# ANTIBODIES SPECIFIC FOR SCLEROSTIN AND METHODS FOR INCREASING BONE MINERALIZATION

## TECHNICAL FIELD

The present invention relates generally to pharmaceutical products and methods and, more specifically, to methods and sclerostin-specific antibodies suitable for increasing the mineral content of bone. Such compositions and methods may be used to treat a wide variety of conditions including, for example, osteopenia, osteoporosis, fractures, and other disorders in which low bone mineral density is a hallmark of the disease.

## BACKGROUND OF THE INVENTION

Two or three distinct phases of changes to bone mass occur over the life of an individual (*see* Riggs, *West J. Med.* 154:63-77 (1991)). The first phase occurs in both men and women and proceeds to attainment of a peak bone mass. This first phase is achieved through linear growth of the endochondral growth plates and radial growth due to a rate of periosteal apposition. The second phase begins around age 30 for trabecular bone (flat bones such as the vertebrae and pelvis) and about age 40 for cortical bone (*e.g.*, long bones found in the limbs) and continues to old age. This phase is characterized by slow bone loss and occurs in both men and women. In women, a third phase of bone loss also occurs, most likely due to postmenopausal estrogen deficiencies. During this phase alone, women may lose an additional 10% of bone mass from the cortical bone and 25% from the trabecular compartment (*see* Riggs, *supra*).

Loss of bone mineral content can be caused by a wide variety of conditions and may result in significant medical problems. For example, osteoporosis is a debilitating disease in humans and is characterized by marked decreases in skeletal bone mass and mineral density, structural deterioration of bone, including degradation of bone microarchitecture and corresponding increases in bone fragility, and susceptibility to fracture in afflicted individuals. Osteoporosis in humans is preceded by clinical osteopenia (bone mineral density that is greater than one standard deviation but less than 2.5 standard deviations below the mean value for young adult bone), a condition found in approximately 25 million people in the United States. Another 7-8 million patients in the United States have been diagnosed with clinical osteoporosis (defined as bone mineral content greater than 2.5 standard deviations below that of mature young adult bone). Osteoporosis is one of the most expensive diseases for the health care

system, costing tens of billions of dollars annually in the United States. In addition to health care-related costs, long-term residential care, and lost working days add to the financial and social costs of this disease. Worldwide, approximately 75 million people are at risk for osteoporosis.

The frequency of osteoporosis in the human population increases with age. Among Caucasians, osteporosis is predominant in women who, in the United States, comprise 80% of the osteoporosis patient pool. The increased fragility and susceptibility to fracture of skeletal bone in the aged is aggravated by the greater risk of accidental falls in this population. More than 1.5 million osteoporosis-related bone fractures are reported in the United States each year. Fractured hips, wrists, and vertebrae are among the most common injuries associated with osteoporosis. Hip fractures in particular are extremely uncomfortable and expensive for the patient, and for women, correlate with high rates of mortality and morbidity.

Although osteoporosis has been regarded as an increase in the risk of fracture due to decreased bone mass, none of the presently available treatments for skeletal disorders can substantially increase the bone density of adults. A strong perception among many physicians is that drugs are needed that could increase bone density in adults, particularly in the bones of the wrist, spinal column, and hip that are at risk in osteopenia and osteoporosis.

Current strategies for the prevention of osteoporosis may offer some benefit to individuals but cannot ensure resolution of the disease. These strategies include moderating physical activity (particularly in weight-bearing activities) with the onset of advanced age, providing adequate calcium in the diet, and avoiding consumption of products containing alcohol or tobacco. For patients presenting clinical osteopenia or osteoporosis, the prevalent current therapeutic drugs and strategies are directed to reducing further loss of bone mass by inhibiting the process of bone absorption, a natural aspect of the bone remodeling process that occurs constitutively.

For example, estrogen is now being prescribed to retard bone loss. However, some controversy exists over whether patients gain any long-term benefit and whether estrogen has any effect at all on patients over 75 years old. Moreover, use of estrogen is believed to increase the risk of breast and endometrial cancer. Calcitonin, osteocalcin with vitamin K, or high doses of dietary calcium, with or without vitamin D, have also been suggested for postmenopausal women. High doses of calcium, however, can often have unpleasant gastrointestinal side effects, and serum and urinary calcium levels must be continuously monitored (*e.g.*, Khosla and Rigss, *Mayo Clin. Proc.* *70*:978-982, 1995).

Other therapeutic approaches to osteoporosis include bisphosphonates (*e.g.*, Fosamax™, Actonel™, Bonviva™, Zometa™, olpadronate, neridronate, skelid, bonefos), parathyroid hormone, calcilytics, calcimimetics (*e.g.*, cinacalcet), statins, anabolic steroids, lanthanum and strontium salts, and sodium fluoride. Such therapeutics, however, are often associated with undesirable side effects (for example, calcitonin and steroids may cause nausea and provoke an immune reaction, bisphosphonates and sodium fluoride may inhibit repair of fractures, even though bone density increases modestly) that may preclude their efficacious use (*see* Khosla and Rigss, *supra*).

No currently practiced therapeutic strategy for treating a condition associated with excessive or insufficient bone mineralization, such as osteoporosis or other disorders characterized by loss of bone mineralization, involves a drug that alters (*i.e.*, increases or decreases in a statistically significant manner) bone mass. In particular, no current strategy therapeutically stimulates or enhances the growth of new bone mass. The present invention provides compositions and methods which can be used to increase bone mineralization, and which therefore may be used to treat a wide variety of conditions in which an increase in bone mass is desirable. The present invention also offers other related advantages.

## BRIEF SUMMARY OF THE INVENTION

Briefly stated, the present invention provides antibodies that specifically bind to a TGF-beta binding protein, sclerostin (SOST), and provides immunogens comprising SOST peptides derived from regions of SOST that interact with a member of the TGF-beta superfamily such as a bone morphogenic protein. In one embodiment, the invention provides an isolated antibody, or an antigen-binding fragment thereof, that binds specifically to a SOST polypeptide, which comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); or AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in GenBank Acc. NOs.

U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); or NM_001204 (SEQ ID NO:82). In a particular embodiment, the antibody, or the antigen-binding fragment thereof, binds specifically to a polypeptide that comprises an amino acid sequence set forth in SEQ ID NO:2-6, 12-15, 21, 22, 25, 26, 47, 48, 49, or 50, and in other particular embodiments, the antibody binds specifically to a polypeptide that comprises an amino acid sequence set forth in SEQ ID NO: 5, 6, or 14.

In one embodiment, the invention provides an isolated antibody, or an antigen-binding fragment thereof, that is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids that comprises an amino acid sequence of SEQ ID NOs:2-19, 21-28, or 47-50, wherein the antibody binds specifically to a SOST polypeptide, which comprises an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, and wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide (set forth in any one of GenBank sequences provided herein), and wherein the BMP Type II Receptor binding sites is capable of binding to a BMP Type II Receptor polypeptide (set forth in any one of GenBank sequences provided herein). In certain preferred embodiments, an antibody is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids that comprises an amino acid sequence of SEQ ID NO:5, 6, 10, 11, 14, or 18.

The present invention further provides an antibody, or an antigen-binding fragment thereof, that binds specifically to a SOST polypeptide and that impairs formation of a SOST homodimer, wherein the SOST polypeptide comprises an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, and wherein the antibody binds to a polypeptide that comprises an amino acid sequence of SEQ ID NOs:29-31, 33-36, 41-43, or 51-54.

In another embodiment, the invention provides an isolated antibody, or an antigen-binding fragment thereof, that is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NOs: 29-46, 51, 52, 53, or 54, wherein the antibody, or the antigen-binding fragment thereof, binds specifically to a SOST polypeptide that comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, and wherein the antibody impairs formation of a SOST homodimer.

In certain particular embodiments of the invention, the antibody is a polyclonal

antibody. In other embodiments, the antibody is a monoclonal antibody, which is a mouse, human, rat, or hamster monoclonal antibody. The invention also provides a hybridoma cell or a host cell that is capable of producing the monoclonal antibody. In other embodiments of the invention, the antibody is a humanized antibody or a chimeric antibody. The invention further provides a host cell that produces the humanized or chimeric antibody. In certain embodiments the antigen-binding fragment of the antibody is a $F(ab')_2$, Fab', Fab, Fd, or Fv fragment. The invention also provides an antibody that is a single chain antibody and provides a host cell that is capable of expressing the single chain antibody. In another embodiment, the invention provides a composition comprising such antibodies and a physiologically acceptable carrier.

The invention provides an immunogen comprising a peptide comprising 6, 7, 8, 9, 10, 11, or 12 consecutive amino acids of a SOST polypeptide, which SOST polypeptide comprises an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, and wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide, wherein wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); or AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); or NM_001204 (SEQ ID NO:82).

In another embodiment, an immunogen comprises a peptide comprising at least 21 consecutive amino acids and no more than 50 consecutive amino acids of a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide (set forth in

any one of GenBank sequences provided herein), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide (set forth in any one of GenBank sequences provided herein).

In certain embodiments the invention provides an immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NOs: 2-19, 21-28, 47, 48, 49, or 50, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, which comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); or AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); or NM_001204 (SEQ ID NO:82). In a particular embodiment, the invention provides an immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NO:5, 6, 10, 11, 14, or 18.

The invention also provides an immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NOs: 29-46, 51, 52, 53, or 54, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, which comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, and wherein the antibody impairs formation of a SOST homodimer. In another embodiment, an immunogen comprises a peptide comprising 6, 7, 8, 9, 10, 11, or 12 consecutive amino acids of a SOST polypeptide, wherein the SOST polypeptide comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, and wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that impairs formation of a SOST homodimer. In certain embodiments, the invention provides an immunogen that comprises a peptide

comprising at least 21 consecutive amino acids and no more than 50 consecutive amino acids of a SOST polypeptide, which polypeptide comprises SEQ ID NO:1, 20, 58, 60, 62, or 68, and wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that impairs formation of a SOST homodimer.

In certain particular embodiments, the subject invention immunogens are associated with a carrier molecule. In certain embodiments, the carrier molecule is a carrier polypeptide, and in particular embodiments, the carrier polypeptide is keyhole limpet hemocyanin.

The present invention also provides a method for producing an antibody that specifically binds to a SOST polypeptide, comprising immunizing a non-human animal with an immunogen comprising a peptide of 6, 7, 8, 9, 10, 11, or 12 consecutive amino acids or at least 21 and no more than 50 consecutive amino acids of a SOST polypeptide having the sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, that is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); or AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); or NM_001204 (SEQ ID NO:82). In another embodiment, the present invention provides a method for producing an antibody that specifically binds to a SOST polypeptide, comprising immunizing a non-human animal with an immunogen comprising a peptide at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NO: 2-19, 21-28, 47, 48, 49, or 50, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, which comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein

(BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide. In a particular embodiment, the immunogen comprises a peptide at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NO:5, 6, 10, 11, 14, or 18.

In other preferred embodiments, the invention provides a method for producing an antibody that specifically binds to a SOST polypeptide, comprising immunizing a non-human animal with an immunogen comprising a peptide of 6, 7, 8, 9, 10, 11, or 12 consecutive amino acids or at least 21 and no more than 50 consecutive amino acids of a SOST polypeptide having the sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, that is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that is capable of impairing formation of a SOST homodimer. In another embodiment, the invention provides a method for producing an antibody that specifically binds to a SOST polypeptide, comprising immunizing a non-human animal with an immunogen comprising a peptide at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence of SEQ ID NO: 29-46, 51, 52, 53, or 54, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide and impairs formation of a SOST homodimer.

The present invention also provides a method for identifying an antibody that modulates a TGF-beta signaling pathway, comprising contacting an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, or 68 with at least one SOST peptide comprising an amino acid sequence of SEQ ID NO: 2-19, or 21-54, under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that modulates a TGF-beta signaling pathway. In another embodiment, the invention provides a method for identifying an antibody that impairs binding of a BMP to a SOST polypeptide, comprising contacting (i) an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, or 68 with (ii) at least one SOST peptide comprising an amino acid sequence of SEQ ID NO: 2-19, 21-28, or 47-50 under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that impairs binding of a BMP to a SOST polypeptide. In particular embodiments of the method for

identifying an antibody that modulates a TGF-beta signaling pathway and for identifying an antibody that impairs binding of a BMP to a SOST polypeptide, the SOST peptide comprises an amino acid sequence of SEQ ID NO:5, 6, 10, 11, 14, or 18.

In another embodiment, the invention provides a method for identifying an antibody that impairs SOST homodimer formation, comprising contacting (i) an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, or 68, with (ii) at least one SOST peptide comprising an amino acid sequence of SEQ ID NO: 29-46 or 51-54 under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that that impairs SOST homodimer formation.

In another embodiment, the invention provides a method for identifying an antibody that increases bone mineral content, comprising contacting (i) an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, or 68 with (ii) at least one SOST peptide comprising an amino acid sequence of SEQ ID NO: 2-19, or 21-54 under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that increases bone mineral content. In a particular embodiment, the peptide comprises an amino acid sequence of SEQ ID NO:5, 6, 10, 11, 14, or 18.

In certain particular embodiments for identifying an antibody that modulates a TGF-beta signaling pathway, for identifying an antibody that impairs binding of a BMP to a SOST polypeptide, for identifying an antibody that impairs SOST homodimer formation, or for identifying an antibody that increases bone mineral content, the antibody is present in a biological sample or the antibody is a purified antibody. In certain embodiments the purified antibody is a polyclonal antibody, a monoclonal antibody, a chimeric antibody, a humanized antibody, or an antigen-binding fragment of any of these antibodies.

These and other embodiments of the present invention will become apparent upon reference to the following detailed description and attached drawings. All references disclosed herein are hereby incorporated by reference in their entireties as if each was incorporated individually.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 presents an alignment of the region containing the characteristic cystine-knot of a SOST polypeptide and its closest homologues. Three disulphide bonds that form the cystine-knot are illustrated as solid lines. An extra disulphide bond, shown by a dotted line, is unique to this family, which connects two β-hairpin tips in the 3D structure. The polypeptides depicted are SOST: sclerostin (SEQ ID NO:95); CGHB: Human Chorionic Gonadotropin β (SEQ ID NO:96); FSHB: follicle-stimulating hormone beta subunit (SEQ ID NO:97); TSHB: thyrotropin beta chain precursor (SEQ ID NO:98); VWF: Von Willebrand factor (SEQ ID NO:99); MUC2: human mucin 2 precursor (SEQ ID NO:100); CER1: Cerberus 1 (*Xenopus laevis* homolog) (SEQ ID NO:101); DRM: gremlin (SEQ ID NO:102); DAN: (SEQ ID NO:103); CTGF: connective tissue growth factor precursor (SEQ ID NO:104); NOV: NovH (nephroblastoma overexpressed gene protein homolog) (SEQ ID NO:105); CYR6: (SEQ ID NO:106).

Figure 2 illustrates a 3D model of the core region of SOST (SOST_Core).

Figure 3 presents a 3D model of the core region of SOST homodimer.

Figure 4A and B provides an amino acid sequence alignment of Noggin from five different animals: human (NOGG_HUMAN (SEQ ID NO:107); chicken (NOGG_CHICK, SEQ ID NO:108); African clawed frog (NOGG_XENLA, SEQ ID NO:109); NOGG_FUGRU, SEQ ID NO:110); and zebrafish (NOGG_ZEBRA, SEQ ID NO:111); and SOST from human (SOST_HUMAN, SEQ ID NO:1), rat (SOST_RAT, SEQ ID NO:20), and mouse (SOST_Mouse, SEQ ID NO:112).

Figure 5 illustrates the Noggin/BMP-7 complex structure. The BMP homodimer is shown on the bottom portion of the figure in surface mode. The Noggin homodimer is shown on top of the BMP dimer in cartoon mode. The circles outline the N-terminal binding region, the core region, and the linker between the N-terminal and core regions.

Figure 6 depicts a 3D model of the potential BMP-binding fragment located at the SOST N-terminal region. A BMP dimer is shown in surface mode, and the potential BMP-binding fragment is shown in stick mode. A phenylalanine residue fitting into a hydrophobic pocket on the BMP surface is noted.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention provides antibodies that specifically bind to a SOST polypeptide methods for using such antibodies. The present invention also provides SOST polypeptide immunogens that may be used for generation and analysis of these antibodies. The

antibodies may be useful to block or impair binding of a SOST polypeptide, which is a TGF-beta binding protein, to a ligand, particularly a bone morphogenic protein, and may also block or impair binding of the SOST polypeptide to one or more other ligands.

The invention relates in part to the surprising discovery, within the sclerostin polypeptide sequence, of specific short peptide sequences that are specifically recognized by anti-sclerostin antibodies capable of competitively inhibiting binding of sclerostin polypeptides to BMP, where such sclerostin-BMP binding otherwise would occur via a BMP Type I Receptor binding site and/or a BMP Type II Receptor binding site. A molecule such as an antibody that inhibits the binding of the TGF-beta binding protein to one or more members of the TGF-beta family of proteins, including one or more bone morphogenic proteins (BMPs), should be understood to include, for example, a molecule that allows the activation of a TGF-beta family member or BMP, or allows binding of TGF-beta family members including one or more BMPs to their respective receptors by removing or preventing the TGF-beta member from binding to the TGF-binding-protein.

The present invention also provides peptide and polypeptide immunogens that, unexpectedly, may be used to generate and/or identify antibodies or fragments thereof that are capable of inhibiting, preventing, or impairing (*e.g.*, decreasing in a statistically significant manner) binding of the TGF-beta binding protein SOST to one or more BMPs. Exemplary peptide immunogens may comprise 6, 7, 8, 9, 10, 11, 12, 20-25, 21-50, 26-30, 31-40, 41-50, 51-60, 61-70, or 71-75 consecutive amino acids of a sclerostin polypeptide as provided herein (or of a variant thereof), such peptides comprising, for instance, amino acid sequences as set forth in SEQ ID NOS:2-19, 21-53, and 54. The present invention also provides peptide and polypeptide immunogens that may be used to generate and/or identify antibodies or fragments thereof that are capable of inhibiting, preventing, or impairing the formation of SOST homodimers. The antibodies of the present invention are useful for increasing the mineral content and mineral density of bone, thereby ameliorating numerous conditions that result in the loss of bone mineral content, including for example, disease, genetic predisposition, accidents that result in the lack of use of bone (*e.g.*, due to fracture), therapeutics that effect bone resorption or that kill bone forming cells, and normal aging.

Sclerosteosis

Sclerosteosis is a disease related to abnormal bone mineral density in humans. Sclerosteosis is a term that was applied by Hansen (Hansen, H. G., *Sklerosteose in*: Opitz et al.,

eds. Handbuch der Kinderheilkunde, (Berlin: Springer 1967) 351-355) to a disorder similar to van Buchem hyperostosis corticalis generalisata but possibly differing in radiologic appearance of the bone changes and in the presence of asymmetric cutaneous syndactyly of the index and middle fingers in many cases. Sclerosteosis is now understood to be an autosomal semi-dominant disorder that is characterized by widely disseminated sclerotic lesions of the bone in the adult. The condition is progressive. Sclerosteosis also has a developmental aspect that is associated with syndactyly (two or more fingers fused together). Sclerosteosis Syndrome is associated with large stature, and many affected individuals attain a height of six feet or more. In addition, the jaw of persons with this condition has an unusually square appearance. The bone mineral content of homozygotes can be 1 to 6 fold greater than normal individuals, and bone mineral density can be 1 to 4 fold above normal values (*e.g.*, in comparison to unaffected siblings).

Sclerosteosis Syndrome occurs primarily in Afrikaaners of Dutch descent in South Africa. Approximately 1 of every 140 individuals in the Afrikaaner population is a carrier of the mutated gene (heterozygotes). The mutation shows 100% penetrance. Anecdotal reports indicate that increased bone mineral density has been observed in heterozygotes but they have no associated pathologies (*e.g.*, syndactyly or skull overgrowth).

No abnormality of the pituitary-hypothalamus axis has been observed in patients with sclerosteosis. In particular, no over-production of growth hormone and cortisone occurs, and sex hormone levels are normal in affected individuals. Bone turnover markers (such as osteoblast specific alkaline phosphatase, osteocalcin, type 1 procollagen C' propeptide (PICP), and total alkaline phosphatase (*see* Comier, *Curr. Opin. in Rheu.* 7:243 (1995)) indicate that hyperosteoblastic activity is associated with the disease but normal to slightly decreased osteoclast activity is observed as measured by markers of bone resorption (pyridinoline, deoxypryridinoline, N-telopeptide, urinary hydroxyproline, plasma tartrate-resistant acid phosphatases, and galactosyl hydroxylysine (*see* Comier, *supra*)).

Sclerosteosis is characterized by the continual deposition of bone throughout the skeleton during the lifetime of the affected individuals. In homozygotes the continual deposition of bone mineral leads to an overgrowth of bone in areas of the skeleton where mechanoreceptors are absent (*e.g.*, skull, jaw, cranium). In homozygotes with Sclerosteosis, the overgrowth of the bones of the skull leads to cranial compression and eventually to death due to excessive hydrostatic pressure on the brain stem. A generalized and diffuse sclerosis is observed in all other parts of the skeleton. Cortical areas of the long bones are greatly thickened resulting in a

substantial increase in bone strength. Trabecular connections are increased in thickness, which in turn increases the strength of the trabecular bone. Sclerotic bones appear unusually opaque to x-rays.

The rare genetic mutation that is responsible for Sclerosteosis Syndrome has been localized to the region of human chromosome 17. A gene within this region encodes a novel member of the TGF-beta binding-protein family (*see, e.g.*, U.S. Patent Nos. 6,395,511, 6,489,445, and 6,495,736; Brunkow et al., *Am. J. Hum. Genet.* 68:577-89 (2001)). Therapeutics related to altering or modulating the level of sclerostin may therefore be useful in treating conditions and diseases related to abnormal bone development or deterioration. As described in more detail below, antibodies that specifically bind to this TGF-beta binding-protein, sclerostin (also referred to herein as Beer or as SOST), may be used to increase bone mineral content thus treating, preventing, retarding progression, or ameliorating the symptoms of a number of diseases.

TGF-Beta Superfamily

Among significant molecules to which reference is made herein include any known or novel members of the Transforming Growth Factor-beta (TGF-beta) superfamily, which includes bone morphogenic proteins (BMPs). Also included in the TGF-beta superfamily are TGF-beta receptors, which should be understood to refer to one or more receptors that are specific for a particular member of the TGF-beta superfamily (including BMPs), and TGF-beta binding proteins, which should be understood to refer to one or more polypeptides with specific binding affinity for a particular member or subset of members of the TGF-beta superfamily (including BMPs). A specific example of a TGF-beta binding protein includes sclerostin or SOST. Polynucleotide sequences encoding SOST and SOST variants in various animals, including humans, are provided herein in SEQ ID NOs: 55, 56, 57, 59, 61, 63, 65, and 67 and 69 (the encoded polypeptide sequences are provided in SEQ ID NOs: 1, 20, 58, 60, 62, 64, 66, 68, and 70, respectively). (*See, e.g.,* U.S. Patent Nos. 6,395,511; 6,489,445; and 6,495,736. *See* also *e.g.*, Balemans et al., 2002 *Dev. Biol.* 250:231; Schmitt et al., 1999 *J. Orthopaed. Res.* 17:269; Khalil, 1999 *Microbes Infect.* 1:1255; Miyazono et al., 1993 *Growth Factors* 8:11; von Bubnoff et al., 2001 *Dev. Biol.* 239:1; Koli et al., 2001 *Microsc. Res. Tech.* 52:354; Ebara et al., 2002 *Spine* 27(16 Suppl. 1):S10; Bondestam, 2002, *Ligands & Signaling Components of the Transforming Growth Factor β Family*, Helsinki University Biomedical Dissertations No. 17).

The TGF-beta superfamily contains a variety of growth factors that share

common sequence elements and structural motifs at both secondary and tertiary levels. This protein family exerts a wide spectrum of biological responses that affect a large variety of cell types. Many of the members of the TGF-beta family have important functions in pattern formation and tissue specification during embryonal development. In adults, TGF-beta family members are involved, for example, in wound healing, bone repair and bone remodeling, and in modulation of the immune system. In addition to the TGF-beta polypeptides, this superfamily includes BMPs, activins, inhibins, Growth and Differentiation Factors (GDFs), and Glial-Derived Neurotrophic Factors (GDNFs). Primary classification is established through general sequence features that bin a specific protein into a general subfamily. Additional stratification within the sub-family is possible due to stricter sequence conservation between members of the smaller group. In certain instances, such as with BMP-5, BMP-6, and BMP-7, the amino acid percent identity may be as high as 75% among members of the smaller group. This level of identity enables a single representative sequence to illustrate the key biochemical elements of the sub-group that separates it from other members of the larger family.

