threads **146** of the tension member **108**, the proximal end **1140** of the tension member **1108** may have a head **1146** that is wider than the shank **1144**. The proximal member **1104** may have a head **1112** with an aperture **1113** leading into the interior of the proximal member **1104**, defining a surrounding shoulder **1116** on which the head **1146** of the tension member **1108** can rest.
(163) The distal end **1142** may have distal threads **1148** that facilitate coupling of the tension member **1108** to the distal member **1106** engagement of the distal threads **1148** with interior threads **1149** of the distal member **1106**. The distal end **1142** may further have a distal tip (not shown) that is sufficiently sharp for bone penetration, or alternatively, may have a distal tip **1150**, as shown, that is blunt, as the distal tip **1150** need not penetrate the bone because the tension member **1108** may not be inserted into the bone until after penetration has already been performed via formation of the pilot hole and/or insertion of the distal member **1106** into the bone.

(164) The head **1146** may have one or more driver engagement features that are operable independently of the driver engagement feature **230** of the head **1112**. For example, the head **1146** may have a slot **1152** (shown in FIG. **11**C) that facilitates rotation of the tension member **1108** with a driver such as a flat-head screwdriver.
(165) In use, the proximal member **1104** and the distal member **1106** may be assembled and driven into the bone over a guide wire, as will be set forth in the method **1300** of FIG. **17**. Then the guide wire may be removed, and the tension member **1108** may be inserted into the proximal member **1104** and the distal member **1106** by inserting the distal end **1142** through the aperture **1113**, through the proximal member **1104**, and into the distal member **1106** such that the distal threads **1148** of the distal end **1142** reach the interior threads **1149** of the distal member **1106**. A driver may be used to rotate the tension member **1108**, causing the distal threads **1148** to engage the interior threads **1149**. When the distal threads **1148** have been fully received in the interior threads **1149**, the head **1146** of the proximal end **1140** of the tension member **1108** may rest on the shoulder **1116** of the head **1112** of the proximal member **1104**, preventing further distal motion of the head **1146**.
(166) With the tension member **1108** in place within the proximal member **1104** and the distal member **1106**, the bone screw **100** may be further driven into the bone to move the distal member **1106** distally relative to the proximal member **1104**, causing the tension member **1108** to elongate. The head **1146** of the tension member **1108** may continue to press against the shoulder **1116** of the proximal member **1104** as the interior threads **1149** of the distal member **1106** move distally.
(167) Like the bone screw **100**, the bone screw **1100** may have a length limiting mechanism **1210** that controls the extent to which the bone screw **1100** can increase in length. The length limiting mechanism **1210** may function in a manner similar to that of the length limiting mechanism **210** of the bone screw **100**.
(168) Specifically, the length limiting mechanism **1210** may have a distal stop feature and a proximal stop feature that engage each other when the distal member **1106** has reached its maximum displacement relative to the proximal member **1104** to prevent further distal motion of the distal member **1106** relative to the proximal member **1104**. The distal stop feature may be a protrusion **1212** on a distal shank **1120** of the distal member **1106**. The protrusion **1212** may extend radially outwardly, away from the longitudinal axis **102** of the bone screw **1100**. The proximal stop feature may be a shoulder **1216** defined at the distal end of a relief **1218** formed in a proximal interior surface **1114** of the proximal member **1104**. The protrusion **1212** may extend radially into the relief **1218** such that distal motion of the distal member **1106** causes the protrusion **1212** to abut the shoulder **1216**, arresting further distal motion of the distal member **1106** relative to the proximal member **1104**.
(169) FIGS. **16**A and **16**B are side elevation, section views of the bone screw **1100** of FIG. **11**. upon initial insertion into bone, and upon further insertion to tension the bone screw, respectively. FIG. **16**A may depict the bone screw **1100** immediately after performance of the step **1350** of the method **1300** of FIG. **17**, i.e., after the tension member **1108** has been inserted into and coupled to the proximal member **1104** and the distal member **1106**, but before further torque has been applied to the bone screw **1100** to drive the distal member **1106** further into the second bone portion **162**. FIG. **16**B may depict the bone screw **1100** after performance of the step **1360** of the method **1300** of FIG. **17**, after the bone screw **1100** has been elongated to its maximum length. Again, the interface **164** has been closed by the compression applied between the first bone portion **160** and the second bone portion **162** by the bone screw **1100** in its elongated form.
(170) Notably, the bone screw **100** and the bone screw **1100** may not always be elongated to their maximum lengths. In some embodiments, it may be beneficial to stop applying torque to the bone screw **100** and/or the bone screw **1100** before maximum length has been reached.
(171) FIG. **17** is a flowchart depicting a method **1300** of inserting a bone screw into bone along a guide wire, according to one embodiment. As shown, the method **1300** may commence with a step **1310** in which the guide wire is inserted into the two bone portions, such as the first bone portion

160 and the second bone portion **162** of FIGS. **6**A and **6**B, at the desired location for the bone screw. Then the method **1300** may proceed to a step **1320** in which a cannulated drill (for example, with a stepped diameter as mentioned above), is inserted over the guide wire and used to form the pilot hole at the desired location.
(172) With the pilot hole formed, the method **1300** may proceed to a step **1330** in which the bone screw is inserted over the guide wire, without the tension member. The bone screw may partially or fully inserted into the bone at this stage, with the guide wire in place. The step **1330** may be similar to the step **310** of the method **300**. Then, in a step **1340**, the guide wire may be removed, leaving the variable-length cavity of the bone screw vacant.
(173) In a step **1350**, the tension member may be inserted into the variable-length cavity of the bone screw, and connected to the proximal and distal members of the bone screw to undergo tension as the screw elongates. Then, in a step **1360**, further torque may be applied to the fully-assembled bone screw so that the bone screw elongates and places the tension member under tension, as in the step **320** of the method **300**. Optionally, in a further step (not shown), further torque may be applied to the bone screw, as in the step **330** of the method **300**.
(174) Notably, in some alternative embodiments, an elongating bone screw may have a head designed to embed partially or fully in the proximal bone portion. In such embodiments, threading may be provided on the screw head. One such example will be shown and described in connection with FIG. **18**.
(175) FIG. **18** is a side elevation view of a bone screw **1400** according to another embodiment of the present disclosure. Like the bone screw **1100** of FIGS. **11**A through **15**, the bone screw **1400** may be insertable into the bone over a guide wire **1402**. The bone screw **1400** may also have a proximal member **1404**, a distal member **1406**, and a tension member (not shown) that is functionally similar to the tension member **1108** of FIGS. **11**A through **15**.
(176) The proximal member **1404** may have a head **1412** with a generally conical shape, tapered such that the head **1412** has a diameter that decreases along the distal direction. The head **1412** may have proximal threads **1414**. The proximal threads **1414** may also have a tapered major diameter and a tapered minor diameter, and may have a pitch that is smaller than the pitch of bone-engaging threads **1422** of the distal member **1406**.
(177) Thus, as the proximal threads **1414** engage the proximal bone portion and the bone-engaging threads **1422** of the distal member **1406**, the proximal member **1404** may advance more slowly than the distal member **1406**. This differential in rates of advancement may cause the bone screw **1400** to elongate, even as the head **1412** is being embedded in the proximal bone portion.
(178) Such an embodiment may help distribute compressive stress from the head **1412** over a larger volume of bone, and may also avoid leaving any portion of the head **1412** protruding proximally from the proximal bone. More precisely, if desired, the head **1412** may be fully embedded in the proximal bone portion. If desired, the differential pitch between the proximal threads **1414** and the bone-engaging threads **1422** may be selected such that the bone screw **1400** reaches maximum length as the proximal surface of the head **1412** becomes flush with the exterior cortex of the proximal bone portion.
(179) In some embodiments, it may be desirable to use a variable-length bone screw with a portion of an exterior diameter similar in size to a minor diameter of distal bone-engaging threads with the ability to be implantable over a guide wire, as will be set forth in the method **2500** of FIG. **33**. FIGS. **19**A through **23** show a bone screw **2100** that is configured to facilitate use with a guide wire and that has a portion of an exterior diameter that is similar in size to a minor diameter of distal bone-engaging threads.
(180) The bone screw **2100** may have a longitudinal axis **2102**, a proximal member **2104**, a distal member **2106**, a nut **2004**, and a tension member **2108**. As shown, the longitudinal axis **2102** of the bone screw **2100** may be an axis extending along the geometric center and/or axis of radial symmetry of the bone screw **2100**, along the longest length of the bone screw **2100**. The terms

"proximal" and "distal" are generally used with reference to displacement along the longitudinal axis **2102**, although they are sometimes used as adjectives to describe features of a proximal or distal member, such as the proximal member **2104** and the distal member **2106**.

(181) FIG. **19**A is a perspective view of the bone screw **2100**, according to one embodiment. FIG. **19**B is a side elevation view of the bone screw **2100** shown in FIG. **19**A in a shortened state. FIG. **19**C is a side elevation view of the bone screw **2100** shown in FIG. **19**A in a lengthened state. FIG. **20** is an exploded perspective view of the bone screw **2100** shown in FIG. **19**A with a guidewire **2002**. FIGS. **21**A, **21**B. **21**C, and **21**D are side elevation, section views of the bone screw, a proximal member, a distal member, and a tension member, respectively, of the bone screw **2100** shown in FIG. **19**A. FIG. **22** is a side elevation, section view of the nut **2004** shown in FIG. **20**. FIG. **23** is a front elevation, section view of the bone screw **2100** shown in FIG. **19**A, taken along the section lines shown in FIG. **19**B.

(182) Various parts of the bone screw **2100** may be identical or similar to their counterparts on the bone screw **100** and/or the bone screw **1100**; the descriptions of components of the bone screw **100** and the bone screw **1100** are applicable to their counterparts in the bone screw **2100**. All statements made regarding the bone screw **100** and/or the bone screw **1100** may be applied to the bone screw **2100**, unless they would be contradicted by the differences between the bone screw **2100** and the bone screw **100** and/or the bone screw **1100**.

(183) The tension member **2108** may be coupled to the proximal member **2104** and the distal member **2106** and may be positioned in a variable-length cavity **2130** in a manner similar to that of coupling of the tension member **108** to the proximal member **104** and the distal member **106** of bone screw **100**, and positioning of the tension member **108** in the variable-length cavity **130**. The tension member **2108** may have a proximal end **2140**, a distal end **2142**, and a tube **2145** that connects the proximal end **2140** to the distal end **2142**. The tube **2145** may define a cannulation **2141** extending from the proximal end **2140** to the distal end **2142**. Tube **2145** may have a slot **2143**, extending along the longitudinal axis **2102**. Slot **2143** may be on one side of tube **2145**; alternatively, multiple slots **2143** (not shown) may be on multiple sides of tube **2145**, and may optionally be spaced apart in radially symmetrical fashion. Slot **2143** may have a width, and slot **2143** may extend along a partial or a full length of tube **2145**. The number of slots **2143**, the width and the length of each slot **2143**, along with a wall thickness of tube **2145**, may be selected to provide a predetermined cross-sectional area such that a predetermined amount of force (e.g., tension) may yield a desired change in length of tension member **2108** (i.e., providing a predetermined stiffness for the tension member **2108**). The slot **2143** is optional and may be omitted if the tension member **2108** is to have a greater stiffness.

(184) The proximal end **2140** of tension member **2108** may have proximal threads **2146** that facilitate coupling of the tension member **2108** to the proximal member **2104** via threaded engagement with interior threads **2147** within the proximal member **2104**. The distal end **2142** of tension member **2108** may have a distal flange **2148** that facilitates coupling of the tension member **2108** to the nut **2004** via abutment of the distal flange **2148** on a distal surface **2157** of nut **2004**. The nut **2004** may have a proximal surface **2158** that facilitates coupling of the nut **2004** to the distal member **2106** via abutment of the proximal surface **2158** on a corresponding surface **2149** of the distal member **2106**. The nut **2004** may have interior threads **2156** that engage proximal threads **2146** to facilitate passing nut **2004** over the proximal end **2140** of the tension member **2108**. In alternative embodiments (not shown), the interior threads **2156** may be omitted, leaving an interior surface (not shown) sized to slide over the proximal threads **2146** of the proximal member **2104**. The distal end **2142** of the tension member **2108** may have a slot **2152** that facilitates rotation of the tension member **2108** with a driver such as a flat-head screwdriver to facilitate engagement of proximal thread **2146** of tension member **2108** and interior threads **2147** of proximal member **2104**.

(185) Alternatively, the nut **2004** and the tension member **2108** may be made as a unitary component (not shown). By making nut **2004** discrete from the tension member **2108**, the tension

member **2108** may be made from smaller diameter tubing material, which may decrease manufacturing cost. However, a nut **2004** and tension member **2108** may be assembled into bone screw **2100** in the same manner as shown in FIG. **20**, and bone screw **2100** may otherwise function as described herein.

(186) The proximal member **2104** may have a head **2112** at a proximal end of proximal member **2104**, a proximal shank **2110** at a distal end of proximal member **2104**, and a proximal interior surface **2114** that defines a proximal portion **2132** of variable-length cavity **2130**. The proximal interior surface **2114** may include a proximal engagement surface **2222** that interacts with a distal engagement surface **2226** on distal member **2106** to share loads (in particular, bending loads) between proximal member **2104** and distal member **2106** in a similar fashion as described previously for proximal engagement surface **222** and distal engagement surface **226** of bone screw **100**.

(187) Proximal engagement surface **2222** and distal engagement surface **2226** may beneficially be displaced (for example, proximally) from torque transmission socket **2123** and torque transmission protrusion **2125**. Torque transmission socket **2123** and torque transmission protrusion **2125** may act a fulcrum about which bending loads are applied between proximal member **2104** and distal member **2106**. Thus, displacement of the proximal and distal load sharing features (for example, proximal engagement surface **2222** and distal engagement surface **2226**) along longitudinal axis **2102** away from torque transmission socket **2123** and torque transmission protrusion **2125** may provide a longer moment arm to resist bending loads, and thereby resist undesired deformation of proximal member **2104** and/or distal member **2106**.

(188) Proximal member **2104** may have apertures **2214** that receive pins **2213** that extend transverse to longitudinal axis **2102**. The pins **2213** may keep the proximal member **2104** and the distal member **2106** assembled and/or serve as motion stops for motion of the proximal end of the distal member **2106** within the proximal portion **2132** of the variable-length cavity **2130**, as will be described subsequently. Optionally, the pins **2213** may be shaped such that they are flush with an exterior surface of proximal shank **2110**. More particularly, the ends of the pins **2213** may be beveled, rounded, and/or otherwise shaped to provide sufficient surface area to secure the pins **2213** within the apertures **2214** without extending beyond the generally cylindrical exterior of the proximal shank **2110**.

