

BONE-TARGETING ANTIBODIES

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. Provisional Application 62/448,763, filed on January 20, 2017, the disclosure of which is incorporated by reference herein in its entirety.

SEQUENCE LISTING

[0002] The instant application contains a Sequence Listing which has been submitted electronically in ASCII format and is hereby incorporated by reference in its entirety. Said ASCII copy, created on January 11, 2018, is named 022548_WO012_SL.txt and is 75,113 bytes.

FIELD OF THE INVENTION

[0003] The invention relates to antibodies modified with bone-targeting peptides and methods of their use for treating pathophysiological bone degeneration.

BACKGROUND OF THE INVENTION

[0004] Proper bone development and maintenance are important factors for normal health. In the average human, bone development occurs until the age of about 20 years old, where bone density is typically at its maximum. Thereafter, bone density can diminish without proper diet and physical exertion. Normal bone maintenance, however, requires homeostatic bone turnover, where old bone is removed and replaced with new bone.

[0005] Yet, there are numerous diseases and conditions that can affect bone development and maintenance. For example, bone development is affected in diseases such as osteogenesis imperfecta, where bone strength is compromised, which leads to children with fragile bones that can easily break. Moreover, lack of homeostatic bone turnover can occur in otherwise healthy individuals as they age, leading to osteoporosis,

where bone density is compromised over time, and ultimately to fragile bones and bone fractures.

[0006] Still further, there are certain diseases wherein bone health is affected collaterally to the primary disease and involved in other comorbid sequelae, such as in chronic kidney disease (CKD). CKD is a progressive disease in which kidney function declines over time, often leading to cardiovascular diseases linked to poor bone health and altered bone turnover rates. It has been shown that treatments that improve bone health concomitantly alleviate the associated cardiovascular diseases. Such reports suggest that normal bone turnover rates could be influential on, if not causative of, other diseases. Therefore, improved methodologies for regulating bone development and/or maintenance could have a widespread direct or indirect effect on improving the health of individuals suffering from numerous disparate diseases and conditions.

[0007] TGF β is a member of the transforming growth factor-beta (TGF β) superfamily and is important in bone formation during mammalian development (see Chen *et al.*, Int. J. Biol. Sci. 8(2): 272–88 (2012)). TGF β appears to be equally important for homeostatic bone maintenance. Interestingly, TGF β has been shown to be expressed at higher levels in individuals with CKD, suggesting that it is a viable target for therapeutic intervention. Systemic treatment of a *jck* mouse model of CKD with anti-TGF β antibodies demonstrated a reduction in high bone turnover rates (Liu *et al.*, J. Bone Miner Res. 29(5): 1141-57 (2014)). However, this study did not investigate the degree to which localization of the anti-TGF β antibodies in bone may improve treatment efficacy. Given that TGF β is involved in a multitude of cellular processes including DNA damage response, allergic immune responses, and wound epithelialization, just to name a few, a more targeted approach for controlling TGF β activity is desirable to minimize potential undesired side-effects. Therefore, a more precise approach for regulating TGF β activity is needed to provide improved treatments for regulating bone development and/or maintenance.

SUMMARY OF THE INVENTION

[0008] Provided herein are antibodies, such as anti-TGF β antibodies, that are effectively targeted to bone. In a first aspect, the present disclosure provides an

antibody, or an antigen-binding fragment thereof, comprising a heavy chain, a light chain, and one or more poly-aspartate (poly-D) peptides. In one particular embodiment, the antibody or antigen-binding fragment comprises a heavy chain, a light chain, and one or more poly-aspartate (poly-D) peptides connected to the heavy chain and/or the C-terminus of the light chain.

[0009] In one embodiment, the antibody or antigen-binding fragment thereof exhibits at least a 2-fold increase in localization to bone compared to an antibody with the same heavy chain and light chain but lacking the one or more poly-D peptides.

[0010] In one embodiment, the one or more poly-D peptides are connected to the antibody or antigen-binding fragment thereof by chemical conjugation. In another embodiment, the one or more poly-D peptides are connected at the hinge region of the heavy chain. In a further embodiment, the one or more poly-D peptides are connected to the N-terminus or C-terminus of the light chain. In a still further embodiment, the one or more poly-D peptides are connected to the antibody or antigen-binding fragment thereof by one or more spacers/linkers (e.g., polyethylene glycol (PEG) spacers and peptide linkers).

[0011] In one embodiment, one or more poly-D peptides are integral with an amino acid sequence of the heavy chain and/or one or more poly-D peptides are integral with an amino acid sequence of the light chain. A poly-D peptide that is “integral” with an amino acid sequence is included in the same polypeptide chain. For example the integral poly-D peptide can be translated from the same RNA chain as the heavy or light chain sequence, which may be encoded from a recombinant DNA plasmid. In one embodiment, one or more poly-D peptides are integral with the N-terminus and/or one or more poly-D peptides are integral with the C-terminus of the heavy chain. Two or more poly-D peptides can be linked in tandem, separated by zero, one or more other amino acid residues (*i.e.*, non-aspartate amino acids) or a peptide linker to the N-terminus or the C-terminus of the heavy chain. In a further embodiment, one or more poly-D peptides are integral with the N-terminus and/or one or more poly-D peptides are integral with the C-terminus of the light chain. For example, two or more poly-D peptides can be linked in tandem being separated by zero, one or more other amino acid residues (*i.e.*, non-aspartate amino acids) or a peptide linker to the N-terminus or

the C-terminus of the light chain. In one embodiment, a poly-D peptide is integral with the C-terminus of the heavy chain. In another embodiment, a poly-D peptide is integral with the C-terminus of the heavy chain and a poly-D peptide is integral with the N-terminus of the heavy chain.

[0012] In one embodiment, the light chain does not comprise a poly-D peptide. In another embodiment, the heavy chain does not comprise a poly-D peptide.

[0013] In one embodiment, the one or more poly-D peptides each independently comprise 2 - 30 aspartic acid residues. For example, a poly-D peptide can include 2, or 3, or 4, or 5, or 6, or 7, or 8, or 9, or 10, or 11, or 12, or 13, or 14, or 15, or 16, or 17, or 18, or 19, or 20, or 21, or 22, or 23, or 24, or 25, or 26, or 27, or 28, or 29, or 30 aspartic acid residues. In another embodiment, the one or more poly-D peptides each independently comprise 6, 7, 8, 9, 10 or 11 aspartic acid residues. In another embodiment, the one or more poly-D peptides each comprise 10 aspartic acid residues; such peptides are called "D10" (SEQ ID NO: 1) herein. In some embodiments, the antibody or fragment may include 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, or more than 12 poly-D peptides.

[0014] In another embodiment, the antibody is any of isotypes IgG₁, IgG₂, IgG₃, IgG₄, IgA₁, IgA₂, IgM, IgE, or IgD. In another embodiment, the antibody is an IgG₁ or IgG₄ isotype. In another embodiment, the antibody or antigen-binding fragment thereof specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃, such as one or more of human TGFβ₁, TGFβ₂, and TGFβ₃.

[0015] In one embodiment, an antibody fragment is contemplated having one or more poly-aspartate (poly-D) peptides. It is envisioned that the antibody fragment would exhibit at least a 2-fold increase in localization to bone compared to the same antibody fragment but lacking the one or more poly-D peptides. The antibody fragment can, for example, be any or a combination of the following: Fab, F(ab')₂, monospecific Fab₂, bispecific Fab₂, trispecific Fab₃, monovalent IgG, scFv, bispecific diabody, trispecific triabody, scFv-sc, a minibody, IgNAR, V-NAR, hclgG, or VhH. In one embodiment, the antibody fragment binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃, such as one or more of human TGFβ₁, TGFβ₂, and TGFβ₃. The antibody or antibody fragment herein may be fully human, humanized, or chimeric.

[0016] In a second aspect, the present disclosure provides a method of producing an antibody or an antigen-binding fragment thereof targeted to bone that includes the steps of providing an antibody heavy chain, providing an antibody light chain, providing one or more poly-D peptides attached to the heavy chain and/or one or more poly-D peptides attached to the light chain, and combining the heavy chain and the light chain to produce an antibody or antigen-binding fragment thereof targeted to bone.

[0017] In one embodiment, the one or more poly-D peptides attached to the heavy chain and/or the one or more poly-D peptides attached to the light chain are attached by chemical conjugation. In another embodiment, the one or more poly-D peptides attached to the heavy chain and/or the one or more poly-D peptides attached to the light chain are attached by recombination.

[0018] In a third aspect, the present disclosure provides an anti-TGF β antibody targeted to bone that includes a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 2, 3, 4, and 5 (with or without the heavy chain C-terminal lysine), and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 6, 7, 8, 11, and 12, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 2 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 6.