The crystal structure of TGF-beta2 has been determined. The general fold of the TGF-beta2 monomer contains a stable, compact, cysteine knotlike structure formed by three disulphide bridges. Dimerization, which is stabilized by one disulphide bridge, is antiparallel.

TGF-beta family members signal by inducing the formation of hetero-oligomeric receptor complexes. Transduction of TGF-beta signals involves two distinct subfamilies of transmembrane serine/threonine kinase receptors, type I and type II. At least seven type I receptors and five type II receptors have been identified (see Kawabata et al., *Cytokine Growth Factor Rev.* 9:49-61 (1998); Miyazono et al., *Adv. Immunol.* 75:115-57 (2000). Each member of the TGF-beta family binds to a characteristic combination of type I and type II receptors, both of which are needed for signaling. In the current model for TGF-beta receptor activation, a TGF-beta ligand first binds to the type II receptor (TbR-II), which then recruits a type I receptor (TbR-I) to form a ligand/type II/type I ternary complex. The type I receptor, cannot bind ligand in the absence of TbR-II. TbR-II then phosphorylates TbR-I predominantly in a domain rich in glycine and serine residues (GS domain) in the juxtamembrane region, thereby activating TbR-I. The activated type I receptor kinase then phosphorylates particular members of the Smad family of proteins that translocate to the nucleus where they modulate transcription of specific genes.

Bone Morphogenic Proteins (BMPs): Key Regulatory Proteins of Bone Mineral Density

A major advance in the understanding of bone formation was the identification of

the BMPs, also known as osteogenic proteins (OPs), which regulate cartilage and bone differentiation in vivo. BMPs/OPs induce endochondral bone differentiation through a cascade of events by which mesenchymal stem cells differentiate into chondrocytes that lay down a cartilage structure that is reabsorbed and replaced by bone tissue (*see* Balemans et al., *Dev. Biol.* 250:231-50 (2002)). Thus, this process involves formation of cartilage, hypertrophy and calcification of the cartilage, vascular invasion, differentiation of osteoblasts, and formation of bone. As described above, the BMPs/OPs (BMP 2-14, and osteogenic protein 1 and -2, OP-1 and OP-2) (*see, e.g.,* GenBank P12643 (BMP-2); GenBank P12645 (BMP3); GenBank P55107 (BMP-3b, Growth/differentiation factor 10) (GDF-10)); GenBank P12644 (BMP4); GenBank P22003 (BMP5); GenBank P22004 (BMP6); GenBank P18075 (BMP7); GenBank P34820 (BMP8); GenBank Q9UK05 (BMP9); GenBank O95393 (BM10); GenBank O95390 (BMP11, Growth/differentiation factor 11 precursor (GDF-11)); GenBank O95972 (BM15)) are members of the TGF-beta superfamily. The striking evolutionary conservation among members of the BMP/OP sub-family suggests that they are important in the normal development and function of animals. In addition to postfetal chondrogenesis and osteogenesis, the BMPs/OPs play multiple roles in skeletogenesis, including the development of craniofacial and dental tissues. Different BMP family members also have biological activities in various other cell types, including monocytes, epithelial cells, mesenchymal cells, and neuronal cells. BMPs regulate cell proliferation and differentiation, chemotaxis and apoptosis, and also control fundamental roles, for example, left-right asymmetry, neurogenesis, mesoderm patterning, and embryonic development and organogenesis of a number of organs including the kidney, gut, lung, teeth, limb, amnion, and testis (*see* Balemans, *supra*).

BMPs are synthesized as large precursor proteins. Upon dimerization, the BMPs are proteolyically cleaved within the cell to yield carboxy-terminal mature proteins that are then secreted from the cell. BMPs, like other TGF-beta family members, initiate signal transduction by binding cooperatively to both type I and type II serine/threonine kinase receptors. Type I receptors for which BMPs may act as ligands include BMPR-IA (also known as ALK-3), BMPR-IB (also known as ALK-6), ALK-1, and ALK-2 (also known as ActR-I). Of the type II receptors, BMPs bind to BMP type II receptor (BMPR-II), Activin type II (ActR-II), and Activin type IIB (ActR-IIB). (*See* Balemans et al., *supra,* and references cited therein). Polynucleotide sequences and the encoded amino acid sequence of BMP type I receptor polypeptides are provided in the GenBank database, for example, GenBank NM_004329 (SEQ ID NO:71 encoded by SEQ ID NO:85); D89675 (SEQ ID NO:72 encoded by SEQ ID NO:86);

NM_001203 (SEQ ID NO:73 encoded by SEQ ID NO:87); S75359 (SEQ ID NO:74 encoded by SEQ ID NO:88); NM_030849 (SEQ ID NO:75 encoded by SEQ ID NO:89); and D38082 (SEQ ID NO:76 encoded by SEQ ID NO:90). Other polypeptide sequences of type I receptors are provided in the GenBank database, for example, NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79). Polynucleotide sequences and the encoded amino acid sequence of BMP type II receptor polypeptides are provided in the GenBank database and include, for example, U25110 (SEQ ID NO:80 encoded by SEQ ID NO:91); NM_033346 (SEQ ID NO:81 encoded by SEQ ID NO:92); NM_001204 (SEQ ID NO:82 encoded by SEQ ID NO:93); and Z48923 (SEQ ID NO:83 encoded by SEQ ID NO:94). Additional polypeptide sequences of type II receptors are also provided in the GenBank database, for example, CAA88759 (SEQ ID NO:84).

BMPs, similar to other cystine-knot proteins, form a homodimer structure (Scheufler et al., *J. Mol. Biol.* 287:103-15 (1999)). According to evolutionary trace analysis performed on the BMP/TGF-β family, the BMP type I receptor binding site and type II receptor binding site were mapped to the surface of the BMP structure (Innis et al., *Protein Eng.* 13:839-47 (2000)). The location of the type I receptor binding site on BMP was later confirmed by the x-ray structure of BMP-2/BMP Receptor IA complex (Nickel et al., *J. Joint Surg. Am.* 83A(Suppl 1(Pt 1)):S7-S14 (2001)). The predicted type II receptor binding site is in good agreement with the x-ray structure of TGF-β3/TGF-β Type II receptor complex (Hart et al., *Nat. Struct. Biol.* 9:203-208 (2002)), which is highly similar to the BMP/BMP Receptor IIA system.

The BMP and Activin sub-families are subject to significant post-translational regulation by TGF-beta binding proteins. An intricate extracellular control system exists, whereby a high affinity antagonist is synthesized and exported, and subsequently forms a complex selectively with BMPs or activins to disrupt their biological activity (Smith, *Trends Genet.* 15:3-6 (1999)). A number of such TGF-beta binding proteins have been identified, and on the basis of sequence divergence, the antagonists appear to have evolved independently because of the lack of primary sequence conservation. In vertebrates, antagonists include noggin, chordin, chordin-*like*, follistatin, FSRP, the DAN/Cerberus protein family, and sclerostin (SOST) (*see* Balemans et al., *supra*, and references cited therein). The mechanism of antagonism seems to differ for the different antagonists (Iemura et al. (1998) *Proc. Natl. Acad. Sci. USA* 95:9337-9342).

The type I and type II receptor binding sites on the BMP antagonist noggin have also been mapped. Noggin binds to BMPs with high affinity (Zimmerman *et al.*, 1996). A

study of the noggin/BMP-7 complex structure revealed the binding interactions between the two proteins (Groppe et al., *Nature* 420:636-42 (2002)). Superposition of the noggin-BMP-7 structure onto a model of the BMP signaling complex showed that noggin binding effectively masks both pairs of binding epitopes (*i.e.,* BMP Type I and Type II receptor binding sites) on BMP-7. The cysteine-rich scaffold sequence of noggin is preceded by an N-terminal segment of about 20 amino acid residues that are referred to as the "clip" (residues 28-48). The type I receptor-binding site is occluded by the N-terminal portion of the clip domain of Noggin, and the type II receptor binding site is occluded by the carboxy terminal portion of the clip domain. Two β-strands in the core region near the C-terminus of noggin also contact BMP-7 at the type II receptor binding site. This binding mode enables a Noggin dimer to efficiently block all the receptor binding sites (two type I and two type II receptor binding sites) on a BMP dimer.

Sclerostin Polypeptides and Encoding Polynucleotides

The BMP antagonist sclerostin (U.S. Patent Nos. 67,395,511, 6,489,445, and 6,495,736; see also SEQ ID NOs: 1, 20, 58, 60, 62, 64, 66, 68, and 70), possesses a nearly identical cysteine (disulfide) scaffold when compared with Human DAN, Human Gremlin, and Human Cerberus, and SCGF (U.S. Patent No. 5,780,263) but almost no homology at the nucleotide level (for background information, *see generally* Hsu et al., *Mol. Cell* 1:673-683 (1998)). Sclerostin should also be understood to include variants of this TGF-beta binding-protein (*e.g.*, SEQ ID NOs. 60 and 62). As used herein, a TGF-beta binding-protein variant polynucleotide refers to nucleic acid molecule that encodes a polypeptide having an amino acid sequence that is a modification (insertion, deletion, or substitution of one or more nucleotides) of SEQ ID NOs: 55-57, 59, 61, 63, 65, 67, or 69. Such variants include naturally-occurring polymorphisms or allelic variants of TGF-beta binding-protein encoding polynucleotides, as well as synthetic polynucleotides that encode conservative amino acid substitutions of these amino acid sequences. A variety of criteria known to those skilled in the art indicate whether amino acids at a particular position in a peptide or polypeptide are similar. For example, a similar amino acid or a conservative amino acid substitution is one in which an amino acid residue is replaced with an amino acid residue having a similar side chain, which include amino acids with basic side chains (*e.g.*, lysine, arginine, histidine); acidic side chains (*e.g.*, aspartic acid, glutamic acid); uncharged polar side chains (*e.g.*, glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine, histidine); nonpolar side chains (*e.g.*, alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan); beta-branched side chains (*e.g.*,

threonine, valine, isoleucine), and aromatic side chains (*e.g.*, tyrosine, phenylalanine, tryptophan). Proline, which is considered more difficult to classify, shares properties with amino acids that have aliphatic side chains (*e.g.*, Leu, Val, Ile, and Ala). In certain circumstances, substitution of glutamine for glutamic acid or asparagine for aspartic acid may be considered a similar substitution in that glutamine and asparagine are amide derivatives of glutamic acid and aspartic acid, respectively.

Additional variant forms of a TGF-beta binding protein encoding polynucleotide are nucleic acid molecules that contain substitutions, insertions or deletions of one or more nucleotides found within the nucleotide sequences described herein. A variant or mutant of a TGF-beta binding protein may be constructed or identified so that the altered version of the TGF-beta binding protein competes with the wildtype TGF-beta binding protein. Such competition would preferably block the activity of the wildtype TGF-beta binding protein and thus lead to increased bone density.

An isolated polynucleotide is a nucleic acid molecule (polynucleotide or oligonucleotide) that is not integrated in the genomic DNA of an organism. A polynucleotide is considered to be isolated if, for example, it is cloned into a vector that is not a part of the natural environment. For example, a DNA molecule that encodes a TGF-binding protein that has been separated from the genomic DNA of a eukaryotic cell is an isolated DNA molecule. Another example of an isolated nucleic acid molecule is a chemically-synthesized nucleic acid molecule that is not integrated into the genome of an organism. The isolated nucleic acid molecule may be DNA, cDNA, RNA, or composed at least in part of nucleic acid analogs.

TGF-beta binding-protein variant polynucleotides can be identified by determining whether the polynucleotides hybridize with a nucleic acid molecule having the nucleotide sequence of SEQ ID NOs: 55-57, 59, 61, 63, 65, 67, or 69 under stringent conditions. In addition, TGF-beta binding-protein variant polynucleotides encode a protein having a cysteine backbone. TGF-beta binding-protein variant polynucleotides may also be identified by sequence comparison. As used herein, two amino acid sequences have "100% amino acid sequence identity" if the amino acid residues of the two amino acid sequences are the same when aligned for maximal correspondence. Similarly, two nucleotide sequences have "100% nucleotide sequence identity" if the nucleotides of the two nucleotide sequences are the same when aligned for maximal correspondence. Sequence comparisons can be performed using standard software programs such as those included in the LASERGENE bioinformatics computing suite, which is produced by DNASTAR (Madison, Wisconsin), or the BLAST

algorithm available at the NCBI web site ([Internet]<:http:www.ncbi.nlm.nih.gov>). Other methods for comparing two or more nucleotide or amino acid sequences by determining optimal alignment are well-known to those of skill in the art (*see*, for example, Peruski and Peruski, *The Internet and the New Biology: Tools for Genomic and Molecular Research* (ASM Press, Inc. 1997), Wu et al. (eds.), "Information Superhighway and Computer Databases of Nucleic Acids and Proteins," in *Methods in Gene Biotechnology*, pages 123-151 (CRC Press, Inc. 1997), and Bishop (ed.), *Guide to Human Genome Computing*, 2nd Edition (Academic Press, Inc. 1998)).

A variant TGF-beta binding protein should have at least a 50% amino acid sequence identity to SEQ ID NOs: 1, 20, 58, 60, 62, 64, 66, and 68, and preferably greater than 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 98% identity. Alternatively, TGF-beta binding-protein variants can be identified by having at least a 70% nucleotide sequence identity to SEQ ID NOs: 55-57, 59, 61, 63, 65, 67, or 69. Moreover, the present invention contemplates TGF-beta binding-protein polynucleotide variants having greater than 75%, 80%, 85%, 90%, or 95% identity to SEQ ID NO:55 or 57. Regardless of the particular method used to identify a TGF-beta binding-protein variant polynucleotide or variant TGF-beta binding protein, such a variant can be functionally characterized by, for example, its ability to bind to and/or inhibit the signaling of a selected member of the TGF-beta family of proteins, or by its ability to bind specifically to an anti-TGF-beta binding-protein antibody.

Within the context of this invention, a "functional fragment" of a TGF-beta binding-protein polynucleotide refers to a nucleic acid molecule that encodes a portion of a TGF-beta binding-protein polypeptide that either (1) possesses a functional activity as described herein or (2) specifically binds to an anti-TGF-beta binding protein antibody. For example, a functional fragment of a TGF-beta binding protein encoding polynucleotide described herein comprises a portion of the nucleotide sequence of SEQ ID Nos: 55-57, 59, 61, 63, 65, 67, or 69.

An "isolated polypeptide" referred to herein is a polypeptide that is removed from its natural environment. For example, a naturally-occurring protein is isolated if it is separated from some or all of the coexisting materials in the natural system, such as carbohydrate, lipid, nucleic acids, or proteinaceous impurities associated with the polypeptide in nature. Preferably, such isolated polypeptides are at least about 90% pure, more preferably at least about 95% pure, and most preferably at least about 99% pure.

Antibodies Specific for TGF-Beta Binding Proteins

The present invention provides antibodies that specifically bind to SOST and also

provides SOST polypeptide immunogens that may be used for generation and analysis of these antibodies and also provides methods for using such antibodies. The antibodies of the present invention as described herein specifically bind to a SOST polypeptide and thereby block or inhibit the binding of a BMP to the SOST polypeptide, that is, prevent or impair the interaction between the BMP and SOST. The effect of blocking this interaction is to alter (increase or decrease in a statistically significant manner) bone mineral density, preferably to increase bone mineral density.

Polypeptides or peptides useful for immunization and/or analysis of SOST-specific antibodies may also be selected by analyzing the primary, secondary, and tertiary structure of a TGF-beta binding protein according to methods known to those skilled in the art and described herein, in order to determine amino acid sequences more likely to generate an antigenic response in a host animal. *See, e.g.*, Novotny, *Mol. Immunol.* 28:201-207 (1991); Berzofsky, *Science* 229:932-40 (1985)). Modeling and x-ray crystallography data may also be used to predict and/or identify which portions or regions of a TGF-beta binding protein interact with which portions of a TGF-beta binding protein ligand, such as a BMP. TGF-beta binding protein peptide immunogens may be designed and prepared that include amino acid sequences within or surrounding the portions or regions of interaction. These antibodies may be useful to block or impair binding of the TGF-beta binding protein to the same ligand and may also block or impair binding of the TGF-beta binding protein to one or more other ligands.

Antibodies or antigen binding fragments thereof contemplated by the present invention include antibodies that are capable of specifically binding to SOST and competitively inhibiting binding of a TGF-beta polypeptide, such as a BMP, to SOST. For example, the antibodies contemplated by the present invention competitively inhibit binding of the SOST polypeptide to the BMP Type I receptor site on a BMP, or to the BMP Type II receptor binding site, or may competitively inhibit binding of SOST to both the Type I and Type II receptor binding sites on a BMP. Without wishing to be bound by theory, when an anti-SOST antibody competitively inhibits binding of the Type I and/or Type II binding sites of the BMP polypeptide to SOST, thus blocking the antagonistic activity of SOST, the receptor binding sites on BMP are available to bind to the Type I and Type II receptors, thereby increasing bone mineralization. The binding interaction between a TGF-beta binding protein such as SOST and a TGF-beta polypeptide such as a BMP generally occurs when each of the ligand pairs forms a homodimer. Therefore instead of or in addition to using an antibody specific for SOST to block, impair, or prevent binding of SOST to a BMP by competitively inhibiting binding of SOST to BMP, a

SOST specific antibody may be used to block or impair SOST homodimer formation.

By way of example, one dimer of human Noggin, which is a BMP antagonist that has the ability to bind a BMP with high affinity (Zimmerman et al., *supra*), was isolated in complex with one dimer of human BMP-7 and analyzed by multiwavelength anomalous diffraction (MAD) (Groppe et al., *Nature* 420:636-42 (2002)). As discussed herein, this study revealed that Noggin dimer may efficiently block all the receptor binding sites (two type I and two type II receptor binding sites) on a BMP dimer. The location of the amino acids of Noggin that contact BMP-7 may be useful in modeling the interaction between other TGF-beta binding proteins, such as sclerostin (SOST), and BMPs, and thus aiding the design of peptides that may be used as immunogens to generate antibodies that block or impair such an interaction.

In one embodiment of the present invention, an antibody, or an antigen-binding fragment thereof, that binds specifically to a SOST polypeptide competitively inhibits binding of the SOST polypeptide to at least one or both of a bone morphogenic protein (BMP) Type I Receptor binding site and a BMP Type II Receptor binding site that are located on a BMP. The epitopes on SOST to which these antibodies bind may include or be included within contiguous amino acid sequences that are located at the N-terminus of the SOST polypeptide (amino acids at about positions1-56 of SEQ ID NO:1). The polypeptides may also include a short linker peptide sequence that connects the N-terminal region to the core region, for example, polypeptides as provided in SEQ ID NO:47 (human) and SEQ ID NO:48 (rat). Shorter representative N-terminus peptide sequences of human SOST (*e.g.*, SEQ ID NO:1) include SEQ ID NOS:2-6, and representative rat SOST (*e.g.*, SEQ ID NO:20) peptide sequences include SEQ ID NOS:12-15.

Antibodies that specifically bind to a SOST polypeptide and block or competitively inhibit binding of the SOST polypeptide to a BMP, for example, by blocking or inhibiting binding to amino acids of a BMP corresponding to one or more of the Type I and Type II receptor binding sites may also specifically bind to peptides that comprise an amino acid sequence corresponding to the core region of SOST (amino acids at about positions 57-146 of SEQ ID NO:1). Polypeptides that include the core region may also include additional amino acids extending at either or both the N-terminus and C-terminus, for example, to include cysteine residues that may be useful for conjugating the polypeptide to a carrier molecule. Representative core polypeptides of human and rat SOST, for example, comprise the amino acid sequences set forth in SEQ ID NO:49 and SEQ ID NO:50, respectively. Such antibodies may also bind shorter polypeptide sequences. Representative human SOST core peptide sequences

are provided in SEQ ID NOs:21-24 and representative rat SOST core sequences are provided in SEQ ID NOs:25-28.

In another embodiment, antibodies that specifically bind to a SOST polypeptide impair (inhibit, prevent, or block, *e.g.*, decrease in a statistically significant manner) formation of a SOST homodimer. Because the interaction between SOST and a BMP may involve a homodimer of SOST and a homodimer of the BMP, an antibody that prevents or impairs homodimer formation of SOST may thereby alter bone mineral density, preferably increasing bone mineral density. In one embodiment, antibodies that bind to the core region of SOST prevent homodimer formation. Such antibodies may also bind to peptides that comprise contiguous amino acid sequences corresponding the core region, for example, SEQ ID NOs: 29, 30 and 53 (human SOST) and SEQ ID NOs:31 and 54 (rat SOST). Antibodies that bind to an epitope located on the C-terminal region of a SOST polypeptide (at about amino acid positions 147-190 of either SEQ ID NO:1 or 20) may also impair homodimer formation. Representative C-terminal polypeptides of human and rat SOST, for example, comprise the amino acid sequences set forth in SEQ ID NO:51 and SEQ ID NO:52, respectively. Such antibodies may also bind shorter polypeptide sequences. Representative human SOST C-terminal peptide sequences are provided in SEQ ID NOs:33-36 and representative rat SOST C-terminal sequences are provided in SEQ ID NOs:41-43.

The SOST polypeptides and peptides disclosed herein to which antibodies may specifically bind are useful as immunogens. These immunogens of the present invention may be used for immunizing an animal to generate a humoral immune response that results in production of antibodies that specifically bind to a Type I or Type II receptor binding site or both located on a BMP include peptides derived from the N-terminal region of SOST or that may prevent SOST homodimer formation.

Such SOST polypeptides and peptides that are useful as immunogens may also be used in methods for screening samples containing antibodies, for example, samples of purified antibodies, antisera, or cell culture supernatants or any other biological sample that may contain one or more antibodies specific for SOST. These peptides may also be used in methods for identifying and selecting from a biological sample one or more B cells that are producing an antibody that specifically binds to SOST (*e.g.*, plaque forming assays and the like). The B cells may then be used as source of a SOST specific antibody-encoding polynucleotide that can be cloned and/or modified by recombinant molecular biology techniques known in the art and described herein.

A "biological sample" as used herein refers in certain embodiments to a sample containing at least one antibody specific for a SOST polypeptide, and a biological sample may be provided by obtaining a blood sample (from which serum or plasma may be prepared), biopsy specimen, tissue explant, organ culture, or any other tissue or cell preparation from a subject or a biological source. A sample may further refer to a tissue or cell preparation in which the morphological integrity or physical state has been disrupted, for example, by dissection, dissociation, solubilization, fractionation, homogenization, biochemical or chemical extraction, pulverization, lyophilization, sonication, or any other means for processing a sample derived from a subject or biological source. The subject or biological source may be a human or non-human animal, a primary cell culture (*e.g.*, B cells immunized in vitro), or culture adapted cell line including but not limited to genetically engineered cell lines that may contain chromosomally integrated or episomal recombinant nucleic acid sequences, immortalized or immortalizable cell lines, somatic cell hybrid cell lines, differentiated or differentiatable cell lines, transformed cell lines, and the like.

SOST peptide immunogens may also be prepared by synthesizing a series of peptides that, in total, represent the entire polypeptide sequence of a SOST polypeptide and that each have a portion of the SOST amino acid sequence in common with another peptide in the series. This overlapping portion would preferably be at least four amino acids, and more preferably 5, 6, 7, 8, 9, or 10 amino acids. Each peptide may be used to immunize an animal, the sera collected from the animal, and tested in an assay to identify which animal is producing antibodies that impair or block binding of SOST to a TGF-beta protein. Antibodies are then prepared from such identified immunized animals according to methods known in the art and described herein.

Peptides, polypeptides, and other non-peptide molecules that specifically bind to a TGF-beta binding protein such as SOST are contemplated by this invention. As used herein, a molecule is said to "specifically bind" to a TGF-beta binding protein if it reacts at a detectable level with the TGF-beta binding protein, but does not react detectably with peptides and polypeptides containing an unrelated sequence, or a sequence of a different TGF-beta binding protein. Preferred binding molecules include antibodies, which may be, for example, polyclonal, monoclonal, single chain, chimeric, anti-idiotypic, or CDR-grafted immunoglobulins, or fragments thereof, such as proteolytically generated or recombinantly produced immunoglobulin $F(ab')_2$, Fab, Fab' Fv, and Fd fragments.