(189) Distal member **2106** may have distal bone-engaging threads **2122** located on a distal end of distal member **2106**, and may have a distal shank **2120** located proximal to distal bone-engaging threads **2122**. Distal bone-engaging threads **2122** may have a major diameter **2244** and a minor diameter **2242**. Advantageously, distal shank **2120** of distal member **2106** may have an exterior diameter **2252** that is similar in size to minor diameter **2242** to facilitate insertion of bone screw **2100** into bone. Distal member **2016** may have a distal interior surface **2124** that defines a distal portion **2134** of variable-length cavity **2130**.

(190) Like the bone screw **100**, the bone screw **2100** may have a length limiting mechanism **2210** that controls the extent to which the bone screw **2100** can increase or decrease in length. Pins **2213** positioned in apertures **2214** on proximal member **2104** may interact with a proximal shoulder **2216**, a distal shoulder **2217** and a relief **2218** located therebetween on distal member **2106** to form the length limiting mechanism **2210** in a similar fashion as described previously for length limiting mechanism **210**.

(191) Specifically, the length limiting mechanism **2210** may cause the bone screw **2100** to have a minimum length **2260** and a maximum length **2262** when the distal member **2106** has reached its minimum and maximum displacement along longitudinal axis **2102**, respectively, relative to the proximal member **2104**. The length limiting mechanism **2210** may include pins **2213** positioned in apertures **2214** of proximal member **2104**, a distal shoulder **2217** of distal member **2106**, and/or a proximal shoulder **2216** of distal member **2106**. The pins **2213** may act as a stop feature, moving between the proximal shoulder **2216** and the distal shoulder **2217** to define the range of extension

of the bone screw **2100**.

(192) Specifically, the minimum length **2260** may be caused by the abutment of pins **2213** against distal shoulder **2217** as shown in FIG. **21**A. The maximum length **2262** may be caused by the abutment of pins **2213** against the proximal shoulder **2216**. The minimum length **2260** and the maximum length **2262** may serve to provide a predetermined amount of minimum and maximum tension, respectively, in tension member **2108**.

(193) Beneficially, the minimum length **2260** and the maximum length **2262** may be determined with the same length limiting mechanism **2210**, for example, as two opposing abutting surfaces (e.g. the distal shoulder **2217** and the proximal shoulder **2216**) that define opposing ends the range of relative motion of a single intervening part (e.g., the pins **2213**). Thus, the displacement between the current length of the bone screw **2100** and the minimum length **2260** or the maximum length **2262** may easily be referenced (for example, via fluoroscopic visualization) from the displacement between the pins **2213** and the distal shoulder **2217** and the proximal shoulder **2216**, respectively.

(194) Further, having both motion stops (for the minimum length **2260** and the maximum length **2262**) be part of a single mechanism may facilitate variation in providing different bone screws **2100** with different length displacements (i.e., different displacements between the minimum length **2260** and the maximum length **2262**). For example, distal engagement surface **2226** and/or proximal engagement surface **2222** may be shortened or lengthened to adjust the provide different length displacements.

(195) Like the bone screw **100**, the bone screw **2100** may have a torque transmission feature that facilitates the transmission of torque between proximal member **2104** and distal member **2016**. The torque transmission feature may include a torque transmission socket **2123** on proximal member **2104** and a torque transmission protrusion **2125** on distal member **2106**, such that the torque transmission protrusion **2125** may engage the torque transmission socket **2123** to transmit torque between the proximal member **2104** and the distal member **2106**. Beneficially, the torque transmission socket **2123** and the torque transmission protrusion **2125** may include female and male spline shapes, respectively, that help to minimize hoop stresses incident to torque transmission, in a manner similar to that of embodiments described previously.

(196) The torque transmission protrusion **2125** may advantageously have a torque transmission feature (e.g., the spline shapes mentioned above or other shapes designed to receive torque) with a larger diameter than the distal shank **2120** of the distal member **2106**. In other words, the torque transmission feature may exist as a positive feature extending beyond the envelope of the distal shank **2120**, rather than existing as a reduced cross-sectional size relative to the distal shank **2120**. This may help the torque transmission protrusion **2125** and/or the torque transmission socket **2123** have sufficient mechanical strength to withstand the torsional, tensile, and/or bending loads that may be applied across the interface between the proximal member **2104** and the distal member **2106** during insertion in the bone and/or subsequent operation of the bone screw **2100** within the patient's body.

(197) Various head configurations may be used for the bone screw **2100**, or indeed for any of the bone screws in the present disclosure. Some examples will be shown and described in connection with FIGS. **24**A, **24**B, and **24**C.

(198) FIG. **24**A is a side elevation view of a head of a bone screw according to one embodiment. FIG. **24**B is a side elevation view of a head of a bone screw according to another embodiment. FIG. **24**C is a side elevation view of a head of a bone screw according to yet another embodiment.

(199) The variable-length bone screw (for example, the bone screw **2100** or any other bone screw disclosed herein) may have a rounded head, such as head **2112** of FIG. **24**A, adapted to contact a bone surface. The head **2112** may be configured to reside on the exterior of the bone. The rounded shape shown in FIG. **24**A may help avoid damage to surrounding soft tissues. In alternative embodiments, an exterior head may have any shape known in the art, including but not limited to domed shapes. In some embodiments, a head may be shaped to reside in a countersink,

counterbore, or other enlargement (not shown) formed in the hole that is to receive the bone screw **2100**.

(200) Alternatively, the bone screw **2100** (or any other bone screw disclosed herein) may have a threaded head a shown in FIG. **24**B, with proximal bone-engaging threads **2414**, adapted to engage a bone so that a proximal surface **2415** of the threaded head may not protrude beyond the surface of the bone in which it is embedded. In some embodiments, the proximal surface **2415** may be flush with the bone surface. In others, it may be recessed within the bone.

(201) Furthermore in yet other alternative embodiments, the threaded head of any bone screw disclosed herein may have bevel **2416** on a proximal end of the threaded head (i.e., a proximal-most surface), as shown in FIG. **24**C. The bevel **2416** may facilitate insertion of the bone screw **2100** at an angle that is nonperpendicular to the surface of the bone. In some embodiments, upon full insertion of the bone screw **2100** into bone at an oblique angle to a bone surface, the bevel **2416** may cause the proximal end of the threaded head to be parallel to, and flush with, the bone surface. Once the bone screw **2100** has been inserted to the desired depth, the surgeon may further rotate (or back out) the bone screw **2100** until the bevel **2416** has reached an orientation that is generally coplanar with the surrounding bone.

(202) Distal bone-engaging threads **2122** may have a first pitch P**1**, or a thread crest-to-thread crest distance, as shown in FIG. **19**A. Proximal bone-engaging threads **2414** may have a second pitch P**2** as shown in FIGS. **24**B and **24**C. First pitch P**1** and second pitch P**2** may be selected to that as the bone screw **2100** is fully inserted into bone, the bone screw **2100** is stretched from a minimum length to a length greater than the minimum length. For example, first pitch P**1** may be 3 mm, and second pitch P**2** may be 2 mm. Upon the proximal bone-engaging threads engaging a proximal portion of a bore within the bone, a full revolution of the bone screw **2100** may result in a 1 mm increase in length of the bone screw **2100**, since the distal member **2106** will advance 1 more millimeter than proximal member **2104**. As an example, proximal bone-engaging threads **2414** may have five full threads, and distal bone-engaging threads **2122** may have five or more full threads. Thus, after five full revolutions that result in all five of the proximal threads being fully engaged in a bone, the bone screw **2100** may increase in length by 5 mm. If desired, the bone screw **2100** may be designed such that length increase brings the bone screw **2100** to its maximum length **2262**. In alternative embodiments, the increase in length that occurs with full insertion of the bone screw **2100** may be less (for example, 25%, 50%, or 75%) of the maximum elongation permitted by the bone screw **2100**.

(203) The values of first pitch P**1** and second pitch P**2**, along with the number of proximal bone-engaging threads **2414**, may be selected to provide a predetermined amount of lengthening of the bone screw **2100** upon full insertion into a bone. In some embodiments, the number of proximal bone-engaging threads **2414** may be between 3 and 6, inclusive. More precisely, in some embodiments, the number of proximal bone-engaging threads **2414** may be 4, 5, or a number between 4 and 5 (for example, resulting from a residual thread that only extends partway around the longitudinal axis of the bone screw **2100**).

(204) In some embodiments, the difference between the values of first pitch P**1** and second pitch P**2** may be between 0.25 mm and 1.25 mm, inclusive. Further, in some embodiments, the difference in pitch may be between 0.5 mm and 1.0 mm, inclusive.

(205) In one embodiment, a 3.5 mm diameter by 50 mm minimum length bone screw **2100** may have a first pitch P**1** of 1.3 mm, a second pitch P**2** of 0.8 mm, and 5 proximal bone-engaging threads **2414**, resulting in 2.5 mm of potential length increase during implantation. In another embodiment, a 7.5 mm diameter by 100 mm minimum length bone screw **2100** may have a first pitch P**1** of 3 mm, a second pitch P**2** of 2 mm, and have 5 proximal bone-engaging threads **2414**, resulting in 5 mm of potential length increase.

(206) In some embodiments, it may be desirable to use a variable-length bone screw with a proximal drive feature on a distal member containing distal bone-engaging threads and that can

work in conjunction with a guide wire, as set forth in the method **2500** of FIG. **33**. FIGS. **25**A through **30** show a bone screw **3100** that is configured to facilitate use with a guidewire **3002** and that has a proximal drive feature on a distal member containing distal bone-engaging threads. The bone screw **3100** may have a longitudinal axis **3102**, a proximal member **3104**, a distal member **3106**, a tension member **3108**, a nut **3004**, a support ring **3006**, and a retaining ring **3008**.

(207) FIG. **25**A is a perspective view of bone screw **3100** according to one embodiment. FIG. **25**B is a side elevation view of the bone screw **3100** shown in FIG. **25**A in a shortened state. FIG. **25**C is a side elevation view of the bone screw **3100** shown in FIG. **25**A in a lengthened state. FIG. **26** is an exploded perspective view of the bone screw **3100** shown in FIG. **25**A with a guidewire **3002**. FIGS. **27**A, **27**B, **27**C, and **27**D are side elevation, section views of the bone screw **3100** in a first plane (FIGS. **27**A, **27**C, and **27**D), the bone screw **3100** in a second plane orthogonal to the first plane (FIG. **27**B), a support ring **3006**, a distal member **3106**, a tension member **3108**, and a nut **3004**. FIGS. **28**, **29**, and **30** are side elevations, section views of the nut **3004**, the support ring **3006**, and proximal member **3104**, respectively, shown in FIG. **26**.

(208) Various parts of the bone screw **3100** may be identical or similar to their counterparts on the bone screw **2100** and/or other bone screw embodiments presented herein; these parts may not be described again here. All statements made regarding the bone screw **2100** apply to the bone screw **3100** unless they would be contradicted by the differences between the two.

(209) The bone screw **3100** may be configured to allow the proximal member **3104** to be assembled over the proximal end of the distal member **3106**. Then, tension member **3108** may be inserted through the proximal member **3104**, into the distal member **3106**, and into the nut **3004**. The support ring **3006** may then be attached to the proximal end of the distal member **3106**, and a retaining ring **3008** may then be inserted into an internal groove **3219** in proximal member **3104** to form an assembly that is inserted into the bone over guidewire **3002**.

(210) The assembled bone screw **3100**, also referred to as bone screw **3100**, may have interior threads **3156** of nut **3004** engaged with distal threads **3148** of tension member **3108**. The nut **3004** may have a slot **3152** that serves as a drive feature by engaging a driver, such as a flat blade screwdriver (not shown), to facilitate engagement of interior threads **3156** with distal threads **3148**.

(211) The support ring **3006** may have an inner surface **3159** that is a coupled to a proximal exterior surface **3248** of distal member **3106** by a coupling mechanism known in the art such as threading, retention with a retaining ring, crimping, swaging, pinning, press fitting, adhesive or chemical bonding, soldering. brazing, welding, or combinations thereof. The support ring **3006** may be positioned on the distal member **3106** such that a distal surface **3154** of support ring **3006** abuts the shoulder **3182** on distal member **3106**, and a distal engagement surface **3226** of support ring **3006** is generally fitted around the proximal end of distal member **3106**, extending between the proximal surface **3184** of distal member **3106** and the shoulder **3182**.

(212) The tension member **3108** may be coupled to the proximal member **3104** and the distal member **3106** and may be positioned in a variable-length cavity **3130** similar to the way that tension member **108** is coupled to the proximal member **104** and the distal member **106** of bone screw **100** and positioned in variable-length cavity **130**. The tension member **3108** may have a proximal end **3140**, a distal end **3142**, and a tube **3145** that connects the proximal end **3140** to the distal end **3142**, and a cannulation **3141** that extends from the proximal end **3140** to the distal end **3142**. Tube **3145** may have a slot **3143**, extending along the longitudinal axis **3102**. Slot **3143** and tube **3145** may have the same features and operation as previously described for slot **2143** and tube **2145**.

(213) The proximal end **3140** of tension member **3108** may have a head **3146** that facilitates coupling of the tension member **3108** to the proximal member **3104** via abutment of a distal surface **3150** of head **3146** with a shoulder **3216** inside proximal member **3104**. The distal end **3142** of tension member **3108** may have distal threads **3148** that engage interior threads **3156** of nut **3004**. The nut **3004** may have a proximal surface **3158** that facilitates coupling of the nut **3004** to the

distal member **3106** via abutment of the proximal surface **3158** on a corresponding surface **3149** of the distal member **3106**. The surface **3149** may reside in a distal socket **3138** at the distal end of the distal member **3106**. The distal socket **3138** may be sized to receive and contain part or all of the nut **3004**.

(214) The proximal member **3104** may have a head **3112** at a proximal end of proximal member **3104**, a proximal shank **3110** at a distal end of proximal member **3104**, a proximal interior surface **3114**, and an interior surface **3115** adjacent to and proximal to proximal interior surface **3114**. Together, proximal interior surface **3114** and interior surface **3115** may define a proximal portion **3132** of variable-length cavity **3130**. The interior surface **3115** may include a proximal engagement surface **3222** that interacts with a distal engagement surface **3226** on support ring **3006** in a similar fashion as described previously for proximal engagement surface **222** and distal engagement surface **226** of bone screw **100**, defining a bending transmission feature or load sharing feature similar in function to those described in connection with previous embodiments.

(215) Distal member **3106** may have distal bone-engaging threads **3122** located on a distal end of distal member **3106** and may have a distal shank **3120** located proximal to distal bone-engaging threads **3122**. Distal member **3106** may have a distal interior surface **3124** that defines a distal portion **3134** of variable-length cavity **3130**.