[0019] In a fourth aspect, the present disclosure provides an anti-TGF β antibody targeted to bone that includes a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine), and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 20, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15.

[0020] In a fifth aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 14 (with or without the heavy chain C-terminal lysine) and a light chain comprising the amino acid sequence of SEQ ID NO: 15 (e.g., mAb2 F6). The antibody specifically binds one or more of TGF β 1, TGF β 2, and TGF β 3. In one embodiment, the antibody specifically binds TGF β 1.

[0021] In a sixth aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 17 (with or without the heavy chain C-terminal lysine), and a light chain comprising the amino acid sequence of SEQ ID NO: 15 (e.g., mAb2 F16). The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃. In one embodiment, the antibody specifically binds TGFβ₁.

[0022] In a seventh aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 16 (with or without the heavy chain C-terminal lysine), and a light chain comprising the amino acid sequence of SEQ ID NO: 15 (e.g., mAb2 F11). The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃. In one embodiment, the antibody specifically binds TGFβ₁.

[0023] In an eighth aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 17 (with or without the heavy chain C-terminal lysine), and a light chain comprising the amino acid sequence of SEQ ID NO: 18 (e.g., mAb2 F17). The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃. In one embodiment, the antibody specifically binds TGFβ₁.

[0024] In a ninth aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 16 (with or without the heavy chain C-terminal lysine), and a light chain comprising the amino acid sequence of SEQ ID NO: 18 (e.g., mAb2 F12). The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃. In one embodiment, the antibody specifically binds TGFβ₁.

[0025] In a tenth aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 14 (with or without the heavy chain C-terminal lysine), and a light chain comprising the amino acid sequence of SEQ ID NO: 18 (e.g., mAb2 F7). The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃. In one embodiment, the antibody specifically binds TGFβ₁.

[0026] In an eleventh aspect, the present disclosure provides a human IgG₄ antibody that includes a heavy chain comprising the amino acid sequence of SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine), and a light chain comprising the amino acid sequence of SEQ ID NO: 18 (e.g., mAb2 F2). The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃. In one embodiment, the antibody specifically binds TGFβ₁.

[0027] In a twelfth aspect, the present disclosure provides an anti-TGFβ antibody targeted to bone including a heavy chain comprising an amino acid sequence encoded by a nucleic acid sequence in set forth in any of SEQ ID NOS: 23, 24, 25, and 26 (with or without the codon for the heavy chain C-terminal lysine) and a light chain comprising an amino acid sequence encoded by a nucleic acid sequence in set forth in any of SEQ ID NOS: 27, 28, 29, 30, 31, and 32, with the proviso that the heavy chain amino acid sequence is not encoded by the nucleic acid sequence set forth in SEQ ID NO: 23 (with or without the codon for the heavy chain C-terminal lysine) when the light chain amino acid sequence is encoded by the nucleic acid sequence in set forth in SEQ ID NO: 27.

[0028] In a thirteenth aspect, the present disclosure provides a human IgG₄ antibody including a heavy chain comprising an amino acid sequence encoded by the nucleic acid sequence set forth in SEQ ID NO: 25 (with or without the codon for the heavy chain C-terminal lysine) and a light chain comprising an amino acid sequence encoded by the nucleic acid sequence set forth in SEQ ID NO: 27. The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃.

[0029] In a fourteenth aspect, the present disclosure provides a human IgG₄ antibody including a heavy chain comprising an amino acid sequence encoded by the nucleic acid sequence set forth in SEQ ID NO: 26 (with or without the codon for the heavy chain C-terminal lysine) and a light chain comprising an amino acid sequence encoded by the nucleic acid sequence set forth in SEQ ID NO: 27. The antibody specifically binds one or more of TGFβ₁, TGFβ₂, and TGFβ₃.

[0030] In a fifteenth aspect, the present disclosure provides a method for treating an individual for bone loss including administering to the individual an effective amount of an anti-TGFβ antibody or an antigen-binding fragment thereof targeted to bone and detecting at least one of a reduction in TGFβ levels, a reduction in TGFβ activity, a

reduction in bone loss, a reduction in rate of bone loss, an increase in bone density, an increase in bone strength, and a reduction in IL-11 levels.

[0031] In one embodiment, the individual is a human. In another embodiment, the anti-TGF β antibody or antibody fragment specifically binds one or more of TGF β 1, TGF β 2, and TGF β 3. In a further embodiment, the anti-TGF β antibody includes a heavy chain, a light chain, and one or more poly-aspartate (poly-D) peptides. The antibody exhibits at least a 2-fold increase in localization to bone compared to an antibody with the same heavy chain and light chain but lacking the one or more poly-D peptides. In one embodiment, the antibody is any of isotypes IgG₁, IgG₂, IgG₃, IgG₄, IgA₁, IgA₂, IgM, IgE, and IgD. In another embodiment, the antibody is an IgG₁ or IgG₄ isotype. In one embodiment, the individual has chronic kidney disease and/or a bone disease, including metastasis of cancer to bone. The bone disease can be osteogenesis imperfecta or osteoporosis. In one embodiment, the effective amount of the anti-TGF β antibody or antibody fragment targeted to bone is administered subcutaneously, intravenously, or intramuscularly.

[0032] In a sixteenth aspect, the present disclosure provides a pharmaceutical composition comprising an antibody or antigen-binding fragment of the present invention and a pharmaceutically acceptable carrier. For example, the antibody may include a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 2, 3, 4, and 5 (with or without the heavy chain C-terminal lysine) and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 6, 7, 8, 11, and 12, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 2 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 6. In another embodiment, the antibody may include a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine); and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 20, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15.

[0033] In an seventeenth aspect, the present disclosure provides an isolated nucleic acid molecule including a nucleic acid sequence encoding the heavy chain, the light chain, or both, of an anti-TGF β antibody targeted to bone, wherein the heavy chain of the anti-TGF β antibody comprises an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine) and the light chain of the anti-TGF β antibody comprises an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 20, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15.

[0034] In an eighteenth aspect, the present disclosure provides an expression vector including a nucleic acid sequence encoding the heavy chain, the light chain, or both, of an anti-TGF β antibody targeted to bone, wherein the heavy chain of the anti-TGF β antibody comprises an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine); and the light chain of the anti-TGF β antibody comprises an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 20, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15.

[0035] In a nineteenth aspect, the present disclosure provides a host cell comprising one or more expression vectors including nucleic acid sequences encoding an anti-TGF β antibody targeted to bone, wherein the heavy chain of the anti-TGF β antibody comprises a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine); and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 20, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15. In one embodiment, the host cell is a mammalian cell or a prokaryotic cell. In another embodiment, the host cell is a Chinese Hamster Ovary (CHO) cell or an *Escherichia coli* (*E. coli*) cell.

[0036] In a twentieth aspect, the present disclosure provides a method of producing an anti-TGF β antibody or an antigen-binding fragment thereof targeting bone. The

method includes growing a host cell under conditions permitting production of the antibody or antigen-binding fragment thereof. The host cell comprises (i) a nucleic acid sequence encoding a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine); and (ii) a nucleic acid sequence encoding a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 29, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15. In one embodiment, the method further includes formulating the antibody or antigen-binding fragment thereof as a pharmaceutical composition comprising an acceptable carrier.

[0037] In a twenty-first aspect, the present disclosure provides a pharmaceutical composition comprising an anti-TGF β antibody targeted to bone. The anti-TGF β antibody targeted to bone includes a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 2, 3, 4, and 5 (with or without the heavy chain C-terminal lysine) and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 6, 7, 8, 11, and 12, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 2 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 6, or the anti-TGF β antibody targeted to bone includes a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17 (with or without the heavy chain C-terminal lysine); and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 29, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 (with or without the heavy chain C-terminal lysine) when the light chain amino acid sequence is SEQ ID NO: 15. In one embodiment, the pharmaceutical composition is formulated as a liquid drug product. In another embodiment, the pharmaceutical composition is formulated as a lyophilized drug product.

[0038] In a twenty-second aspect, the present disclosure provides an anti-TGF β antibody targeted to bone. The heavy chain of the antibody comprises: a heavy chain complementarity-determining region 1 (HCDR1) comprising the amino acid sequence of

SEQ ID NO: 33, an HCDR2 comprising the amino acid sequence of SEQ ID NO:34, and an HCDR3 comprising the amino acid sequence of SEQ ID NO: 35. The light chain of the antibody comprises: a light chain complementarity-determining region 1 (LCDR1) comprising the amino acid sequence of SEQ ID NO: 36, an LCDR2 comprising the amino acid sequence of SEQ ID NO: 37, and an LCDR3 comprising the amino acid sequence of SEQ ID NO: 38. And, the antibody further comprises a D10 polypeptide at one of more of the N terminus of the heavy chain, the C terminus of the heavy chain, the N terminus of the light chain, and the C terminus of the light chain.