Particularly useful are anti-TGF-beta binding-protein antibodies that "specifically

bind" TGF-beta binding-protein of SEQ ID NOs: 1, 20, 58, 60, 62, 64, 66, or 68, but not to other TGF-beta binding-proteins such as Dan, Cerberus, SCGF, or Gremlin. Antibodies are understood to specifically bind a TGF-beta binding-protein, or a specific TGF-beta family member, if they bind with a $K_a$ of greater than or equal to $10^4$ $M^{-1}$, more preferably greater than or equal to about $10^5$ $M^{-1}$, more preferably greater than or equal to about $10^6$ $M^{-1}$, still more preferably greater than or equal to $10^7$ $M^{-1}$, and still more preferably greater than or equal to $10^8$ $M^{-1}$, and do not bind to other TGF-beta binding-proteins. Affinity of an antibody for its cognate antigen is also commonly expressed as a dissociation constant $K_D$, and an anti-SOST antibody specifically binds to a TGF-beta family member if it binds with a $K_D$ of less than or equal to $10^{-4}$ M, more preferably less than or equal to about $10^{-5}$ M, more preferably less than or equal to about $10^{-6}$ M, still more preferably less than or equal to $10^{-7}$ M, and still more preferably less than or equal to $10^{-8}$ M. Furthermore, antibodies of the present invention preferably block, impair, or inhibit (*e.g.*, decrease with statistical significance) binding of a TGF-beta binding-protein to a TGF-beta family member.

The affinity of an antibody or binding partner, as well as the extent to which an antibody inhibits binding can be readily determined by one of ordinary skill in the art using conventional techniques, for example those described by Scatchard et al. (*Ann. N.Y. Acad. Sci.* 51:660-672, (1949)) or by surface plasmon resonance (SPR; BIAcore, Biosensor, Piscataway, NJ). For surface plasmon resonance, target molecules are immobilized on a solid phase and exposed to ligands in a mobile phase running along a flow cell. If ligand binding to the immobilized target occurs, the local refractive index changes, leading to a change in SPR angle, which can be monitored in real time by detecting changes in the intensity of the reflected light. The rates of change of the SPR signal can be analyzed to yield apparent rate constants for the association and dissociation phases of the binding reaction. The ratio of these values gives the apparent equilibrium constant (affinity) (*see, e.g.*, Wolff et al., *Cancer Res.* 53:2560-65 (1993)).

An antibody according to the present invention may belong to any immunoglobulin class, for example IgG, IgE, IgM, IgD, or IgA. It may be obtained from or derived from an animal, for example, fowl (*e.g.*, chicken) and mammals, which includes but is not limited to a mouse, rat, hamster, rabbit, or other rodent, a cow, horse, sheep, goat, camel, human, or other primate. The antibody may be an internalising antibody.

Methods well known in the art may be used to generate antibodies, polyclonal antisera, or monoclonal antibodies that are specific for a TGF-beta binding protein such as SOST. Antibodies also may be produced as genetically engineered immunoglobulins (Ig) or Ig

fragments designed to have desirable properties. For example, by way of illustration and not limitation, antibodies may include a recombinant IgG that is a chimeric fusion protein having at least one variable (V) region domain from a first mammalian species and at least one constant region domain from a second, distinct mammalian species. Most commonly, a chimeric antibody has murine variable region sequences and human constant region sequences. Such a murine/human chimeric immunoglobulin may be "humanized" by grafting the complementarity determining regions (CDRs) derived from a murine antibody, which confer binding specificity for an antigen, into human-derived V region framework regions and human-derived constant regions. Fragments of these molecules may be generated by proteolytic digestion, or optionally, by proteolytic digestion followed by mild reduction of disulfide bonds and alkylation. Alternatively, such fragments may also be generated by recombinant genetic engineering techniques.

Certain preferred antibodies are those antibodies that inhibit or block a TGF-beta binding protein activity within an *in vitro* assay, as described herein. Binding properties of an antibody to a TGF-beta binding protein may generally be assessed using immunodetection methods including, for example, an enzyme-linked immunosorbent assay (ELISA), immunoprecipitation, immunoblotting, countercurrent immunoelectrophoresis, radioimmunoassays, dot blot assays, inhibition or competition assays, and the like, which may be readily performed by those having ordinary skill in the art (*see, e.g.,* U.S. Patent Nos. 4,376,110 and 4,486,530; Harlow et al., *Antibodies: A Laboratory Manual,* Cold Spring Harbor Laboratory (1988)).

An immunogen may be comprised of cells expressing a TGF-beta binding protein such as a SOST polypeptide, purified or partially purified SOST polypeptide, or variants or fragments (*i.e.*, peptides) thereof, or peptides derived from a SOST polypeptide. Such peptides may be generated by proteolytic cleavage of a larger polypeptide, by recombinant molecular methodologies, or may be chemically synthesized. For instance, nucleic acid sequences encoding SOST polypeptide are provided herein, such that those skilled in the art may routinely prepare SOST polypeptide for use as immunogens. Peptides may be chemically synthesized by methods as described herein and known in the art. Alternatively, peptides may be generated by proteolytic cleavage of a SOST polypeptide, and individual peptides isolated by methods known in the art such as polyacrylamide gel electrophoresis or any number of liquid chromatography or other separation methods. Peptides useful as immunogens typically may have an amino acid sequence of at least 4 or 5 consecutive amino acids from a SOST polypeptide amino acid

sequence such as those described herein, and preferably have at least 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 18, 19 or 20 consecutive amino acids of a SOST polypeptide. Certain other preferred peptide immunogens comprise at least 6 but no more than 12 or more consecutive amino acids of a SOST polypeptide sequence, and other preferred peptide immunogens comprise at least 20 but no more than 75 consecutive amino acids, and other preferred peptide immunogens comprise at least 21 but no more than 50 consecutive amino acids of a SOST polypeptide. Other preferred peptide immunogens comprise 21-25, 26-30, 31-35, 36-40, 41-50, or any whole integer number of amino acids between and including 21 and 100 consecutive amino acids, and between 100 and 190 consecutive amino acids of a SOST polypeptide sequence.

Polyclonal antibodies that bind specifically to SOST can be prepared using methods described herein and well-known to persons skilled in the art (*see*, for example, Green et al., "Production of Polyclonal Antisera," in *Immunochemical Protocols* (Manson, ed.), pages 1-5 (Humana Press 1992); Harlow et al., *Antibodies: A Laboratory Manual,* Cold Spring Harbor Laboratory (1988); Williams et al., "Expression of foreign proteins in *E. coli* using plasmid vectors and purification of specific polyclonal antibodies," in *DNA Cloning 2: Expression Systems, 2nd Edition*, Glover et al. (eds.), page 15 (Oxford University Press 1995)). Antibodies to a TGF-beta binding-protein can be obtained, for example, by immunizing an animal with the TGF-beta binding-protein product of an expression vector, or by immunizing with an isolated TGF-beta binding protein or a peptide fragment thereof, as described herein. Although polyclonal antibodies are typically raised in animals such as rats, mice, rabbits, goats, cattle, or sheep, an anti-TGF-beta binding-protein antibody of the present invention may also be obtained from a subhuman primate. General techniques for raising diagnostically and therapeutically useful antibodies in baboons may be found, for example, in WO 91/11465 (1991) and in Losman et al., *Int. J. Cancer 46*:310, 1990.

Preparation of an immunogen for injection into animals may include covalent coupling of the TGF-beta binding protein (or variant or fragment thereof), to another immunogenic protein, for example, a carrier protein such as keyhole limpet hemocyanin (KLH) or bovine serum albumin (BSA) or the like. A polypeptide or peptide immunogen may include one or more additional amino acids at either the N-terminal or C-terminal end that facilitate the conjugation procedure (*e.g.*, the addition of a cysteine to facilitate conjugation of a peptide to KLH). Other amino acid residues within a polypeptide or peptide may be substituted to prevent conjugation at that particular amino acid position to a carrier polypeptide (*e.g.*, substituting a serine residue for cysteine at internal positions of a polypeptide/peptide) or may be substituted to

facilitate solubility or to increase immunogenicity.

TGF-beta binding protein peptide, polypeptide, or TGF-beta binding protein-expressing cells to be used as an immunogen may be emulsified in an adjuvant, for example, Freund's complete or incomplete adjuvant or the Ribi Adjuvant System (Corixa Corporation, Seattle, WA). *See also, e.g.*, Harlow et al., *supra*. The immunogen may be injected into the animal via any number of different routes, including intraperitoneally, intramuscularly, intraocularly, intradermally, or subcutaneously. In general, after the first injection, animals receive one or more booster immunizations according to a preferred schedule that may vary according to, *inter alia*, the antigen, the adjuvant (if any), and/or the particular animal species. The immune response may be monitored by periodically bleeding the animal and preparing and analyzing sera in an immunoassay, such as an ELISA or Ouchterlony diffusion assay, or the like, to determine the specific antibody titer. Once an adequate antibody titer is established, the animals may be bled periodically to accumulate the polyclonal antisera or may be exsanguinated. Polyclonal antibodies that bind specifically to the TGF-beta binding protein or peptide may then be purified from such antisera, for example, by affinity chromatography using protein A. Alternatively, affinity chromatography may be performed wherein the TGF-beta binding protein or peptide or an antibody specific for an Ig constant region of the particular immunized animal species is immobilized on a suitable solid support.

Antibodies for use in the invention include monoclonal antibodies that are prepared by conventional immunization and cell fusion procedures as described herein an known in the art. Monoclonal anti-TGF-beta binding-protein antibodies may be generated using a variety of techniques. Monoclonal antibodies that bind to specific antigens may be obtained by methods known to those skilled in the art (*see*, for example, Kohler et al., *Nature* 256:495, 1975; Coligan et al. (eds.), *Current Protocols in Immunology*, 1:2.5.1-2.6.7 (John Wiley & Sons 1991); U.S. Patent Nos. RE 32,011, 4,902,614, 4,543,439, and 4,411,993; *Monoclonal Antibodies, Hybridomas: A New Dimension in Biological Analyses*, Plenum Press, Kennett, McKearn, and Bechtol (eds.) (1980); and *Antibodies: A Laboratory Manual*, Harlow and Lane (eds.), Cold Spring Harbor Laboratory Press (1988); Picksley et al., "Production of monoclonal antibodies against proteins expressed in *E. coli*," in *DNA Cloning 2: Expression Systems, 2nd Edition*, Glover et al. (eds.), page 93 (Oxford University Press 1995)). Antibody fragments may be derived therefrom using any suitable standard technique such as proteolytic digestion, or optionally, by proteolytic digestion (for example, using papain or pepsin) followed by mild reduction of disulfide bonds and alkylation. Alternatively, such fragments may also be

generated by recombinant genetic engineering techniques.

Briefly, monoclonal antibodies can be obtained by injecting an animal, for example, a rat, hamster, or preferably a mouse, with an immunogen comprising a TGF-beta binding-protein gene product, or peptide fragment thereof, according to methods known in the art and described herein. The presence of specific antibody production may be monitored after the initial injection (injections may be administered by any one of several routes as described herein for generation of polyclonal antibodies) and/or after a booster injection by obtaining a serum sample and detecting the presence of an antibody that binds to a TGF-beta binding-protein or peptide using any one of several immunodetection methods known in the art and described herein. From animals producing antibodies that bind to the TGF-beta binding protein, lymphoid cells, most commonly cells from the spleen or lymph node, are removed to obtain B-lymphocytes. The B-lymphocytes are then fused with a drug-sensitized myeloma cell fusion partner, preferably one that is syngeneic with the immunized animal and that optionally has other desirable properties (*e.g.,* inability to express endogenous Ig gene products, *e.g.,* P3X63 - Ag 8.653 (ATCC No. CRL 1580); NS0, SP20) to produce hybridomas, which are immortal eukaryotic cell lines. The lymphoid (*e.g.*, spleen) cells and the myeloma cells may be combined for a few minutes with a membrane fusion-promoting agent, such as polyethylene glycol or a nonionic detergent, and then plated at low density on a selective medium that supports the growth of hybridoma cells but not unfused myeloma cells. A preferred selection media is HAT (hypoxanthine, aminopterin, thymidine). After a sufficient time, usually about one to two weeks, colonies of cells are observed. Single colonies are isolated, and antibodies produced by the cells may be tested for binding activity to the TGF-beta binding protein, or variant or fragment thereof, using any one of a variety of immunoassays known in the art and described herein. Hybridomas producing monoclonal antibodies with high affinity and specificity for SOST are preferred. Hybridomas that produce monoclonal antibodies that specifically bind to a TGF-beta binding protein or variant or fragment thereof are therefore contemplated by the present invention. The hybridomas are cloned (*e.g.*, by limited dilution cloning or by soft agar plaque isolation) and positive clones that produce an antibody specific to the antigen are selected and cultured. Antibodies that block, inhibit, or impair binding of the TGF-beta binding protein to a TGF-beta family member are preferred.

The monoclonal antibodies from the hybridoma cultures may be isolated from the supernatants of hybridoma cultures. An alternative method for production of a murine monoclonal antibody is to inject the hybridoma cells into the peritoneal cavity of a syngeneic

mouse, for example, a mouse that has been treated (*e.g.*, pristane-primed) to promote formation of ascites fluid containing the monoclonal antibody. Monoclonal antibodies can be isolated and purified by a variety of well-established techniques. Such isolation techniques include affinity chromatography with Protein-A Sepharose, size-exclusion chromatography, and ion-exchange chromatography (*see*, for example, Coligan at pages 2.7.1-2.7.12 and pages 2.9.1-2.9.3; Baines et al., "Purification of Immunoglobulin G (IgG)," in *Methods in Molecular Biology, Vol. 10*, pages 79-104 (The Humana Press, Inc. 1992)). Monoclonal antibodies may be purified by affinity chromatography using an appropriate ligand selected based on particular properties of the antibody (*e.g.*, heavy or light chain isotype, binding specificity, etc.). Examples of a suitable ligand, immobilized on a solid support, include Protein A, Protein G, an anti-constant region (light chain or heavy chain) antibody, an anti-idiotype antibody, and a TGF-beta binding protein, or fragment or variant thereof.

In addition, an anti-TGF-beta binding-protein antibody of the present invention may be a human monoclonal antibody. Human monoclonal antibodies may be generated by any number of techniques with which those having ordinary skill in the art will be familiar. Such methods include, but are not limited to, Epstein Barr Virus (EBV) transformation of human peripheral blood cells (*e.g.*, containing B lymphocytes), *in vitro* immunization of human B cells, fusion of spleen cells from immunized transgenic mice carrying inserted human immunoglobulin genes, isolation from human immunoglobulin V region phage libraries, or other procedures as known in the art and based on the disclosure herein. For example, human monoclonal antibodies may be obtained from transgenic mice that have been engineered to produce specific human antibodies in response to antigenic challenge. Methods for obtaining human antibodies from transgenic mice are described, for example, by Green et al., *Nature Genet.* 7:13, 1994; Lonberg et al., *Nature* 368:856, 1994; Taylor et al., *Int. Immun.* 6:579, 1994; U.S. Patent No. 5,877,397; Bruggemann et al., 1997 *Curr. Opin. Biotechnol. 8*:455-58; Jakobovits et al., 1995 *Ann. N. Y. Acad. Sci. 764*:525-35. In this technique, elements of the human heavy and light chain locus are introduced into strains of mice derived from embryonic stem cell lines that contain targeted disruptions of the endogenous heavy chain and light chain loci. (*See also* Bruggemann et al., *Curr. Opin. Biotechnol.* 8:455-58 (1997)). For example, human immunoglobulin transgenes may be mini-gene constructs, or transloci on yeast artificial chromosomes, which undergo B cell-specific DNA rearrangement and hypermutation in the mouse lymphoid tissue. Human monoclonal antibodies may be obtained by immunizing the transgenic mice, which may then produce human antibodies specific for the antigen. Lymphoid cells of the immunized transgenic

mice can be used to produce human antibody-secreting hybridomas according to the methods described herein. Polyclonal sera containing human antibodies may also be obtained from the blood of the immunized animals.

Another method for generating human TGF-beta binding protein specific monoclonal antibodies includes immortalizing human peripheral blood cells by EBV transformation. *See, e.g.*, U.S. Patent No. 4,464,456. Such an immortalized B cell line (or lymphoblastoid cell line) producing a monoclonal antibody that specifically binds to a TGF-beta binding protein (or a variant or fragment thereof) can be identified by immunodetection methods as provided herein, for example, an ELISA, and then isolated by standard cloning techniques. The stability of the lymphoblastoid cell line producing an anti-TGF-beta binding protein antibody may be improved by fusing the transformed cell line with a murine myeloma to produce a mouse-human hybrid cell line according to methods known in the art (*see, e.g.*, Glasky et al., *Hybridoma* 8:377-89 (1989)). Still another method to generate human monoclonal antibodies is *in vitro* immunization, which includes priming human splenic B cells with antigen, followed by fusion of primed B cells with a heterohybrid fusion partner. *See, e.g.*, Boerner et al., 1991 *J. Immunol. 147*:86-95.

In certain embodiments, a B cell that is producing an anti-SOST antibody is selected and the light chain and heavy chain variable regions are cloned from the B cell according to molecular biology techniques known in the art (WO 92/02551; US patent 5,627,052; Babcook et al., *Proc. Natl. Acad. Sci. USA* 93:7843-48 (1996)) and described herein. Preferably B cells from an immunized animal are isolated from the spleen, lymph node, or peripheral blood sample by selecting a cell that is producing an antibody that specifically binds to SOST. B cells may also be isolated from humans, for example, from a peripheral blood sample. Methods for detecting single B cells that are producing an antibody with the desired specificity are well known in the art, for example, by plaque formation, fluorescence-activated cell sorting, in vitro stimulation followed by detection of specific antibody, and the like. Methods for selection of specific antibody producing B cells include, for example, preparing a single cell suspension of B cells in soft agar that contains SOST or a peptide fragment thereof. Binding of the specific antibody produced by the B cell to the antigen results in the formation of a complex, which may be visible as an immunoprecipitate. After the B cells producing the specific antibody are selected, the specific antibody genes may be cloned by isolating and amplifying DNA or mRNA according to methods known in the art and described herein.

For particular uses, fragments of anti-TGF-beta binding protein antibodies may

be desired. Antibody fragments, $F(ab')_2$, Fab, Fab', Fv, Fc, Fd, retain the antigen binding site of the whole antibody and therefore bind to the same epitope. These antigen-binding fragments derived from an antibody can be obtained, for example, by proteolytic hydrolysis of the antibody, for example, pepsin or papain digestion of whole antibodies according to conventional methods. As an illustration, antibody fragments can be produced by enzymatic cleavage of antibodies with pepsin to provide a 5S fragment denoted $F(ab')_2$. This fragment can be further cleaved using a thiol reducing agent to produce 3.5S Fab' monovalent fragments. Optionally, the cleavage reaction can be performed using a blocking group for the sulfhydryl groups that result from cleavage of disulfide linkages. As an alternative, an enzymatic cleavage using papain produces two monovalent Fab fragments and an Fc fragment directly. These methods are described, for example, by Goldenberg, U.S. patent No. 4,331,647, Nisonoff et al., *Arch. Biochem. Biophys. 89*:230, 1960; Porter, *Biochem. J. 73*:119, 1959; Edelman et al., in *Methods in Enzymology 1*:422 (Academic Press 1967); and by Coligan at pages 2.8.1-2.8.10 and 2.10.-2.10.4. Other methods for cleaving antibodies, such as separating heavy chains to form monovalent light-heavy chain fragments (Fd), further cleaving of fragments, or other enzymatic, chemical, or genetic techniques may also be used, so long as the fragments bind to the antigen that is recognized by the intact antibody.

An antibody fragment may also be any synthetic or genetically engineered protein that acts like an antibody in that it binds to a specific antigen to form a complex. For example, antibody fragments include isolated fragments consisting of the light chain variable region, "Fv" fragments consisting of the variable regions of the heavy and light chains, recombinant single chain polypeptide molecules in which light and heavy variable regions are connected by a peptide linker (scFv proteins), and minimal recognition units consisting of the amino acid residues that mimic the hypervariable region. The antibody of the present invention preferably comprises at least one variable region domain. The variable region domain may be of any size or amino acid composition and will generally comprise at least one hypervariable amino acid sequence responsible for antigen binding and which is adjacent to or in frame with one or more framework sequences. In general terms, the variable (V) region domain may be any suitable arrangement of immunoglobulin heavy ($V_H$) and/or light ($V_L$) chain variable domains. Thus, for example, the V region domain may be monomeric and be a $V_H$ or $V_L$ domain, which is capable of independently binding antigen with acceptable affinity. Alternatively, the V region domain may be dimeric and contain $V_H$-$V_H$, $V_H$-$V_L$, or $V_L$-$V_L$, dimers. Preferably, the V region dimer comprises at least one $V_H$ and at least one $V_L$ chain that are non-covalently associated (hereinafter referred to

as $F_V$). If desired, the chains may be covalently coupled either directly, for example via a disulfide bond between the two variable domains, or through a linker, for example a peptide linker, to form a single chain Fv ($scF_V$).

The variable region domain may be any naturally occurring variable domain or an engineered version thereof. By engineered version is meant a variable region domain that has been created using recombinant DNA engineering techniques. Such engineered versions include those created, for example, from a specific antibody variable region by insertions, deletions, or changes in or to the amino acid sequences of the specific antibody. Particular examples include engineered variable region domains containing at least one CDR and optionally one or more framework amino acids from a first antibody and the remainder of the variable region domain from a second antibody.

The variable region domain may be covalently attached at a C-terminal amino acid to at least one other antibody domain or a fragment thereof. Thus, for example, a $V_H$ domain that is present in the variable region domain may be linked to an immunoglobulin $C_H1$ domain, or a fragment thereof. Similarly a $V_L$ domain may be linked to a $C_K$ domain or a fragment thereof. In this way, for example, the antibody may be a Fab fragment wherein the antigen binding domain contains associated $V_H$ and $V_L$ domains covalently linked at their C-termini to a CH1 and $C_K$ domain, respectively. The CH1 domain may be extended with further amino acids, for example to provide a hinge region or a portion of a hinge region domain as found in a Fab' fragment, or to provide further domains, such as antibody CH2 and CH3 domains.

Another form of an antibody fragment is a peptide comprising for a single complementarity-determining region (CDR). CDR peptides ("minimal recognition units") can be obtained by constructing polynucleotides that encode the CDR of an antibody of interest. Such polynucleotides are prepared, for example, by using the polymerase chain reaction to synthesize the variable region using mRNA of antibody-producing cells as a template (*see*, for example, Larrick et al., *Methods: A Companion to Methods in Enzymology 2*:106, 1991; Courtenay-Luck, "Genetic Manipulation of Monoclonal Antibodies," in *Monoclonal Antibodies: Production, Engineering and Clinical Application*, Ritter et al. (eds.), page 166 (Cambridge University Press 1995); and Ward et al., "Genetic Manipulation and Expression of Antibodies," in *Monoclonal Antibodies: Principles and Applications*, Birch et al., (eds.), page 137 (Wiley-Liss, Inc. 1995)).

Alternatively, the antibody may be a recombinant or engineered antibody obtained by the use of recombinant DNA techniques involving the manipulation and re-expression of DNA encoding antibody variable and/or constant regions. Such DNA is known and/or is readily

available from DNA libraries including for example phage-antibody libraries (*see* Chiswell and McCafferty, *Tibtech.* 10:80-84 (1992)) or if desired can be synthesized. Standard molecular biology and/or chemistry procedures may be used to sequence and manipulate the DNA, for example, to introduce codons to create cysteine residues, or to modify, add or delete other amino acids or domains as desired.

Chimeric antibodies, specific for a TGF-beta binding protein, and which include humanized antibodies, may also be generated according to the present invention. A chimeric antibody has at least one constant region domain derived from a first mammalian species and at least one variable region domain derived from a second, distinct mammalian species (*see, e.g.,* Morrison et al., *Proc. Natl. Acad. Sci. USA*, 81:6851-55 (1984)). In preferred embodiments, a chimeric antibody may be constructed by cloning the polynucleotide sequence that encodes at least one variable region domain derived from a non-human monoclonal antibody, such as the variable region derived from a murine, rat, or hamster monoclonal antibody, into a vector containing a nucleotide sequence that encodes at least one human constant region (s*ee, e.g.,* Shin et al., *Methods Enzymol.* 178:459-76 (1989); Walls et al., *Nucleic Acids Res.* 21:2921-29 (1993)). By way of example, the polynucleotide sequence encoding the light chain variable region of a murine monoclonal antibody may be inserted into a vector containing a nucleotide sequence encoding the human kappa light chain constant region sequence. In a separate vector, the polynucleotide sequence encoding the heavy chain variable region of the monoclonal antibody may be cloned in frame with sequences encoding a human IgG constant region, for example, the human IgG1 constant region. The particular human constant region selected may depend upon the effector functions desired for the particular antibody (*e.g.*, complement fixing, binding to a particular Fc receptor, etc.). Preferably, the constructed vectors will be transfected into eukaryotic cells for stable expression of the chimeric antibody. Another method known in the art for generating chimeric antibodies is homologous recombination (*e.g.*, U.S. Patent No. 5,482,856).