(216) A driver engagement feature **3230** may be advantageously located on a proximal end of distal member **3106** so that bone screw **3100** may be driven by a driver, such as a flat blade screwdriver (not shown), that engages driver engagement feature **3230** so that torque is transmitted directly to the distal bone-engaging threads **3122** via the distal shank **3120**. Thus, torque may be transmitted directly through a monolithic structure to provide the most efficient method (i.e., lowest input torque) for inserting distal bone-engaging threads **3122** into bone and causing the bone screw **3100** to lengthen from a minimum length **3260** to a maximum length **3262**, when compared to transmitting torque through a torque transmission mechanism, such as a torque transmission protrusion **2125** engaged in a torque transmission socket **2123**, where additional input torque is required to overcome frictional forces aligned with the longitudinal axis **2102** therebetween.

(217) Further to the foregoing, in known elongating bone screws, a torque transmission feature may be the source of significant resistance to screw elongation, as the torque imparted to the bone screw may induce significant friction (and thence, resistance to the relative sliding motion needed for elongation) between the proximal and distal members. Thus, it may be a benefit to have the driver engagement feature **3230** present on distal member **3106**. This placement of driver engagement feature **3230** may enable proximal member **3104** to be rotatably and slidably coupled to distal member **3106**. Permitting relative rotation between proximal member **3104** and distal member **3106** may facilitate assembly and/or facilitate implantation of bone screw **3100**, particularly in embodiments in which the proximal member **3104** has bone-engaging threads like those of FIGS. **24**A and/or **24**B. In such embodiments, if desired, proximal member **3104** may have its own driver engagement feature (not shown) so that proximal member **3104** can be rotated into engagement with the bone independently of rotation of distal member **3106** to engage bone with the distal bone-engaging threads **3122**.

(218) Driver engagement feature **3230** is shown in FIG. **26** in the form of a slot, but any other shape for transmitting torque between a driver and a socket may be used as known in the art. For example, a cruciate shape, a square shape, polygonal shape, a hexalobular shape, and/or the like may be used. It may be beneficial to retain side openings like those of the driver engagement feature **3230** in the drive socket to allow head **3146** of tension member **3108** to extend outwardly to engage abutment features of the proximal member **3104**, as described previously.

(219) Like the bone screw **100**, the bone screw **3100** may have a length limiting mechanism **3210** that controls the extent to which the bone screw **3100** can increase or decrease in length. Distal surface **3150** and a proximal surface **3151** of head **3146** of tension member **3108** may interact with a shoulder **3216** of proximal member **3104** and/or a distal shoulder **3217** of driver engagement

feature **3230**, and a distal surface **3154** of support ring **3006**, respectively, to form a length limiting mechanism **3210** similar in function to the length limiting mechanism **210** described previously.
(220) Specifically, the length limiting mechanism **3210** may cause the bone screw **3100** to have a minimum length **3260** and a maximum length **3262** when the distal member **3106** has reached its minimum and maximum displacement along longitudinal axis **3102**, respectively, relative to the proximal member **3104**. The minimum length **3260** may be caused by the abutment of distal surface **3150** of head **3146** against shoulder **3216** of proximal member **3104** and/or distal shoulder **3217** of driver engagement feature **3230**. The maximum length **2262** may be caused by the abutment of proximal surface **3151** of head **3146** of tension member **3108** against distal surface **3154** of support ring **3006**. A relief **3218** defined by the interior surface **3115** of proximal member **3104**, located between the shoulder **3216** of proximal member **3104** and the distal surface **3154** of support ring **3006**, may provide space for the head **3146** of tension member **3108** to move from a maximal spacing away from distal surface **3154** when bone screw **3100** is at minimum length **3260** to making contact with distal surface **3154** when bone screw **3100** is at maximum length **3262**.
(221) Advantageously, during the insertion of bone screw **3100** into a bone, the amount of remaining lengthening (e.g., the distance between the current length and the maximum length) may be directly visualized by radiograph when bone screw **3100** is comprised of components made of metal. The remaining length may be determined by observing the distance between 1) the proximal surface **3151** of head **3146** of tension member **3108**, and 2) distal surface **3154** of support ring **3006** connected to distal member **3106**. Additionally or alternatively, the amount of stretch may be determined by using a screwdriver (not shown) that has axially sliding first and second contact surfaces that contain features such as markings or grooves that register against the proximal end of the proximal member and the proximal end of the distal member, respectively. In either case, etchings and/or other radiographic markings may be applied to proximal member **3104** and/or distal member **3106** to help measure the length of the bone screw **3100** radiographically during insertion.
(222) As another advantage, the distal shank **3120** of the distal member **3106** may have a constant cross-sectional shape from the distal-most end of the proximal member **3104** to the proximal end of the distal bone-engaging threads **3122** of the distal member **3106**. This may provide smoother insertion of the bone screw **3100** into the bone, as the distal shank **3120** may lack any feature that would snag on the bone. The bone screw **3100** may lengthen during the insertion process as in previous embodiments, and the constant cross-sectional shape of the distal shank **3120** may help avoid resistance to expansion. Further, the constant cross-sectional shape of the distal shank **3120** may help avoid trapping bone encircling the distal shank **3120** as the bone screw **3100** shortens during bone compression incident to the healing process.
(223) The minimum length **3260** and the maximum length **3262** may serve to provide a predetermined amount of minimum and maximum tension, respectively, in tension member **3108**. For example, the minimum length **3260** may be selected so that the corresponding strain in tension member **3108** corresponds to point A in diagram **2700**, and the maximum length may be selected so that the corresponding strain in tension member **3108** corresponds to point C or point C′ in diagram **2700**, as will be described subsequently.
(224) Tension member **3108** may be pre-stretched, thereby inducing pre-strain, during assembly of nut **3004** to tension member **3108** when tension member **3108** is positioned in the variable-length cavity **3130** by further tightening nut **3004** after distal surface **3150** of head **3146** engages shoulder **3216** of proximal member **3104** (or alternatively, after distal surface **3150** of head **3146** engages distal shoulder **3217** of driver engagement feature **3230**). The amount of pre-strain may be selected to correspond to point A shown in diagram **2700**. Alternatively or additionally, tension member **3108** may be pre-stretched, thereby inducing pre-strain, by thermal processing, as described below.
(225) In some embodiments, it may be desirable to releasably pre-stretch a variable-length bone screw, such as the bone screw **3100** or any of the other bone screw embodiments disclosed herein,

prior to insertion into a first bone portion and a second bone portion. Then, the variable-length bone screw may be inserted into the bone portions, and then the pre-stretch may be released so that the variable-length bone screw imparts compression between the bone portions without the need for elongation of the bone screw during insertion of the bone screw into the bone. An embodiment of pre-stretch and release of a variable-length bone screw is provided in FIG. **31** through FIG. **36**.
(226) FIG. **31** is a perspective view of a bone screw **4100** and a pre-stretch driver **4010** according to one embodiment. FIG. **32** is an exploded perspective view of the bone screw **4100** and the pre-stretch driver **4010** shown in FIG. **31**. FIG. **33** is a side elevation, section view of the bone screw **4100** and the pre-stretch driver **4010** shown in FIG. **31**. FIGS. **34**A and **34**B are side elevation, section views of the bone screw **4100** and the pre-stretch driver **4010** shown in FIG. **31** in unstretched and stretched state, respectively. FIGS. **35**A and **35**B are exploded perspective views of the proximal end of the bone screw **4100** and the distal end of a sleeve of the pre-stretch driver **4010** shown in FIG. **31**. FIG. **36** is a side elevation, section view of the proximal member **4104** shown in FIG. **31**.
(227) FIG. **31** shows a pre-stretch driver **4010** attached to a variable-length bone screw, or bone screw **4100**. Bone screw **4100** may share the same components as bone screw **3100**, except that bone screw **4100** comprises proximal member **4104** in place of proximal member **3104**. Therefore, bone screw **4100** may include proximal member **4104**, distal member **3106**, tension member **3108**, nut **3004**, support ring **3006** and retaining ring **3008**.
(228) Proximal member **4104** may have the same features and may have the same operation as proximal member **3104** and may include the following additional features. As shown in FIGS. **35**B and **36**, proximal member **4104** may include recesses **4012** and a countersink **4014** on the proximal end of proximal member **4104**. An internal groove **4016** may be located immediately distal to countersink **4014**.
(229) In this embodiment, recesses **4012**, countersink **4014**, internal groove **4016**, and driver engagement feature **3230** may all, combined, constitute a driver engagement feature. The driver engagement feature may be configured to mate with the pre-stretch driver **4010** such that the pre-stretch driver **4010** is actuatable to urge the proximal member **4104** to move proximally relative to the distal member **3106** to cause elongation of the tension member **3108** independently of engagement of the bone screw **4100** with the bone.
(230) Driver engagement feature **3230** may act as a push feature in addition to a torque-receiving feature, as the torque output feature **4028** of the pre-stretch driver **4010** may engage the slot of the driver engagement feature **3230** in a manner that allows the torque output feature **4028** to rotate the driver engagement feature **3230** and urge the driver engagement feature **3230** to move distally relative to the remaining elements of the driver engagement feature of the bone screw **4100** (i.e., recesses **4012**, countersink **4014**, and internal groove **4016**). Internal groove **4016** may act as a retention feature that can be retained (e.g., by the clips **4092**) to keep the proximal member **4104** from moving distally while the distal member **3106** is urged distally by the torque output feature **4028**.
(231) The ability of the distal member **3106** to rotate relative to the proximal member **4104** may provide greater flexibility during insertion of the bone screw **4100** into the bone. Specifically, in some embodiments, the pre-stretch driver **4010** may be used to tension the bone screw **4100** fully (i.e., to the maximum length **4072** and the maximum length **4076**). However, in alternative embodiments, the pre-stretch driver **4010** may be used to tension the bone screw **4100** only partway (i.e., to a length between the minimum length **4070** and the maximum length **4072**, and between the minimum length **4074** and the maximum length **4076**). The bone screw **4100** may then be inserted into the bone in such a partially-stretched state. The torque output feature **4028** may be used to rotate the distal member **3106**, causing further elongation of the bone screw **4100** during insertion. The proximal member **4104** may not rotate during this process, reducing friction with the surrounding bone, and enabling the pre-stretch driver **4010** to maintain the desired level of pre-

stretch until the tension on the bone screw **4100** imparted by insertion into the bone exceeds the tension applied by the pre-stretch driver **4010**.

(232) Advantageously, the slot shape of the driver engagement feature **3230** may enable the driver engagement feature **3230** to slide distally, relative to the torque output feature **4028**, allowing the bone screw **4100** to elongate further than the level of pre-stretch provided by the pre-stretch driver **4010**, without disengaging the bone screw **4100** from the pre-stretch driver **4010**.

(233) As shown in FIG. **32**, the pre-stretch driver **4010** may include a driver shaft **4020**, a knob **4040**, a retaining ring **4060**, and a sleeve **4080**. Driver shaft **4020** may have a torque input feature **4022** near its proximal end, a torque output feature **4028** near its distal end, and a shaft **4026** extending therebetween. An external groove **4024** may be located on the shaft **4026**, and a distal shoulder **4030** may be located immediately proximal to torque output feature **4028**.

(234) Torque output feature **4028** is shown generally in the form of a blade-shape to engage the driver engagement feature **3230** of distal member **3106** that is generally in the form of a pair of slots formed in opposing sidewalls of the proximal end of the distal member **3106** of the bone screw **4100**. However, as mentioned previously, other shapes for transmitting torque between a driver and an implant are known in the art, including but not limited to cruciate shapes, polygonal shapes, hexalobular shapes, and/or the like; any of the foregoing may be used in alternative embodiments.

(235) Sleeve **4080** may have external threads **4082** located near its proximal end, a shaft **4088** located near its distal end, and a handle **4086** extending therebetween. Scale **4084** may be located just distal to external threads **4082** on sleeve **4080**. Protrusions **4090** and clips **4092** extend from the distal end of sleeve **4080**. Clips **4092** may have elastic resiliency in a radial direction transverse to a long axis of the sleeve **4080**.

(236) When the pre-stretch driver **4010** is connected to the bone screw **4100**, protrusions **4090** are engaged in recesses **4012** to facilitate transmission of torque (or counter-torque). The protrusions **4090** and recesses **4012** are shown in a radial pattern of four instances, but any complementary positive and negative shape that effectively transmits torque may be used. Protrusions can reside on either pre-stretch driver **4010** or bone screw **4100**, with complementary recesses on the other of pre-stretch driver **4010** and bone screw **4100**.

(237) As in previous embodiments, the proximal end (e.g., the “head”) of proximal member **4104** may take any of the forms shown in FIGS. **24**A, **24**B, and **24**C. Thus, in some embodiments, proximal member **4104** may be modified to have threading and/or a proximal-facing surface that is nonperpendicular to the longitudinal axis of the bone screw **4100**. If needed, the interfacing features of the pre-stretch driver **4010** may be modified to accommodate such a design change, allowing pre-stretch of such bone screw embodiments.

(238) Returning to FIG. **32**, when the pre-stretch driver **4010** is connected to the bone screw **4100**, clips **4092** may be engaged in internal groove **4016**. To facilitate assembly of the pre-stretch driver **4010** to the bone screw **4100**, countersink **4014** on proximal member **4104** may include an angled surface that will urge the clips **4092** to deflect inward radially, until the clips **4092** spring back outward radially to engage internal groove **4016** when the pre-stretch driver **4010** is fully seated against the proximal end of bone screw **4100** and protrusions **4090** of sleeve **4080** are received in recesses **4012** of proximal member **4104**.

(239) The knob **4040** may be pre-assembled to driver shaft **4020** by sliding the knob **4040** over the distal end of driver shaft **4020** and then positioning the knob **4040** adjacent to torque input feature **4022**. Then, retaining ring **4060** may be assembled to external groove **4024** on driver shaft **4020** to retain knob **4040** on driver shaft **4020**.

(240) To attach the pre-stretch driver **4010** to the bone screw **4100**, the sleeve **4080** may be attached to the proximal member **4104** of bone screw **4100** so that clips **4092** are engaged in internal groove **4016** and protrusions **4090** of sleeve **4080** are received in recesses **4012** of proximal member **4104**, as described above. Then, driver shaft **4020** with knob **4040** (for example,

pre-assembled on driver shaft **4020**) may be inserted into the proximal end of sleeve **4080** and advanced distally until torque output feature **4028** is engaged in driver engagement feature **3230** of distal member **3106**. Then, internal threads **4044** of knob **4040** may be engaged with external threads **4082** to couple the driver shaft **4020**, knob **4040**, and sleeve **4080** together.