[0039] In a twenty-third aspect, the present disclosure provides an anti-TGF β antibody targeted to bone, wherein the heavy chain of the antibody comprises the heavy chain complementarity-determining regions (CDR) 1-3 in SEQ ID NO: 39 and the light chain CDR1-3 in SEQ ID NO: 40, wherein the antibody further comprises a D10 polypeptide at one of more of the N terminus of the heavy chain, the C terminus of the heavy chain, the N terminus of the light chain, and the C terminus of the light chain. In some embodiments, the antibody comprises a heavy chain variable domain (V_H or HCVD) comprising the amino acid sequence of SEQ ID NO: 39 and a light chain variable domain (V_L or LCVD) comprising the amino acid sequence of SEQ ID NO: 40.

[0040] In a twenty-fourth aspect, the present disclosure provides a polynucleotide sequence encoding: an anti-TGF β antibody targeted to bone, wherein the heavy chain of the antibody comprises an HCDR1 comprising the amino acid sequence of SEQ ID NO: 33, an HCDR2 comprising the amino acid sequence of SEQ ID NO: 34, and an HCDR3 comprising the amino acid sequence of SEQ ID NO: 35, the light chain of the antibody comprises an LCDR1 comprising the amino acid sequence of SEQ ID NO: 36, an LCDR2 comprising the amino acid sequence of SEQ ID NO: 37, and an LCDR3 comprising the amino acid sequence of SEQ ID NO: 38, and the antibody further comprises a D10 polypeptide at one of more of the N terminus of the heavy chain, the C terminus of the heavy chain, the N terminus of the light chain, and the C terminus of the light chain; or an anti-TGF β antibody targeted to bone, wherein the heavy chain of the antibody comprises the heavy chain complementarity-determining regions (CDR) 1-3 in SEQ ID NO: 39 and the light chain CDR1-3 in SEQ ID NO: 40, wherein the antibody further comprises a D10 polypeptide at one of more of the N terminus of the heavy

chain, the C terminus of the heavy chain, the N terminus of the light chain, and the C terminus of the light chain.

[0041] In a twenty-fifth aspect, the present disclosure provides a bone-targeting antibody, such as a bone-targeting anti-TGF β antibody or antigen-binding fragment, of the present invention for use in a treatment method described herein.

[0042] In a twenty-sixth aspect, the disclosure provides the use of a bone-targeting antibody, such as a bone targeting anti-TGF β antibody or antigen-binding fragment, of the present invention, for the manufacture of a medicament for a treatment method described herein.

[0043] Particular embodiments contemplated herein are further described below. The above-described and other features and advantages of the present invention will be more fully understood from the following detailed description of the invention taken together with the accompanying claims. It is noted that the scope of the claims is defined by the recitations therein and not by the specific discussion of features and advantages set forth in the present description.

BRIEF DESCRIPTION OF DRAWINGS

[0044] FIG. 1 depicts a D10 peptide chemically conjugated to an anti-TGF β (α -TGF β) antibody.

[0045] FIG. 2 depicts the process of chemically conjugating a peptide bearing a linker (peptide linker) and a maleimide functional group to reduced hinge region disulfides on a murine IgG1 antibody.

[0046] FIG. 3A depicts a reducing SDS-PAGE gel of chemical conjugates of a D10 peptide-linker with an anti-TGF β murine IgG1, mAb1. The upper band(s) represents the heavy chain and the lower band the light chain.

[0047] FIG. 3B depicts peptide to antibody ratio (PAR) values vs. the peptide-maleimide:mAb ratio in the chemical conjugation reaction of Example 1, which shows a linear increase in the PAR with increasing number of peptides up to 8 mol:mol PAR.

[0048] FIGS. 4A-4G depict size-exclusion chromatography of 1:1 molar mixtures of TGF β 1 and chemical conjugates of a D10 peptide with either trastuzumab (Herceptin®) or the anti-TGF β antibody mAb1. FIG. 4A depicts the SEC profile of the chemical

conjugate of D10 peptide with mAb1. FIG. 4B depicts the SEC profile of a 1:1 molar mixture of the mAb1-D10 chemical conjugate with TGF β 1. FIG. 4C depicts the SEC profile of unmodified mAb1. FIG. 4D depicts the SEC profile of a 1:1 molar mixture of mAb1 with TGF β 1. FIG. 4E depicts the SEC profile of Herceptin®. FIG. 4F depicts the SEC profile of a chemical conjugate of D10 peptide with Herceptin®. FIG. 4G depicts the SEC profile of the chemical conjugate of D10 with Herceptin® mixed in a 1:1 ratio with TGF β 1.

[0049] FIG. 5A depicts the A_{280} trace from hydroxyapatite chromatography of mAb1 and a D10-mAb1 conjugate (x-axis = minutes, y-axis = absorbance (normalized)).

[0050] FIG. 5B depicts SDS-PAGE gel of fractions from the flowthrough (FT) and peak 4.

[0051] FIG. 6A depicts hydroxyapatite chromatography of chemical conjugates with increasing numbers of peptides. The absorbance at 280 nm of the eluate for each conjugate is shown (x-axis = minutes, y-axis = absorbance (normalized)).

[0052] FIG. 6B depicts the fraction of analyte bound (upper curve, circles, scale left) and the retention time (lower curve, triangles, scale right) as a function of the number of peptides conjugated as determined by SDS-PAGE.

[0053] FIG. 7 depicts an *in vitro* TGF β neutralization assay performed with A549 cells with a control conjugate (PAR=0) and conjugates with an average of 4 or 9 peptides compared to unmodified mAb1.

[0054] FIG. 8A depicts the time-dependent biodistribution of fluorophore-labeled mAb1 and a chemical conjugate at 1 mg/kg (1 mpk) containing approximately 4.5 peptides. The times at which the animals were imaged are indicated in each panel. Per photograph, the left mouse received mAb1, and right mouse received the chemical conjugate. Image intensities have been adjusted to reveal differences in distribution.

[0055] FIG. 8B depicts the ratio of fluorescence found in the region of interest corresponding to the distal femur and the region of interest corresponding to the heart in the images shown in FIG. 8A. Circles correspond to mAb1 antibody and squares correspond to the D10 peptide conjugated with mAb1 (D10 mAb1).

[0056] FIG. 9A diagrammatically depicts possible locations of D10 peptides on an IgG subtype antibody for creating a series of mAb1 fusion variant antibodies to be

obtained by attachment of D10 peptides to the heavy and/or light chain termini using recombinant methods. The sites of addition of D10 peptides are indicated by the circles and the use of peptide linker sequences is indicated by wavy lines (the longer wavy line represents a longer linker than the shorter wavy line).

[0057] FIG. 9B depicts a series of fusion variant antibodies (fusion variants) derived by placement of the peptides, as shown in FIG. 9A. Recombinant fusion variants with various combinations of the position of attachment and peptide numbers were generated. The smaller numbers below each diagram depict the identity of each recombinant fusion variant as referred to herein for the sake of clarity. As referred to herein, fusion variants are designated either with “fusion” or “F” followed by the intended variant number. For example, “Fusion 1” and “F1” both refer to an antibody having the configuration of the antibody “1” without a D10 peptide. The longer wavy line represents a longer linker than the shorter wavy line.

[0058] FIG. 10 depicts SDS-PAGE of the indicated purified recombinant mAb1 fusion variants under reducing (upper gel) or non-reducing (lower gel) conditions.

[0059] FIG. 11 depicts thermostability of recombinant mAb1 fusion variants as determined by differential scanning fluorimetry (DSF). The transition to a partially-denatured form at each temperature is detected by an increase in dye fluorescence. The slope of fluorescence increase with temperature ($-d(RFU)/dT$) was calculated and is displayed versus the temperature of the sample. The rate of the denaturation is maximal at the minima of the curves which represent the midpoint of the thermal transitions (T_m). For reference, the structures of each of the recombinant mAb1 fusion variants are shown diagrammatically.

[0060] FIGS. 12A and 12B depict the neutralization of TGF β in eliciting the production of IL-11 by A549 cells *in vitro* by eight recombinant mAb1 fusion variants shown diagrammatically in FIG. 9B.

[0061] FIG. 13 depicts the affinity of recombinant mAb1 fusion variants and mAb1 chemical conjugates to hydroxyapatite as assessed by column chromatography on a column of ceramic hydroxyapatite.

[0062] FIG. 14 depicts the biodistribution of selected fluorophore-labeled recombinant mAb1 fusion variants and mAb1 chemical conjugates in CD-1 mice obtained by live imaging at various times post-administration.