A non-human/human chimeric antibody may be further genetically engineered to create a "humanized" antibody. Such a humanized antibody may comprise a plurality of CDRs derived from an immunoglobulin of a non-human mammalian species, at least one human variable framework region, and at least one human immunoglobulin constant region. Useful strategies for designing humanized antibodies may include, for example by way of illustration and not limitation, identification of human variable framework regions that are most homologous to the non-human framework regions of the chimeric antibody. Without wishing to

be bound by theory, such a strategy may increase the likelihood that the humanized antibody will retain specific binding affinity for a TGF-beta binding protein, which in some preferred embodiments may be substantially the same affinity for a TGF-beta binding protein or variant or fragment thereof, and in certain other preferred embodiments may be a greater affinity for TGF-beta binding protein. *See, e.g.*, Jones et al., 1986 *Nature* 321:522-25; Riechmann et al., 1988 *Nature* 332:323-27. Designing such a humanized antibody may therefore include determining CDR loop conformations and structural determinants of the non-human variable regions, for example, by computer modeling, and then comparing the CDR loops and determinants to known human CDR loop structures and determinants. *See, e.g.*, Padlan et al., 1995 *FASEB* 9:133-39; Chothia et al., 1989 *Nature*, 342:377-383. Computer modeling may also be used to compare human structural templates selected by sequence homology with the non-human variable regions. *See, e.g.*, Bajorath et al., 1995 *Ther. Immunol. 2*:95-103; EP-0578515-A3. If humanization of the non-human CDRs results in a decrease in binding affinity, computer modeling may aid in identifying specific amino acid residues that could be changed by site-directed or other mutagenesis techniques to partially, completely or supra-optimally (*i.e.*, increase to a level greater than that of the non-humanized antibody) restore affinity. Those having ordinary skill in the art are familiar with these techniques, and will readily appreciate numerous variations and modifications to such design strategies.

One such method for preparing a humanized antibody is called veneering. As used herein, the terms "veneered FRs" and "recombinantly veneered FRs" refer to the selective replacement of FR residues from, *e.g.*, a rodent heavy or light chain V region, with human FR residues in order to provide a xenogeneic molecule comprising an antigen-binding site that retains substantially all of the native FR polypeptide folding structure. Veneering techniques are based on the understanding that the ligand binding characteristics of an antigen-binding site are determined primarily by the structure and relative disposition of the heavy and light chain CDR sets within the antigen-binding surface. Davies et al., *Ann. Rev. Biochem. 59*:439-73, 1990. Thus, antigen binding specificity can be preserved in a humanized antibody only wherein the CDR structures, their interaction with each other, and their interaction with the rest of the V region domains are carefully maintained. By using veneering techniques, exterior (*e.g.*, solvent-accessible) FR residues that are readily encountered by the immune system are selectively replaced with human residues to provide a hybrid molecule that comprises either a weakly immunogenic, or substantially non-immunogenic veneered surface.

The process of veneering makes use of the available sequence data for human

antibody variable domains compiled by Kabat et al., in *Sequences of Proteins of Immunological Interest*, 4th ed., (U.S. Dept. of Health and Human Services, U.S. Government Printing Office, 1987), updates to the Kabat database, and other accessible U.S. and foreign databases (both nucleic acid and protein). Solvent accessibilities of V region amino acids can be deduced from the known three-dimensional structure for human and murine antibody fragments. Initially, the FRs of the variable domains of an antibody molecule of interest are compared with corresponding FR sequences of human variable domains obtained from the above-identified sources. The most homologous human V regions are then compared residue by residue to corresponding murine amino acids. The residues in the murine FR that differ from the human counterpart are replaced by the residues present in the human moiety using recombinant techniques well known in the art. Residue switching is only carried out with moieties which are at least partially exposed (solvent accessible), and care is exercised in the replacement of amino acid residues that may have a significant effect on the tertiary structure of V region domains, such as proline, glycine, and charged amino acids.

In this manner, the resultant "veneered" antigen-binding sites are thus designed to retain the rodent CDR residues, the residues substantially adjacent to the CDRs, the residues identified as buried or mostly buried (solvent inaccessible), the residues believed to participate in non-covalent (*e.g.*, electrostatic and hydrophobic) contacts between heavy and light chain domains, and the residues from conserved structural regions of the FRs which are believed to influence the "canonical" tertiary structures of the CDR loops. These design criteria are then used to prepare recombinant nucleotide sequences that combine the CDRs of both the heavy and light chain of a antigen-binding site into human-appearing FRs that can be used to transfect mammalian cells for the expression of recombinant human antibodies that exhibit the antigen specificity of the rodent antibody molecule.

An additional method for selecting antibodies that specifically bind to a TGF-beta binding protein or variant or fragment thereof is by phage display. *See, e.g.*, Winter et al., 1994 *Annu. Rev. Immunol.* 12:433-55; Burton et al., 1994 *Adv. Immunol.* 57:191-280. Human or murine immunoglobulin variable region gene combinatorial libraries may be created in phage vectors that can be screened to select Ig fragments (Fab, Fv, sFv, or multimers thereof) that bind specifically to TGF-beta binding protein or variant or fragment thereof. *See, e.g.*, U.S. Patent No. 5,223,409; Huse et al., 1989 *Science* 246:1275-81; Sastry et al., *Proc. Natl. Acad. Sci. USA* 86:5728-32 (1989); Alting-Mees et al., *Strategies in Molecular Biology* 3:1-9 (1990); Kang et al., 1991 *Proc. Natl. Acad. Sci. USA* 88:4363-66; Hoogenboom et al., 1992 *J. Molec. Biol.*

227:381-388; Schlebusch et al., 1997 *Hybridoma* 16:47-52 and references cited therein. For example, a library containing a plurality of polynucleotide sequences encoding Ig variable region fragments may be inserted into the genome of a filamentous bacteriophage, such as M13 or a variant thereof, in frame with the sequence encoding a phage coat protein. A fusion protein may be a fusion of the coat protein with the light chain variable region domain and/or with the heavy chain variable region domain. According to certain embodiments, immunoglobulin Fab fragments may also be displayed on a phage particle (*see, e.g.,* U.S. Patent No. 5,698,426).

Heavy and light chain immunoglobulin cDNA expression libraries may also be prepared in lambda phage, for example, using λImmunoZap™(H) and λImmunoZap™(L) vectors (Stratagene, La Jolla, California). Briefly, mRNA is isolated from a B cell population, and used to create heavy and light chain immunoglobulin cDNA expression libraries in the λ ImmunoZap(H) and λImmunoZap(L) vectors. These vectors may be screened individually or co-expressed to form Fab fragments or antibodies (*see* Huse et al., *supra*; *see also* Sastry et al., *supra*). Positive plaques may subsequently be converted to a non-lytic plasmid that allows high level expression of monoclonal antibody fragments from *E. coli.*

Similarly, portions or fragments, such as Fab and Fv fragments, of antibodies may also be constructed using conventional enzymatic digestion or recombinant DNA techniques to incorporate the variable regions of a gene that encodes a antibody specific for a TGF-beta binding protein. Within one embodiment, in a hybridoma the variable regions of a gene expressing a monoclonal antibody of interest are amplified using nucleotide primers. These primers may be synthesized by one of ordinary skill in the art, or may be purchased from commercially available sources. (*See, e.g.,* Stratagene (La Jolla, California), which sells primers for mouse and human variable regions including, among others, primers for $V_{Ha}$, $V_{Hb}$, $V_{Hc}$, $V_{Hd}$, $C_{H1}$, $V_L$ and $C_L$ regions.) These primers may be used to amplify heavy or light chain variable regions, which may then be inserted into vectors such as ImmunoZAP™ H or ImmunoZAP™ L (Stratagene), respectively. These vectors may then be introduced into *E. coli*, yeast, or mammalian-based systems for expression. Large amounts of a single-chain protein containing a fusion of the $V_H$ and $V_L$ domains may be produced using these methods (*see* Bird et al., *Science 242*:423-426, 1988). In addition, such techniques may be used to humanize a non-human antibody V region without altering the binding specificity of the antibody.

In certain particular embodiments of the invention, combinatorial phage libraries may also be used for humanization of non-human variable regions. *See, e.g.,* Rosok et al., 1996 *J. Biol. Chem. 271*:22611-18; Rader et al., 1998 *Proc. Natl. Acad. Sci. USA 95*:8910-15. A

phage library may be screened to select an Ig variable region fragment of interest by immunodetection methods known in the art and described herein, and the DNA sequence of the inserted immunoglobulin gene in the phage so selected may be determined by standard techniques. *See,* Sambrook et al., 2001 *Molecular Cloning: A Laboratory Manual,* Cold Spring Harbor Press. The selected Ig-encoding sequence may then be cloned into another suitable vector for expression of the Ig fragment or, optionally, may be cloned into a vector containing Ig constant regions, for expression of whole immunoglobulin chains.

In certain other embodiments, the invention contemplates SOST-specific antibodies that are multimeric antibody fragments. Useful methodologies are described generally, for example in Hayden et al. 1997, *Curr Opin. Immunol.* 9:201-12; Coloma et al., 1997 *Nat. Biotechnol.* 15:159-63. For example, multimeric antibody fragments may be created by phage techniques to form miniantibodies (U.S. Patent No. 5,910 573) or diabodies (Holliger et al., 1997, *Cancer Immunol. Immunother.* 45:128-130).

In certain embodiments of the invention, an antibody specific for SOST may be an antibody that is expressed as an intracellular protein. Such intracellular antibodies are also referred to as intrabodies and may comprise an Fab fragment, or preferably comprise a scFv fragment (*see, e.g.*, Lecerf et al., *Proc. Natl. Acad. Sci. USA* 98:4764-49 (2001). The framework regions flanking the CDR regions can be modified to improve expression levels and solubility of an intrabody in an intracellular reducing environment (*see, e.g.*, Worn et al., *J. Biol. Chem.* 275:2795-803 (2000). An intrabody may be directed to a particular cellular location or organelle, for example by constructing a vector that comprises a polynucleotide sequence encoding the variable regions of an intrabody that may be operatively fused to a polynucleotide sequence that encodes a particular target antigen within the cell (*see, e.g.*, Graus-Porta et al., *Mol. Cell Biol.* 15:1182-91 (1995); Lener et al., *Eur. J. Biochem.* 267:1196-205 (2000)). An intrabody may be introduced into a cell by a variety of techniques available to the skilled artisan including via a gene therapy vector, or a lipid mixture (*e.g.,* Provectin™ manufactured by Imgenex Corporation, San Diego, CA), or according to photochemical internalization methods.

Introducing amino acid mutations into an immunoglobulin molecule specific for a TGF-beta binding protein may be useful to increase the specificity or affinity for TGF-beta binding protein or to alter an effector function. Immunoglobulins with higher affinity for TGF-beta binding protein may be generated by site-directed mutagenesis of particular residues. Computer assisted three-dimensional molecular modeling may be employed to identify the amino acid residues to be changed, in order to improve affinity for the TGF-beta binding protein.

*See, e.g.*, Mountain et al., 1992, *Biotechnol. Genet. Eng. Rev.* 10: 1-142. Alternatively, combinatorial libraries of CDRs may be generated in M13 phage and screened for immunoglobulin fragments with improved affinity. *See, e.g.*, Glaser et al., 1992, *J. Immunol.* 149:3903-3913; Barbas et al., 1994 *Proc. Natl. Acad. Sci. USA* 91:3809-13; U.S. Patent No. 5,792, 456.

Effector functions may also be altered by site-directed mutagenesis. *See, e.g.*, Duncan et al., 1988 *Nature* 332:563-64; Morgan et al., 1995 *Immunology* 86:319-24; Eghtedarzedeh-Kondri et al., 1997 *Biotechniques* 23:830-34. For example, mutation of the glycosylation site on the Fc portion of the immunoglobulin may alter the ability of the immunoglobulin to fix complement. *See, e.g.,* Wright et al., 1997 *Trends Biotechnol.* 15:26-32. Other mutations in the constant region domains may alter the ability of the immunoglobulin to fix complement, or to effect antibody-dependent cellular cytotoxicity. *See, e.g.*, Duncan et al., 1988 *Nature* 332:563-64; Morgan et al., 1995 *Immunology 86*:319-24; Sensel et al., 1997 *Mol. Immunol.* 34:1019-29.

According to certain embodiments, non-human, human, or humanized heavy chain and light chain variable regions of any of the Ig molecules described herein may be constructed as single chain Fv (scFv) polypeptide fragments (single chain antibodies). *See, e.g.*, Bird et al., 1988 *Science* 242:423-426; Huston et al., 1988 *Proc. Natl. Acad. Sci. USA* 85:5879-5883. Multi-functional scFv fusion proteins may be generated by linking a polynucleotide sequence encoding an scFv polypeptide in-frame with at least one polynucleotide sequence encoding any of a variety of known effector proteins. These methods are known in the art, and are disclosed, for example, in EP-B1-0318554, U.S. Patent No. 5,132,405, U.S. Patent No. 5,091,513, and U.S. Patent No. 5,476,786. By way of example, effector proteins may include immunoglobulin constant region sequences. *See, e.g.*, Hollenbaugh et al., 1995 *J. Immunol. Methods* 188:1-7. Other examples of effector proteins are enzymes. As a non-limiting example, such an enzyme may provide a biological activity for therapeutic purposes (*see, e.g.,* Siemers et al., 1997 *Bioconjug. Chem.* 8:510-19), or may provide a detectable activity, such as horseradish peroxidase-catalyzed conversion of any of a number of well-known substrates into a detectable product, for diagnostic uses. Still other examples of scFv fusion proteins include Ig-toxin fusions, or immunotoxins, wherein the scFv polypeptide is linked to a toxin.

The scFv or any antibody fragment described herein may, in certain embodiments, be fused to peptide or polypeptide domains that permits detection of specific

binding between the fusion protein and antigen (*e.g.*, a TGF-beta binding protein). For example, the fusion polypeptide domain may be an affinity tag polypeptide for detecting binding of the scFv fusion protein to a TGF-beta binding protein by any of a variety of techniques with which those skilled in the art will be familiar. Examples of a peptide tag, include avidin, streptavidin or His (*e.g.*, polyhistidine). Detection techniques may also include, for example, binding of an avidin or streptavidin fusion protein to biotin or to a biotin mimetic sequence (*see, e.g.*, Luo et al., 1998 *J. Biotechnol. 65*:225 and references cited therein), direct covalent modification of a fusion protein with a detectable moiety (*e.g.*, a labeling moiety), non-covalent binding of the fusion protein to a specific labeled reporter molecule, enzymatic modification of a detectable substrate by a fusion protein that includes a portion having enzyme activity, or immobilization (covalent or non-covalent) of the fusion protein on a solid-phase support. Other useful affinity polypeptides for construction of scFv fusion proteins may include streptavidin fusion proteins, as disclosed, for example, in WO 89/03422, U.S. 5,489,528, U.S. 5,672,691, WO 93/24631, U.S. 5,168,049, U.S. 5,272,254; avidin fusion proteins (*see, e.g.*, EP 511,747); an enzyme such as glutathione-S-transferase; and *Staphylococcus aureus* protein A polypeptide.

The polynucleotides encoding an antibody or fragment thereof that specifically bind a TGF-beta binding protein, as described herein, may be propagated and expressed according to any of a variety of well-known procedures for nucleic acid excision, ligation, transformation, and transfection using any number of known expression vectors. Thus, in certain embodiments expression of an antibody fragment may be preferred in a prokaryotic host, such as *Escherichia coli* (*see, e.g.*, Pluckthun et al., 1989 *Methods Enzymol.* 178:497-515). In certain other embodiments, expression of the antibody or a fragment thereof may be preferred in a eukaryotic host cell, including yeast (*e.g.*, *Saccharomyces cerevisiae*, *Schizosaccharomyces pombe*, and *Pichia pastoris*), animal cells (including mammalian cells) or plant cells. Examples of suitable animal cells include, but are not limited to, myeloma (such as a mouse NSO line), COS, CHO, or hybridoma cells. Examples of plant cells include tobacco, corn, soybean, and rice cells.

One or more replicable expression vectors containing DNA encoding a variable and/or constant region may be prepared and used to transform an appropriate cell line, for example, a non-producing myeloma cell line, such as a mouse NSO line or a bacteria, such as *E.coli*, in which production of the antibody will occur. In order to obtain efficient transcription and translation, the DNA sequence in each vector should include appropriate regulatory sequences, particularly a promoter and leader sequence operatively linked to the variable domain sequence.

Particular methods for producing antibodies in this way are generally well known and routinely used. For example, basic molecular biology procedures are described by Maniatis et al. (*Molecular Cloning, A Laboratory Manual*, 2nd ed., Cold Spring Harbor Laboratory, New York, 1989; *see also* Maniatis et al, 3rd ed., Cold Spring Harbor Laboratory, New York, (2001)). DNA sequencing can be performed as described in Sanger *et al* (PNAS 74:5463, (1977)) and the Amersham International plc sequencing handbook, and site directed mutagenesis can be carried out according to methods known in the art (Kramer et al., *Nucleic Acids Res.* 12:9441, (1984); Kunkel *Proc. Natl. Acad. Sci. USA* 82:488-92 (1985); Kunkel et al., *Methods in Enzymol.* 154:367-82 (1987); the Anglian Biotechnology Ltd handbook). Additionally, numerous publications describe techniques suitable for the preparation of antibodies by manipulation of DNA, creation of expression vectors, and transformation of appropriate cells (Mountain A and Adair, J R *in Biotechnology and Genetic Engineering Reviews* (ed. Tombs, M P, 10, Chapter 1, 1992, Intercept, Andover, UK); International Patent Specification No. WO 91/09967).

In certain embodiments, the antibody according to the invention may have one or more effector or reporter molecules attached to it. A reporter molecule may be a detectable moiety or label such as an enzyme, cytotoxic agent or other reporter molecule, including a dye, radionuclide, luminescent group, fluorescent group, or biotin, or the like. The TGF-beta binding protein-specific immunoglobulin or fragment thereof may be radiolabeled for diagnostic or therapeutic applications. Techniques for radiolabeling of antibodies are known in the art. *See, e.g.*, Adams 1998 *In Vivo* 12:11-21; Hiltunen 1993 *Acta Oncol. 32*:831-9. Therapeutic applications are described in greater detail below and may include use of the TGF-beta binding protein specific antibody (or fragment thereof) in conjunction with other therapeutic agents. The effector or reporter molecules may be attached to the antibody through any available amino acid side-chain, terminal amino acid, or carbohydrate functional group located in the antibody, provided that the attachment or attachment process does not adversely affect the binding properties such that the usefulness of the molecule is abrogated. Particular functional groups include, for example any free amino, imino, thiol, hydroxyl, carboxyl, or aldehyde group. Attachment of the antibody and the effector and/or reporter molecule(s) may be achieved via such groups and an appropriate functional group in the effector or reporter molecule. The linkage may be direct or indirect through spacing or bridging groups.

Effector molecules include, for example, antineoplastic agents, toxins (such as enzymatically active toxins of bacterial (such as *Pseudomonas aeruginosa* exotoxin A) or plant origin and fragments thereof (*e.g.*, ricin and fragments thereof, plant gelonin, bryodin from

*Bryonia dioica*, or the like. *See, e.g.*, Thrush et al., 1996 *Annu. Rev. Immunol. 14*:49-71; Frankel et al., 1996 *Cancer Res. 56*:926-32). Additional effector molecules include biologically active proteins (for example, enzymes), nucleic acids and fragments thereof, naturally occurring and synthetic polymers, for example, polysaccharides and polyalkylene polymers such as poly(ethylene glycol) and derivatives thereof, radionuclides, particularly radioiodide, and chelated metals. Suitable reporter groups include chelated metals, fluorescent compounds or compounds that may be detected by NMR or ESR spectroscopy. Particularly useful effector groups are calichaemicin and derivatives thereof (see, for example, South African Patent Specifications Nos. 85/8794, 88/8127 and 90/2839).

Numerous other toxins, including chemotherapeutic agents, anti-mitotic agents, antibiotics, inducers of apoptosis (or "apoptogens", *see, e.g.,* Green and Reed, 1998, *Science 281*:1309-1312), or the like, are known to those familiar with the art, and the examples provided herein are intended to be illustrative without limiting the scope and spirit of the invention. Particular antineoplastic agents include cytotoxic and cytostatic agents, for example alkylating agents, such as nitrogen mustards (*e.g.,* chlorambucil, melphalan, mechlorethamine, cyclophosphamide, or uracil mustard) and derivatives thereof, triethylenephosphoramide, triethylenethiophosphor-amide, busulphan, or cisplatin; antimetabolites, such as methotrexate, fluorouracil, floxuridine, cytarabine, mercaptopurine, thioguanine, fluoroacetic acid or fluorocitric acid, antibiotics, such as bleomycins (*e.g.,* bleomycin sulphate), doxorubicin, daunorubicin, mitomycins (*e.g.,* mitomycin C), actinomycins (*e.g.,* dactinomycin) plicamycin, calichaemicin and derivatives thereof, or esperamicin and derivatives thereof; mitotic inhibitors, such as etoposide, vincristine or vinblastine and derivatives thereof; alkaloids, such as ellipticine; polyols such as taxicin-I or taxicin-II; hormones, such as androgens (*e.g.,* dromostanolone or testolactone), progestins (*e.g.,* megestrol acetate or medroxyprogesterone acetate), estrogens (*e.g.,* dimethylstilbestrol diphosphate, polyestradiol phosphate or estramustine phosphate) or antiestrogens (*e.g.,* tamoxifen); anthraquinones, such as mitoxantrone, ureas, such as hydroxyurea; hydrazines, such as procarbazine; or imidazoles, such as dacarbazine.

Chelated metals useful as effector molecules include chelates of di-or tripositive metals having a coordination number from 2 to 8 inclusive. Particular examples of such metals include technetium (Tc), rhenium (Re), cobalt (Co), copper (Cu), gold (Au), silver (Ag), lead (Pb), bismuth (Bi), indium (In), gallium (Ga), yttrium (Y), terbium (Tb), gadolinium (Gd), and scandium (Sc). In general the metal is preferably a radionuclide. Particular radionuclides include $^{99m}Tc$, $^{186}Re$, $^{188}Re$, $^{58}Co$, $^{60}Co$, $^{67}Cu$, $^{195}Au$, $^{199}Au$, $^{110}Ag$, $^{203}Pb$, $^{206}Bi$, $^{207}Bi$, $^{111}In$, $^{67}Ga$, $^{68}Ga$,

$^{88}Y$, $^{90}Y$, $^{160}Tb$, $^{153}Gd$, and $^{47}Sc$. The chelated metal may be for example one of the above types of metal chelated with any suitable polydentate chelating agent, for example acyclic or cyclic polyamines, polyethers, (*e.g.,* crown ethers and derivatives thereof), polyamides; porphyrins; and carbocyclic derivatives. In general, the type of chelating agent will depend on the metal in use. One particularly useful group of chelating agents in conjugates according to the invention, however, comprises acyclic and cyclic polyamines, especially polyaminocarboxylic acids, for example diethylenetriaminepentaacetic acid and derivatives thereof, and macrocyclic amines, e.g. cyclic tri-aza and tetra-aza derivatives (for example, as described in International Patent Specification No. WO 92/22583); and polyamides, especially desferrioxamine and derivatives thereof.

When a thiol group in the antibody is used as the point of attachment, the effector molecule may be attached according to a reaction that occurs with a thiol-reactive group present in the effector or reporter molecule. Examples of such groups include an á-halocarboxylic acid or ester, such as iodoacetamide, an imide, such as maleimide, a vinyl sulphone, or a disulphide. These and other suitable linking procedures are generally and more particularly described in International Patent Specifications Nos. WO 93/06231, WO 92/22583, WO 90/091195, and WO 89/01476.