(241) This assembly of the pre-stretch driver **4010** may retain pre-stretch driver **4010** to bone screw **4100**. Specifically, shaft **4026** extends through the space between clips **4092** when the pre-stretch driver **4010** is assembled to bone screw **4100**, clips **4092** are prevented from flexing radially inward and from releasing from internal groove **4016**, so that the attachment between the pre-stretch driver **4010** and the bone screw **4100** is secured. The distal end of knob **4040** can then be referenced against scale **4084** to indicate the remaining amount of linear change, or stretch, of an overall length of bone screw **4100**.

(242) When the pre-stretch driver **4010** is attached to the bone screw **4100** with the bone screw **4100** at its shortest length as shown in FIG. **34**A, the distance between the distal end of the proximal member **4104** and the distal end of the distal member **3106** may be at minimum length **4070** and the length of tension member may be at minimum length **4074**. To stretch the bone screw **4100**, knob **4040** may be rotated clockwise to advance the external threads **4082** distally relative to internal threads **4044**, causing inner shoulder **4042** of knob **4040** to bear against assembled retaining ring **4060**, thus causing sleeve **4080** and attached proximal member **4104** to advance proximally relative to distal member **3106** and thus stretching tension member **3108**. Scale **4084** may show increasing stretch (for example, from the “0” marking of FIG. **32** to the “2” marking, to the “4” marking, with intervening markings to show smaller increments). The markings of the scale **4084** may represent millimeters of stretch.

(243) Continued relative rotation of knob **4040** with respect to driver shaft **4020** may continue to stretch the variable-length screw until length limiting mechanism **3210** is engaged so that maximum length **3262** is achieved, resulting in a distance between the distal end of the proximal member **4104** and distal member **3106** is at maximum length **4072** and the length of tension member is at maximum length **4076**. In some embodiments, pre-stretch driver **4010** may be used to pre-stretch bone screw **4100** to the maximum length **3262**. In alternative embodiments (for example, where compression over a smaller displacement is sufficient), pre-stretch driver **4010** may be used to pre-stretch bone screw **4100** to an intermediate length between minimum length **3260** and maximum length **3262**.

(244) Pre-stretch driver **4010** may operate to not only pre-stretch bone screw **4100**, but also to facilitate insertion of bone screw **4100** into bone in the pre-stretched configuration. With bone screw **4100** at the desired pre-stretch length, pre-stretch driver **4010** and bone screw **4100** may be retained together, as described above, until pre-stretch driver **4010** has been activated to release pre-stretch of bone screw **4100**. Torque input feature **4022** of pre-stretch driver **4010** may be connected to a torquing device, such a chuck on a motorized drill or manual handle. The torquing device may be used to rotate bone screw **4100**, in the pre-stretched configuration, into the hole in the first and second bone portions, until the screw **4100** has reached its desired position. Then, pre-stretch driver **4010** may be disconnected from the torquing device and activated to release the pre-stretch.

(245) To release the pre-stretch driver **4010** from bone screw **4100**, such as after placement of pre-stretched bone screw **4100** into bone portions, knob **4040** may be rotated counterclockwise relative to driver shaft **4020** until internal threads **4044** are disengaged from external threads **4082**. This may cause the pre-stretch driver **4010** to cease maintaining pre-stretch of the bone screw **4100**, allowing bone screw **4100** to apply compression to the bone (i.e., compressing the first and second bone portions together as in previous embodiments). However, bone screw **4100** may still retain pre-stretch to the extent that reactionary forces in the first and second bone portions urge it to remain elongated. As with other bone screws disclosed herein, the bone screw **4100** may be inserted incrementally, with visual, fluoroscopic, and/or other verification of the position of the

bone screw **4100** used between advancements to confirm its position.
(246) With the bone screw **4100** inserted to the desired depth within the first and second bone portions and with the pre-stretch released as described above, pre-stretch driver may be disassembled and removed from bone screw **4100**. With the internal threads **4044** disengaged from external threads **4082**, driver shaft **4020** may be withdrawn from sleeve **4080**. Sleeve **4080** may then be disengaged from proximal member **4104** by pulling sleeve **4080** proximally away from proximal member **4104**, causing clips **4092** to flex radially inward to release from internal groove **4016**.
(247) When the pre-stretch driver **4010** is assembled and in engagement with bone screw **4100**, distal shoulder **4030** of driver shaft **4020** may bear directly on the proximal surface **3184** of distal member **3106**, which may advantageously directly transmit end loads applied by the user to the pre-stretch driver **4010** (e.g. compressive loads applied by pushing the pre-stretch driver **4010** distally) to distal bone-engaging threads **3122** to facilitate insertion of distal bone-engaging threads **3122** into the bone. This direct transmission of compressive load may help the surgeon to more directly apply pressure to the distal bone-engaging threads **3122** and/or receive tactile feedback indicating how the bone screw **4100** is seating in the bone, whether the insertion depth is appropriate, etc.
(248) Of course, pre-stretching is optional. In some embodiments (for example, bone screw **3100**), a more conventional driver without pre-stretch capability may be used. For example, a driver (not shown) may have a shaft terminating at a flat head (for example, resembling torque output feature **4028** of driver shaft **4020**) that directly engages and rotates driver engagement feature **3230** of distal member **3106**. Such a driver may also provide direct transmission of compressive loads from the driver to the distal member **3106**, and thence to the distal bone-engaging threads **3122**, providing the benefits cited above for direct load transmission.
(249) The following discussion regarding FIGS. **37-40** uses bone screw **2100** as an example, but the discussion is equally applicable to all embodiments of bones screws described herein, including bone screw **3100** and bone screw **4100**.
(250) FIG. **37** is a flowchart depicting a method of inserting a variable-length bone screw into bone, according to one embodiment. As shown, the method **2500** may commence with a step **2510** in which a first guide wire is inserted into a first bone portion and a second bone portion. Then, in a step **2520**, a first cannulated drill may be used to drill over the first guide wire to create a counterbore in the first bone portion. In a step **2530**, a second cannulated drill may be used to drill over the first guide wire to create a pilot hole in the first and second bone portions. With one of the first or second cannulated drills in the first and/or second bone portions, step **2540** may be performed in which the first guide wire, partially residing in a cannulation of the first or second cannulated drill, is replaced with a second guide wire, such as a guidewire **2002**.
(251) After step **2540**, step **2550** may commence, in which one of the first and second cannulated drills is removed from the first and/or second bone portions, thus leaving the second guide wire in the first and second bone portions. Then, a step **2560** may follow, in which a variable-length screw, such as bone screw **2100**, is advanced in the first and second bone portions over the second guide wire. Then, a step **2570** may provide for further advancement of the variable-length screw in the bone portions, thereby causing the variable-length screw to extend from a first length, such as minimum length **2260**, to a second length, such as maximum length **2262**, wherein the second length is longer than the first length. After step **2570**, step **2580** may provide for removal of the second guidewire from the first and second bone portions.
(252) FIG. **38** is a diagram **2700** depicting stress versus strain behavior of a tension member according to one embodiment. Diagram **2700** depicts the stress versus strain behavior of tension member **2108** in an isolated state, and as assembled in bone screw **2100** (as shown in FIG. **21**A). Upper curve **2760** depicts the stress versus strain behavior of the isolated tension member **2108**, such as tension member **2108**, as it is loaded from no stress to a stress level just below its ultimate,

or failure, stress. Upper curve **2760** may also be called a loading curve. Lower curve **2770** depicts the stress versus strain behavior of the isolated tension member **2108** as it is unloaded from a stress level just below its ultimate stress to zero stress. Lower curve **2770** may also be called an unloading curve.

(253) Tension member **2108**, as assembled in bone screw **2100** as shown in FIG. **21**A, may have a stress versus strain behavior as depicted by the combination of curve segment A-B **2710**, curve segment B-C **2720**, curve segment C-D **2730**, and curve segment D-A **2740**. Point A, also called pre-strain, may represent bone screw **2100** in its minimum length **2260**, and point C may represent bone screw **2100** in its maximum length **2262**. Point A may be advantageously selected to be in proximity to the left end of the lower plateau stress, or in the range of 1.5% to 2.5% strain as shown in diagram **2700**, and more specifically around 2% strain. Point C may be advantageously selected to be in proximity to the right end of the upper plateau stress, or in range of 5.5% to 6.5% strain as shown in diagram **2700**, and more specifically around 6% strain.

(254) Advantageously, path shown in FIG. **38** may retain the bone screw in the superelastic range of the tension member **2108**. The minimum length **2260** and the maximum length **2262** may be calibrated to accomplish this. Other screws known in the art are inserted with the resilient member unloaded (for example, at point A′). Then, the screw must undergo significant elongation (the strain from point A′ to point B) before there is appreciable compression on the bone. Then, after the bone screw has compressed the fracture, the bone screw may shorten until the compressive load again falls off (between point A and point A′) so that the bone is no longer loaded. The healing benefits of compression may thus not be obtained.

(255) Conversely, the bone screw **2100** may optionally be calibrated such that the bone screw **2100** begins with some pre-tensioning of the tension member **2108**. Thus, the bone screw **2100** may begin at or near point A or point B, rather than at point A′. Even if the bone screw **2100** compresses a fracture (or union) enough to reduce the bone screw **2100** back to the minimum length **2260**, the bone screw **2100** may continue to apply compression to the bone, at least at or near the lower plateau level. Beneficially, the maximum length **2262** may be selected such that the tension member **2108** cannot be tensioned beyond point C. which could lead to plastic deformation and/or failure of the tension member **2108**.

(256) Thus, the tension member **2108** may impart a first compressive force (for example, the lower plateau stress as at point A) between the proximal member and the distal member when the tension member is at the minimum length and a second compression force (for example, the upper plateau stress as at point C) between the proximal member and the distal member when the tension member is at the maximum length. Since point A and point C are at the lower and upper plateau stresses, respectively, the first compression force divided by the second compression force may be similar in value to the lower plateau stress divided by the upper plateau stress.

(257) Alternatively, tension member **2108**, as assembled in bone screw **2100** as shown in FIG. **21**A. may have a stress versus strain behavior as depicted by the combination of curve segments A-B **2710**, curve segment B-C′ **2780**, curve segment C′-D′ **2750**, and curve segment D′-A **2790**. Point C′ may be advantageously selected to be in proximity to the mid-range strain of the upper plateau stress, or in range of 3% to 5% strain as shown in diagram **2700**, and preferably around 4% strain. Alternatively, if no pre-strain in the tension member is desired, then tension member **2108**, as assembled in bone screw **2100** as shown in FIG. **21**A, may have a stress versus strain behavior as depicted by the combination of curve segments A′-B **2715**, curve segment B-C′ **2780**, curve segment C′-D′ **2750**, and curve segment D′-A′ **2795**.

(258) Bone screw **2100** with a tension member **2108** that is at 0% strain at minimum length **2260** is referred to as a relaxed bone screw (such as a point A′ at the origin in diagram **2700**), and bone screw **2100** with a tension member **2108** that is at a strain that is in proximity to the left-hand end of a lower plateau stress (such as point A in diagram **2700**) at minimum length **2260** is referred to as a pre-strained bone screw. An advantage of a pre-strained bone screw over a relaxed bone screw

is that the pre-strained bone screw operates within a much narrower range of stress in the tension member between its minimum length and maximum length, providing more consistent stress over the operable length range. Another advantage of a pre-strained bone screw over a relaxed bone screw is that the pre-strained bone screw has a high level of stress in the tension member even at lengths that are very close to the minimum length, whereas the relaxed bone screw has almost no stress in the tension member at lengths that are very close to the minimum length. Stress in the tension member **2108** is directly proportional to the compression force imparted between the proximal member **2104** and the distal member **2106**, which in turn impart that compression between first bone portion **160** and second bone portion **162** as shown in FIGS. **6**A and **6**B. Thus, compared to a relaxed bone screw, a pre-strained bone screw may provide more consistent compression over its operable length, and may provide a much higher level of compression at lengths that are very close to the minimum length.

(259) Methods of creating pre-strain in tension member **2108** include, but are not limited to, stretching and thermal processing. To create pre-strain by stretching, tension member **2108** may be dimensioned and assembled into bone screw **2100** as shown in FIG. **21**A such that, with the tension member in a relaxed state, apertures **2214** in proximal member **2104** are distal to distal shoulder **2217** in distal member **2106** such that pins **2213** cannot be inserted into apertures **2214**. Distal member **2106** may be moved distally relative to proximal member **2104** to cause the tension member **2108** to stretch and to cause the distal shoulder **2217** to move distal to apertures **2214**, so that pins **2213** may be inserted into the apertures **2214** and into the space on distal member **2106** created by relief **2218**, which may then pre-strain the tension member **2108** with a pre-determined amount of strain (for example, the 1.5% to 2.5% strain level referenced above for Point A of FIG. **38**).

(260) To create pre-strain by thermal processing, the tension member **2108** with a first length can be made from nitinol and cooled below its martensitic finish temperature. While in the martensitic state, the tension member can be stretched to a second length that is longer than the first length. Because the nitinol is in the martensitic state, deformation may be achieved by a crystal structure twinning effect and the nitinol may remain in its deformed state after it is stretched and released while it remains below the martensitic finish temperature. With the tension member **2108** deformed at the second length and while remaining a temperature below the martensitic finish temperature, the tension member may be assembled into bone screw **2100** as shown in FIG. **21**A. After assembly, bone screw **2100** may be heated above its austenitic finish temperature, causing tension member **2108** to attempt to return to its first length, thereby inducing a strain that will be related to the difference in length between the second length and the first length when the bone screw is at minimum length **2260**. This induced strain may be the pre-strain identified as point A in diagram **2700** (for example, again amounting to the 1.5% to 2.5% strain level referenced above for Point A of FIG. **38**).

(261) Thermal processing may additionally or alternatively be used to help even out insertion and healing compression levels provided by the bone screw **2100**. The diagram **2700** shows how hysteresis may cause the bone screw **2100** to apply a lower level of compression to the first and second bone portions after installation, than the level experienced by the surgeon during installation of the bone screw **2100**. This may not be desirable, as it may be optimal to maintain a minimum level of compression between the first and second bone portions during the healing process, but with the loss in compressive stress incident to hysteresis, it may not be safe to apply the higher insertion compression needed to obtain the desired level of compression during healing. Thermal processing may be used to help obtain a compression stress that is close to or the same as the insertion stress experienced by the tension member **2108** during insertion, as will be set forth below.