[0063] FIG. 15 depicts the amount of fluorescent dye-labeled antibody, recombinant mAb1 fusion variant and mAb1 chemical conjugate localized to the vertebral column after administration to CD-1 mice. Fluorescence was measured by an IVIS instrument over a 3 week period. The logarithm of the maximum fluorescence within the ROI is shown.

[0064] FIG. 16 depicts fluorescence images of resected spine and femurs of mice administered recombinant mAb1 fusion variants mAb1 F6, mAb1 F16, and mAb1 F17 and mAb1 chemical conjugate ("Conj") in the study described in Example 13 and FIG. 15 after 10 and 21 days.

[0065] FIGS. 17A and 17B depict the fluorescence levels of mAb2 F1 and mAb2 F6 in 10 μ L serum, and resected lumbar portion of spine, distal (trabecular) femur, kidney and heart after 24 and 96 hr as described in Example 15.

[0066] FIG. 18A shows that bone targeting via mAb1-D10 (mAb1 F6) profoundly influences serum PK following single dose administration. mAb1 F6 exhibits 13 to 14 fold lower serum exposure (AUC), faster serum clearance, and shorter serum half-life ($t_{1/2}$) than mAb1 as measured by ELISA. Data are expressed as mean $\pm$ SD: Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1) was observed as measured by analysis of variance (AVOVA), Dunnet's Multiple Comparison Test. mAb1 is murinized inhibitory anti-TGF β monoclonal antibody and mAb1 F6 is a recombinant murinized inhibitory anti-TGF β monoclonal antibody with an aspartate polypeptide D10 attached to the C-terminus of the heavy chain of mAb1. AUC for Imaging/Bone was normalized to 1.0. Doses were 5 mg/kg for each mAb1 F6 and mAb1.

[0067] FIG. 18B shows that mAb1 F6 exhibits a 22 fold higher exposure (AUC) in the bone as measured by Optical Imaging compared to mAb1. Data expressed as mean $\pm$ SD: Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1) was observed as measured by AVOVA, Dunnet's Multiple Comparison Test. Doses were 1 mg/kg for each mAb1 F6 and mAb1.

[0068] FIG. 19 illustrates multiple dose peak-trough PK profiles. Bone targeting (via mAb1 F6) profoundly influences multiple dose peak-trough serum PK. mAb1 F6 exhibits lower serum concentrations than mAb1 at both 24 and 48 hr post-dose and following the first dose and dose 23. Fold-differences were lower for mAb1 F6 by 3 to 4.5 fold at 24 hr and 6 to 9 fold at 48 hr. Accumulation also appeared less with mAb1 F6 than with mAb1. Data expressed as mean $\pm$ SD: Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1) was observed as measured by unpaired t-test. Serum concentrations were measured via mass spectrometry.

[0069] FIG. 20 shows that bone targeting (mAb1 F6) and mAb1 increase BV/TV (%) in a dose responsive fashion in G610C (OI) mice. Significant changes on BV/TV (%) compared to control antibody 13C4 (mouse IgG1 antibody) treated G610C mice were observed at doses of 1 and 5 mg/kg, for both treatments. G610C mice treated with 13C4 (13C4) exhibited significant decreases in BV/TV compared to WT background strain (WT 13C4). Data expressed as mean $\pm$ SD: Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1; $\#p \leq 0.05$ 13C4 compared to WT 13C4) was observed as measured by one way ANOVA. BV/TV (%) measured via μ CT imaging.

[0070] FIG. 21 shows that bone targeting (mAb1 F6) and mAb1 increase maximum force to failure in a dose responsive fashion in G610C (OI) mice. Significant changes on maximum force to failure compared to 13C4-treated G610C mice were observed at 1 and 5 mg/kg for mAb1 F6 and 5 mg/kg, only, for mAb1. G610C mice treated with an antibody control (13C4) exhibited significant decreases in maximum force to failure compared to WT background strain. Data expressed as mean $\pm$ SD: Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1; $\#p \leq 0.05$ 13C4 compared to WT 13C4) was observed as measured by one-way ANOVA. Maximum force to failure was measured via biomechanical compression test.

[0071] FIG. 22 shows the effects of mAb1 and mAb1 F6 on BV/TV in G610C mice. The antibodies were dosed at various frequencies (3 x weekly, 1 x weekly, 1 x every 2 weeks, or 1 x every 4 weeks) at 5 mg/kg for 12 weeks. Antibody 13C4 was used as control. Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1; $\#p \leq 0.05$ 13C4 compared to WT 13C4) was observed as measured by one way ANOVA. BV/TV was measured via μ CT imaging.

[0072] FIG. 23 shows the effects of mAb1 and mAb1 F6 on maximum force to failure in G610C mice. The antibodies were dosed at various frequencies (3 x weekly, 1 x weekly, 1 x every 2 weeks, or 1 x every 4 weeks) at 5 mg/kg for 12 weeks. Antibody 13C4 was used as control. Statistical significance ($*p \leq 0.05$ mAb1 or mAb1 F6 compared to 13C4) was observed as measured by one-way ANOVA. Maximum force to failure was measured via biomechanical compression test.

[0073] FIG. 24 shows the effects of mAb1 and mAb1 F6 on BV/TV (%) and the antibodies' average serum levels in G610C mice. The antibodies were dosed 1 x every 2 weeks or 1 x weekly at 5 mg/kg for 12 weeks. Antibody 13C4 was used as control. Statistical significance ($*p \leq 0.05$ mAb1 or mAb1 F6 compared to 13C4; $^{\#}p \leq 0.05$ 13C4 compared to WT 13C4) was observed as measured by one-way ANOVA. BV/TV (%) was measured via μ CT imaging.

[0074] FIG. 25 shows the effects of mAb1 and mAb1 F16 on BV/TV (%) in G610C mice. The antibodies were dosed 3 x weekly at 5 mg/kg for 8 weeks. Antibody 13C4 was used as control. Statistical significance ($*p \leq 0.05$ mAb1 or mAb1 F16 compared to 13C4; $^{\#}p \leq 0.05$ 13C4 compared to WT 13C4) was observed as measured by one-way ANOVA. BV/TV (%) was measured via μ CT imaging.

[0075] FIG. 26 shows the effects of mAb1 and mAb1 F11 on BV/TV (%) in wild type mice. The antibodies were dosed 3 x weekly at 5 mg/kg for 9 weeks. Statistical significance ($*p \leq 0.05$ mAb1 or mAb1 F11 compared to 13C4) was observed as measured by one-way ANOVA. BV/TV (%) was measured via μ CT imaging.

[0076] FIG. 27 shows the total radiant efficiency in the lumbar of wild type mice after receiving a single intraperitoneal dose of vehicle or fluorescently labeled mAb1 or mAb1 F6. Statistical significance ($*p \leq 0.05$ mAb1 F6 compared to mAb1) was observed as measured by one-way ANOVA.

[0077] FIG. 28 shows the total radiant efficiency in the heart of wild type mice after receiving a single intraperitoneal dose of vehicle or fluorescently labeled mAb1 or mAb1 F6. Statistical significance ($*p \leq 0.05$ mAb1 compared to mAb1 F6) was observed as measured by one-way ANOVA.

[0078] FIG. 29 shows the total radiant efficiency in the liver of wild type mice after receiving a single intraperitoneal dose of vehicle or fluorescently labeled mAb1 or mAb1

F6. Statistical significance ($*p \leq 0.05$ mAb1 compared to mAb1 F6) was observed as measured by one-way ANOVA.

[0079] FIG. 30 shows the total radiant efficiency in the intestine of wild type mice after receiving a single intraperitoneal dose of vehicle or fluorescently labeled mAb1 or mAb1 F6.

[0080] FIG. 31 shows the total radiant efficiency in the indicated tissues of wild type mice at 24 hrs or 96 hrs after receiving a single intraperitoneal dose of fluorescently labeled mAb2 or mAb2 D10. Statistical significance ($*p \leq 0.05$ mAb1 compared to mAb1 F6) was observed as measured by t test.

[0081] FIG. 32 shows the lumbar/serum total radiant efficiency ratios in wild type mice at 24 hrs or 96 hrs after receiving a single intraperitoneal dose of fluorescently labeled mAb2 or mAb2 D10.

[0082] FIG. 33 shows the femur/serum total radiant efficiency ratios in wild type mice at 24 hrs or 96 hrs after receiving a single intraperitoneal dose of fluorescently labeled mAb2 or mAb2 D10. Statistical significance ($*p \leq 0.05$ mAb2 D10 compared to mAb2) was observed as measured by t test.