The invention also contemplates the generation of anti-idiotype antibodies that recognize an antibody (or antigen-binding fragment thereof) that specifically binds to a SOST polypeptide as provided herein, or a variant or fragment thereof. Anti-idiotype antibodies may be generated as polyclonal antibodies or as monoclonal antibodies by the methods described herein, using an anti- TGF-beta binding protein antibody (or antigen-binding fragment thereof) as immunogen. Anti-idiotype antibodies or fragments thereof may also be generated by any of the recombinant genetic engineering methods described above, or by phage display selection. An anti-idiotype antibody may react with the antigen binding site of the anti-SOST antibody such that binding of the antibody to a a SOST polypeptide is competitively inhibited. Alternatively, an anti-idiotype antibody as provided herein may not competitively inhibit binding of an anti-TGF-beta binding protein antibody to a TGF-beta binding protein.

In certain embodiments of the invention, an antibody that specifically binds to SOST may be used to detect expression of the SOST polypeptide. In certain particular embodiments, one antibody or a panel of antibodies may be exposed to cells that express a SOST polypeptide and expression of the SOST polypeptide may be determined by detection using another SOST specific antibody that binds to a different epitope than the antibody or antibodies first used in the assay.

ASSAYS FOR SELECTING AGENTS THAT INCREASE BONE DENSITY

As discussed above, the present invention provides methods for selecting and/or isolating agents that are capable of increasing bone density. In certain preferred embodiments, the agent is an antibody that specifically binds to SOST (a TGF-beta binding protein) or a variant or a fragment thereof. For example, within one embodiment of the present invention, methods are provided for determining whether an agent is capable of increasing bone mineral content, comprising the steps of (a) contacting or mixing a candidate agent with a TGF-beta binding protein and a member of the TGF-beta family of proteins and (b) determining whether the candidate agent stimulates signaling by the TGF-beta family of proteins, or impairs or inhibits the binding of the TGF-beta binding protein to one or more members of the TGF-beta family of proteins. Within certain embodiments, the agent enhances the ability of TGF-beta to function as a positive regulator of mesenchymal cell differentiation.

In a preferred embodiment of the invention, a method is provided for identifying an antibody that modulates a TGF-beta signaling pathway comprising contacting an antibody that specifically binds to a SOST polypeptide with a SOST peptide, including but not limited to the peptides disclosed herein, under conditions and for a time sufficient to permit formation of an antibody plus (+) SOST (antibody/SOST) complex and then detecting the level (*e.g.*, quantifying the amount) of the SOST/antibody complex to determine the presence of an antibody that modulates a TGF-beta signaling pathway. The method may be performed using SPR or any number of different immunoassays known in the art and disclosed herein, including an ELISA, immunoblot, or the like. A TGF-beta signaling pathway includes a signaling pathway by which a BMP binds to a type I and a type II receptor on a cell to stimulate or induce the pathway that modulates bone mineral content. In certain preferred embodiments of the invention, an antibody that specifically binds to SOST stimulates or enhances the pathway for increasing bone mineral content. Such an antibody may be identified using the methods disclosed herein to detect binding of an antibody to SOST specific peptides.

The subject invention methods may also be used for identifying antibodies that impair, inhibit (including competitively inhibit), or prevent binding of a BMP to a SOST polypeptide by detecting whether an antibody binds to SOST peptides that are located in regions or portions of regions on SOST to which a BMP binds, such as peptides at the amino terminal end of SOST and peptides that include amino terminal amino acid residues and a portion of the core region (docking core) of SOST (*e.g.*, SEQ ID NOs:2-19, 21-28, and 47-50). The methods of the present invention may also be used to identify an antibody that impairs, prevents, or

inhibits, formation of SOST homodimers. Such an antibody that binds specifically to SOST may be identified by detecting binding of the antibody to peptides that are derived from the core or the carboxy terminal region of SOST (*e.g.*, SEQ ID NOs: 29-46 and 51-54).

Within other embodiments of the invention, methods are provided for determining whether an agent is capable of increasing bone mineral content, comprising the steps of (a) contacting a candidate agent to cells that express a TGF-beta binding-protein and (b) determining whether the expression of the TGF-beta binding-protein in the exposed cells decreases or whether an activity of the TGF-beta binding protein decreases, and thereby determining whether the compound is capable of increasing bone mineral content. Within one embodiment, the cells may include spontaneously transformed or untransformed normal human bone from bone biopsies or rat parietal bone osteoblasts.

Immunoassays may be used for detecting and quantifying the expression of a TGF-beta binding protein and include, for example, Countercurrent Immuno-Electrophoresis (CIEP), radioimmunoassays, radioimmunoprecipitations, Enzyme-Linked Immuno-Sorbent Assays (ELISA), immunoblot assays such as dot blot assays and Western blots, inhibition or competition assays, and sandwich assays (*see* U.S. Patent Nos. 4,376,110 and 4,486,530; *see also Antibodies: A Laboratory Manual, supra*). Such immunoassays may use an antibody that is specific for a TGF-beta binding protein such as the anti-sclerostin antibodies described herein, or may use an antibody that is specific for a reporter molecule that is attached to the TGF-beta binding protein. The level of polypeptide expression may also be determined by quantifying the amount of TGF-beta binding protein that binds to a TGF-beta binding protein ligand. By way of example, binding of sclerostin in a sample to a BMP may be detected by surface plasmon resonance. Alternatively, the level of expression of mRNA encoding the specific TGF-beta binding protein may be quantified.

In other embodiments, an antibody specific for SOST may be used in a method, such as a competition assay, in which candidate agents are screened to identify an agent that will compete with the antibody for binding to the TGF-binding protein. The interaction between an antibody and a TGF-beta protein may be determined using immunoassay methods known in the art and described herein.

By way of example, a family member of the TGF-beta superfamily, such as a TGF-beta binding protein or a TGF-beta superfamily member that is a ligand of TGF-beta binding protein, is first bound to a solid phase, followed by addition of a candidate agent. A ligand of the TGF-beta superfamily member that is bound to the solid phase is added

concurrently or added in a subsequent step, the solid phase washed, and the quantity of ligand that bound to the family member determined, which indicates whether the candidate agent blocks binding of the ligand to the TGF-beta member. Alternatively, the ligand of the TGF-beta superfamily member may be attached to the solid phase, and the TGF-beta superfamily member may be added concurrently or subsequently to the addition of the candidate molecule. The amount of ligand that binds to the TGF-beta superfamily member can be measured by labeling the ligand with a detectable molecule according to methods known in the art and described herein. Alternatively, the binding of the ligand to the TGF-beta superfamily member may be measured by adding one or more detecting molecules, such as an antibody or fragment thereof that specifically binds to the ligand and quantifying the amount of the molecule that binds to the ligand. Agents that are suitable for use in increasing bone mineral content as described herein are those agents that decrease the binding of TGF-beta binding protein to its ligand that is a member of the TGF-beta superfamily in a statistically significant manner.

Within other embodiments of the invention, methods are provided for determining whether an agent is capable of increasing bone mineral content, comprising the steps of (a) contacting a candidate agent to cells that express a TGF-beta protein and (b) determining whether the activity of TGF-beta protein from the exposed cells is altered, and therefrom determining whether the compound is capable of increasing bone mineral content. Similar to the methods described herein, a wide variety of methods may be used to assess changes in TGF-beta binding-protein expression when a cell producing the TGF-beta binding protein is exposed to a selected test compound.

Within another embodiment of the present invention, methods are provided for determining whether an agent is capable of increasing bone mineral content, comprising the steps of (a) contacting a candidate agent with a TGF-beta-binding-protein and a selected member of the TGF-beta family of proteins, and (b) determining whether the selected agent up-regulates the signaling of the TGF-beta family of proteins or inhibits the binding of the TGF-beta binding-protein to the TGF-beta family member. Within certain embodiments, the molecule enhances the ability of a TGF-beta family member to function as a positive regulator of mesenchymal cell differentiation.

Similar to the above-described methods, a variety of methods may be used to assess stimulation of a TGF-beta family member by a test compound, such as an antibody that specifically binds to SOST. One such representative method (*see also* Durham et al., *Endo.* *136*:1374-1380) comprises attaching a TGF-beta family member, such as a BMP (*e.g.*, BMP-2,

BMP-4, BMP-5, BMP-6, BMP-7) to the solid phase at a concentration that is equivalent to its Kd. The dissociation constant (Kd) may be determined according to methods for measuring binding rate constants known in the art, such as surface plasmon resonance using a BIAcore instrument according to techniques known in the art and described by the manufacturer (Biosensor, Piscataway, NJ). A collection of antagonist candidate agents is then added at a fixed concentration (typically, 20 μM for small organic molecule collections (an isolated organic small molecule as used herein means that the molecule is greater than 90% pure as determined according to methods well known in the art (*e.g.*, NMR, melting point) and 1 μM for candidate antibodies). An agent is considered an antagonist of this interaction when the agent inhibits binding of the BMP to SOST, that is, a decrease in the level of binding is observed, by at least 40%, preferably 50% or 60%, and more preferably 80% or 90% compared to the level of BMP binding to SOST that is observed in the absence of the agent. Such an agent may be further evaluated as a potential inhibitor on the basis of titration studies according to which its inhibition constant and its influence on TGF-beta binding-protein binding affinity is determined. Comparable specificity control assays may also be conducted to establish the selectivity profile for the identified antagonist according to studies using assays dependent on the BMP ligand action (*e.g.* BMP/BMP receptor competition study).

Within yet other embodiments of the present invention, methods are provided for determining whether a candidate agent is capable of increasing bone mineral content, comprising the step of determining whether a candidate agent inhibits the binding of TGF-beta binding-protein to bone, or an analogue thereof. As used herein, it should be understood that bone or analogues thereof refers to hydroxyapatite, or a surface composed of a powdered form of bone, crushed bone or intact bone. Similar to the methods described herein, a wide variety of methods may be used to assess the inhibition of TGF-beta binding-protein localization to bone matrix (*see, e.g.,* Nicolas et al., *Calcif. Tissue Int.* 47:206-12 (1995)).

While the methods described herein may refer to the analysis of an individual candidate agent, the present invention should not be so limited. In particular, the agent may be contained within a mixture of candidate agents. As described herein, the candidate agents may be small organic molecules or may be antibodies or fragments thereof or other peptides or polypeptides. Antibodies or fragments may be identified by screening a library of antibodies or antibody fragments or prepared by methods described herein. Hence, the recited methods may further comprise the step of isolating an agent that inhibits the binding of TGF-beta binding-protein to a TGF-beta family member.

In one embodiment of the invention, an antibody or antigen-binding fragment thereof that specifically binds to a SOST polypeptide is capable of competitively inhibiting binding of a TGF-beta family member to the SOST polypeptide. The capability of the antibody or antibody fragment to impair or blocking binding of a TGF-beta family member, such as a BMP, to SOST may be determined according to any of the methods described herein. The antibody or fragment thereof that specifically binds to SOST may impair, block, or prevent binding of a TGF-beta family member to SOST by impairing SOST homodimer formation. An antibody that specifically binds to SOST may also be used to identify an activity of SOST by inhibiting or impairing SOST from binding to a BMP. Alternatively, the antibody or fragment thereof may be incorporated in a cell-based assay or in an animal model in which SOST has a defined activity to determine whether the antibody alters (increases or decreases in a statistically significant manner) that activity. An antibody or fragment thereof that specifically binds to SOST may be used to examine the effect of such an antibody in a signal transduction pathway and thereby modulate (stimulate or inhibit) the signaling pathway. Preferably, binding of an antibody to SOST results in a stimulation or induction of a signaling pathway.

PRODUCTION OF PROTEINS

Polypeptides described herein include the TGF binding protein sclerostin and variants thereof and antibodies or fragments thereof that specifically bind to sclerostin. The polynucleotides that encode these polypeptides include derivatives that are substantially similar to the polynucleotides (and, when appropriate, to the proteins including peptides and polypeptides that are encoded by the polynucleotides and their derivatives). As used herein, a nucleotide sequence is deemed to be "substantially similar" if (a) the nucleotide sequence is derived from the coding region of the polynucleotides described herein and includes, for example, portions of the sequence or allelic variations of the sequences discussed above, or alternatively, encodes a molecule that inhibits the binding of TGF-beta binding-protein to a member of the TGF-beta family; (b) the polynucleotide is capable of hybridizing to polynucleotide as provided herein under moderate, high or very high stringency (*see* Sambrook et al., *Molecular Cloning: A Laboratory Manual*, 3nd ed., Cold Spring Harbor Laboratory Press, NY, 2001); and/or (c) the polynucleotide sequences are degenerate with respect to codon sequences for a particular amino acid of the polynucleotide sequences described in (a) or (b). Further, the nucleic acid molecule disclosed herein includes both complementary and non-complementary sequences, provided the sequences otherwise meet the criteria set forth herein.

Within the context of the present invention, high stringency means standard hybridization conditions (*e.g.*, 5XSSPE, 0.5% SDS at 55-65° C, or the equivalent; 5xSSPE (1xSSPE = 180 mM sodium chloride; 10 mM sodium phosphate; 1 mM EDTA (pH 7.7); 5xDenhardt's solution (100x Denhardt's = 2% (w/v) bovine serum albumin, 2% (w/v) Ficoll, 2% (w/v) polyvinylpyrrolidone); and 0.5% SDS). Post-hybridization washes at high stringency are typically performed in 0.5xSSC (1xSSC = 150 mM sodium chloride, 15 mM trisodium citrate) or in 0.5xSSPE at 55-60° C.).

Polynucleotides encoding SOST may be isolated from genomic or cDNA libraries, from cells in a biological sample, tissues, or cell lines, and prepared using any variety of techniques (*see, e.g.,* Sambrook, *supra*). For example, a polynucleotide may be amplified from cDNA prepared from a suitable cell or tissue. These polynucleotides may be amplified by polymerase chain reaction (PCR) using sequence specific primers that are designed on the basis of the sequences provided herein, and which may be purchased or synthesized. Polynucleotides may also be obtained by screening cDNA or genomic DNA libraries using sequence specific probes and primers. General methods for screening libraries by PCR are provided by, for example, Yu et al., "Use of the Polymerase Chain Reaction to Screen Phage Libraries," in *Methods in Molecular Biology, Vol. 15: PCR Protocols: Current Methods and Applications*, White (ed.), pages 211-215 (Humana Press, Inc. 1993). Moreover, techniques for using PCR to isolate related genes are described by, for example, Preston, "Use of Degenerate Oligonucleotide Primers and the Polymerase Chain Reaction to Clone Gene Family Members," in *Methods in Molecular Biology, Vol. 15: PCR Protocols: Current Methods and Applications*, White (ed.), pages 317-337 (Humana Press, Inc. 1993).

The sequence of a TGF-beta binding-protein cDNA or TGF-beta binding-protein genomic fragment can be determined using standard methods. Moreover, the identification of genomic fragments containing a TGF-beta binding-protein promoter or regulatory element can be achieved using well-established techniques, such as deletion analysis (*see, generally*, Ausubel (1995)).

As an alternative, a polynucleotide encoding a TGF-beta binding-protein can be obtained by synthesizing DNA molecules using mutually priming long oligonucleotides and the nucleotide sequences described herein (*see, e.g.,* Ausubel (1995) at pages 8-8 to 8-9). If PCR is incorporated into the method DNA molecules at least two kilobases in length can be synthesized (Adang et al., *Plant Molec. Biol. 21*:1131, 1993; Bambot et al., *PCR Methods and Applications 2*:266, 1993; Dillon et al., "Use of the Polymerase Chain Reaction for the Rapid Construction of

Synthetic Genes," in *Methods in Molecular Biology, Vol. 15: PCR Protocols: Current Methods and Applications*, White (ed.), pages 263-268, (Humana Press, Inc. 1993); Holowachuk et al., *PCR Methods Appl. 4*:299, 1995).

Nucleic acid molecules encoding a variant TGF-beta binding-protein can be obtained by screening various cDNA or genomic libraries with polynucleotide probes having nucleotide sequences based upon SEQ ID NO:55-57, 59, 61, 63, 65, 67, and 69, using procedures described herein. TGF-beta binding-protein polynucleotide variants can also be constructed synthetically. For example, a nucleic acid molecule can be designed that encodes a polypeptide having a conservative amino acid change when compared with the amino acid sequence of SEQ ID NOs: 1, 20, 58, 60, 62, 64, 66, 68, or 70. That is, variants can be obtained that contain one or more amino acid substitutions of SEQ ID NOs: 1, 20, 58, 60, 62, 64, 66, 68, or 70, in which an alkyl amino acid is substituted for an alkyl amino acid in a TGF-beta binding-protein amino acid sequence; an aromatic amino acid is substituted for an aromatic amino acid in a TGF-beta binding-protein amino acid sequence; a sulfur-containing amino acid is substituted for a sulfur-containing amino acid in a TGF-beta binding-protein amino acid sequence; a hydroxy-containing amino acid is substituted for a hydroxy-containing amino acid in a TGF-beta binding-protein amino acid sequence; an acidic amino acid is substituted for an acidic amino acid in a TGF-beta binding-protein amino acid sequence; a basic amino acid is substituted for a basic amino acid in a TGF-beta binding-protein amino acid sequence; or a dibasic monocarboxylic amino acid is substituted for a dibasic monocarboxylic amino acid in a TGF-beta binding-protein amino acid sequence.

Among the common amino acids, for example, a conservative amino acid substitution is illustrated by a substitution among amino acids within each of the following groups: (1) glycine, alanine, valine, leucine, and isoleucine (non-polar alkyl group-containing side chain); (2) phenylalanine, tyrosine, and tryptophan (aromatic side chain) (3) serine and threonine (hydroxyl group side chain), (4) aspartate and glutamate (carboxylic acid group side chain); (5) glutamine and asparagines (amide group-containing side chain) and (6) lysine, arginine and histidine (amino group side chain). In making such substitutions, it is important to, where possible, maintain the cysteine backbone outlined in Figure 1.

Conservative amino acid changes in SOST can be introduced by substituting nucleotides for the nucleotides recited in any one of SEQ ID NOs: 55-57, 59, 61, 63, 65, 67, or 69. Such conservative amino acid variants can be obtained, for example, by oligonucleotide-directed mutagenesis, linker-scanning mutagenesis, mutagenesis using the polymerase chain

reaction, and the like (*see* Ausubel (1995) at pages 8-10 to 8-22; and McPherson (ed.), *Directed Mutagenesis: A Practical Approach* (IRL Press 1991)). The functional activity of such variants can be determined using standard methods and assays described herein. Alternatively, a variant TGF-beta binding-protein polypeptide retains the ability to specifically bind to anti-SOST antibodies.

Routine deletion analyses of nucleic acid molecules can be performed to obtain "functional fragments" of a nucleic acid molecule that encodes a TGF-beta binding-protein polypeptide. By way of illustration, DNA molecules having the nucleotide sequence of any one of SEQ ID NOs:55-57, 59, 61, 63, 65, 67, or 69 can be digested with *Bal*31 nuclease to obtain a series of nested deletions. The fragments are then inserted into expression vectors in proper reading frame, and the expressed polypeptides are isolated and tested for activity, or for the ability to bind anti-TGF-beta binding-protein antibodies. One alternative to exonuclease digestion is to use oligonucleotide-directed mutagenesis to introduce deletions or stop codons to specify production of a desired fragment. Alternatively, particular fragments of a TGF-beta binding-protein encoding polynucleotide can be synthesized using the polymerase chain reaction. In addition to assays and methods disclosed herein, standard techniques for functional analysis of proteins are described by, for example, Treuter et al., *Molec. Gen. Genet. 240*:113, 1993; Content et al., "Expression and preliminary deletion analysis of the 42 kDa 2-5A synthetase induced by human interferon," in *Biological Interferon Systems, Proceedings of ISIR-TNO Meeting on Interferon Systems*, Cantell (ed.), pages 65-72 (Nijhoff 1987); Herschman, "The EGF Receptor," in *Control of Animal Cell Proliferation, Vol. 1*, Boynton et al., (eds.) pages 169-199 (Academic Press 1985); Coumailleau et al., *J. Biol. Chem. 270*:29270, 1995; Fukunaga et al., *J. Biol. Chem. 270*:25291, 1995; Yamaguchi et al., *Biochem. Pharmacol. 50*:1295, 1995; and Meisel et al., *Plant Molec. Biol. 30*:1, 1996.

The structure of the polypeptides encoded by the nucleic acid molecules described herein may be predicted from the primary translation products using the hydrophobicity plot function of, for example, P/C Gene or Intelligenetics Suite (Intelligenetics, Mountain View, California), or according to the methods described by Kyte and Doolittle (*J. Mol. Biol. 157*:105-132, 1982). Polypeptides may be prepared in the form of acidic or basic salts or in neutral form. In addition, individual amino acid residues may be modified by oxidation or reduction. Furthermore, various substitutions, deletions, or additions may be made to the amino acid or nucleic acid sequences, the net effect of which is to retain or further enhance or decrease the biological activity of the mutant or wild-type protein. Preferably, a

SOST variant, or a fragment thereof retains or has enhanced ability to bind to a SOST specific antibody. Moreover, due to degeneracy in the genetic code, for example, the nucleotide sequences encoding the same amino acid sequence may vary considerably.

Other derivatives of the proteins provided herein include conjugates of the proteins with other proteins or polypeptides. This may be accomplished, for example, by the synthesis of N-terminal or C-terminal fusion proteins that may be added to facilitate purification or identification of proteins (*see* U.S. Patent No. 4,851,341, *see also,* Hopp et al., *Bio/Technology* 6:1204, 1988.) Alternatively, fusion proteins such as FLAG®/TGF-beta binding-protein may be constructed in order to assist in the identification, expression, and analysis of the protein.

Proteins described herein may be constructed using a wide variety of techniques described herein. Further, mutations may be introduced at particular loci by synthesizing oligonucleotides that contain a mutant sequence that are flanked by restriction sites, enabling ligation to fragments of the native sequence. Following ligation, the resulting reconstructed sequence encodes a derivative having the desired amino acid insertion, substitution, or deletion.

Alternatively, oligonucleotide-directed site-specific (or segment specific) mutagenesis procedures may be employed to provide an altered polynucleotide having particular codons altered according to the substitution, deletion, or insertion. Exemplary methods of making the alterations set forth above are disclosed by Walder et al. (*Gene 42*:133, 1986); Bauer et al. (*Gene 37*:73, 1985); Craik (*BioTechniques*, January 1985, 12-19); Smith et al. (*Genetic Engineering: Principles and Methods*, Plenum Press, 1981); and Sambrook et al. (*supra*). Deletion or truncation derivatives of proteins (*e.g.,* a soluble extracellular portion) may also be constructed by using convenient restriction endonuclease sites adjacent to the desired deletion. Subsequent to restriction, overhangs may be filled in and the DNA religated. Exemplary methods of making the alterations set forth above are disclosed by Sambrook et al. (*Molecular Cloning: A Laboratory Manual*, 3d Ed., Cold Spring Harbor Laboratory Press (2001)).

Mutations that are made in the nucleic acid molecules preferably preserve the reading frame of the coding sequences. Furthermore, the mutations will preferably not create complementary regions that when transcribed could hybridize to produce secondary mRNA structures, such as loops or hairpins, which would adversely affect translation of the mRNA. Although a mutation site may be predetermined, it is not necessary that the nature of the mutation *per se* be predetermined. For example, in order to select for optimum characteristics of mutants at a given site, random mutagenesis may be conducted at the target codon and the

expressed mutants screened for gain, loss, or retention of biological activity. Alternatively, mutations may be introduced at particular loci by synthesizing oligonucleotides containing a mutant sequence, flanked by restriction sites enabling ligation to fragments of the native sequence. Following ligation, the resulting reconstructed sequence encodes a derivative having the desired amino acid insertion, substitution, or deletion. Nucleic acid molecules that encode proteins of the present invention may also be constructed using techniques such as polymerase chain reaction (PCR) mutagenesis, chemical mutagenesis (Drinkwater and Klinedinst, *PNAS 83*:3402-3406, 1986), forced nucleotide misincorporation (*e.g.*, Liao and Wise *Gene 88*:107-111, 1990), or use of randomly mutagenized oligonucleotides (Horwitz et al., *Genome 3*:112-117, 1989).