(262) FIG. **39** is a diagram depicting stress versus strain behavior of exemplary superelastic material at two different temperatures. Superelastic materials, such as nitinol, may have a

temperature-dependent stress strain behavior as depicted in diagram **2800**. Upper curve **2810** depicts the loading and lower curve **2820** depicts the unloading of a superelastic material at a temperature **2**. Upper curve **2830** depicts the loading and lower curve **2840** depicts the unloading of the superelastic material at a temperature 1. Temperature 1 is higher than Temperature 2. For example, experiments performed with a tension member made from superelastic nitinol demonstrated the following upper and lower plateau stresses at 6% strain: at 37° C., 68,000 psi and 46,000 psi (Upper Plateau 1 and Lower Plateau 1, respectively); at 8° C., 44,000 psi and 23,000 psi (Upper Plateau 2 and Lower Plateau 2, respectively). Thus, by cooling the tension member **2108** from 37°° C. to 8° C., the stress/strain curve may shift from Upper Plateau 2 to Lower Plateau 1 because the 44,000 psi upper plateau stress at the lower temperature is close in value to the 46,000 psi lower plateau stress at the higher temperature (i.e., body temperature).

(263) By inserting bone screw **2100** at 8° C. into first and second bone portions and causing bone screw **2100** to lengthen from minimum length **2260** to a longer length, up to maximum length **2262**, the tension member **2108** may stretch at the upper plateau stress of 44,000 psi. After warming to body temperature, tension member **2108** may urge the proximal member **2104** and the distal member **2106** to move toward each other at the lower plateau stress of 46,000 psi. Thus, a compression force, which is proportional to the stress in tension member **2108**, imparted by bone screw **2100** on first and second bone portions may be similar, or close in value, for insertion and for maintaining compression between first and second bone portions.

(264) FIG. **40** is a flowchart depicting a method of inserting a variable-length bone screw into bone, such as bone screw **2100**, according to one embodiment. As shown, the method **2900** may commence with a step **2910** of providing a superelastic material having a first upper plateau stress and a first lower plateau stress at body temperature, and having a second upper plateau stress lower than the first upper plateau stress and a second lower plateau stress lower than the first lower plateau stress at a second temperature that is lower than body temperature. Then, in a step **2920**, bone screw **2100** may be provided, with a tension member **2108** made from the superelastic material. The bone screw **2100** may be cooled to the second temperature in step **2930**. Once cooled, the bone screw **2100** may be inserted into a first bone portion and a second bone portion such that the insertion of the variable-length bone screw causes the tension member **2108** to stretch at the second upper plateau stress in step **2940**. Following insertion, the bone screw **2100** may be warmed to body temperature in step **2950** (for example, by natural heat transfer within the body). Once at body temperature, in a step **2960**, the bone screw **2100** may shorten by an amount corresponding to the amount of decrease in the distance between first and second bone portions, causing the tension member **2108** to shorten at the first lower plateau stress.

(265) The second temperature may be selected such that the second upper plateau stress and first lower plateau stress are similar in value, so that the compression force generated by the tension member during insertion at the second temperature will be similar to the compressive force generated by the tension member at body temperature as the variable-length screw contracts in length during the healing process. Stresses that are “similar in value” generally means values that differ by less than 25%. In some embodiments, stresses that are similar in value may differ by less than 10%, or more specifically, by less than 5%. Thus, with similar compression forces exerted by the tension member **2108** during and after insertion, the forces imparted by the bone screw **2100** to the first and second bone portions may also be similar during insertion and during length contraction of the variable-length bone screw.

(266) FIG. **41** is a perspective view of a bone screw **5100** according to one embodiment. FIG. **42** is an exploded perspective view of the bone screw **5100** shown in FIG. **41** with a guidewire. FIG. **43** is a front elevation, section view of the bone screw **5100** shown in FIG. **41**. FIG. **44** is an enlarged view of the proximal end of the bone screw **5100** shown in FIG. **43**. FIG. **45** is a front elevation, section view of a proximal nut **5005**, a tension member **5108**, and distal nut **5004**. Bone screw **5100** may include a proximal member **5104**, a distal member **5106**, the proximal nut **5005**, the tension

member **5108**, and the distal nut **5004**. Assembled bone screw **5100** may be insertable over a guidewire **5002**.
(267) As shown in FIG. **45**, proximal nut **5005** may have a proximal surface **5170**, a distal surface **5172**, and interior threads **5174** extending from proximal surface **5170** to distal surface **5172**. Proximal nut **5005** may have a longitudinal axis **5006** (shown in FIG. **43**), which may be transverse, or more precisely perpendicular, to the longitudinal axis **5102** of the bone screw **5100**. Proximal nut **5005** may be termed an “interpositional member.” In this application, an “interpositional member” is any member that can be positioned to help control interaction between two other members or features. An interpositional member may have a wide variety of shapes and features different from those of proximal nut **5005**. In some embodiments, proximal nut **5005** may be replaced with a clip, clamp, or other fastening device that controls relative positioning between any two or more of proximal member **5104**, distal member **5106**, and tension member **5108**. In other embodiments, proximal nut **5005** may be integrated into tension member **5108**, and the function served by proximal nut **5005** may be carried out by the proximal end of tension member **5108**. Proximal nut **5005** may be formed as a separate piece from proximal member **5104** and distal member **5106**, and may serve to simplify the structure and/or manufacture of proximal member **5104** and/or distal member **5106**.
(268) Tension member **5108** may have a proximal end **5140**, a distal end **5142**, and a cannulation **5141** extending from proximal end **5140** to distal end **5142**. Tension member **5108** may have proximal threads **5146** near proximal end **5140**, distal threads **5148** near distal end **5142**, and a shank **5144** distal, proximate, and/or adjacent to proximal threads **5146**. A tube **5145** may extend from shank **5144** to distal threads **5148** such that cannulation **5141** extends the full length of tension member **5108** from proximal end **5140** and distal end **5142**. Alternatively, if placement over a guidewire is not desired, tension member **5108** may be solid. As in previous embodiments, tension member **5108** may optionally be made of a biocompatible superelastic material, which may be a shape memory alloy such as Nitinol.
(269) Distal nut **5004** may have a proximal surface **5158**, a distal surface **5157**, and interior threads **5156** extending from proximal surface **5158** to distal surface **5157**. In alternative embodiments, different fastening systems may be used. In some embodiments, distal nut **5004** may be integrated with tension member **5108**, and the function served by distal nut **5004** may be carried out by distal end **5142** of tension member **5108**.
(270) As shown in FIGS. **42** and **44**, distal member **5106** may have distal bone-engaging threads **5122** proximate a distal end of distal member **5106** and an aperture **5176** extending transverse to a longitudinal axis **5102** and through distal member **5106**. Aperture **5176** may be bounded distally by a distal shoulder **5217** and proximally by a proximal shoulder **5216**, and aperture **5176** may further include a first distal aperture on one side of longitudinal axis **5102** and a second distal aperture on an opposed side of longitudinal axis **5102**. Distal member **5106** may further have a driver engagement feature **5230** for receipt of torque input, a proximal surface **5184**, and an interior shoulder **5186**. Driver engagement feature **5230** is shown as an aperture with a polygonal shape, but may, in alternative embodiments, be an aperture with a different shape (such as a Hexalobular receiver), or may be a positive feature such as a polygonal or Hexalobular protrusion. Advantageously, driver engagement feature **5230** may have a shape, such as hexagonal or Hexalobular shape, that is matable with the torque features on conventional orthopedic drivers. This may facilitate revision and/or removal of bone screw **5100** subsequent to implantation, as the surgeon may be able to remove or positionally adjust bone screw **5100** without having the same driver used to implant bone screw **5100**.
(271) Various parts of the bone screw **5100** may be identical or similar to their counterparts on the bone screw **100**, **2100**, **3100** and/or other bone screw embodiments presented herein; these parts may not be described again here. All statements made regarding the bone screw **100**, **2100**, **3100** apply to the bone screw **5100** unless they would be contradicted by the differences between the

two.

(272) The bone screw **5100** may be configured to allow the proximal member **5104** to be assembled over the proximal end of the distal member **5106**. Then, proximal nut **5005** may be inserted through an aperture **5113** of proximal member **5104** and through aperture **5176** of distal member **5106**. Distal nut **5004** may be threadedly attached to the distal end of tension member **5108**. Tension member **5108** with distal nut **5004** threadedly attached may be coupled to distal member **5106** by inserting proximal end **5140** of tension member **5108** into the distal end of the distal member **5106**, into the proximal member **5104**, and threadedly attaching proximal nut **5005** to proximal threads **5146**.

(273) In alternative embodiments, distal nut **5004** and tension member **5108** may be made into a unitary member (not shown), which may eliminate an assembly step and reduce cost. The remainder of the assembly steps may be the same as set forth above.

(274) The distal nut **5004** may have interior threads **5156** engaged with distal threads **5148** of tension member **5108**. The distal nut **5004** may have a driver engagement feature (not shown) on its distal end to facilitate engagement of interior threads **5156** with distal threads **5148**. The driver engagement feature may be a polygonal or Hexalobular aperture or projection, or any other known torque receiving feature.

(275) Proximal nut **5005** may have interior threads **5174** engaged with proximal threads **5146** of tension member **5108**. The threaded engagements described above between tension member **5108**. proximal nut **5005** and distal nut **5004** may, alternatively, be substituted with other coupling mechanisms known in the art such as snap fittings, retention with a retaining ring, crimping, swaging, pinning, press fitting, adhesive or chemical bonding, soldering, brazing, welding, or combinations thereof.

(276) The tension member **5108** may be coupled to the proximal member **5104** and the distal member **5106** and may be positioned in a variable-length cavity **5130**, which may be similar in function to variable-length cavity **130** of bone screw **100**. Tube **5145** may have one or more slots (not shown), extending along the longitudinal axis **5102**. Slots (not shown) of tube **5145** may have the same features and operation as previously described for slot **2143** and tube **2145**. As in tube **2145**, the number of slots in tube **5145**, the width and the length of each slot, along with a wall thickness of tube **5145**, may be selected to provide a predetermined cross-sectional area to provide a predetermined stiffness for tension member **5108**. Such slots are optional and may be omitted if the tension member **5108** is to have a greater stiffness.

(277) Distal nut **5004** may be coupled to the distal member **5106** via abutment of the proximal surface **5158** on a corresponding surface **5149** of the distal member **5106**. The corresponding surface **5149** may reside in a distal socket **5138** at the distal end of the distal member **5106**. The distal socket **5138** may be sized to receive and contain part or all of the distal nut **5004**.

(278) FIG. **46**A is a front elevation, section of proximal member **5104**, according to one embodiment. The proximal member **5104** may have a head **5112** at a proximal end of proximal member **5104**, a proximal shank **5110** at a distal end of proximal member **5104**, a proximal engagement surface **5222**. Head **5112** may be wider than proximal shank **5110** such that head **5112** generally resides outside the bone, or in a countersink formed in the bone, such that head **5112** prevents proximal member **5104** from further distal motion into the bone, thereby maintaining compression within the bone. Proximal engagement surface **5222** may be an interior, generally cylindrical surface that defines a proximal portion **5132** of variable-length cavity **5130**. The proximal engagement surface **5222** may interact with a distal engagement surface **5226** of distal member **5106** in a similar fashion as described previously for proximal engagement surface **222** and distal engagement surface **226** of bone screw **100**, defining a bending transmission feature or load sharing feature similar in function to those described in connection with previous embodiments.

(279) Advantageously, proximal engagement surface **5222** may be smooth, and may lack inwardly

protruding elements, along the entire length of the proximal engagement surface **5222** that surrounds distal member **5106**. This may facilitate manufacture of proximal member **5104** and/or assembly of proximal member **5104** with distal member **5106**.

(280) Aperture **5113** may extend transverse to longitudinal axis **5102** and through proximal shank **5110**. In this application, "transverse" refers to a feature that extends nonparallel to another. Aperture **5113** may further be perpendicular to longitudinal axis **5102**, but in alternative embodiments, may be both nonparallel and nonperpendicular to longitudinal axis **5102**. Aperture **5113** may be bounded proximally by proximal shoulder **5178** and bounded distally by distal shoulder **5180**, and aperture **5113** may further include a first proximal aperture on one side of longitudinal axis **5102** and a second proximal aperture on an opposed side of longitudinal axis **5102**. Proximal member **5104** may also have internal groove **5219**. Internal groove **5219** may be a generally cylindrical undercut within head **5112**, defining an interior ledge **5220** that can be used to retain proximal member **5104** on an inserter and/or pre-tensioning device, as will be shown and described subsequently.

(281) FIG. **46**B is a front elevation, section of a proximal member **5105**, according to one alternative embodiment. Proximal member **5105** may share all of the same features as described for proximal member **5104**, except in place of head **5112** and internal groove **5219**, proximal member **5105** may have proximal bone-engaging threads **5414**. Proximal member **5105** may thus be referred to as "headless." In operation, proximal bone-engaging threads **5414** may be rotated into engagement with surrounding bone, such that proximal member **5105** is substantially entirely contained within the bone. Thus positioned, proximal bone-engaging threads **5414** may function in a manner similar to head **5112** by keeping proximal member **5105** from moving further distally into the bone, thereby maintaining the desired level of compression within the bone. In some instances, proximal member **5105** may provide advantages, as it may not protrude from the surface of the bone.

(282) Either proximal member **5104** or proximal member **5105** may be used in combination with distal member **5106**. Distal member **5106** may have a distal shank **5120** located proximal to distal bone-engaging threads **5122**. Distal member **5106** may have a distal interior surface **5124** that defines a distal portion **5136** of variable-length cavity **5130**.

(283) Driver engagement feature **5230** may be advantageously located on a proximal end of distal member **5106** so that bone screw **5100** may be driven by a driver, such as a hex screwdriver (not shown), that engages driver engagement feature **5230** so that torque is transmitted directly to the distal bone-engaging threads **5122** via the distal shank **5120**. "Direct" transmission of torque refers to torque that is received in the same member that bears the threads being driven into the bone via the torque. Advantageously, having a monolithic structure (e.g., distal shank **5120**) between driver engagement feature **5230** and distal bone-engaging threads **5122** may make application of torque more constant and predictable for the surgeon, and help the surgeon more accurately gauge the type and quality of bone being penetrated. Direct torque transmission may also reduce the input torque that must be applied to the driver to drive bone screw **5100** into place. Thus, torque may be transmitted directly through a monolithic structure to provide the most efficient method (i.e., lowest input torque) for inserting distal bone-engaging threads **5122** into bone, which has the advantages previously described.

(284) Driver engagement feature **5230** is shown in FIG. **44** in the form of an aperture with a hex shape, but any other shape or feature for transmitting torque between a driver and a socket may be used as known in the art. For example, a cruciate shape, a slot shape, a square shape, other polygonal shape, a hexalobular shape, and/or the like may be used, and may be embodied in an aperture or a protrusion.

(285) Like the bone screws **100**, **2100**, **3100**, the bone screw **5100** may have a length limiting mechanism **5210** that controls the extent to which the bone screw **5100** can increase or decrease in length, thereby determining a maximum length and a minimum length for the bone screw **5100**.