DETAILED DESCRIPTION OF THE INVENTION

[0083] The present invention provides antibodies and antigen-binding fragments thereof that are connected to one or more bone-targeting poly-D peptides such that the antibodies and fragments preferentially home to the bones in a patient in need thereof. The bone-targeting feature of such an antibody or fragment allows the antibody and fragment to target bone tissues specifically and reduces the patient's systemic exposure to the antibody or fragment, thereby enhancing the efficacy of the drug while minimizing undesired adverse side effects.

[0084] As used herein, the term "poly-D peptide" refers to a peptide sequence having a plurality of aspartic acid or aspartate or "D" amino acids, such as about 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, or more aspartic acid amino acids (residues). In one embodiment, a poly-D peptide can include about 2 to about 30, or about 3 to about 15, or about 4 to about 12, or about 5 to about 10, or about 6 to about 8, or about 7 to about 9, or about 8 to about 10, or about 9 to about 11, or about 12 to about 14 aspartic acid residues. In

one embodiment, poly-D peptides include only aspartate residues. In another embodiment, poly-D peptides may include one or more other amino acids or similar compounds. As used herein, the term “D10” refers to a contiguous sequence of ten aspartic acid amino acids, as seen in SEQ ID NO: 1. In some embodiments, an antibody or antibody fragment of the invention may include 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, or more than 12 poly-D peptides.

[0085] The poly-D peptide can be connected to an antibody or antigen-binding fragment of interest via recombinant technology or chemical conjugation. As used herein, the term “fusion variant” or “variant” refers to an assembled antibody construct (see FIG. 9B) that includes at least one of a heavy chain or a light chain or antibody fragment or subpart that incorporates or is otherwise associated with a poly-D peptide, such as a D10 sequence. For example, a poly-D peptide can be connected to an antibody chain in a fusion variant by recombinant technology (e.g., where a poly-D peptide sequence is integral with the amino acid sequence of the heavy chain, light chain, or antibody fragment or subpart), chemical conjugation, or both.

[0086] As used herein, the term “chemical conjugate” refers to an assembled antibody that includes at least one of a heavy chain or a light chain or antibody fragment or subpart to which one or more poly-D peptides are connected by chemical reaction with, for example, the cysteine residues present in the amino acid sequence of the heavy chain, light chain, antibody fragment, or subpart. Exemplary cysteine residues that can be used for conjugation are those in the heavy chain hinge region. Cysteine residues or other residues appropriate for conjugation can also be introduced to the antibody chain by mutagenesis. A spacer/linker such as a peptide linker or a chemical moiety (e.g., a maleimide function group and a polyethylene glycol (PEG)) may be used between the poly-D peptide and the antibody component in the conjugation. Methods for chemical conjugation of desired moieties to antibodies are well known in the art. See, e.g., Behrens and Liu, mAbs 6:1, 46-53 (2014).

[0087] As used herein, the term “integral” refers to the integration of a poly-D peptide with an antibody chain via recombinant technology such that the poly-D peptide is transcribed from the same RNA transcript as the antibody chain and resides in the same polypeptide sequence as the antibody chain. In such cases, the poly-D peptide

can be connected to the antibody chain, with or without any peptide linker or amino acid spacer, at the antibody chain's either or both termini, or integrated internally to the antibody chain, without affecting the antibody chain's proper folding, the antibody molecule's assembly, or the antibody's binding to its antigen.

[0088] Exemplary formats of the bone-targeting antibodies of the present invention are shown in FIG. 9B (formats F2-F20). The bone-targeting peptide (represented by circles) can be attached or fused to (e.g., integral with) either or both termini of the heavy chain and/or light chain of the antibody. In some embodiments, the bone-targeting peptide is not attached to the light chain through the light chain's N-terminus. The attachment or fusion can be a direct connection (i.e., without a spacer or linker), or through a spacer or linker (represented by the wavy lines; e.g., a peptide linker). Specific examples of these formats are shown in Tables 1 and 7 below.

[0089] Any suitable spacer or linker can be used herein to attach the bone-targeting peptide by, e.g., recombinant technology or chemical conjugation, to an antibody of interest. For example, a peptide linker having one, two, three, or more repeats of the G4S peptide (SEQ ID NO: 9) may be used. Other suitable peptide linkers can also be used. See, e.g., Chen *et al.*, Adv Drug Deliv Rev 65(10):1357-1369 (2013).

Exemplary Bone-Targeting Antibodies and Antigen-Binding Fragments Thereof

[0090] The present invention discloses antibodies and antigen-binding fragments having one or more poly-D (poly-aspartate or poly-Asp) peptides (e.g., a D10 sequence) attached thereto. These modified antibodies and fragments have improved localization to bone. In one particular embodiment, these antibodies are anti-TGF β antibodies, as described herein. While not wishing to be bound by theory, it is believed that effectively targeting anti-TGF β antibodies to bone with one or more poly-D peptides may provide a new therapy for individuals with diseases characterized by pathophysiological bone degeneration associated with TGF β .

[0091] However, while numerous embodiments and examples herein are expressed in the context of using α -TGF β antibodies and D10 sequences, it is contemplated that other antibodies or proteins suitable for treating an abnormal bone condition or a bone disease can be modified with bone-targeting moieties as described herein. For

example, therapeutic antibodies for treating bone loss, stimulating bone growth, or targeting abnormal cells (e.g., cancer cells) in bone can be linked to one or more bone-targeting peptides as described herein. The therapeutic antibodies may bind to proteins or peptides involved in bone formation or maintenance. Further, other bone localization or targeting peptides may be used.

[0092] As used herein, the terms “ α -TGF β antibody” and “anti-TGF β antibody” can be used interchangeably and refer to an antibody, or an antigen-binding fragment thereof, that is specific for TGF β 1, TGF β 2, and/or TGF β 3. For example, at least one antigen-binding site (or paratope) of an α -TGF β antibody, or an antigen-binding fragment thereof, binds to an epitope found on human TGF β 1, TGF β 2, and/or TGF β 3.

[0093] In one embodiment, a contemplated α -TGF β antibody-D10 construct may be created by chemical conjugation. For example, chemical conjugation may be performed by methods known in the art such as those disclosed in U.S. Patent Nos. 7,763,712, 4,671,958, and 4,867,973, each of which is incorporated by reference. In another example, a peptide or other linker can be used to attach a D10 peptide to an antibody (see FIGS. 1 and 2). In a further embodiment, reduction of thiol groups at the hinge region (e.g., hinge region cysteine residues) of the antibody allows chemical conjugation of poly-D peptides using a PEG spacer. Similarly, other cysteine residues of contemplated antibodies and antibody fragments, either native to the antibodies and fragments or introduced by mutagenesis, can be chemically conjugated with poly-D peptides. One such contemplated assembly scheme of an α -TGF β antibody chemically conjugated with a D10 peptide is illustrated in FIG. 2.

[0094] In another embodiment, a contemplated α -TGF β antibody-D10 construct may be created by recombinant expression, where the D10 sequence is added to the amino acid sequence of the heavy chain and/or light chain of the α -TGF β antibody. For example, the nucleic acid sequences encoding the amino acid sequences of the heavy and/or light chains can be modified to encode a D10 sequence that would be expressed either at the N-terminus, the C-terminus, or both N-terminus and C-terminus of the heavy and/or light chains of the α -TGF β antibody. Similarly, one or more D10 sequences could be added to an amino acid sequence of an antibody heavy chain at or near the hinge region and/or within the amino acid sequence of an antibody light chain.

Each nucleic acid sequence for the D10 harboring-heavy and/or light chain may be incorporated into an expression vector and subsequently transfected into a host cell capable of expressing and translating the nucleic acid sequence into the corresponding amino acid sequence. Moreover, the host cell is capable of assembling the expressed amino acid sequences into the functional protein by combining each of the heavy chain and light chain with its complementary sequence to form an α -TGF β antibody-D10 construct. Examples of contemplated recombinant α -TGF β antibody-D10 fusion variants are illustrated in FIGS. 9A and 9B.

[0095] While a poly-D peptide is discussed herein, other similar peptides may also be used to enable targeting of an antibody, another protein, or a peptide to bone. For example, aspartic acid repeat sequences may have more or fewer residues than a D10 sequence, such as about 2, or about 4, or about 6, or about 8, or about 12, or about 14, or about 16, or, about 18, or about 20, or about 30, or 6, 7, 8, 9, 10 or 11 residues, and the like. Further, other natural amino acids with similar chemical properties, such as glutamate, or non-natural amino acids and/or other chemically equivalent compounds may be substituted for or used in combination with aspartic acid, as well.

[0096] In one embodiment, it is contemplated that an antibody with one or more poly-D peptides attached thereto will exhibit at least about a 2-fold, or about a 3-fold, or about at 5-fold, or about a 10-fold, or about a 20-fold increase in localization to bone compared to the same antibody without the one or more poly-D peptides.