The present invention also provides for the manipulation and expression of the polynucleotides provided herein and of polynucleotides encoding the subject invention antibodies by culturing host cells containing a vector capable of expressing such polynucleotides. An expression vector refers to recombinant nucleic acid construct that is capable of directing the expression of desired protein. The vector may be composed of deoxyribonucleic acids (DNA), synthetic or cDNA-derived, ribonucleic acids (RNA), or a combination of the two (*e.g.*, a DNA-RNA chimera). A cDNA polynucleotide is generally understood to mean a DNA polynucleotide prepared by transcribing an RNA molecule, such as mRNA. These vectors or vector constructs that include a polynucleotide sequence encoding the desired protein preferably are operably linked to suitable transcriptional or translational regulatory elements. Suitable regulatory elements may be derived from a variety of sources, including bacterial, fungal, viral, mammalian, insect, or plant genes. Selection of appropriate regulatory elements is dependent on the host cell chosen, and may be readily accomplished by one of ordinary skill in the art. Examples of regulatory elements include a transcriptional promoter and enhancer or RNA polymerase binding sequence, a transcriptional terminator, and a ribosomal binding sequence including a translation initiation signal. Optionally, the vector may include a polyadenylation sequence, one or more restriction sites, as well as one or more selectable markers such as neomycin phosphotransferase or hygromycin phosphotransferase or any other markers known in the art. Additionally, depending on the host cell chosen and the vector employed, other genetic elements such as an origin of replication, additional nucleic acid restriction sites, enhancers, sequences conferring inducibility of transcription, and selectable markers, may also be incorporated into the vectors described herein.

Nucleic acid molecules that encode any of the proteins described above may be

readily expressed by a wide variety of prokaryotic and eukaryotic host cells, including bacterial, mammalian, yeast or other fungi, viral, insect, or plant cells. Methods for transforming or transfecting such cells to express foreign DNA are well known in the art (*see, e.g.*, Itakura et al., U.S. Patent No. 4,704,362; Hinnen et al., *Proc. Natl. Acad. Sci. USA 75*:1929-1933, 1978; Murray et al., U.S. Patent No. 4,801,542; Upshall et al., U.S. Patent No. 4,935,349; Hagen et al., U.S. Patent No. 4,784,950; Axel et al., U.S. Patent No. 4,399,216; Goeddel et al., U.S. Patent No. 4,766,075; and Sambrook et al. *Molecular Cloning: A Laboratory Manual*, 3nd ed., Cold Spring Harbor Laboratory Press, 2001; for plant cells see Czako and Marton, *Plant Physiol.* 104:1067-1071, 1994; and Paszkowski et al., *Biotech. 24*:387-392, 1992).

Bacterial host cells suitable for carrying out the present invention include *E. coli* BL21(DE3), BL21(DE3)pLysS, BL21(DE3)pLysE, DH1, DH4I, DH5, DH5I, DH5IF', DH5IMCR, DH10B, DH10B/p3, DH11S, C600, HB101, JM101, JM105, JM109, JM110, K38, RR1, Y1088, Y1089, CSH18, ER1451, and ER1647 (see, for example, Brown (Ed.), *Molecular Biology Labfax* (Academic Press 1991)); *B. subtilis* (BR151, YB886, MI119, MI120, and B170 (see, for example, Hardy, "Bacillus Cloning Methods," in *DNA Cloning: A Practical Approach*, Glover (Ed.) (IRL Press 1985)); *Salmonella typhimurium*; and various species within the genera *Pseudomonas*, *Streptomyces*, and *Staphylococcus*, as well as many other bacterial species well known to one of ordinary skill in the art. A representative exampleof a bacterial host cell includes *E. coli* DH5α (Stratagene, LaJolla, California).

Bacterial expression vectors preferably comprise a promoter that functions in the host cell, one or more selectable phenotypic markers, and a bacterial origin of replication. Representative promoters include the β-lactamase (penicillinase) and lactose promoter system (*see* Chang et al., *Nature 275*:615, 1978), the T7 RNA polymerase promoter (Studier et al., *Meth. Enzymol. 185*:60-89, 1990), the lambda promoter (Elvin et al., *Gene 87*:123-126, 1990), the *trp* promoter (Nichols and Yanofsky, *Meth. in Enzymology 101*:155, 1983), and the *tac* promoter (Russell et al., *Gene 20*:231, 1982). Additional promoters include promoters capable of recognizing the T4, T3, Sp6 and T7 polymerases, the $P_R$ and $P_L$ promoters of bacteriophage lambda, the *recA*, heat shock, *lacUV5*, *tac*, *lpp-lacSpr*, *phoA*, and *lacZ* promoters of *E. coli*, promoters of *B. subtilis*, the promoters of the bacteriophages of *Bacillus*, *Streptomyces* promoters, the *int* promoter of bacteriophage lambda, the *bla* promoter of pBR322, and the CAT promoter of the chloramphenicol acetyl transferase gene. Prokaryotic promoters have been reviewed by Glick, *J. Ind. Microbiol. 1*:277, 1987, Watson et al., *Molecular Biology of the Gene, 4th Ed.* (Benjamin Cummins 1987), and by Ausubel et al. (1995). Representative

selectable markers include various antibiotic resistance markers such as the kanamycin or ampicillin resistance genes. Many plasmids suitable for transforming host cells are well known in the art, including among others, pBR322 (*see* Bolivar et al., *Gene 2*:95, 1977), the pUC plasmids pUC18, pUC19, pUC118, pUC119 (*see* Messing, *Meth. in Enzymology 101*:20-77, 1983 and Vieira and Messing, *Gene 19*:259-268, 1982), and pNH8A, pNH16a, pNH18a, and Bluescript M13 (Stratagene, La Jolla, California).

Yeast and fungi host cells suitable for carrying out the present invention include, among others, *Saccharomyces pombe*, *Saccharomyces cerevisiae*, the genera *Pichia* or *Kluyveromyces* and various species of the genus *Aspergillus* (McKnight et al., U.S. Patent No. 4,935,349). Suitable expression vectors for yeast and fungi include, among others, YCp50 (ATCC No. 37419) for yeast, and the amdS cloning vector pV3 (Turnbull, *Bio/Technology 7*:169, 1989), YRp7 (Struhl et al., *Proc. Natl. Acad. Sci. USA 76*:1035-1039, 1978), YEp13 (Broach et al., *Gene 8*:121-133, 1979), pJDB249 and pJDB219 (Beggs, *Nature 275*:104-108, 1978) and derivatives thereof.

Preferred promoters for use in yeast include promoters from yeast glycolytic genes (Hitzeman et al., *J. Biol. Chem. 255*:12073-12080, 1980; Alber and Kawasaki, *J. Mol. Appl. Genet. 1*:419-434, 1982) or alcohol dehydrogenase genes (Young et al., in *Genetic Engineering of Microorganisms for Chemicals*, Hollaender et al. (eds.), p. 355, Plenum, New York, 1982; Ammerer, *Meth. Enzymol. 101*:192-201, 1983). Examples of useful promoters for fungi vectors include those derived from *Aspergillus nidulans* glycolytic genes, such as the *adh3* promoter (McKnight et al., *EMBO J. 4*:2093-2099, 1985). The expression units may also include a transcriptional terminator. An example of a suitable terminator is the *adh3* terminator (McKnight et al., *supra*, 1985).

As with bacterial vectors, the yeast vectors will generally include a selectable marker, which may be one of any number of genes that exhibit a dominant phenotype for which a phenotypic assay exists to enable transformants to be selected. Preferred selectable markers are those that complement host cell auxotrophy, provide antibiotic resistance, or enable a cell to utilize specific carbon sources, and include *leu2* (Broach et al., *ibid.*), *ura3* (Botstein et al., *Gene 8*:17, 1979), or *his3* (Struhl et al., *ibid.*). Another suitable selectable marker is the *cat* gene, which confers chloramphenicol resistance on yeast cells. Many yeast cloning vectors have been designed and are readily available. These vectors include YIp-based vectors such as YIp5, YRp vectors such as YRp17, YEp vectors such as YEp13, and YCp vectors such as YCp19. One skilled in the art will appreciate that a wide variety of suitable vectors are available for

expression in yeast cells.

Techniques for transforming fungi are well known in the literature and have been described, for instance, by Beggs (*ibid.*), Hinnen et al. (*Proc. Natl. Acad. Sci. USA 75*:1929-1933, 1978), Yelton et al. (*Proc. Natl. Acad. Sci. USA 81*:1740-1747, 1984), and Russell (*Nature 301*:167-169, 1983). The genotype of the host cell may contain a genetic defect that is complemented by the selectable marker present on the expression vector. Choice of a particular host and selectable marker is well within the level of ordinary skill in the art.

Protocols for the transformation of yeast are also well known to those of ordinary skill in the art. For example, transformation may be readily accomplished either by preparation of spheroplasts of yeast with DNA (*see* Hinnen et al., *PNAS USA 75*:1929, 1978) or by treatment with alkaline salts such as LiCl (*see* Itoh et al., *J. Bacteriology 153*:163, 1983). Transformation of fungi may also be carried out using polyethylene glycol as described by Cullen et al. (*Bio/Technology 5*:369, 1987).

Viral vectors include those that comprise a promoter that directs the expression of an isolated nucleic acid molecule encoding a desired protein as described above. A wide variety of promoters may be used within the context of the present invention, including for example, promoters such as MoMLV LTR; RSV LTR (*e.g.*, Gorman et al., *Proc. Natl. Acad. Sci. USA 79*:6777, 1982); Friend MuLV LTR; adenoviral promoter (Ohno et al., *Science 265*:781-784, 1994); neomycin phosphotransferase promoter/enhancer; late parvovirus promoter (Koering et al., *Hum. Gene Therap. 5*:457-463, 1994); Herpes TK promoter (*see, e.g.,* McKnight, *Cell* 31:355, 1982); SV40 promoter (*e.g., SV40* early promoter (Benoist et al., *Nature 290*:304, 1981); metallothionein IIa gene enhancer/promoter; mouse metallothionein I gene (Hamer et al., *J. Molec. Appl. Genet. 1*:273, 1982); mouse mammary tumor virus promoter (*see, generally*, Etcheverry, "Expression of Engineered Proteins in Mammalian Cell Culture," in *Protein Engineering: Principles and Practice*, Cleland et al. (eds.), pages 163-181 (John Wiley & Sons, Inc. 1996)); cytomegalovirus immediate early promoter, and the cytomegalovirus immediate late promoter. Alternatively, a prokaryotic promoter, such as the bacteriophage T3 RNA polymerase promoter, can be used to control TGF-beta binding-protein gene expression in mammalian cells if the prokaryotic promoter is regulated by a eukaryotic promoter (Zhou et al., *Mol. Cell. Biol. 10*:4529, 1990; Kaufman et al., *Nucl. Acids Res. 19*:4485, 1991).

Within particularly preferred embodiments of the invention, the promoter is a tissue-specific promoter (*see e.g.*, WO 91/02805; EP 0,415,731; and WO 90/07936). Representative examples of suitable tissue specific promoters include neural specific enolase

promoter, platelet derived growth factor beta promoter, bone morphogenic protein promoter, human alpha1-chimaerin promoter, synapsin I promoter and synapsin II promoter. In addition to the above-noted promoters, other viral-specific promoters (*e.g.*, retroviral promoters (including those noted above, as well as others such as HIV promoters), hepatitis, herpes (*e.g.*, EBV), and bacterial, fungal or parasitic (*e.g.*, malarial) -specific promoters may be utilized in order to target a specific cell or tissue that is infected with a virus, bacteria, fungus, or parasite.

Mammalian cells suitable for carrying out the present invention include, among others COS, CHO, SaOS, osteosarcomas, KS483, MG-63, primary osteoblasts, and human or mammalian bone marrow stroma. Additional mammalian host cells include African green monkey kidney cells (Vero; ATCC CRL 1587), human embryonic kidney cells (293-HEK; ATCC CRL 1573), baby hamster kidney cells (BHK-21; ATCC CRL 8544), canine kidney cells (MDCK; ATCC CCL 34), Chinese hamster ovary cells (CHO-K1; ATCC CCL61), rat pituitary cells (GH1; ATCC CCL82), HeLa S3 cells (ATCC CCL2.2), rat hepatoma cells (H-4-II-E; ATCC CRL 1548) SV40-transformed monkey kidney cells (COS-1; ATCC CRL 1650) and murine embryonic cells (NIH-3T3; ATCC CRL 1658).

Mammalian expression vectors for use in carrying out the present invention will include a promoter capable of directing the transcription of a cloned gene or cDNA. Preferred promoters include viral promoters and cellular promoters. Bone specific promoters include the promoter for bone sialo-protein and the promoter for osteocalcin. Viral promoters include the cytomegalovirus immediate early promoter (Boshart et al., *Cell 41*:521-530, 1985), cytomegalovirus immediate late promoter, SV40 promoter (Subramani et al., *Mol. Cell. Biol.* 1:854-864, 1981), MMTV LTR, RSV LTR, metallothionein-1, adenovirus E1a. Cellular promoters include the mouse metallothionein-1 promoter (Palmiter et al., U.S. Patent No. 4,579,821), a mouse $V_K$ promoter (Bergman et al., *Proc. Natl. Acad. Sci. USA 81*:7041-7045, 1983; Grant et al., *Nucleic Acids Res.* 15:5496, 1987) and a mouse $V_H$ promoter (Loh et al., *Cell* 33:85-93, 1983). The choice of promoter will depend, at least in part, upon the level of expression desired or the recipient cell line to be transfected.

Such expression vectors may also contain a set of RNA splice sites located downstream from the promoter and upstream from the DNA sequence encoding the peptide or protein of interest. Preferred RNA splice sites may be obtained from adenovirus and/or immunoglobulin genes. Also contained in the expression vectors is a polyadenylation signal located downstream of the coding sequence of interest. Suitable polyadenylation signals include the early or late polyadenylation signals from SV40 (Kaufman and Sharp, *ibid.*), the

polyadenylation signal from the Adenovirus 5 E1B region and the human growth hormone gene terminator (DeNoto et al., *Nucleic Acids Res. 9*:3719-3730, 1981). The expression vectors may include a noncoding viral leader sequence, such as the Adenovirus 2 tripartite leader, located between the promoter and the RNA splice sites. Preferred vectors may also include enhancer sequences, such as the SV40 enhancer. Expression vectors may also include sequences encoding the adenovirus VA RNAs. Suitable expression vectors can be obtained from commercial sources (*e.g.*, Stratagene, La Jolla, California).

Vector constructs comprising cloned DNA sequences can be introduced into cultured mammalian cells by, for example, liposome-mediated transfection, calcium phosphate-mediated transfection (Wigler et al., *Cell 14*:725, 1978; Corsaro and Pearson, *Somatic Cell Genetics 7*:603, 1981; Graham and Van der Eb, *Virology 52*:456, 1973), electroporation (Neumann et al., *EMBO J. 1*:841-845, 1982), or DEAE-dextran mediated transfection (Ausubel et al. (eds.), *Current Protocols in Molecular Biology*, John Wiley and Sons, Inc., NY, 1987); retroviral, adenoviral and protoplast fusion-mediated transfection (*see* Sambrook et al., *supra*). Naked vector constructs can also be taken up by muscular cells or other suitable cells subsequent to injection into the muscle of a mammal (or other animal). To identify cells that have been stably transfected with the vector containing the cloned DNA, a selectable marker is generally introduced into the cells along with the gene or cDNA of interest. Preferred selectable markers for use in cultured mammalian cells include genes that confer resistance to drugs, such as neomycin, hygromycin, and methotrexate. The selectable marker may be an amplifiable selectable marker. Preferred amplifiable selectable markers are the DHFR gene and the neomycin resistance gene. Selectable markers are reviewed by Thilly (*Mammalian Cell Technology*, Butterworth Publishers, Stoneham, Massachusetts).

Mammalian cells containing a suitable vector are allowed to grow for a period of time, typically 1-2 days, to begin expressing the DNA sequence(s) of interest. Drug selection is then applied to select for growth of cells that are expressing the selectable marker in a stable fashion. For cells that have been transfected with an amplifiable, selectable marker, the drug concentration may be increased in a stepwise manner to select for increased copy number of the cloned sequences, thereby increasing expression levels. Cells expressing the introduced sequences are selected and screened for production of the protein of interest in the desired form or at the desired level. Cells that satisfy these criteria can then be cloned and scaled up for production.

Numerous insect host cells known in the art can also be useful within the present

invention. For example, baculoviruses as vectors for expressing heterologous DNA sequences in insect cells may be used (Atkinson et al., *Pestic. Sci.* 28:215-224 (1990)). The baculovirus system provides an efficient means to introduce cloned TGF-beta binding-protein encoding polynucleotides into insect cells. Suitable expression vectors are based upon the *Autographa californica* multiple nuclear polyhedrosis virus (AcMNPV), which contain well known promoters such as *Drosophila* heat shock protein (hsp) 70 promoter, *Autographa californica* nuclear polyhedrosis virus immediate-early gene promoter (*ie-1*), and the delayed early *39K* promoter, baculovirus p10 promoter, and the *Drosophila* metallothionein promoter. Suitable insect host cells include cell lines derived from IPLB-*Sf*-21, a *Spodoptera frugiperda* pupal ovarian cell line, such as *Sf*9 (ATCC CRL 1711), *Sf*21AE, and *Sf*21 (Invitrogen Corporation; San Diego, CA), as well as *Drosophila* Schneider-2 cells. Established techniques for producing recombinant proteins in baculovirus systems are provided by Bailey et al., "Manipulation of Baculovirus Vectors," in *Methods in Molecular Biology, Volume 7: Gene Transfer and Expression Protocols*, Murray (ed.), pages 147-168 (The Humana Press, Inc. 1991); Patel et al., "The baculovirus expression system," in *DNA Cloning 2: Expression Systems, 2nd Edition*, Glover *et al.* (eds.), pages 205-244 (Oxford University Press 1995); Ausubel (1995) at pages 16-37 to 16-57, by Richardson (ed.), *Baculovirus Expression Protocols* (The Humana Press, Inc. 1995); and Lucknow, "Insect Cell Expression Technology," in *Protein Engineering: Principles and Practice*, Cleland et al. (eds.), pages 183-218 (John Wiley & Sons, Inc. 1996).

Alternatively, numerous plant host cells are known in the art and can also be useful for expressing polynucleotides, for example, *Agrobacterium rhizogenes* (Sinkar et al. *J. Biosci.* (*Bangalore*) 11:47-58, 1987). Expression vectors can also be introduced into plant protoplasts, intact plant tissues, or isolated plant cells. General methods of culturing plant tissues are provided, for example, by Miki et al., "Procedures for Introducing Foreign DNA into Plants," in *Methods in Plant Molecular Biology and Biotechnology*, Glick et al. (eds.), pages 67-88 (CRC Press, 1993).

Within related embodiments of the present invention, proteins of the present invention may be expressed in a transgenic animal whose germ cells and somatic cells contain a gene that encodes the desired protein and that is operatively linked to a promoter effective for the expression of the gene. Alternatively, in a similar manner, transgenic animals may be prepared that lack the desired gene (*e.g.*, "knock-out" mice). Such transgenics may be prepared in a variety of non-human animals, including mice, rats, rabbits, sheep, dogs, goats, and pigs (*see* Hammer et al., *Nature 315*:680-683, 1985, Palmiter et al., *Science 222*:809-814, 1983,

Brinster et al., *Proc. Natl. Acad. Sci. USA 82*:4438-4442, 1985, Palmiter and Brinster, *Cell 41*:343-345, 1985, and U.S. Patent Nos. 5,175,383, 5,087,571, 4,736,866, 5,387,742, 5,347,075, 5,221,778, and 5,175,384). Briefly, an expression vector, including a nucleic acid molecule to be expressed together with appropriately positioned expression control sequences, is introduced into pronuclei of fertilized eggs, for example, by microinjection. Integration of the injected DNA is detected by blot analysis of DNA from tissue samples. It is preferred that the introduced DNA be incorporated into the germ line of the animal so that it is passed on to the animal's progeny. Tissue-specific expression may be achieved through the use of a tissue-specific promoter, or through the use of an inducible promoter, such as the metallothionein gene promoter (Palmiter et al., 1983, *supra*), which allows regulated expression of the transgene.

Proteins can be isolated by, among other methods, culturing suitable host and vector systems to produce the recombinant translation products of the present invention. Supernatants from such cell lines, or protein inclusion bodies, or whole cells from which the protein is not secreted into the supernatant, can then be treated by a variety of purification procedures in order to isolate the desired proteins. For example, the supernatant may be first concentrated using commercially available protein concentration filters, such as an Amicon or Millipore Pellicon ultrafiltration unit. Following concentration, the concentrate may be applied to a suitable purification matrix such as an affinity matrix, for example, a specific antibody bound to a suitable support. Alternatively, a nion or cation exchange resins or size-exclusion matrices may be employed in order to purify the protein. As a further alternative, one or more reverse-phase high performance liquid chromatography (RP-HPLC) steps may be used to further purify the protein. Other methods of isolating the proteins of the present invention are well known in the art. The purity of an isolated protein or polypeptide may be determined by SDS-PAGE analysis followed by Coomassie blue staining or by silver staining.

General methods for expressing and recovering foreign protein produced by a mammalian cell system is provided by, for example, Etcheverry, "Expression of Engineered Proteins in Mammalian Cell Culture," in *Protein Engineering: Principles and Practice*, Cleland et al. (eds.), pages 163 (Wiley-Liss, Inc. 1996). Standard techniques for recovering protein produced by a bacterial system is provided by, for example, Grisshammer *et al.*, "Purification of over-produced proteins from *E. coli* cells," in *DNA Cloning 2: Expression Systems, 2nd Edition*, Glover *et al.* (eds.), pages 59-92 (Oxford University Press 1995). Established methods for isolating recombinant proteins from a baculovirus system are described by Richardson (ed.), *Baculovirus Expression Protocols* (The Humana Press, Inc., 1995).

More generally, a TGF-beta binding-protein can be isolated by standard techniques, such as affinity chromatography, size exclusion chromatography, ion exchange chromatography, HPLC, and the like. Additional variations in TGF-beta binding-protein isolation and purification can be devised by those of skill in the art. For example, anti-TGF-beta binding-protein antibodies, obtained as described herein, can be used to isolate large quantities of protein by immunoaffinity purification. Purification of antibodies of the present invention are further described herein.

DETECTABLE LABELS

A detectable label is a molecule or atom that can be conjugated to a polypeptide (including an antibody or fragment thereof) or a polynucleotide to produce a molecule useful for diagnosis. Examples of detectable labels include chelators, photoactive agents, radioisotopes, fluorescent agents, paramagnetic ions, enzymes, and other marker moieties. A TGF binding protein or an antibody that specifically binds to the TGF binding protein or candidate molecules described above may be labeled with a variety of compounds including, for example, fluorescent molecules, toxins, and radionuclides. Representative examples of fluorescent molecules include fluorescein, *Phycobili* proteins, such as phycoerythrin, rhodamine, Texas red, and luciferase. Representative examples of toxins include ricin, abrin diphtheria toxin, cholera toxin, gelonin, pokeweed antiviral protein, tritin, *Shigella* toxin, and *Pseudomonas* exotoxin A. Representative examples of radionuclides include Cu-64, Ga-67, Ga-68, Zr-89, Ru-97, Tc-99m, Rh-105, Pd-109, In-111, I-123, I-125, I-131, Re-186, Re-188, Au-198, Au-199, Pb-203, At-211, Pb-212 and Bi-212. In addition, the antibodies described above may also be labeled or conjugated to one partner of a ligand binding pair. Representative examples include avidin-biotin, streptavidin-biotin, and riboflavin-riboflavin binding protein.

Methods for conjugating or labeling the molecules described herein with the representative labels set forth above may be readily accomplished by one of ordinary skill in the art (*see* Trichothecene Antibody Conjugate, U.S. Patent No. 4,744,981; Antibody Conjugate, U.S. Patent No. 5,106,951; Fluorogenic Materials and Labeling Techniques, U.S. Patent No. 4,018,884; Metal Radionuclide Labeled Proteins for Diagnosis and Therapy, U.S. Patent No. 4,897,255; and Metal Radionuclide Chelating Compounds for Improved Chelation Kinetics, U.S. Patent No. 4,988,496; *see also* Inman, *Methods In Enzymology*, Vol. 34, *Affinity Techniques, Enzyme Purification: Part B*, Jakoby and Wilchek (eds.), Academic Press, New York, p. 30, 1974; *see also* Wilchek and Bayer, "The Avidin-Biotin Complex in Bioanalytical

Applications," *Anal. Biochem. 171*:1-32, 1988). An immunoconjugate is a composition comprising an antibody, such as an anti-TGF-beta binding protein antibody, or an antibody fragment thereof, and a detectable label. Preferably the antibody moiety of the immunoconjugate specifically binds to its cognate antigen with the same or slightly reduced binding affinity after conjugation as before conjugation.