Proximal nut **5005** may be an interpositional member that is configured to cooperate with proximal member **5104** and distal member **5106** to form a length limiting mechanism, as described below.
(286) Proximal nut **5005**, when secured to proximal end **5140** of tension member **5108**, may interact with proximal member **5104** by the abutment of distal surface **5172** and proximal surface **5170** of proximal nut **5005** with distal shoulder **5180** and proximal shoulder **5178** of proximal member **5104**, respectively. Essentially, proximal nut **5005** may retain proximal end **5140** of tension member **5108** at a fixed location relative to proximal member **5104**, in a manner that accommodates relative motion between distal member **5106** and proximal nut **5005**.
(287) More specifically, with the proximal nut **5005** coupled to the proximal member **5104** as described, distal surface **5172** and proximal surface **5170** of proximal nut **5005** may interact with distal shoulder **5217** and proximal shoulder **5216** of distal member **5106**, respectively, to form a length limiting mechanism **5210** similar in function to the length limiting mechanism **210**, **2210**, **3210** described previously.
(288) Specifically, the length limiting mechanism **5210** may cause the bone screw **5100** to have a minimum length and a maximum length when the distal member **5106** has reached its minimum and maximum displacement along longitudinal axis **5102**, respectively, relative to the proximal member **5104**. The minimum length may be caused by the abutment of distal surface **5172** of proximal nut **5005** against distal shoulder **5217** of distal member **5106**. The maximum length may be caused by the abutment of proximal surface **5170** of proximal nut **5005** against proximal shoulder **5216** of distal member **5106**. A longitudinal space between distal shoulder **5217** and proximal shoulder **5216** of distal member **5106** may provide space for the proximal nut to move from a maximal spacing away from proximal shoulder **5216** when bone screw **5100** is at minimum length to contacting proximal shoulder **5216** when bone screw **3100** is at maximum length.
(289) Furthermore, the longitudinal distance between distal shoulder **5217** and proximal shoulder **5216** of distal member **5106**, a first distance, is greater than a longitudinal distance between proximal surface **5170** and distal surface **5172**, a second distance. The difference between the first and second distances may provide the difference in longitudinal distance between the minimum length and maximum length, advantageously limiting the amount of stretch imparted to tension member **5108**. Limiting the amount of stretch imparted to tension member **5108** may ensure that values are not exceeded for any one of the tension member's ultimate tensile strength, yield strength, a target maximum strain value, low cycle fatigue strength, or high cycle fatigue strength. Stated differently, providing a maximum length for bone screw **5100** may help protect tension member **5108** from failure, or even from deformation outside the elastic zone, as described in connection with previous embodiments.
(290) Although in the embodiment shown, aperture **5176** of distal member **5106** is longer than aperture **5113** of proximal member **5104**, those of skill in the art will recognize that in alternative embodiments (not shown), a proximal member may have the longer aperture, while the distal member may have the shorter aperture. As in the present embodiment, the difference in length between the proximal and distal apertures may determine the displacement between maximum and minimum lengths of the bone screw.
(291) Returning to the discussion of bone screw **5100**, the maximum strain (i.e., strain experienced by tension member **5108** at the maximum length of bone screw **5100**) may be between 2 and 8 percent of the length of tension member **5108**. More precisely, the maximum strain may be between 4 and 6 percent. Still more precisely, the maximum strain may be between 5.5 and 6.0 percent.
(292) To aid in maintaining the proximal nut **5005** in the desired transverse position relative to the longitudinal axis **5102** of assembled bone screw **5100**, shank **5144** of tension member **5108** may be sized to be a close sliding fit with distal interior surface **5124** of distal member **5106**. Furthermore, the longitudinal length of shank **5144** may be advantageously selected to ensure a close sliding fit as described at both the minimum and maximum length of bone screw **5100**.

(293) Proximal member **5105**, shown in FIG. **46**B, may be used in place of proximal member **5104**, and may be coupled to distal member **5106**, tension member **5108**, and proximal nut **5005** in the same manner as proximal member **5104**. Proximal member **5105**, distal member **5106**, tension member **5108**, and proximal nut **5005** may define a bone screw **5101** that is similar in function to bone screw **5100**, with the exception of the operation of proximal bone-engaging threads **5414** on proximal member **5105**, as described above.
(294) Like the bone screws **100**, **1100**, and **2100**, the bone screws **5100** and **5101** may provide a torque transmission feature that transmits torque from the proximal member **5104** or proximal member **5105** to the distal member **5106**. In addition to the length-limiting function set forth above, proximal nut **5005** may be an interpositional member that is configured to cooperate with proximal member **5104** and distal member **5106** to transmit torque between proximal member **5104** and distal member **5106**, as described below.
(295) The transmission of torque may be achieved by side walls of aperture **5113** of proximal member **5104** (or proximal member **5105**) abutting, in a circumferential direction (a circular direction revolving around longitudinal axis **5102**), side walls of proximal nut **5005**, then circumferential abutment of side walls of proximal nut **5005** against side walls of aperture **5176** of distal member **5106**. Thus, torque that is applied to proximal member **5104** (or proximal member **5105**) may be transmitted to proximal nut **5005**, and then the torque may be further transmitted from proximal nut **5005** to distal member **5106**, providing rotational coupling between the proximal member **5104** (or proximal member **5105**) and distal member **5106**.
(296) An advantage of this rotational coupling as described is that it may enable the bone screw **5100** (or bone screw **5101**) to be inserted into or removed from bone in the same manner as a one-piece screw having similar outer geometry. Specifically, a single input torque applied to the driver engagement feature **5230** of distal member **5106** may effectively, simultaneously, drive head **5112** (or proximal bone-engaging threads **5414**) and distal bone-engaging threads **5122**.
(297) As a further advantage, proximal nut **5005** may serve a dual purpose, both as a discrete component of the torque transmission feature, and as a discrete component of the length limiting mechanism **5210**, as previously described. This dual purpose of the proximal nut **5005** may reduce the number of components and/or features required for a variable-length bone screw design with torque transmission and length limiting features, thereby reducing costs and making for a more robust device.
(298) Use of proximal nut **5005** may also simplify manufacturing of proximal member **5104** and/or distal member **5106**. For example, interaction of proximal nut **5005** with distal shoulder **5180** and proximal shoulder **5178** of proximal member **5104** may avoid the need for other interior features within proximal portion **5132** of variable-length cavity **5130**, thereby simplifying manufacture of proximal member **5104**.
(299) As another advantage, the distal shank **5120** of the distal member **5106** may have a constant cross-sectional shape from the distal-most end of the proximal member **5104** to the proximal end of the distal bone-engaging threads **5122** of the distal member **5106** which may have the same advantages as previously described in connection with other embodiments.
(300) Bone screws **5100** and **5101** may be provided in a range of lengths and sizes, where “length” refers to overall length along longitudinal axis **5102** and “size” refers to the outer diameter of distal bone-engaging threads, measured transverse to the longitudinal axis **5102**. Exemplary sizes may be provided in a range from 2.5 mm to 8.0 mm, in 0.5 mm increments, or any size between 2.5 mm and 8.0 mm. Exemplary lengths may be provided from 15 mm to 180 mm in 5 mm increments, or for smaller size screws, 2 mm increments, or any length between 15 mm to 180 mm. For sizes smaller than 3.5 mm, it may be advantageous to configure the tension member **108**, **1108**, **2108**, **3108** and **5108** in the form of a solid rod or wire instead of a tube.
(301) FIG. **47** is an exploded perspective view of bone screw **5100** and a pre-stretch driver **5010** according to one embodiment. FIG. **48** is an exploded perspective view of the bone screw **5101** and

the pre-stretch driver **5011** according to one alternative embodiment. FIG. **49** is a side elevation, section view of the bone screw **5100** and the pre-stretch driver **5010** shown in FIG. **48**. FIG. **50** is a side elevation, section view of the bone screw **5101** and the pre-stretch driver **5011** shown in FIG. **48**. Pre-stretch driver **5010** and pre-stretch driver **5011** may be similar in configuration and operation, except that pre-stretch driver **5010** may be configured to engage and retain proximal member **5104**, while pre-stretch driver **5011** may be configured to engage and retain proximal member **5105**.

(302) Pre-stretch driver **5010** may have a first drive shaft **5020** and a headed sleeve **5080**. Pre-stretch driver **5011** may include the same first drive shaft **5020** as pre-stretch driver **5010**, and may also have a headless sleeve **5081**. Headed sleeve **5080** may be configured to mate with bone screw **5100**, and headless sleeve **5081** may be configured to mate with bone screw **5101**.

(303) First drive shaft **5020** may have a torque input feature **5022** near its proximal end configured to be connected to a handle or a power driver and a knob **5302** configured to receive torque input from a hand or a tool. Torque input feature may be a polygonal (for example, hexagonal) boss, or in alternative embodiments, may be a negative and/or differently-shaped feature. Knob **5302** may be sized to be easily rotated by hand, and may be sized to provide optimal mechanical advantage for pre-stretching bone screw **5100** and/or bone screw **5101**. Knob **5302** may be rotatably coupled to shaft **5026**.

(304) First drive shaft **5020** may also have external threads **5304** configured to engage internal threads **5322** on headed sleeve **5080** or to engage internal threads **5323** on headless sleeve **5081**. External threads **5304** may be formed as a single piece with knob **5302**, and may thus be rotatable relative to shaft **5026**. First drive shaft **5020** may have a thrust bearing **5306** located distal to and proximate external threads **5304**, and a male torque feature **5308**. Male torque feature **5308** may be received within a cylindrical bore **5324** within headed sleeve **5080** (such that torque is not transmitted between male torque feature **5308** and bore **5324**) or a complimentarily shaped female torque feature **5325** within headless sleeve **5081**. Thrust bearing **5306** may be received within a corresponding cylindrical bore portion within the headed sleeve **5080** and/or the headless sleeve **5081**, and may help maintain coaxiality between first drive shaft **5020** and headed sleeve **5080** and/or headless sleeve **5081**.

(305) First drive shaft **5020** may further have a shaft **5026** extending from male torque feature **5308** to a torque output feature **5028** that is located near its distal end. First drive shaft **5020** may have an external groove **5024** and a distal shoulder **5030** located on its distal end. External groove **5024** may be configured to appear in a window **5312** of headed sleeve **5080** and in a window **5313** of headless sleeve **5081** when pre-stretch driver **5010** and pre-stretch driver **5011**, respectively, are fully assembled.

(306) A second drive shaft **5300** may have a torque input feature **5023** near its proximal end, configured to connect to a handle or a power driver, and a proximal shaft **5033** configured to provide a sliding fit within internal threads **5323** of headless sleeve **5081**. Second drive shaft **5300** may a shaft **5027** extending from proximal shaft **5033** to a torque output feature **5029** that is located near its distal end. Second drive shaft **5300** may have a proximal groove **5035**, a distal groove **5037**, and a distal shoulder **5031** located on its distal end. Proximal groove **5035** and distal groove **5037** are configured to appear in window **5313** of headless sleeve **5081** when components (i.e., second drive shaft **5300** and headless sleeve **5081**) are assembled into pre-stretch driver **5011**.

(307) External groove **5024**, proximal groove **5035**, and distal groove **5037** may each serve as reference markers to indicate, to a user, the relative axial positions of first drive shaft **5020**, second drive shaft **5300**, headed sleeve **5080**, and/or headless sleeve **5081**, as applicable. Alternate embodiments of external groove **5024**, proximal groove **5035**, and distal groove **5037** include, but are not limited to, a laser mark line, an electro-etched line, or any other demarcation that indicates a longitudinal position.

(308) As shown in FIG. **46**A, internal groove **5219** and head **5112** of proximal member **5104** may,

combined, constitute a driver engagement feature. The driver engagement feature may be configured to mate with the pre-stretch driver **5010** such that the pre-stretch driver **5010** is actuatable to urge the proximal member **5104** to move proximally relative to the distal member **5106** to cause elongation of the tension member **5108** independently of engagement of the bone screw **5100** with the bone.

(309) Similarly, as shown in FIG. **46**B, proximal bone-engaging threads **5414** of proximal member **5105** may constitute a driver engagement feature. The driver engagement feature may be configured to mate with the pre-stretch driver **5011** such that the pre-stretch driver **5011** is actuatable to urge the proximal member **5105** to move proximally relative to the distal member **5106** to cause elongation of the tension member **5108** independently of engagement of the bone screw **5101** with the bone.

(310) As shown in FIG. **49**, headed sleeve **5080** may be attached to bone screw **5100** by first engaging clips **5092** into internal groove **5219** by causing cantilever arms **5314** to resiliently spring inward as the distal end of headed sleeve **5080** is pushed into the proximal end of bone screw **5100**. Thus, clips **5092** and internal groove **5219** may each act as a coupling interface that facilitates coupling of headed sleeve **5080** to bone screw **5100**. First drive shaft **5020** may be passed into the proximal end of headed sleeve **5080** and advanced distally until torque output feature **5028** engages driver engagement feature **5230** and distal shoulder **5030** contacts interior shoulder **5186** of distal member **5106**, thus completing the assembly of pre-stretch driver **5010** to bone screw **5100** in a first state, in which the variable-length bone screw is at its minimum length. In this assembled stated, shaft **5026** blocks clips **5092** from springing inward, thus providing a secure axial connection between the pre-stretch driver **5010** and bone screw **5100**.

(311) In its first state, external groove **5024** may appear in window **5312**, located within the longitudinal bounds of engaged groove **5318**, indicating that torque output feature **5028** is within driver engagement feature **5230**. If, during assembly of first drive shaft **5020** to headed sleeve **5080**, torque output feature **5028** is just short of engaging driver engagement feature **5230**, then external groove **5024** may appear in window **5312**, within the longitudinal bounds of disengaged groove **5316**, thereby indicating that additional rotation and distal advancement of the first drive shaft **5020** relative to headed sleeve **5080** may be required in order to fully engage torque output feature **5028** of first drive shaft **5020** with driver engagement feature **5230**. Engaged groove **5318** and disengaged groove **5316** may be separated from each other by a ridge, etched with text, colored differently, and/or otherwise demarcated to indicate their significance to a user.

(312) Once in the first state, knob **5302** may be rotated clockwise relative to headed sleeve **5080** to cause the distal shoulder **5030** to push distally against interior shoulder **5186** to cause proximal member **5104** to move proximally relative to distal member **5106** to cause elongation of tension member **5108**. Alternatively, a distal portion of first drive shaft **5020** may be configured (for example, with a flange or other radially-extending feature—not shown) to push distally against proximal surface **5184** to cause proximal member **5104** to move proximally relative to the distal member **5106** to cause elongation of the tension member **5108**. Continued rotation of knob **5302** may continue to advance first drive shaft **5020** distally relative to headed sleeve **5080** until length limiting mechanism **5210** is engaged so that maximum length is achieved, resulting in a maximum length of bone screw **5100**. Alternatively, knob **5302** may be rotated to cause the variable-length bone screw **5100** to be at a length that is intermediate to the minimum length and the maximum length. In this manner, the surgeon can tune the displacement of pre-stretch applied across the fracture, and thus the amount of shortening that can occur in bone screw **5100** before the bone screw **5100** ceases applying compression across the fracture.