[0097] Moreover, while an α -TGF β antibody is described herein, any antibody that binds other proteins involved in bone formation or bone maintenance may be similarly modified to target the antibody to bone, as desired. Antibodies or antigen-binding fragments thereof contemplated herein may be from any species or represent hybrid antibodies combining heavy chains and light chains from different species, and may be specific for any desired epitope. In addition, antibodies that may be used herein are not limited by isotype, and may be any of IgG₁, IgG₂, IgG₃, IgG₄, IgA₁, IgA₂, IgM, IgE, or IgD. Antibody fragments may also be used. For example, D10 sequences or other bone-targeting compounds may be attached to Fab and/or Fc fragments or any other antibody fragment to achieve a desired result as described herein. Further, D10 sequences can be attached to scFv fragments and other similar fusion proteins. In

another embodiment, D10 sequences can be attached to antibodies having a S228P core-hinge mutation (numbered according to the EU numbering system; or alternatively S241P according to the Kabat system; see Kabat *et al.*, Sequences of Proteins of Immunological Interest, 4th ed., United States Government Printing Office, 165–492 (1987); and Silva *et al.* Jour. Biol. Chem. 290:5462-5469 (2015)).

[0098] In a further embodiment, antibodies and/or other proteins contemplated herein may be conjugated with additional molecules. For example, antibodies or other proteins contemplated herein may be conjugated with chemical labels that allow tracking of the antibodies/proteins when injected or otherwise introduced into a subject. For example, radiolabels, fluorescent compounds, and the like may be attached to the antibodies/proteins to aid their tracking *in vivo*. Further, antibodies and/or other proteins contemplated herein may also be conjugated with additional compounds having a therapeutic effect, such as small molecules, pharmaceuticals, antineoplastic agents, growth hormones, vitamins, etc., such that the antibodies and/or other proteins may serve as a vehicle for one or more of such compounds.

[0099] In some embodiments, the bone-targeting anti-TGF β antibody comprises a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 2, 3, 4, and 5, and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 6, 7, 8, 11, and 12, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 2 when the light chain amino acid sequence is SEQ ID NO: 6. Exemplary antibodies are mAb1 F3, mAb1 F4, mAb1 F5, mAb1 F6, mAb1 F8, mAb1 F9, mAb1 F10, mAb1 F11, mAb1 F13, mAb1 F14, mAb1 F15, mAb1 F16, mAb1 F18, mAb1 F19, and mAb1 F20 (Table 1).

[00100] In other embodiments, the bone-targeting anti-TGF β antibody comprises a heavy chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 13, 14, 16, and 17, and a light chain comprising an amino acid sequence set forth in any of SEQ ID NOS: 15, 18, 19, 20, 21, and 22, with the proviso that the heavy chain amino acid sequence is not SEQ ID NO: 13 when the light chain amino acid sequence is SEQ ID NO: 15. Exemplary antibodies are mAb2 F3, mAb2 F4, mAb2 F5, mAb2 F6, mAb2 F8, mAb2 F9, mAb2 F10, mAb2 F11, mAb2 F13, mAb2 F14, mAb2 F15, mAb2 F16, mAb2 F18, mAb2 F19, and mAb2 F20 (Table 7).

[00101] In some embodiments, the antibodies of the present invention, such as the anti-TGF β antibodies, do not have the C-terminal lysine in the heavy chain. The C-terminal lysine may be removed during manufacture or by recombinant technology (*i.e.*, the coding sequence of the heavy chain does not include a codon for the C-terminal terminal lysine). Thus contemplated within the invention also are antibodies comprising the heavy chain amino acid sequence of SEQ ID NO: 2 or 13 without the C-terminal lysine. A poly-D peptide may be attached to the C-terminus of a heavy chain with or without the C-terminal lysine.

Treatment Methods

[00102] In one particular embodiment, a method of treating an individual such as a human patient for bone loss associated with TGF β includes administering an effective amount of an anti-TGF β antibody targeted to bone to the individual. The method can further include a step of measuring or detecting a reduction in TGF β levels or activity, a reduction in bone loss or the rate of bone loss, an increase in bone density, and/or an increase in bone strength.

[00103] An “effective amount,” as used herein, refers to an amount of a therapeutic agent, such as an α -TGF β antibody or antibody fragment, that when administered to an individual in need thereof improves an individual’s health, such as, for example, by reducing TGF β levels or activity associated with bone, reducing bone loss or the rate of bone loss, increasing bone density, and/or increasing bone strength.

[00104] As used herein, the term “individual” refers to an animal. Examples of individuals include humans, domesticated animals, household pets, and other animals without limitation. Further examples of individuals include animals having a bone disease associated with TGF β .

[00105] In another embodiment, pharmaceutical antibody formulations or compositions including aqueous liquid drug product formulations and lyophilized drug product formulations containing one or more bone-targeting anti-TGF β antibodies such as chemical conjugates or recombinant fusion variants are contemplated. Pharmaceutical compositions including bone-targeting anti-TGF β antibody and/or antibody fragments can be formulated as described in U.S. Patent Application

Publication No. US 2014/0286933 A9, which is incorporated herein by reference, or otherwise as is known in the art.

[00106] In one particular embodiment, a method for treating bone disease includes administering an effective amount of an anti-TGF β antibody targeted to bone to an individual with a bone disease, such as a bone diseases associated with chronic kidney disease, cancer metastasis to bone, or abnormal metabolic conditions. In another particular embodiment, a method for treating osteogenesis imperfecta includes administering an effective amount of an anti-TGF β antibody targeted to bone to an individual with osteogenesis imperfecta. In a further particular embodiment, a method for treating osteoporosis includes administering an effective amount of an anti-TGF β antibody targeted to bone to an individual with osteoporosis.

[00107] In some embodiments, the patients are treated with a combination of a bone-targeting antibody or antibody fragment of the present invention and another therapeutic agent, such as a therapeutic agent for a bone loss condition (e.g., bisphosphonates). The antibody or antibody fragment and the other therapeutic agent can be administered to the patient simultaneously or sequentially.

[00108] In some embodiments, the bone-targeting antibodies and other components used in the treatment methods of the present invention can be provided in kits or articles of manufacture.

Methods of Making Antibodies

[00109] The antibodies or fragments of the present invention can be made by methods well established in the art. DNA sequences encoding the heavy and light chains of the antibodies can be inserted into expression vectors such that the genes are operatively linked to necessary expression control sequences such as transcriptional and translational control sequences. Expression vectors include plasmids, retroviruses, adenoviruses, adeno-associated viruses (AAV), plant viruses such as cauliflower mosaic virus, tobacco mosaic virus, cosmids, YACs, EBV derived episomes, and the like. The antibody light chain coding sequence and the antibody heavy chain coding sequence can be inserted into separate vectors, and may be operatively linked to the same or different expression control sequences (e.g., promoters). In one embodiment,

both coding sequences are inserted into the same expression vector and may be operatively linked to the same expression control sequences (e.g., a common promoter), to separate identical expression control sequences (e.g., promoters), or to different expression control sequences (e.g., promoters). The antibody coding sequences may be inserted into the expression vector by standard methods (e.g., ligation of complementary restriction sites on the antibody gene fragment and vector, or blunt end ligation if no restriction sites are present).

[00110] In addition to the antibody chain genes, the recombinant expression vectors may carry regulatory sequences that control the expression of the antibody chain genes in a host cell. Examples of regulatory sequences for mammalian host cell expression include viral elements that direct high levels of protein expression in mammalian cells, such as promoters and/or enhancers derived from retroviral LTRs, cytomegalovirus (CMV) (such as the CMV promoter/enhancer), Simian Virus 40 (SV40) (such as the SV40 promoter/enhancer), adenovirus, (e.g., the adenovirus major late promoter (AdMLP)), polyoma and strong mammalian promoters such as native immunoglobulin and actin promoters.

[00111] In addition to the antibody chain genes and regulatory sequences, the recombinant expression vectors of the invention may carry additional sequences, such as sequences that regulate replication of the vector in host cells (e.g., origins of replication) and selectable marker genes. For example, the selectable marker gene confers resistance to drugs, such as G418, hygromycin or methotrexate, on a host cell into which the vector has been introduced. Selectable marker genes may include the dihydrofolate reductase (DHFR) gene (for use in dhfr-host cells with methotrexate selection/amplification), the neo gene (for G418 selection), and the glutamate synthetase gene.