PHARMACEUTICAL COMPOSITIONS

As noted above, the present invention also provides a variety of pharmaceutical compositions, comprising one of the above-described molecules that inhibits binding of the TGF-beta binding-protein to a member of the TGF-beta family along with a pharmaceutically or physiologically acceptable carrier, excipient, or diluent. Any suitable carrier known to those of ordinary skill in the art may be employed in the pharmaceutical compositions of the present invention. Carriers for therapeutic use are well known, and are described, for example, in *Remingtons Pharmaceutical Sciences*, Mack Publishing Co. (A.R. Gennaro ed. (1985)). Generally, such carriers should be nontoxic to recipients at the dosages and concentrations employed. Ordinarily, the preparation of such compositions entails combining the therapeutic agent with buffers; antioxidants such as ascorbic acid, low molecular weight (less than about 10 residues) polypeptides; proteins; amino acids; carbohydrates including maltose, glucose, sucrose, or dextrins; chelating agents such as EDTA; glutathione; and other stabilizers and excipients. Neutral buffered saline or saline mixed with nonspecific serum albumin are exemplary diluents. Alternatively, compositions of the present invention may be formulated as a lyophilizate.

In general, the type of carrier is selected based on the mode of administration. Pharmaceutical compositions may be formulated for any appropriate manner of administration, including, for example, topical, oral, nasal, intrathecal, rectal, vaginal, sublingual or parenteral administration, including subcutaneous, intravenous, intramuscular, intrasternal, intracavernous, intrameatal, or intraurethral injection or infusion. A pharmaceutical composition (*e.g.*, for oral administration or delivery by injection) may be in the form of a liquid (*e.g.*, an elixir, syrup, solution, emulsion or suspension). A liquid pharmaceutical composition may include, for example, one or more of the following: sterile diluents such as water for injection, saline solution, preferably physiological saline, Ringer's solution, isotonic sodium chloride, fixed oils that may serve as the solvent or suspending medium, polyethylene glycols, glycerin, propylene glycol or other solvents; antibacterial agents; antioxidants; chelating agents; buffers such as

acetates, citrates or phosphates and agents for the adjustment of tonicity such as sodium chloride or dextrose. A parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic. The use of physiological saline is preferred, and an injectable pharmaceutical composition is preferably sterile.

The compositions described herein may be formulated for sustained release (*i.e.*, a formulation such as a capsule or sponge that effects a slow release of compound following administration). Such compositions may generally be prepared using well known technology and administered by, for example, oral, rectal or subcutaneous implantation, or by implantation at the desired target site. Sustained-release formulations may contain an agent dispersed in a carrier matrix and/or contained within a reservoir surrounded by a rate controlling membrane. Carriers for use within such formulations are biocompatible, and may also be biodegradable; preferably the formulation provides a relatively constant level of active component release. The amount of active compound contained within a sustained release formulation depends upon the site of implantation, the rate and expected duration of release and the nature of the condition to be treated or prevented. Illustrative carriers useful in this regard include microparticles of poly(lactide-co-glycolide), polyacrylate, latex, starch, cellulose, dextran and the like. Other illustrative delayed-release carriers include supramolecular biovectors, which comprise a non-liquid hydrophilic core (*e.g.*, a cross-linked polysaccharide or oligosaccharide) and, optionally, an external layer comprising an amphiphilic compound, such as a phospholipid (*see e.g.*, U.S. Patent No. 5,151,254 and PCT applications WO 94/20078, WO/94/23701 and WO 96/06638).

In another illustrative embodiment, biodegradable microspheres (*e.g.*, polylactate polyglycolate) are employed as carriers for the compositions of this invention. Suitable biodegradable microspheres are disclosed, for example, in U.S. Patent Nos. 4,897,268; 5,075,109; 5,928,647; 5,811,128; 5,820,883; 5,853,763; 5,814,344, 5,407,609 and 5,942,252. Modified hepatitis B core protein carrier systems, such as described in WO/99 40934, and references cited therein, will also be useful for many applications. Another illustrative carrier/delivery system employs a carrier comprising particulate-protein complexes, such as those described in U.S. Patent No. 5,928,647, which are capable of inducing a class I-restricted cytotoxic T lymphocyte responses in a host.

In another illustrative embodiment, calcium phosphate core particles are employed as carriers or as controlled release matrices for the compositions of this invention. Exemplary calcium phosphate particles are disclosed, for example, in published patent application No. WO/0046147.

For pharmaceutical compositions comprising a polynucleotide encoding an anti-SOST antibody and/or modulating agent (such that the polypeptide and/or modulating agent is generated *in situ*), the polynucleotide may be present within any of a variety of delivery systems known to those of ordinary skill in the art, including nucleic acid, and bacterial, viral and mammalian expression systems. Techniques for incorporating DNA into such expression systems are well known to those of ordinary skill in the art. The DNA may also be "naked," as described, for example, in Ulmer et al., *Science 259*:1745-1749, 1993 and reviewed by Cohen, *Science 259*:1691-1692, 1993. The uptake of naked DNA may be increased by coating the DNA onto biodegradable beads, which are efficiently transported into the cells.

The development of suitable dosing and treatment regimens for using the particular compositions described herein in a variety of treatment regimens, including *e.g.,* oral, parenteral, intravenous, intranasal, and intramuscular administration and formulation, is well known in the art, some of which are briefly discussed below for general purposes of illustration.

In certain applications, the pharmaceutical compositions disclosed herein may be delivered *via* oral administration to an animal. As such, these compositions may be formulated with an inert diluent or with an assimilable edible carrier, or they may be enclosed in hard- or soft-shell gelatin capsule, or they may be compressed into tablets, or they may be incorporated directly with the food of the diet.

In certain circumstances it will be desirable to deliver the pharmaceutical compositions disclosed herein parenterally, intravenously, intramuscularly, or even intraperitoneally. Such approaches are well known to the skilled artisan, some of which are further described, for example, in U.S. Patent No. 5,543,158; U.S. Patent No. 5,641,515 and U.S. Patent No. 5,399,363. In certain embodiments, solutions of the active compounds as free base or pharmacologically acceptable salts may be prepared in water suitably mixed with a surfactant, such as hydroxypropylcellulose. Dispersions may also be prepared in glycerol, liquid polyethylene glycols, and mixtures thereof and in oils. Under ordinary conditions of storage and use, these preparations generally will contain a preservative to prevent the growth of microorganisms.

Illustrative pharmaceutical forms suitable for injectable use include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersions (for example, see U.S. Patent No. 5,466,468). In all cases the form must be sterile and must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against

the contaminating action of microorganisms, such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (*e.g.*, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), suitable mixtures thereof, and/or vegetable oils. Proper fluidity may be maintained, for example, by the use of a coating, such as lecithin, by the maintenance of the required particle size in the case of dispersion and/or by the use of surfactants. The prevention of the action of microorganisms can be facilitated by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, sorbic acid, thimerosal, and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars or sodium chloride. Prolonged absorption of the injectable compositions can be brought about by the use in the compositions of agents delaying absorption, for example, aluminum monostearate and gelatin.

In one embodiment, for parenteral administration in an aqueous solution, the solution should be suitably buffered if necessary and the liquid diluent first rendered isotonic with sufficient saline or glucose. These particular aqueous solutions are especially suitable for intravenous, intramuscular, subcutaneous and intraperitoneal administration. In this connection, a sterile aqueous medium that can be employed will be known to those of skill in the art in light of the present disclosure. For example, one dosage may be dissolved in 1 ml of isotonic NaCl solution and either added to 1000 ml of hypodermoclysis fluid or injected at the proposed site of infusion, (see for example, *Remington's Pharmaceutical Sciences*, 15th ed., pp. 1035-1038 and 1570-1580). Some variation in dosage will necessarily occur depending on the condition of the subject being treated. Moreover, for human administration, preparations will of course preferably meet sterility, pyrogenicity, and the general safety and purity standards as required by FDA Office of Biologics standards.

In another embodiment of the invention, the compositions disclosed herein may be formulated in a neutral or salt form. Illustrative pharmaceutically-acceptable salts include the acid addition salts (formed with the free amino groups of the protein) and which are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such organic acids as acetic, oxalic, tartaric, mandelic, and the like. Salts formed with the free carboxyl groups can also be derived from inorganic bases such as, for example, sodium, potassium, ammonium, calcium, or ferric hydroxides, and such organic bases as isopropylamine, trimethylamine, histidine, procaine and the like. Upon formulation, solutions will be administered in a manner compatible with the dosage formulation and in such amount as is therapeutically effective.

The carriers can further comprise any and all solvents, dispersion media,

vehicles, coatings, diluents, antibacterial and antifungal agents, isotonic and absorption delaying agents, buffers, carrier solutions, suspensions, colloids, and the like. The use of such media and agents for pharmaceutical active substances is well known in the art. E xcept insofar as any conventional media or agent is incompatible with the active ingredient, its use in the therapeutic compositions is contemplated. Supplementary active ingredients can also be incorporated into the compositions. The phrase "pharmaceutically-acceptable" refers to molecular entities and compositions that do not produce an allergic or similar untoward reaction when administered to a human.

In certain embodiments, liposomes, nanocapsules, microparticles, lipid particles, vesicles, and the like, are used for the introduction of the compositions of the present invention into suitable host cells/organisms. In particular, the compositions of the present invention may be formulated for delivery either encapsulated in a lipid particle, a liposome, a vesicle, a nanosphere, or a nanoparticle or the like. Alternatively, compositions of the present invention can be bound, either covalently or non-covalently, to the surface of such carrier vehicles.

The formation and use of liposome and liposome-like preparations as potential drug carriers is generally known to those of skill in the art (see for example, Lasic, *Trends Biotechnol. 16*(7):307-21, 1998; Takakura, *Nippon Rinsho 56*(3):691-95, 1998; Chandran et al., *Indian J. Exp. Biol. 35*(8):801-09, 1997; Margalit, *Crit. Rev. Ther. Drug Carrier Syst. 12*(2-3):233-61, 1995; U.S. Patent No. 5,567,434; U.S. Patent No. 5,552,157; U.S. Patent No. 5,565,213; U.S. Patent No. 5,738,868 and U.S. Patent No. 5,795,587, each specifically incorporated herein by reference in its entirety). Liposomes have been used successfully with a number of cell types that are normally difficult to transfect by other procedures, including T cell suspensions, primary hepatocyte cultures and PC 12 cells (Renneisen et al., *J. Biol. Chem. 265*(27):16337-42, 1990; Muller et al., *DNA Cell Biol. 9*(3):221-29, 1990). In addition, liposomes are free of the DNA length constraints that are typical of viral-based delivery systems. Liposomes have been used effectively to introduce genes, various drugs, radiotherapeutic agents, enzymes, viruses, transcription factors, allosteric effectors and the like, into a variety of cultured cell lines and animals. Furthermore, he use of liposomes does not appear to be associated with autoimmune responses or unacceptable toxicity after systemic delivery. In certain embodiments, liposomes are formed from phospholipids that are dispersed in an aqueous medium and spontaneously form multilamellar concentric bilayer vesicles (also termed multilamellar vesicles (MLVs).

Alternatively, in other embodiments, the invention provides for

pharmaceutically-acceptable nanocapsule formulations of the compositions of the present invention. Nanocapsules can generally entrap compounds in a stable and reproducible way (see, for example, Quintanar-Guerrero et al., *Drug Dev. Ind. Pharm. 24*(12):1113-28, 1998). To avoid side effects due to intracellular polymeric overloading, such ultrafine particles (sized around 0.1 μm) may be designed using polymers able to be degraded *in vivo*. Such particles can be made as described, for example, by Couvreur et al., *Crit. Rev. Ther. Drug Carrier Syst. 5*(1):1-20, 1988; zur Muhlen et al., *Eur. J. Pharm. Biopharm. 45*(2):149-55, 1998; Zambaux et al., *J. Controlled Release 50*(1-3):31-40, 1998; and U.S. Patent No. 5,145,684.

In addition, pharmaceutical compositions of the present invention may be placed within containers, along with packaging material that provides instructions regarding the use of such pharmaceutical compositions. Generally, such instructions will include a tangible expression describing the reagent concentration, as well as within certain embodiments, relative amounts of excipient ingredients or diluents (*e.g.*, water, saline or PBS) that may be necessary to reconstitute the pharmaceutical composition.

METHODS OF TREATMENT

The present invention also provides methods for increasing the mineral content and mineral density of bone. Briefly, numerous conditions result in the loss of bone mineral content, including for example, disease, genetic predisposition, accidents that result in the lack of use of bone (*e.g.*, due to fracture), therapeutics that effect bone resorption or that kill bone forming cells, and normal aging. Through use of the molecules described herein that inhibit binding of the TGF-beta binding-protein to a TGF-beta family member, such conditions may be treated or prevented. As used herein, that bone mineral content is understood to have increased if bone mineral content has increased in a statistically significant manner at a selected site.

A wide variety of conditions that result in loss of bone mineral content may be treated with the molecules described herein. Patients with such conditions may be identified through clinical diagnosis using well known techniques (see, *e.g.*, Harrison's Principles of Internal Medicine, McGraw-Hill, Inc.). Representative examples of diseases that may be treated included dysplasias, wherein growth or development of bone is abnormal. Representative examples of such conditions include achondroplasia, cleidocranial dysostosis, enchondromatosis, fibrous dysplasia, Gaucher's Disease, hypophosphatemic rickets, Marfan's syndrome, multiple hereditary exotoses, neurofibromatosis, osteogenesis imperfecta, osteopetrosis, osteopoikilosis, sclerotic lesions, fractures, periodontal disease, pseudoarthrosis,

and pyogenic osteomyelitis.

Other conditions that may be treated or prevented include a wide variety of causes of osteopenia (*i.e.*, a condition that causes greater than one standard deviation of bone mineral content or density below peak skeletal mineral content at youth). Representative examples of such conditions include anemic states, conditions caused by steroids, conditions caused by heparin, bone marrow disorders, scurvy, malnutrition, calcium deficiency, idiopathic osteoporosis, congenital osteopenia or osteoporosis, alcoholism, chronic liver disease, senility, postmenopausal state, oligomenorrhea, amenorrhea, pregnancy, diabetes mellitus, hyperthyroidism, Cushing's disease, acromegaly, hypogonadism, immobilization or disuse, reflex sympathetic dystrophy syndrome, transient regional osteoporosis, and osteomalacia.

Within one embodiment of the present invention, bone mineral content or density may be increased by administering to a warm-blooded animal a therapeutically effective amount of a molecule that inhibits a SOST polypeptide from binding to a TGF-beta family member. Examples of warm-blooded animals that may be treated include both vertebrates and mammals, including for example humans, horses, cows, pigs, sheep, dogs, cats, rats, and mice. Representative examples of therapeutic molecules include ribozymes, ribozyme genes, antisense oligonucleotides, and antibodies as described herein.

Within other embodiments of the present invention, methods are provided for increasing bone density comprising the steps of introducing into cells that home to bone, a vector that directs the expression of a molecule that inhibits binding of SOST to a member of the TGF-beta family, and administering the vector containing cells to a warm-blooded animal. Briefly, cells that home to bone may be obtained directly from the bone of patients (*e.g.*, cells obtained from the bone marrow such as CD34+, osteoblasts, osteocytes, and the like), from peripheral blood, or from cultures. Representative examples of suitable vectors include viral vectors such as herpes viral vectors (*e.g.*, U.S. Patent No. 5,288,641); adenoviral vectors (*e.g.*, WO 94/26914, WO 93/9191; Kolls et al., *Proc. Natl. Acad. Sci. USA 91*(1):215-219, 1994; Kass-Eisler et al., *Proc. Natl. Acad. Sci. USA 90*(24):11498-502, 1993; Guzman et al., *Circulation 88*(6):2838-48, 1993; Guzman et al., *Cir. Res. 73*(6):1202-1207, 1993; Zabner et al., *Cell 75*(2):207-216, 1993; Li et al., *Hum. Gene Ther. 4*(4):403-409, 1993; Caillaud et al., *Eur. J. Neurosci. 5*(10:1287-1291, 1993; Vincent et al., *Nat. Genet.* 5(2):130-134, 1993; Jaffe et al., *Nat. Genet. 1*(5):372-378, 1992; and Levrero et al., *Gene 101*(2):195-202, 1991); adeno-associated viral vectors (WO 95/13365; Flotte et al., *PNAS* 90(22):10613-10617, 1993); baculovirus vectors; parvovirus vectors (Koering et al., *Hum. Gene Therap. 5*:457-463, 1994);

pox virus vectors (Panicali and Paoletti, *Proc. Natl. Acad. Sci. USA 79*:4927-4931, 1982; and Ozaki et al., *Biochem. Biophys. Res. Comm.* 193(2):653-660, 1993), and retroviruses (*e.g.*, EP 0,415,731; WO 90/07936; WO 91/0285, WO 94/03622; WO 93/25698; WO 93/25234; U.S. Patent No. 5,219,740; WO 93/11230; WO 93/10218). Viral vectors may likewise be constructed that contain a mixture of different elements (*e.g.*, promoters, envelope sequences, and the like) from different viruses or from non-viral sources. Within various embodiments, either the viral vector itself, or a viral particle that contains the viral vector may be used in the methods and compositions described below.

Within other embodiments of the invention, nucleic acid molecules that encode a molecule that inhibits binding of a SOST polypeptide to a member of the TGF-beta family themselves may be administered by a variety of techniques including, for example, administration of asialoosomucoid (ASOR) conjugated with poly-L-lysine DNA complexes (Cristano et al., *PNAS* 92122-92126, 1993); DNA linked to killed adenovirus (Curiel et al., *Hum. Gene Ther. 3*(2):147-154, 1992); cytofectin-mediated introduction (DMRIE-DOPE, Vical, California); direct DNA injection (Acsadi et al., *Nature 352*:815-818, 1991); DNA ligand (Wu et al., *J. of Biol. Chem. 264*:16985-16987, 1989); lipofection (Felgner et al., *Proc. Natl. Acad. Sci. USA 84*:7413-7417, 1989); liposomes (Pickering et al., *Circ. 89*(1):13-21, 1994; and Wang et al., *PNAS 84*:7851-7855, 1987); microprojectile bombardment (Williams et al., *Proc. Natl. Acad. Sci. USA 88*:2726-2730, 1991); and direct delivery of nucleic acids which encode the protein itself either alone (Vile and Hart, *Cancer Res. 53*: 3860-3864, 1993), or utilizing PEG-nucleic acid complexes.

Determination of increased bone mineral content may be determined directly through the use of X-rays (*e.g.*, Dual Energy X-ray Absorptometry or "DEXA"), or by inference through bone turnover markers such as osteoblast specific alkaline phosphatase, osteocalcin, type 1 procollagen C' propeptide (PICP), and total alkaline phosphatase (*see* Comier, *Curr. Opin. in Rheu. 7*:243 (1995)), or by markers of bone resorption including, but not limited to, pyridinoline, deoxypryridinoline, N-telopeptide, urinary hydroxyproline, plasma tartrate-resistant acid phosphatases, and galactosyl hydroxylysine (*see* Comier, *id.*). The amount of bone mass may also be calculated from body weights or by using other methods (see Guinness-Hey, *Metab. Bone Dis. Relat. Res. 5*:177-181, 1984).

As will be evident to one of skill in the art, the amount and frequency of administration will depend, of course, on such factors as the nature and severity of the indication being treated, the desired response, the condition of the patient, and so forth. Typically, the

compositions may be administered by a variety of techniques, as noted above.

The following examples are offered by way of illustration, and not by way of limitation.

## EXAMPLES

### EXAMPLE 1

### MODELING OF SCLEROSTIN CORE REGION

Homology recognition techniques (*e.g.,* PSI-BLAST (Altschul et al., *Nucleic Acids Res.* 25:3389-402 (1997)), FUGUE (Shi et al., *J. Mol. Biol.* 310:243-57 (2001)) suggested that the core region of SOST (SOST_Core) adopts a cystine-knot fold. FUGUE is a sensitive method for detecting homology between sequences and structures. Human Chorionic Gonadotropin β (hCG-β), for which an experimentally determined 3D structure is known, was identified by FUGUE (Shi et al., *supra*) as the closest homologue of SOST_Core. Therefore, hCG-β was used as the structural template to build 3D models for SOST_Core.

An alignment of SOST_Core and its close homologues is shown in Figure 1. Among the homologues shown in the alignment, only hCG-β (CGHB) had known 3D structure. The sequence identity between SOST_Core and hCG-β was approximately 25%. Eight CYS residues were conserved throughout the family, emphasizing the overall structural similarity between SOST_Core and hCG-β. Three pairs of cystines (1-5, 3-7, 4-8) formed disulfide bonds (shown with solid lines in Figure 1) in a "knot" configuration, which is characteristic to the cystine-knot fold. An extra disulfide bond (2-6), shown as a dotted line in Figure 1, was unique to this family and distinguished the family of proteins from other cystine-knot families (*e.g.,* TGF-β, BMP).

SOST_Core was modeled using PDB (Berman et al., *Acta Crystallogr. D. Biol. Crystallogr.* 58(Pt 6 Pt1):899-907 (2002)) entry 1HCN, the 3D structure of hCG-β (Wu et al., *Structure* 2:545-58 (1994)), as the structural template. Models were calculated with MODELER (Sali & Blundell, *J. Mol. Biol.* 234:779-815 (1993)). A snapshot of the best model is shown in Figure 2.

Most of the cystine-knot proteins form dimers because of the lack of hydrophobic core in a monomer (Scheufler et al., *supra*; Schlunegger and Grutter, *J. Mol. Biol.* 231:445-58 (1993)); Wu et al., *supra*). SOST likely follows the same rule and forms a homodimer to increase its stability. Constructing a model for the dimerized SOST_Core region presented

several challenges because (1) the sequence similarity between SOST_Core and hCG-β was low (25%); (2) instead of a homodimer, hCG-β formed a heterodimer with hCG-α; and (3) a number of different relative conformations of monomers have been observed in dimerized cystine-knot proteins from different families (*e.g.*, PDGF, TGF-β, Neurotrophin, IL-17F, Gonadotropin), which suggested that the dimer conformation of SOST could deviate significantly from the hCG-α/β heterodimer conformation. In constructing the model, hCG-α was replaced with hCG-β from the heterodimer structure (1HCN) using structure superimposition techniques combined with manual adjustment, and then a SOST_Core homodimer model was built according to the pseudo hCG-β homodimer structure. The final model is shown in Figure 3.

## EXAMPLE 2

## MODELING SOST-BMP INTERACTION

This example describes protein modeling of type I and type II receptor binding sites on BMP that are involved with interaction between BMP and SOST.

Competition studies demonstrated that SOST competed with both type I and type II receptors for binding to BMP. In an ELISA-based competition assay, BMP-6 selectively interacted with the sclerostin-coated surface (300 ng/well) with high affinity ($K_D$ = 3.4 nM). Increasing amounts of BMP receptor IA (FC fusion construct) competed with sclerostin for binding to BMP-6 (11 nM) ($IC_{50}$ = 114nM). A 10-fold molar excess of the BMP receptor was sufficient to reduce binding of sclerostin to BMP-6 by approximately 50%. This competition was also observed with a BMP receptor II-FC fusion protein ($IC_{50}$ = 36nM) and DAN ($IC_{50}$ = 43nM). Specificity of the assay was shown by lack of competition for binding to BMP-6 between sclerostin and a rActivin R1B-FC fusion protein, a TGF-β receptor family member that did not bind BMP.

The type I and type II receptor binding sites on a BMP polypeptide have been mapped and were spatially separated (Scheufler et al., *supra*; Innis et al., *supra*; Nickel et al., *supra*; Hart et al. *supra*). Noggin, another BMP antagonist that binds to BMP with high affinity, contacts BMP at both type I and type II receptor binding sites via the N-terminal portion of Noggin (Groppe et al., *supra*). The two β-strands in the core region near the C-terminal also contact BMP at the type II receptor binding site.

A manually tuned alignment of Noggin and SOST indicated that the two polypeptides shared sequence similarity between the N-terminal portions of the proteins and between the core regions. An amino acid sequence alignment is presented in Figure 4. The

cysteine residues that form the characteristic cys-knot were conserved between Noggin and SOST. The overall sequence identity was 24%, and the sequence identity within the N-terminal binding region (alignment positions 1-45) was 33%. Two residues in the Noggin N-terminal binding region, namely Leu (L) at alignment position 21 and Glu (E) at position 23, were reported to play important roles in BMP binding (Groppe et al., *supra*). Both residues were conserved in SOST as well. The sequence similarity within the core region (alignment positions 131-228) was about 20%, but the cys-knot scaffold was maintained and a sufficient number of key residues was conserved, supporting the homology between Noggin and SOST.