(313) Once the bone screw **5100** is stretched to an intermediate length or maximum length, bone screw **5100** may be inserted into a pilot hole created in bone by applying torque to torque input feature **5022** via a handle or a power tool. Once bone screw **5100** is fully seated in the bone, first drive shaft **5020** may be removed from headed sleeve **5080** by turning knob **5302** counterclockwise

and then sliding first drive shaft **5020** axially out of headed sleeve **5080**. Then, headed sleeve **5080** may be disconnected by pulling headed sleeve **5080** away from bone screw **5100** along longitudinal axis **5102**, causing cantilever arms **5134** to flex resiliently inward and thereby disengaging clips **5092** from internal groove **5219**.
(314) Similarly, as shown in FIG. **50**, headless sleeve **5081** may be attached to bone screw **5101** by threading internal threads **5320** onto proximal bone-engaging threads **5414** of proximal member **5105**, thus axially securing headless sleeve **5081** to bone screw **5101**. Then, first drive shaft **5020** may be passed into the proximal end of headless sleeve **5081** and engaging male torque feature **5308** with female torque feature **5325** to rotationally lock headless sleeve **5081** to first drive shaft **5020**. Then, first drive shaft **5020** may be further advanced distally until torque output feature **5028** engages driver engagement feature **5230** and distal shoulder **5030** contacts interior shoulder **5186** of distal member **5106**, thus completing the assembly of pre-stretch driver **5011** with bone screw **5101** in a first state, in which the bone screw **5101** is at its minimum length.
(315) In this first state, external groove **5024** may appear in window **5313**, located within the longitudinal bounds of engaged groove **5319**. If, during assembly of first drive shaft **5020** to headless sleeve **5081**, torque output feature **5028** is just short of engaging driver engagement feature **5230**, then external groove **5024** may appear in window **5313**, located within the longitudinal bounds of disengaged groove **5317**, thereby indicating that additional rotation and distal advancement of the first drive shaft **5020** relative to headless sleeve **5081** is required.
(316) Once in the first state, knob **5302** may be rotated clockwise relative to headless sleeve **5081** to cause the distal shoulder **5030** to push distally against interior shoulder **5186** to cause proximal member **5105** to move proximally relative to distal member **5106** to cause elongation of tension member **5108**. Alternatively, a distal portion of first drive shaft **5020** may be configured to push distally against proximal surface **5184** to cause proximal member **5104** to move proximally relative to distal member **5106** to cause elongation of tension member **5108**. Continued rotation of knob **5302** may continue to advance first drive shaft **5020** distally relative to headless sleeve **5081** until length limiting mechanism **5210** is engaged so that maximum length of bone screw **5101** is achieved. Alternatively, knob **5302** may be rotated to cause bone screw **5101** to be at a length that is intermediate to the minimum length and the maximum length.
(317) Once the bone screw **5101** is stretched to an intermediate length or a maximum length, bone screw **5101** may be inserted into a pilot hole created in bone by applying torque to torque input feature **5022** via a handle or a power tool. Once a distal end of headless sleeve **5081** is fully seated against the bone, first drive shaft **5020** may be removed from headless sleeve **5081** by turning knob **5302** counterclockwise and then sliding first drive shaft **5020** along longitudinal axis **5102** out of headless sleeve **5081**.
(318) Then, second drive shaft **5300** may be inserted into headless sleeve **5081** until torque output feature **5029** engages driver engagement feature **5230**. Then, second drive shaft **5300** may be rotated clockwise relative to headless sleeve **5081** to cause bone screw **5100** to further advance into the bone and to cause proximal bone-engaging threads **5414** to advance into the bone. Upon the proximal bone-engaging threads **5414** fully disengaging with internal threads **5320**, bone screw **5101** may be fully seated in the bone, and the second drive shaft **5300** and headless sleeve **5081** may be withdrawn from bone screw **5101**.
(319) Advantageously, first drive shaft **5020** may be rotationally locked to the headless sleeve **5081** as described above during insertion of bone screw **5101** into bone, as this may ensure that proximal bone-engaging threads **5414** do not inadvertently unthread from internal threads **5320** during insertion of bone screw **5101** into bone. Conversely, it may be advantageous for second drive shaft **5300** to be freely rotatable within headless sleeve **5081** so that, when proximal bone-engaging threads **5414** are positioned to penetrate the bone, proximal member **5105** may rotate while headless sleeve **5081** remains stationary, so that proximal bone-engaging threads **5414** rotate out of engagement with internal threads **5320** of headless sleeve **5081** as they rotate into engagement with

the bone. Thus, male torque feature **5308** may not be present on second drive shaft **5300**.
(320) Furthermore, it may be advantageous for the lead of proximal bone-engaging threads **5414** to match the lead of the distal bone-engaging threads **5122**, so that the compression imparted on the bone, by bone screw **5101**, after first drive shaft **5020** is withdrawn from headless sleeve **5081** is the same as the compression imparted on the bone, by bone screw **5101**, after final insertion using second drive shaft **5300**. Since lead is equal to pitch multiplied by the number of thread starts, it may be advantageous to use a first pitch for distal bone-engaging threads **5122** that is more suited for cancellous bone, and then use a second smaller pitch for proximal bone-engaging threads **5414** more suited for cortical bone. By using a ratio of second pitch to first pitch that is equal to the ratio of number of thread starts for the proximal bone-engaging threads **5414** to the ratio of number of thread starts for distal bone-engaging threads **5122**, the lead will be the same for both threads, thus maintaining constant compression of bone as the proximal bone-engaging threads **5414** are driven into the bone. Alternatively, additional compression may be created as the proximal bone-engaging threads **5414** are driven into the bone by using a lead on the proximal bone-engaging threads **5414** that is smaller than the lead of the distal bone-engaging threads **5122**.
(321) Together, first drive shaft **5020**, second drive shaft **5300**, headed sleeve **5080**, and headless sleeve **5081** may constitute a pre-stretch driver system for inserting into bone a headed screw, such as bone screw **5100** and a headless screw, such as bone screw **5101**. As described previously, the pre-stretch driver system may provide consistent features for indicating improper attachment of a pre-stretch driver to a bone screw, proper attachment of a pre-stretch driver to a bone screw, when the variable-length bone screw is at a minimum length, and/or when a variable-length bone screw is at a maximum length. Additionally, for headless screws such as bone screw **5101**, the pre-stretch driver system may provide features for indicating: the beginning of insertion of proximal bone-engaging threads into bone, and/or the end of insertion of proximal bone-engaging threads into bone.
(322) As in previous embodiments, the proximal end (e.g., the “head”) of proximal member **5104** may take any of the forms shown in FIGS. **24**A, **24**B, and **24**C. Thus, in some embodiments, proximal member **5104** may be modified to have threading and/or a proximal-facing surface that is non-perpendicular to the longitudinal axis of the bone screw **5100**. If needed, the interfacing features of the pre-stretch driver **5010** and/or the pre-stretch driver **5011** may be modified to accommodate such a design change, allowing pre-stretch of such bone screw embodiments.
(323) Of course, pre-stretching is optional. In some embodiments (for example, bone screw **5100**), a more conventional driver without pre-stretch capability may be used. For example, a driver (not shown) may have a shaft terminating at a hex head (for example, resembling torque output feature **5028** of first drive shaft **5020**) that directly engages and rotates driver engagement feature **5230** of distal member **5106**. Such a driver may also provide direct transmission of compressive loads from the driver to the distal member **5106**, and thence to the distal bone-engaging threads **5122**, providing the benefits cited above for direct load transmission.
(324) The embodiments of bone screws described previously, and the embodiments of intramedullary implants described subsequently are generally referred to as dynamic compression implants. Dynamic compression implants may be placed into one or more bones (e.g., two bones on either side of a bone joint, a bone fracture, or a bone cut). Dynamic compression implants may be placed into an existing bone cavity, such as an intramedullary canal, or into a cavity formed in the bone prior to implant insertion, such as a cavity formed by a drill, reamer, punch, broach or other cutting tool, or into a cavity formed by the implant during implant insertion, or any combination of these bone cavity forming methods.
(325) FIG. **51** is an exploded, perspective view of an embodiment of an intramedullary implant. FIG. **52** is a perspective view of the intramedullary implant shown in FIG. **51** in a fully assembled state. An intramedullary implant **6100** may include a proximal member **6104**, a distal member **6106**, and a tension member **6108**, all sharing a common a longitudinal axis **6102**. Intramedullary

implant **6100** may further include an end cap **6114**, a proximal nut **6110**, and a distal nut **6112**. Proximal member **6104** may have a proximal shank **6130**, a first aperture **6140**, and a second aperture **6142**. Distal member **6106** may have a distal shank **6150**, a first aperture **6164**, and a second aperture **6166**. The apertures of proximal member **6104** and distal member **6106** may be configured to receive proximal cross screws **6350** and distal cross screws **6360**, respectively, as shown in FIG. **58**. Alternatively, pins, rods or other cross-fixation members may be used in place of proximal cross screws **6350** and distal cross screws **6360**.

(326) The first aperture **6140**, and a second aperture **6142** of proximal member **6104** and the first aperture **6164**, and a second aperture **6166** of distal member **6106** may be positioned at different longitudinal and/or circumferential positions along proximal shank **6130** and distal shank **6150** to allow the proximal cross screws **6350** and distal cross screws **6360** to be positioned in locations that best accommodate a bony anatomy associated with particular surgical indication. Furthermore, more or fewer apertures may be provided on the proximal member **6104** and the distal member **6106** to best accommodate a particular surgical indication. Exemplary surgical uses of intramedullary implant **6100** may include tibiotalocalcaneal fusions and medial column fusions of the foot.

(327) FIG. **53** is a front elevation, section view of proximal nut **6110**, tension member **6108**, and distal nut **6112**. Proximal nut **6110** may have a proximal surface **6190**, a distal surface **6192**, and internal threads **6194** extending from proximal surface **6190** to distal surface **6192**. Distal nut **6112** may have a proximal surface **6200**, a distal surface **6202**, and internal threads **6204** extending from proximal surface **6200** to distal surface **6202**. Tension member **6108** may have proximal threads **6182**, distal threads **6184**, shank **6186** adjacent and distal to proximal threads **6182**, and a shaft **6180** extending from shank **6186** to distal threads **6184**. Tension member **6108** may be solid or may be cannulated along its entire length if it is desired to place intramedullary implant into bone over a guidewire (not shown).

(328) Advantageously, tension member **6108** may lack any apertures for cross-fixation. Rather, proximal cross screws **6350** and distal cross screws **6360** may pass through first aperture **6140** and second aperture of proximal member **6104** and first aperture **6164** and second aperture **6166** of distal member **6106**, respectively, as shown in FIG. **58**. Proximal cross screws **6350** may be positioned proximally of proximal end of tension member **6108**, and distal cross screws **6360** may be positioned distally of distal end of tension member **6108**. This may simplify assembly of intramedullary implant **6100** and/or help avoid stress concentrations in tension member **6108** that could otherwise be caused by the presence of holes through tension member **6108** for cross fixation.

(329) Various parts of the intramedullary implant **6100** may be identical or similar to their counterparts on the bone screw **5100** and/or other bone screw embodiments presented herein; thus, the disclosures set forth above for bone screw **5100** and/or other bone screws may also be applicable to intramedullary implant **6100**. All statements made regarding the bone screw **5100** and/or other bone screw embodiments presented herein apply to the bone screw **5100** unless they would be contradicted by the differences between the two.

(330) FIG. **54** is a front elevation, section view of proximal member **6104**. FIG. **55** is a front elevation, section view of distal member **6106**. Proximal member **6104** may have a proximal interior surface **6132**, an aperture **6138** adapted to receive proximal nut **6110**, a proximal engagement surface **6136**, and internal thread **6144**. Distal member **6106** may have a distal interior surface **6152**, a distal engagement surface **6156**, a driver engagement feature **6158**, an interior shoulder **6178**, a proximal slot **6168**, a proximal shoulder **6170**, a distal shoulder **6172**, a distal socket **6176**, a corresponding surface **6174**, and internal threads **6179**. Internal threads **6179** may be attachable to external threads on a removal instrument (not shown) adapted for extraction of the assembled intramedullary implant **6100** from bone.

(331) Proximal interior surface **6132** of proximal member **6104** may define a proximal portion

6134 of a variable-length cavity **6120**. Distal interior surface **6152** of distal member **6106** may define a distal portion **6154** of variable-length cavity **6120**.

(332) Proximal member **6104**, distal member **6106**, proximal nut **6110**, tension member **6108**, and distal nut **6112** may be configured to be assembled and to operate in the same manner as proximal member **5104**, distal member **5106**, proximal nut **5005**, tension member **5108**, and distal nut **5004**, such that a proximal end of tension member **6108** is coupled to the proximal member **6104**, and a distal end of tension member **6108** is coupled to the distal member **6106**. Then, in response to motion of the distal member **6106** away from the proximal member **6104**, the tension member **6108** may elongate and urge the distal member **6106** to move toward the proximal member **6104**.

(333) Proximal member **6104**, distal member **6106**, and proximal nut **6110** may be configured to be assembled and to operate in the same manner as proximal member **5104**, distal member **5106** and proximal nut **5005** to define a length-limiting mechanism **6122**. Length-limiting mechanism **6122** may establish a minimum length **6116** of Intramedullary implant **6100** when distal surface **6192** of proximal nut **6110** abuts distal shoulder **6172** of distal member **6106**. Length-limiting mechanism **6122** may further establish a maximum length **6118** of Intramedullary implant **6100** when proximal surface **6190** of proximal nut **6110** abuts proximal shoulder **6170** of distal member **6106**.

(334) The proximal engagement surface **6136** of proximal member **6104** may interact with distal engagement surface **6156** of distal member **6106** in a similar fashion as described previously for proximal engagement surface **5222** and distal engagement surface **5226** of bone screw **5100**, defining a bending transmission feature or load sharing feature similar in function to those described in connection with previous embodiments.