[00112] The expression vectors encoding the antibodies of the present invention are introduced to host cells for expression. The host cells are cultured under conditions suitable for expression of the antibody, which is then harvested and isolated. Host cells include mammalian, plant, bacterial or yeast host cell. Mammalian cell lines available as hosts for expression are well known in the art and include many immortalized cell lines available from the American Type Culture Collection (ATCC). These include, *inter*

alia, Chinese hamster ovary (CHO) cells, NS0 cells, SP2 cells, HEK-293T cells, 293 Freestyle cells (Invitrogen), NIH-3T3 cells, HeLa cells, baby hamster kidney (BHK) cells, African green monkey kidney cells (COS), human hepatocellular carcinoma cells (e.g., Hep G2), A549 cells, and a number of other cell lines. Cell lines may be selected based on their expression levels. Other cell lines that may be used are insect cell lines, such as Sf9 or Sf21 cells.

[00113] Further, expression of antibodies can be enhanced using a number of known techniques. For example, the glutamine synthetase gene expression system (the GS system) is a common approach for enhancing expression under certain conditions.

[00114] Tissue culture media for the host cells may include, or be free of, animal-derived components (ADC), such as bovine serum albumin. In some embodiments, ADC-free culture media is preferred for human safety. Tissue culture can be performed using the fed-batch method, a continuous perfusion method, or any other method appropriate for the host cells and the desired yield.

Pharmaceutical Compositions

[00115] The antibody of the invention can be formulated for suitable storage stability. For example, the antibody can be lyophilized or stored or reconstituted for use using pharmaceutically acceptable excipients. For a combination therapy, the two or more therapeutic agents such as antibodies can be co-formulated, e.g., mixed and provided in a single composition.

[00116] The term “excipient” or “carrier” is used herein to describe any ingredient other than the compound(s) of the invention. The choice of excipient(s) will to a large extent depend on factors such as the particular mode of administration, the effect of the excipient on solubility and stability, and the nature of the dosage form.

“Pharmaceutically acceptable excipient” includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like that are physiologically compatible. Some examples of pharmaceutically acceptable excipients are water, saline, phosphate buffered saline, dextrose, glycerol, ethanol and the like, as well as combinations thereof. In some cases, isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, or

sodium chloride will be included in the composition. Additional examples of pharmaceutically acceptable substances are wetting agents or minor amounts of auxiliary substances such as wetting or emulsifying agents, preservatives or buffers, which enhance the shelf life or effectiveness of the antibody.

[00117] A pharmaceutical composition of the invention may be prepared, packaged, or sold in bulk, as a single unit dose, or as a plurality of single unit doses. As used herein, a “unit dose” is a discrete amount of the pharmaceutical composition comprising a predetermined amount of the active ingredient. The amount of the active ingredient is generally equal to the dosage of the active ingredient which would be administered to a subject or a convenient fraction of such a dosage such as, for example, one-half or one-third of such a dosage.

[00118] The pharmaceutical compositions of the invention are typically suitable for parenteral administration. As used herein, “parenteral administration” of a pharmaceutical composition includes any route of administration characterized by physical breaching of a tissue of a subject and administration of the pharmaceutical composition through the breach in the tissue, thus generally resulting in the direct administration into the blood stream, into muscle, or into an internal organ. Parenteral administration thus includes, but is not limited to, administration of a pharmaceutical composition by injection of the composition, by application of the composition through a surgical incision, by application of the composition through a tissue-penetrating non-surgical wound, and the like. In particular, parenteral administration is contemplated to include, but is not limited to, subcutaneous, intraperitoneal, intramuscular, intrasternal, intravenous, intraarterial, intrathecal, intraventricular, intraurethral, intracranial, intratumoral, and intrasynovial injection or infusions; and kidney dialytic infusion techniques. Regional perfusion is also contemplated. Preferred embodiments may include the intravenous and subcutaneous routes.

[00119] Formulations of a pharmaceutical composition suitable for parenteral administration typically comprise the active ingredient combined with a pharmaceutically acceptable carrier, such as sterile water or sterile isotonic saline. Such formulations may be prepared, packaged, or sold in a form suitable for bolus administration or for continuous administration. Injectable formulations may be prepared, packaged, or sold

in unit dosage form, such as in ampoules or in multi-dose containers containing a preservative. Formulations for parenteral administration include, but are not limited to, suspensions, solutions, emulsions in oily or aqueous vehicles, pastes, and the like. Such formulations may further comprise one or more additional ingredients including, but not limited to, suspending, stabilizing, or dispersing agents. In one embodiment of a formulation for parenteral administration, the active ingredient is provided in dry (i.e., powder or granular) form for reconstitution with a suitable vehicle (e.g., sterile pyrogen free water) prior to parenteral administration of the reconstituted composition.

Parenteral formulations also include aqueous solutions which may contain excipients such as salts, carbohydrates and buffering agents (e.g., a pH of from 3 to 9), but, for some applications, they may be more suitably formulated as a sterile non-aqueous solution or as a dried form to be used in conjunction with a suitable vehicle such as sterile, pyrogen-free water. Exemplary parenteral administration forms include solutions or suspensions in sterile aqueous solutions, for example, aqueous propylene glycol or dextrose solutions. Such dosage forms can be suitably buffered, if desired. Other parentally-administrable formulations which are useful include those which comprise the active ingredient in microcrystalline form, or in a liposomal preparation. Formulations for parenteral administration may be formulated to be immediate and/or modified release. Modified release formulations include delayed-, sustained-, pulsed-, controlled-, targeted and programmed release.

[00120] In some embodiments, the antibody or antigen-binding fragment of the present invention may be administered at 40, 20, or 15 mg/kg or less (such as 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 mg/kg). In some further embodiments, the doses may be 0.01, 0.02, 0.03, 0.04, 0.05, 0.1, 0.2, 0.3, 0.4, or 0.5 mg/kg. The dosing frequency may be, for example, daily, every two, three, four, or five days, weekly, biweekly, or triweekly, monthly, bimonthly, every three months, every six months, or every twelve months, or as needed. The antibody may be administered by intravenous (e.g., intravenous infusion over 0.5-8 hours), subcutaneously, intramuscularly, or any other route of administration that is appropriate for the condition and the drug formulation.

Exemplary Embodiments

[00121] Further particular embodiments of the present invention are described as follows.

1. An antibody, or an antigen-binding fragment thereof, comprising a heavy chain, a light chain, and one or more poly-aspartate (poly-D) peptides connected to (i) the heavy chain, (ii) the C-terminus of the light chain, or (iii) both (i) and (ii).
2. The antibody or antigen-binding fragment of embodiment 1, wherein the one or more poly-D peptides are connected to the antibody or antigen-binding fragment by chemical conjugation.
3. The antibody or antigen-binding fragment of embodiment 2, wherein the one or more poly-D peptides are conjugated to the heavy chain at the hinge region.
4. The antibody or antigen-binding fragment of embodiment 2 or 3, wherein the one or more poly-D peptides are conjugated to the antibody or antigen-binding fragment by a polyethylene glycol (PEG) spacer.
5. The antibody or antigen-binding fragment of embodiment 1, comprising a poly-D peptide integral with an amino acid sequence of the heavy chain or the light chain.
6. The antibody or antigen-binding fragment of embodiment 5, comprising a poly-D peptide integral with the N-terminus of the heavy chain.
7. The antibody or antigen-binding fragment of embodiment 5, comprising a poly-D peptide integral with the C-terminus of the heavy chain.
8. The antibody or antigen-binding fragment of embodiment 5, comprising a first poly-D peptide integral with the N-terminus of the heavy chain and a second poly-D peptide integral with the C-terminus of the heavy chain.
9. The antibody or antigen-binding fragment of any one of embodiments 5-8, comprising a poly-D peptide integral with the C-terminus of the light chain.
10. The antibody or antigen-binding fragment of any one of embodiments 5-9, wherein the poly-D peptide(s) are fused to the heavy or light chain via a peptide linker.
11. The antibody or antigen-binding fragment of embodiment 10, wherein the peptide linker comprises 1-3 repeats of the amino acid sequence GGGGS (SEQ ID NO: 9).

12. The antibody or antigen-binding fragment of any one of the preceding embodiments, wherein the one or more poly-D peptides each independently comprise 2 - 30 aspartic acid residues.

13. The antibody or antigen-binding fragment of embodiment 12, wherein the one or more poly-D peptides each comprise 10 aspartic acid residues (SEQ ID NO: 1).

14. The antibody or antigen-binding fragment of any one of the preceding embodiments, wherein the antibody is an IgG.

15. The antibody or antigen-binding fragment of embodiment 15, wherein the antibody is an IgG₁ or IgG₄.

16. The antibody or antigen-binding fragment of any one of the preceding embodiments, wherein the antibody or antigen-binding fragment specifically binds to one or more of TGFβ₁, TGFβ₂, and TGFβ₃.

17. The antibody or antigen-binding fragment of embodiment 16, wherein the antibody comprises the heavy chain complementarity-determining regions (CDR) 1-3 in SEQ ID NO: 13 and the light chain CDR1-3 in SEQ ID NO: 15.