The Noggin structure was compared to SOST also to understand how two SOST monomers dimerize. As shown in Figure 5, the Noggin structure suggested that the linker between the N-terminal region and the core region not only played a role in connecting the two regions, but also formed part of the dimerization interface between two Noggin monomers. One major difference between Noggin and SOST was that the linker between the N-terminal region and the core region was much shorter in SOST.

The C-terminal region of SOST may play a role in SOST dimerization. The sequence of Noggin ended with the core region, while SOST had an extra C-terminal region. In the Noggin structure a disulfide bond connected the C-termini of two Noggin monomers. Thus, the C-terminal region of SOST started close to the interface of two monomers and could contribute to dimerization. In addition, secondary structure prediction shows that some portions of the C-terminal region of SOST had a tendency to form helices. This region in SOST may be responsible for the dimerization activity, possibly through helix-helix packing, which mimicked the function of the longer linker in Noggin. Another difference between the structure of Noggin and SOST was the amino acid insertion in the SOST core region at alignment positions 169-185 (see Figure 4). This insertion extended a β-hairpin, which pointed towards the dimerization interface in the Noggin structure (shown in Figure 5 as a loop region in the middle of the monomers and above the C-terminal Cys residue). This elongated β-hairpin could also contribute to SOST dimerization.

## EXAMPLE 3

## DESIGN AND PREPARATION OF SOST PEPTIDE IMMUNOGENS

This Example describes the design of SOST peptide immunogens that are used for immunizing animals and generating antibodies that block interactions between BMP and SOST and prevent dimer formation of SOST monomers.

BMP Binding Fragments

The overall similarity between SOST and Noggin and the similarity between the N-terminal regions of the two polypeptides suggest that SOST may interact with BMP in a similar manner to Noggin. That is, the N-terminal region of SOST may interact with both the type I and type II receptor binding sites on BMP, and a portion of the core region (amino acid alignment positions 190-220 in Figure 4) may interact with the type II receptor binding site such that antibodies specific for these SOST regions may block or impair binding of BMP to SOST.

The amino acid sequences of these SOST polypeptide fragments for rat and human SOST are provided as follows.

SOST_N_Linker: The N-terminal region (includes the short linker that connects to the core region)

Human: QGWQAFKNDATEIIPELGEYPEPPPELENNKTMNRAE NGGRPPHHPFETKDVSEYS (SEQ ID NO:47)

Rat: QGWQAFKNDATEIIPGLREYPEPPQELENNQTMNRAEN GGRPPHHPYDTKDVSEYS (SEQ ID NO:48)

SOST_Core_Bind: Portion of the core region that is likely to contact BMP at its type II receptor binding site (extended slightly at both termini to include the CYS residue anchors):

Human: CIPDRYRAQRVQLLCPGGEAPRARKVRLVASC (SEQ ID NO:49)

Rat: CIPDRYRAQRVQLLCPGGAAPRSRKVRLVASC (SEQ ID NO:50)

SOST Dimerization Fragments

The C-terminal region of SOST is likely to be involved in the formation of SOST homodimers (see Example 2). The elongated β-hairpin may also play a role in homodimer formation. Antibodies that specifically bind to such regions may prevent or impair dimerization of SOST monomers, which may in turn interfere with interaction between SOST and BMP. Polypeptide fragments in rat and human SOST corresponding to these regions are as follows.

SOST_C: the C-terminal region

Human: LTRFHNQSELKDFGTEAARPQKGRKPRPRARSAKANQA ELENAY (SEQ ID NO:51)

Rat: LTRFHNQSELKDFGPETARPQKGRKPRPRARGAKANQAE

LENAY (SEQ ID NO:52)

SOST_Core_Dimer: Portion of the core region that is likely involved in SOST dimerization (extended slightly at both termini to include the Cys residue anchors):

Human: CGPARLLPNAIGRGKWWRPSGPDFRC (SEQ ID NO:53)

Rat: CGPARLLPNAIGRVKWWRPNGPDFRC (SEQ ID NO:54)

BMP Binding Fragment at SOST N-terminus

The key N-terminal binding region of SOST (alignment positions 1-35 in Figure 4) was modeled on the basis of the Noggin/BMP-7 complex structure (Protein Data Bank Entry No: 1M4U) and the amino acid sequence alignment (see Figure 4) to identify amino acid residues of the SOST N-terminus that likely interact with BMP. The model of SOST is presented in Figure 6. In the comparative model, phenylalanine (Phe, F) at alignment position 8 (see arrow and accompanying text) in the SOST sequence projects into a hydrophobic pocket on the surface of the BMP dimer. The same "knob-into-hole" feature has been observed in the BMP and type I receptor complex structure (Nickel et al., *supra*), where Phe85 of the receptor fits into the same pocket, which is a key feature in ligand-type I receptor recognition for TGF-β superfamily members (including, for example, TGF-β family, BMP family, and the like). According to the model, a proline (Pro) directed turn is also conserved, which allows the N-terminal binding fragment to thread along the BMP dimer surface, traveling from type I receptor binding site to type II receptor binding site on the other side of the complex. Also conserved is another Pro-directed turn near the carboxy end of the binding fragment, which then connects to the linker region. Extensive contacts between SOST and BMP are evident in Figure 6.

Peptide Immunogens

Peptides were designed to encompass the SOST N-terminal region predicted to make contact with BMP proteins. The peptide sequences are presented below. For immunizing animals, the peptide sequences were designed to overlap, and an additional cysteine was added to the C-terminal end to facilitate crosslinking to KLH. The peptides were then used for immunization. The peptide sequences of the immunogens are as follows.

Human SOST:

QGWQAFKNDATEIIPELGEY (SEQ ID NO:2)

TEIIPELGEYPEPPPELENN (SEQ ID NO:3)

PEPPPELENNKTMNRAENGG (SEQ ID NO:4)

KTMNRAENGGRPPHHPFETK (SEQ ID NO:5)

RPPHHPFETKDVSEYS (SEQ ID NO:6)

Human SOST Peptides with Additional Cys:

QGWQAFKNDATEIIPELGEY-C (SEQ ID NO:7)

TEIIPELGEYPEPPPELENN-C (SEQ ID NO:8)

PEPPPELENNKTMNRAENGG-C (SEQ ID NO:9)

KTMNRAENGGRPPHHPFETK-C (SEQ ID NO:10)

RPPHHPFETKDVSEYS-C (SEQ ID NO:11)

Rat SOST:

QGWQAFKNDATEIIPGLREYPEPP (SEQ ID NO:12)

PEPPQELENNQTMNRAENGG (SEQ ID NO:13)

ENGGRPPHHPYDTKDVSEYS (SEQ ID NO:14)

TEIIPGLREYPEPPQELENN (SEQ ID NO:15)

Rat SOST Peptides with Additional Cys:

QGWQAFKNDATEIIPGLREYPEPP-C (SEQ ID NO:16)

PEPPQELENNQTMNRAENGG-C (SEQ ID NO:17)

ENGGRPPHHPYDTKDVSEYS-C (SEQ ID NO:18)

TEIIPGLREYPEPPQELENN-C (SEQ ID NO:19)

The following peptides were designed to contain the amino acid portion of core region that was predicted to make contact with BMP proteins. Cysteine was added at the C-terminal end of each peptide for conjugation to KLH, and the conjugated peptides were used for immunization. In the Docking Core N-terminal Peptide an internal cysteine was changed to a serine to avoid double conjugation to KLH.

For Human SOST:

Amino acid sequence without Cys residues added:

Docking_Core_N-terminal_Peptide: IPDRYRAQRVQLLCPGGEAP (SEQ ID NO:21)

Docking_Core_Cterm_Peptide: QLLCPGGEAPRARKVRLVAS (SEQ ID

NO:22)

Docking_Core_N-terminal_Peptide: IPDRYRAQRVQLLCPGGEAP-C (SEQ ID NO:23)

Docking_Core_Cterm_Peptide: QLLCPGGEAPRARKVRLVAS-C (SEQ ID NO:24)

For Rat SOST:

Amino acid sequence without Cys residues added or substituted:

Docking_Core_N-terminal_Peptide: IPDRYRAQRVQLLCPGG (SEQ ID NO:25)

Docking_Core_Cterm_Peptide: PGGAAPRSRKVRLVAS (SEQ ID NO:26)

Peptide immunogens with Cys added and substituted:

Docking_Core_N-terminal_Peptide: IPDRYRAQRVQLLSPGG-C (SEQ ID NO:27)

Docking_Core_Cterm_Peptide: PGGAAPRSRKVRLVAS-C (SEQ ID NO:28)

Two regions within SOST that potentially interact to form SOST homodimers include the amino acids with the SOST core region that are not present in Noggin. Human SOST peptides designed to contain this sequence had a C-terminal or N-terminal Cys that was conjugated to KLH. For the rat SOST peptide, a cysteine was added to the carboxy terminus of the sequence (SEQ ID NO:31). The KLH conjugated peptides were used for immunization.

For Human SOST:

CGPARLLPNAIGRGKWWRPS (SEQ ID NO:29)

IGRGKWWRPSGPDFRC (SEQ ID NO:30)

For Rat SOST:

PNAIGRVKWWRPNGPDFR (SEQ ID NO:31)

Rat SOST peptide with cysteine added

PNAIGRVKWWRPNGPDFR-C (SEQ ID NO:32)

The second region within SOST that potentially interacts to form SOST homodimers includes the C-terminal region. Peptide immunogens were designed to include amino acid sequences within this region (see below). For conjugation to KLH, a cysteine residue was added to the C-terminal end, and the conjugated peptides were used for immunization.

For Human SOST:
KRLTRFHNQS ELKDFGTEAA (SEQ ID NO:33)
ELKDFGTEAA RPQKGRKPRP (SEQ ID NO:34)
RPQKGRKPRP RARSAKANQA (SEQ ID NO:35)
RARSAKANQA ELENAY (SEQ ID NO:36)

Peptide immunogens with Cys added at C-terminus:
KRLTRFHNQS ELKDFGTEAA-C (SEQ ID NO:37)
ELKDFGTEAA RPQKGRKPRP-C (SEQ ID NO:38)
RPQKGRKPRP RARSAKANQA-C (SEQ ID NO:39)
RARSAKANQA ELENAY-C (SEQ ID NO:40)

For Rat SOST:
KRLTRFHNQSELKDFGPETARPQ (SEQ ID NO:41)
KGRKPRPRARGAKANQAELENAY (SEQ ID NO:42)
SELKDFGPETARPQKGRKPRPRAR (SEQ ID NO:43)

Peptide immunogens with Cys added at C-terminus:
KRLTRFHNQSELKDFGPETARPQ-C (SEQ ID NO:44)
KGRKPRPRARGAKANQAELENAY-C (SEQ ID NO:45)
SELKDFGPETARPQKGRKPRPRAR-C (SEQ ID NO:46)

## EXAMPLE 4

### ASSAY FOR DETECTING BINDING OF ANTIBODIES TO A TGF-BETA BINDING-PROTEIN

This example describes an assay for detecting binding of a ligand, for example, an antibody or antibody fragment thereof, to sclerostin.

A FLAG®-sclerostin fusion protein was prepared according to protocols

provided by the manufacturer (Sigma Aldrich, St. Louis, MO) and as described in U.S. Patent No. 6,395,511. Each well of a 96 well microtiter plate is coated with anti-FLAG® monoclonal antibody (Sigma Aldrich) and then blocked with 10% BSA in PBS. The fusion protein (20 ng) is added to 100 µl PBS/0.2% BSA and adsorbed onto the 96-well plate for 60 minutes at room temperature. This protein solution is removed and the wells are washed to remove unbound fusion protein. A BMP, for example, BMP-4, BMP-5, BMP-6, or BMP-7, is diluted in PBS/0.2% BSA and added to each well at concentrations ranging from 10 pM to 500 nM. After an incubation for 2 hours at room temperature, the binding solution is removed and the plate is washed three times with 200 µl volumes of PBS/0.2% BSA. Binding of the BMP to sclerostin is detected using polyclonal antiserum or monoclonal antibody specific for the BMP and an appropriate enzyme-conjugated second step reagent according to standard ELISA techniques (*see, e.g.,* Ausubel et al., *Current Protocols in Mol Biol.* Vol 2 11.2.1-11.2.22 (1998)). Specific binding is calculated by subtracting non-specific binding from total binding and analyzed using the LIGAND program (Munson and Podbard, *Anal. Biochem.* 107:220-39 (1980)).

Binding of sclerostin to a BMP is also detected by homogeneous time resolved fluorescence detection (Mellor et al., *J Biomol. Screening,* 3:91-99 (1998)). A polynucleotide sequence encoding sclerostin is operatively linked to a human immunoglobulin constant region in a recombinant nucleic acid construct and expressed as a human Fc-sclerostin fusion protein according to methods known in the art and described herein. Similarly, a BMP ligand is engineered and expressed as a BMP-mouse Fc fusion protein. These two fusion proteins are incubated together and the assay conducted as described by Mellor et al.

## EXAMPLE 5

## SCREENING ASSAY FOR ANTIBODIES THAT INHIBIT BINDING OF TGF-BETA FAMILY MEMBERS TO TGF-BETA BINDING PROTEIN

This example describes a method for detecting an antibody that inhibits binding of a TGF-beta family member to sclerostin. An ELISA is performed essentially as described in Example 4 except that the BMP concentration is held fixed at its Kd (determined, for example, by BIAcore analysis). In addition, an antibody or a library or collection of antibodies is added to the wells to a concentration of 1 µM. Antibodies are incubated for 2 hours at room temperature with the BMP and sclerostin, the solution removed, and the bound BMP is quantified as described (see Example 4). Antibodies that inhibit 40% of the BMP binding observed in the

absence of antibody are considered antagonists of this interaction. These antibodies are further evaluated as potential inhibitors by performing titration studies to determine their inhibition constants and their effect on TGF-beta binding-protein binding affinity. Comparable specificity control assays may also be conducted to establish the selectivity profile for the identified antagonist using assays dependent on the BMP ligand action (*e.g.,* a BMP/BMP receptor competition study).

## EXAMPLE 6

### INHIBITION OF TGF-BETA BINDING-PROTEIN LOCALIZATION TO BONE MATRIX

Evaluation of inhibition of localization to bone matrix (hydroxyapatite) is conducted using modifications to the method of Nicolas (*Calcif. Tissue Int.* 57:206-12 (1995)). Briefly, $^{125}$I-labelled TGF-beta binding-protein is prepared as described by Nicolas (*supra*). Hydroxyapatite is added to each well of a 96-well microtiter plate equipped with a polypropylene filtration membrane (Polyfiltroninc, Weymouth MA). TGF-beta binding-protein diluted in 0.2% albumin in PBS buffer is then added to the wells. The wells containing matrix are washed 3 times with 0.2% albumin in PBS buffer. Adsorbed TGF-beta binding-protein is eluted using 0.3 M NaOH and then quantified.

An antibody or other agent that inhibits or impairs binding of the sclerostin TGF-beta binding protein to the hydroxyapatite is identified by incubating the TGF-beta binding protein with the antibody and applying the mixture to the matrix as described above. The matrix is washed 3 times with 0.2% albumin in PBS buffer. Adsorbed sclerostin is eluted with 0.3 M NaOH and then quantified. An antibody that inhibits the level of binding of sclerostin to the hydroxyapatite by at least 40% compared to the level of binding observed in the absence of antibody is considered a bone localization inhibitor. Such an antibody is further characterized in dose response studies to determine its inhibition constant and its effect on TGF-beta binding-protein binding affinity.

From the foregoing, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

CLAIMS

We claim the following:

1. An isolated antibody, or an antigen-binding fragment thereof, that binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68 wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

2. The antibody, or antigen-binding fragment thereof, according to claim 1 wherein the antibody, or the antigen-binding fragment thereof, binds specifically to a polypeptide that comprises an amino acid sequence selected from the group consisting of SEQ ID NOs:2, 3, 4, 5, 6, 12, 13, 14, 15, 21, 22, 25, 26, 47, 48, 49, and 50.

3. An isolated antibody, or an antigen-binding fragment thereof, that is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids that comprises an amino acid sequence selected from the group consisting of SEQ ID NOs:2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 47, 48, 49, and 50.

4. The antibody, or an antigen-binding fragment thereof, according to claim 3 wherein the antibody binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68.

5. The antibody, or an antigen-binding fragment thereof, according to claim 4 wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor

binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

6. An antibody, or an antigen-binding fragment thereof, that is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids that comprises an amino acid sequence selected from the group consisting of SEQ ID NO:2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 47, 48, 49, and 50 wherein the antibody binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, and wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

7. An isolated antibody, or an antigen-binding fragment thereof, that binds specifically to a SOST polypeptide and that impairs formation of a SOST homodimer, wherein the SOST polypeptide comprises an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68.

8. The antibody of claim 7 wherein the antibody binds to a polypeptide that comprises an

amino acid sequence selected from the group consisting of SEQ ID NOs:29, 30, 31, 33, 34, 35, 36, 41, 42, 43, 51, 52, 53, and 54.

9. An antibody, or an antigen-binding fragment thereof, that is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 51, 52, 53, and 54.

10. The antibody, or an antigen-binding fragment thereof, according to claim 9, wherein the antibody, or the antigen-binding fragment thereof, binds specifically to a SOST polypeptide that comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68.

11. The antibody, or an antigen-binding fragment thereof, according to claim 10, wherein the antibody, or the antigen-binding fragment thereof, impairs formation of a SOST homodimer.

12. An antibody, or an antigen-binding fragment thereof, that is produced by immunizing a non-human animal with a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 51, 52, 53, and 54, wherein the antibody, or the antigen-binding fragment thereof, binds specifically to a SOST polypeptide that comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, and wherein the antibody impairs formation of a SOST homodimer.

13. The antibody of any one of claims 1-12, wherein the antibody is a polyclonal antibody.

14. The antibody of any one of claims 1-12, wherein the antibody is a monoclonal antibody.

15. The antibody of claim 14 wherein the monoclonal antibody is selected from the group consisting of a mouse monoclonal antibody, a human monoclonal antibody, a rat monoclonal antibody, and a hamster monoclonal antibody.

16. A hybridoma cell producing the antibody of claim 14.

17. A host cell that is capable of expressing the antibody of claim 14.

18. The antibody of any one of claims 1-12 wherein the antibody is a humanized antibody or a chimeric antibody.

19. A host cell that is capable of expressing the antibody of claim 18.

20. The antibody of any one of claims 1-12, wherein the antigen-binding fragment is selected from the group consisting of $F(ab')_2$, Fab', Fab, Fd, and Fv.

21. The antibody of any one of claims 1-12 that comprises a single chain antibody.

22. A host cell that is capable of expressing the antibody of claim 21.

23. A composition comprising an antibody, or antigen-binding fragment thereof, according to any one of claims 1-12 and a physiologically acceptable carrier.

24. An immunogen comprising a peptide comprising 6, 7, 8, 9, 10, 11, or 12 consecutive amino acids of a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

25. An immunogen comprising a peptide comprising at least 21 consecutive amino acids and no more than 50 consecutive amino acids of a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NOs:1, 20, 58, 60, 62, or 68, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83);

CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

26. An immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 47, 48, 49, and 50.

27. The immunogen according to claim 26 wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68.

28. The immunogen according to claim 27 wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

29. An immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 47, 48, 49, and 50, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, wherein the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site, wherein the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising an amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID

NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79), and wherein the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

30. An immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 51, 52, 53, and 54.

31. The immunogen according to claim 30 wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68.

32. The immunogen according to claim 31 wherein the antibody impairs formation of a SOST homodimer.

33. An immunogen comprising a peptide of at least 20 amino acids and no more than 75 amino acids comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 51, 52, 53, and 54, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, and wherein the antibody impairs formation of a SOST homodimer.

34. An immunogen comprising a peptide comprising 6, 7, 8, 9, 10, 11, or 12 consecutive amino acids of a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that impairs formation of a SOST homodimer.

35. An immunogen comprising a peptide that comprises at least 21 consecutive amino acids and no more than 50 consecutive amino acids of a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, wherein the peptide is capable of eliciting in a non-human animal an antibody that binds specifically to the SOST polypeptide and that impairs formation of a SOST homodimer.

36. The immunogen of any one of claims 24-35 wherein the peptide is associated with a carrier molecule.

37. The immunogen of claim 36 wherein the carrier molecule is a carrier polypeptide.

38. The immunogen of claim 37 wherein the carrier polypeptide is keyhole limpet hemocyanin.

39. A method for producing an antibody that specifically binds to a SOST polypeptide, comprising immunizing a non-human animal with an immunogen according to any one of claims 24-29, wherein (a) the SOST polypeptide comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68; (b) the antibody competitively inhibits binding of the SOST polypeptide to at least one of (i) a bone morphogenic protein (BMP) Type I Receptor binding site and (ii) a BMP Type II Receptor binding site; (c) the BMP Type I Receptor binding site is capable of binding to a BMP Type I Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. Nos. NM_004329 (SEQ ID NO:71); D89675 (SEQ ID NO:72); NM_001203 (SEQ ID NO:73); S75359 (SEQ ID NO:74); NM_030849 (SEQ ID NO:75); D38082 (SEQ ID NO:76); NP_001194 (SEQ ID NO:77); BAA19765 (SEQ ID NO:78); and AAB33865 (SEQ ID NO:79); and (d) the BMP Type II Receptor binding site is capable of binding to a BMP Type II Receptor polypeptide comprising the amino acid sequence set forth in a sequence selected from the group consisting of GenBank Acc. NOs. U25110 (SEQ ID NO:80); NM_033346 (SEQ ID NO:81); Z48923 (SEQ ID NO:83); CAA88759 (SEQ ID NO:84); and NM_001204 (SEQ ID NO:82).

40. A method for producing an antibody that specifically binds to a SOST polypeptide, said SOST polypeptide comprising an amino acid sequence set forth in SEQ ID NO:1, 20, 58, 60, 62, or 68, comprising immunizing a non-human animal with an immunogen according to any one of claims 30-35, wherein the antibody impairs formation of a SOST homodimer.

41. A method for identifying an antibody that modulates a TGF-beta signaling pathway comprising:

(a) contacting an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, and 68 with at least one SOST peptide comprising an amino acid sequence selected from the group consisting of SEQ ID NO: 2-19, and 21-54, under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and

(b) detecting a level of antibody/SOST peptide complex, and thereby

detecting the presence of an antibody that modulates a TGF-beta signaling pathway.

42. A method for identifying an antibody that impairs binding of a BMP to a SOST polypeptide comprising:

(a) contacting (i) an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, and 68 with (ii) at least one SOST peptide comprising an amino acid sequence selected from the group consisting of SEQ ID NO: 2-19, 21-28, and 47-50 under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and

(b) detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that impairs binding of a BMP to a SOST polypeptide.

43. A method for identifying an antibody that impairs SOST homodimer formation comprising:

(a) contacting (i) an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, and 68, with (ii) at least one SOST peptide comprising an amino acid sequence selected from the group consisting of SEQ ID NO: 29-46 and 51-54 under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and

(b) detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that that impairs SOST homodimer formation.

44. A method for identifying an antibody that increases bone mineral content comprising:

(a) contacting (i) an antibody that specifically binds to a SOST polypeptide which comprises an amino acid sequence set forth in any one of SEQ ID NOS: 1, 20, 58, 60, 62, and 68 with (ii) at least one SOST peptide comprising an amino acid sequence selected from the group consisting of SEQ ID NO: 2-19, and 21-54 under conditions and for a time sufficient to permit formation of an antibody/SOST peptide complex; and

(b) detecting a level of antibody/SOST peptide complex, and thereby detecting the presence of an antibody that increases bone mineral content.

45. The method according to any one of claims 41-44 wherein the antibody is selected from the group consisting of an antibody that is present in a biological sample and a purified antibody.

46. The method according to claim 45 wherein the purified antibody is selected from the group consisting of a polyclonal antibody, a monoclonal antibody, a chimeric antibody, a humanized antibody, and an antigen-binding fragment of an antibody.

47. The antibody according to claim 2 wherein the polypeptide comprises an amino acid

sequence selected from the group consisting of SEQ ID NO:5, 6, and 14.

48. The antibody according to any one of claims 3-6 wherein the peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NO:5, 6, 10, 11, 14, and 18.

49. The immunogen of any one of claims 26-29 wherein the peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NO:5, 6, 10, 11, 14, and 18.

50. A method for producing an antibody that specifically binds to a SOST polypeptide, comprising immunizing a non-human animal with an immunogen according to claim 49, wherein the SOST polypeptide comprises an amino acid sequence set forth in SEQ ID NO:1, 20, 28, 60, 62, or 68.

51. The method of any one of claims 41, 42, and 44 wherein the SOST peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NO:5, 6, 10, 11, 14, and 18.