(335) Proximal member **6104**, distal member **6106**, and proximal nut **6110** may be configured to define a torque transmission feature like the torque transmission feature described for bone screw **5100**. Similarly, proximal member **6104**, distal member **6406**, and proximal nut **6110** may be configured to define a torque transmission feature like the torque transmission feature described for bone screw **5100**. Similarly. proximal member **6504**, distal member **6506**, and proximal nut **6110** may be configured to define a torque transmission feature like the torque transmission feature described for bone screw **5100**. The configuration and operation of distal member **6406**, proximal member **6504**, and distal member **6506** will be shown and described subsequently.

(336) End cap **6114** may have external threads **6210**, driver engagement feature **6212**, and flange **6214**. After implantation of intramedullary implant **6100** into bone, end cap **6114** may be assembled to proximal member **6104** by engaging a driver (not shown) with driver engagement feature **6212** to assemble external threads **6210** to internal threads **6144** and to abut flange **6214** against a proximal surface of proximal member **6104**. Thus assembled, end cap **6114** may prevent biological tissue from migrating into the proximal end of proximal member **6104** and occluding driver engagement feature **6158** and/or internal threads **6179** when intramedullary implant **6100** is implanted in bone.

(337) FIG. **60** is an exploded, perspective view of another embodiment of an intramedullary implant. FIG. **61** is a perspective view of the intramedullary implant shown in FIG. **60** in a fully assembled state. FIG. **62** is a front elevation, section view of the intramedullary implant shown in FIG. **60**. An intramedullary implant **6400** may include the same components as intramedullary implant **6100**. with the exception of a distal member **6406** in place of distal member **6106** of intramedullary implant **6100**. Distal member **6406** may be configured similarly to distal member **6106**, except that distal member **6406** may have distal bone-engaging threads **6460**. Exemplary surgical uses of intramedullary implant **6400** may include fixation of Jone's fractures (fractures of the fifth metatarsal bone), subtalar fusions (fusion of the talocalcaneal joint), olecranon fractures, and distal humerus fractures.

(338) FIG. **63** is an exploded, perspective view of another embodiment of an intramedullary implant. FIG. **64** is a perspective view of the intramedullary implant shown in FIG. **63** in a fully assembled state. FIG. **65** is a front elevation, section view of the intramedullary implant shown in

FIG. **63**. An intramedullary implant **6500** may include the same components as intramedullary implant **6100**. with the exception of a proximal member **6504** and distal member **6506** in place of proximal member **6104** and distal member **6106**, respectively, of intramedullary implant **6100**. Proximal member **6504** may be configured similarly to proximal member **6104**, except that proximal member **6504** may have proximal bone-engaging threads **6540**. Distal member **6506** may be configured similarly to distal member **6106** except that distal member **6506** may have a distal shank **6550** that may be a different size than distal shank **6150** of intramedullary implant **6100**. More precisely, distal shank **6550** may be sized to correspond to a minor diameter of proximal bone-engaging threads **6540** so that a single size bore may be created within an intramedullary canal using a single cutting instrument, such that the bore is sized to closely fit distal shank **6550** and to provide secure engagement of proximal bone-engaging threads **6540** into bone surrounding the bore.

(339) FIG. **56** is a front elevation, section view of the intramedullary implant **6100** shown in FIG. **51**, at the minimum length **6116**. FIG. **57** is a front elevation, section view of the intramedullary implant **6100** shown in FIG. **51**, at the maximum length **6118**. FIG. **58** is an exploded, perspective view of the intramedullary implant **6100** shown in FIG. **51**, proximal cross screws **6350**, distal cross screws **6360**, and a pre-stretch driver **6300**. FIG. **59** an exploded, perspective view of the pre-stretch driver **6300** shown in FIG. **58**.

(340) Similar to pre-stretch driver **5010**, pre-stretch driver **6300** may have a drive shaft **6302** and a sleeve **6304**. Similar to first drive shaft **5020**, drive shaft **6302** may have a torque input feature **6310**, a knob **6312**, external threads **6314**, a thrust bearing **6316**, a shaft **6318**, an external groove **6322**, a distal shoulder **6324**, and a torque output feature **6326**. Further, drive shaft **6302** may have drill guide registration features **6328**, which may be used to attach to engagement features on a drill guide, which may be configured to guide the drilling of pilot holes. Such a drill guide may also guide placement of cross-fixation members, such as proximal cross screws **6350** and distal cross screws **6360**. Further, such a drill guide may also act as a compression instrument by applying compression across two or more bone portions, for example, to help reduce a fracture or apply compression across two bones to be joined.

(341) A method for creating compression across two bones to be joined may include pre-stretching intramedullary implant **6100** using pre-stretch driver **5010**, placing the intramedullary implant into an intramedullary cavity of a bone with the drill guide attached to the drill guide registration features **6328**, using the drill guide to place distal cross-fixation such as a distal cross screw **6360** into bone surrounding the intramedullary cavity and into a distal aperture on the intramedullary implant **6100**, applying compression between two bones to be joined using the drill guide, and placing proximal cross-fixation such as a proximal cross screw **6350** into the bone surrounding the intramedullary cavity and into a proximal aperture on the intramedullary implant **6100**.

(342) Similar to headed sleeve **5080**, sleeve **6304** may have a handle **6330**, a shaft **6332**, a window **6334**, an engaged mark **6336**, and a stop mark **6338**. Sleeve **6304** may be further have external threads **6342** for connecting to internal threads **6144** of proximal member **6104**. Further, sleeve **6304** may have insertion depth grooves **6340**, which may serve as a radiographic indicator of a depth measured from a bone surface to a proximal end of intramedullary implant **6100** when pre-stretch driver **6300** is attached thereto. For example, with pre-stretch driver **6300** attached to intramedullary implant **6100**, insertion depth grooves **6340** may be spaced proximal to a proximal end of intramedullary implant **6100** in increments of 5 mmm or some other desired spacing.

(343) Similar to how pre-stretch driver **5010** connects to bone screw **5100** to cause tension member **5108** to stretch and change an overall length of bone screw **5100** from a minimum length to a maximum length, pre-stretch driver **6300** may be connected to intramedullary implant **6100** to cause tension member **6108** to stretch and change an overall length of intramedullary implant **6100** from minimum length **6116** to maximum length **6118**. External groove **6322** may align with engaged mark **6336** when distal shoulder **6324** is in contact with interior shoulder **6178** and

intramedullary implant **6100** is at minimum length **6116**. External groove **6322** may align with stop mark **6338** when distal shoulder **6324** is in contact with interior shoulder **6178** and intramedullary implant **6100** is at maximum length **6118**.

(344) Reference throughout this specification to “an embodiment” or “the embodiment” means that a particular feature, structure, or characteristic described in connection with that embodiment is included in at least one embodiment. Thus, the quoted phrases, or variations thereof, as recited throughout this specification are not necessarily all referring to the same embodiment.

(345) Similarly, it should be appreciated that in the above description of embodiments, various features are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the present disclosure. This method of disclosure, however, is not to be interpreted as reflecting an intention that any embodiment requires more features than those expressly recited in that embodiment. Rather, inventive aspects lie in a combination of fewer than all features of any single foregoing disclosed embodiment.

(346) As used herein, the term “proximal” means a location relatively closer to a user (i.e., a surgeon) when the user is installing the implant. The term “distal” means a location relatively further from the user. For example, when a user installs a bone screw into a material with a driver, the end of the bone screw engaged with the driver is the proximal end, and the tip of the bone screw that first engages the material is the distal end. The term “cannulated” means having a central bore extending along a longitudinal axis of a part between a proximal end and a distal end of the part.

(347) Recitation of the term “first” with respect to a feature or element does not necessarily imply the existence of a second or additional such feature or element. Elements recited in means-plus-function format are intended to be construed in accordance with 35 U.S.C. § 112(f). It will be apparent to those having skill in the art that changes may be made to the details of the above-described embodiments without departing from the underlying principles set forth herein.

(348) The phrases “connected to,” “coupled to” and “in communication with” refer to any form of interaction between two or more entities, including mechanical, electrical, magnetic, electromagnetic, fluid, and thermal interaction. Two components may be functionally coupled to each other even though they are not in direct contact with each other. The term “coupled” can include components that are coupled to each other via integral formation, as well as components that are removably and/or non-removably coupled with each other. The term “abutting” refers to items that may be in direct physical contact with each other, although the items may not necessarily be attached together. The phrase “fluid communication” refers to two or more features that are connected such that a fluid within one feature is able to pass into another feature. As defined herein the term “substantially” means within +/−20% of a target value, measurement, or desired characteristic.

(349) While specific embodiments and applications of the present disclosure have been illustrated and described, it is to be understood that the scope of this disclosure is not limited to the precise configuration and components disclosed herein. Various modifications, changes, and variations which will be apparent to those skilled in the art may be made in the arrangement, operation, and details of the devices, systems, and methods disclosed herein.

Claims

1. A dynamic compression implant insertable into a bone, the dynamic compression implant comprising: a distal member comprising distal bone-engaging threads; a proximal member configured to slidably engage the distal member; a tension member comprising: a proximal end coupled to the proximal member; and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member;

and an interpositional member, formed separately from the proximal member and the distal member, configured to cooperate with the proximal member and the distal member to form a torque transmission feature that transmits torque between the proximal member and the distal member.

2. The dynamic compression implant of claim 1, wherein a first longitudinal axis of the interpositional member is oriented transverse to a second longitudinal axis of the dynamic compression implant.

3. The dynamic compression implant of claim 2, wherein: the proximal member comprises a first proximal aperture; the distal member comprises a first distal aperture; and the interpositional member extends through the first proximal aperture and the first distal aperture to keep the first proximal aperture and the first distal aperture at the same rotational position about the second longitudinal axis.

4. The dynamic compression implant of claim 3, wherein: the proximal member further comprises a second proximal aperture; the distal member further comprises a second distal aperture; and the interpositional member further extends through the second proximal aperture and the second distal aperture to keep the second proximal aperture and the second distal aperture at the same rotational position about the second longitudinal axis.

5. The dynamic compression implant of claim 1, wherein the interpositional member further cooperates with the proximal member and the distal member to form a length limiting mechanism that prevents motion of the distal member away from the proximal member beyond a maximum length of the dynamic compression implant.

6. The dynamic compression implant of claim 1, wherein the proximal member comprises: a proximal shank; and a head that is wider than the proximal shank.

7. The dynamic compression implant of claim 1, wherein the proximal member comprises proximal bone-engaging threads.

8. The dynamic compression implant of claim 1, wherein the proximal member comprises an aperture configured to receive a cross-fixation fastener.

9. The dynamic compression implant of claim 1, wherein the proximal member comprises a coupling interface configured to mate with a pre-stretch driver to enable the pre-stretch driver to urge the distal member to move distally relative to the proximal member.

10. A dynamic compression implant insertable into a bone in an implanted configuration, the dynamic compression implant comprising: a distal member comprising distal bone-engaging threads; a proximal member configured to slidably engage the distal member in the implanted configuration; a tension member comprising: a proximal end coupled to the proximal member; and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member; and an interpositional member, formed separately from the proximal member and the distal member, configured to cooperate with the proximal member and the distal member to form a length limiting mechanism that prevents motion of the distal member distally away from the proximal member beyond a maximum length of the dynamic compression implant.

11. The dynamic compression implant of claim 10, wherein the length limiting mechanism further prevents motion of the distal member proximally toward the proximal member below a minimum length of the dynamic compression implant.

12. The dynamic compression implant of claim 11, wherein: the proximal member comprises a first proximal aperture; the distal member comprises a first distal aperture; and the interpositional member extends through the first proximal aperture and the first distal aperture.

13. The dynamic compression implant of claim 12, wherein: the first proximal aperture has a first length along a longitudinal axis of the dynamic compression implant; the first distal aperture has a second length along the longitudinal axis; the interpositional member has a width along the

longitudinal axis; the width is close to the first length such that the interpositional member has a close sliding fit within the first proximal aperture; the width is less than the second length; and a difference between the width and the second length is equivalent to a difference between the maximum length and the minimum length.
14. The dynamic compression implant of claim 10, wherein a first longitudinal axis of the interpositional member is oriented transverse to a second longitudinal axis of the dynamic compression implant.
15. The dynamic compression implant of claim 10, wherein the proximal member comprises: a proximal shank; and a head that is wider than the proximal shank.
16. The dynamic compression implant of claim 10, wherein the proximal member comprises proximal bone-engaging threads.
17. The dynamic compression implant of claim 10, wherein the proximal member comprises an aperture configured to receive a cross-fixation fastener.
18. The dynamic compression implant of claim 10, wherein the proximal member comprises a coupling interface configured to mate with a pre-stretch driver to enable the pre-stretch driver to urge the distal member to move distally relative to the proximal member.
19. The dynamic compression implant of claim 10, wherein: the proximal member comprises a proximal engagement surface defining a smooth interior bore; the distal member comprises a distal engagement surface that faces outward; and the proximal engagement surface and the distal engagement surface are sized to form a close sliding fit with each other to define a bending transmission feature.
20. A dynamic fixation system comprising: a dynamic compression implant insertable into a cavity of a bone, the dynamic compression implant defining a second longitudinal axis and comprising: a distal member comprising a distal exterior surface configured to directly engage the bone surrounding the cavity; a proximal member configured to slidably engage the distal member, the proximal member comprising a proximal exterior surface configured to directly engage the bone surrounding the cavity; an interpositional member, formed separately from the proximal member and the distal member and defining a first longitudinal axis, wherein the interpositional member is fixed with respect to the second longitudinal axis; and a tension member comprising: a proximal end coupled to the interpositional member; and a distal end coupled to the distal member such that, in response to motion of the distal member distally away from the proximal member, the tension member elongates and urges the distal member to move proximally toward the proximal member.
21. The dynamic fixation system of claim 20, wherein: the proximal member comprises a bore configured to receive the distal member; and the dynamic fixation system further comprises a pre-stretch driver configured to: retain the proximal member; and engage the distal member from within the bore to urge the distal member to move distally.
22. The dynamic fixation system of claim 20, wherein: one of the proximal member and the distal member comprises bone-engaging threads; and the distal member and the proximal member are both shaped to engage bone surrounding an intramedullary canal.
23. The dynamic fixation system of claim 20, wherein: the dynamic fixation system further comprises a cross-fixation fastener; one of the proximal member and the distal member comprises an aperture extending transversely to a longitudinal axis of the dynamic compression implant; and the aperture is configured to receive the cross-fixation fastener.
24. The dynamic fixation system of claim 23, wherein: the aperture comprises a proximal aperture on the proximal member, proximal to the proximal end of the tension member; the cross-fixation fastener comprises a proximal cross-fixation fastener; the dynamic fixation system further comprises a distal cross-fixation fastener; the distal member comprises a distal aperture extending transversely to the longitudinal axis, distal to the distal end of the tension member; and the distal aperture is configured to receive the distal cross-fixation fastener.

25. The dynamic fixation system of claim 24, wherein the distal aperture is nonparallel to the proximal aperture.