18. The antibody or antigen-binding fragment of embodiment 17, wherein the antibody comprises a heavy chain variable domain (V_H) amino acid sequence corresponding to residues 1-120 of SEQ ID NO: 13 and a light chain variable domain (V_L) amino acid sequence corresponding to residues 1-108 of SEQ ID NO: 15.

19. The antibody or antigen-binding fragment of embodiment 17 or 18, wherein the antibody comprises a human IgG₄ constant region having a proline at position 228 (EU numbering).

20. The antibody or antigen-binding fragment of embodiment 19, wherein the heavy chain of the antibody comprises the amino acid sequence of SEQ ID NO: 13 with or without the heavy chain C-terminal lysine, and the light chain of the antibody comprises the amino acid sequence of SEQ ID NO: 15.

21. The antibody of embodiment 17, wherein the heavy chain comprises the amino acid sequence of SEQ ID NO: 13 with or without the heavy chain C-terminal lysine, SEQ ID NO: 14 with or without the lysine immediately preceding the C-terminal D10 sequence, SEQ ID NO: 16 with or without the heavy chain C-terminal lysine, or SEQ ID NO: 17 with or without the lysine immediately preceding the C-terminal D10

sequence, and the light chain comprises the amino acid sequence of SEQ ID NO: 15, 19, 21, or 22.

22. The antibody or antigen-binding fragment of embodiment 16, wherein the antibody is mouse antibody 1D11 having the heavy and light chain amino acid sequences of SEQ ID NO: 2 with or without the C-terminal lysine and SEQ ID NO: 6, respectively.

23. An IgG₄ antibody that binds human TGFβ₁, TGFβ₂, and TGFβ₃, wherein the heavy chain of the antibody comprises the amino acid sequence of SEQ ID NO: 14 (with or without the lysine immediately preceding the C-terminal D10 sequence), and the light chain comprises the amino acid sequence of SEQ ID NO: 15.

24. An IgG₄ antibody that binds human TGFβ₁, TGFβ₂, and TGFβ₃, wherein the heavy chain of the antibody comprises the amino acid sequence of SEQ ID NO: 17 (with or without the lysine immediately preceding the C-terminal D10 sequence), and the light chain comprises the amino acid sequence of SEQ ID NO: 15.

25. The antibody or antigen-binding fragment of any one of the preceding embodiments, wherein the antibody or antigen-binding fragment exhibits at least a 2-fold increase in localization to bone compared to an antibody with the same heavy chain and light chain but lacking the poly-D peptide(s).

26. A pharmaceutical composition comprising an antibody or antigen-binding fragment of any one of the preceding embodiments and a pharmaceutically acceptable excipient.

27. A method for treating an individual with a bone condition that benefits from inhibition of TGFβ, comprising administering to the individual an effective amount of an anti-TGFβ antibody or antigen-binding fragment of any one of claims 16-25.

28. The method of embodiment 27, further comprising detecting at least one of (1) a reduction in TGFβ levels, (2) a reduction in TGFβ activity, (3) a reduction in bone loss, (4) a reduction in rate of bone loss, (5) an increase in bone density, (6) an increase in bone strength, and (7) a reduction in IL-11 levels.

29. An antibody or antigen-binding fragment of any one of embodiments 16-25 for use in treating an individual with a bone condition that benefits from inhibition of TGFβ.

30. Use of an antibody or antigen-binding fragment of any one of embodiment 16-25 for the manufacture of a medicament for treating an individual with a bone condition that benefits from inhibition of TGF β .

31. The method of embodiment 27, the antibody or antigen-binding fragment for use of embodiment 29, or the use of embodiment 30, wherein the individual is a human.

32. The method, antibody or antigen-binding fragment for use, or use of embodiment 31, wherein the human has osteogenesis imperfecta.

33. The method, antibody or antigen-binding fragment for use, or use of embodiment 31, wherein the human has bone loss or osteoporosis.

34. The method, antibody or antigen-binding fragment for use, or use of embodiment 31, wherein the human has chronic kidney disease.

35. The method, antibody or antigen-binding fragment for use, or use of embodiment 31, wherein the human is a cancer patient with bone metastasis.

36. An isolated nucleic acid molecule, comprising a nucleotide sequence encoding the heavy chain, the light chain, or both, of the antibody or antigen-binding fragment of any one of embodiments 1-25.

37. An expression vector comprising the isolated nucleic acid molecule of embodiment 36.

38. A host cell comprising the expression vector of embodiment 37.

39. The host cell of embodiment 38, wherein the host cell is a mammalian cell.

40. A method of producing an antibody or antigen-binding fragment of any one of embodiments 1-25, the method comprising:

providing a host cell comprising first and second nucleotide sequences encoding the heavy chain and light chain, respectively, of the antibody or antigen-binding fragment,

growing the host cell under conditions permitting production of the antibody or antigen-binding fragment, and

recovering the antibody or antigen-binding fragment.

41. The method of embodiment 40, wherein the first nucleotide sequence comprises SEQ ID NO: 23, 24, 25, or 26 (with or without the codon for the heavy chain C-terminal lysine), and the second nucleotide sequence comprises SEQ ID NO: 27, 29, 31, or 32.

42. A method of producing a bone-targeting antibody or antigen-binding fragment, comprising:

providing an antibody or an antigen-binding fragment thereof and one or more poly-D peptides, and

attaching the poly-D peptides to the antibody through a covalent bond by chemical conjugation.

43. The method of any one of embodiments 40-42, further comprising formulating the antibody or antigen-binding fragment as a pharmaceutical composition comprising a pharmaceutically acceptable carrier.

44. A method of producing a bone-targeting pharmaceutical composition, comprising:

providing an antibody or antigen-binding fragment of any one of embodiments 1-25, and

admixing the antibody or antigen-binding fragment with a pharmaceutically acceptable carrier.

[00122] The invention will be further described in the following examples, which do not limit the scope of the invention described in the claims.

EXAMPLES

[00123] The Examples that follow are illustrative of specific embodiments of the invention, and various uses thereof. They are set forth for explanatory purposes only and are not to be taken as limiting of the invention.

TGF β Antibody

[00124] A first anti-TGF β antibody, referred to herein as mAb1, is a mouse IgG1 monoclonal antibody specific for human TGF- β 1, TGF- β 2, and TGF- β 3 ("pan-specific") and is available from R&D Systems (Clone# 1D11, Minneapolis, MN). The mAb1 antibody served as a template in the examples.

[00125] A second anti-TGF β antibody, referred to herein as mAb2, used in the examples is a human anti-TGF β IgG4 antibody with a hinge mutation S228P (EU numbering). The mAb2 antibody is similar to antibodies disclosed in U.S. Patent No. 9,090,685, which is incorporated by reference. Antibody mAb2 has an estimated molecular weight of 144 KD when un-glycosylated. Its heavy and light chain amino acid sequences are SEQ ID NOS: 13 and 15, respectively. These two sequences are shown below. Variable domains are italicized, and are designated herein as heavy chain variable domain (HCVD, SEQ ID NO: 39) and light chain variable domain (LCVD, SEQ ID NO: 40). CDRs are shown in boxes and are designated heavy chain complementarity-determining region 1 (HCDR1, SEQ ID NO: 33); HCDR2 (SEQ ID NO: 34); and HCDR3 (SEQ ID NO: 35), and light chain complementarity-determining region 1 (LCDR1, SEQ ID NO: 36); LCDR2 (SEQ ID NO: 37); and LCDR3 (SEQ ID NO: 38). The glycosylation site in the constant domain of the heavy chain is in boldface (N297).

*QVQLVQSGAE VKKPGSSVKV SCKASGYTFS **SNVIS**WVRQA PGQGLEWM**GG** VIPIVDIANY*
AQRFKQRVTI *TADESTTTY MELSSLRSED TAVYYCAS***TL GLVLDAMDY**W *GQCTLVTVSS*
 ASTKGPSVFP LAPCSRSTSE STAALGCLVK DYFPEPVTVS WNSGALTSGV HTFPAVLQSS
 GLYSLSSVVT VPSSSLGTKT YTCNVDHKPS NTKVDKRVES KYGPPCPPCP APEFLGGPSV
 FLFPPKPKDT LMISRTPEVT CVVVDVSQED PEVQFNWYVD GVEVHNAKTK PREEQ**FN**STY
 RVVSVLTVLH QDWLNGKEYK CKVSNKGLPS SIEKTISKAK GQPREPQVYT LPPSQEEMTK
 NQVSLTCLVK GFYPSDIAVE WESNGQPENN YKTTTPVLDS DGSFFLYSRL TVDKSRWQEG
 NVFSCSVME ALHNHYTQKS LSLSLGK (SEQ ID NO: 13)

*ETVLTQSPGT LSLSPGERAT LSC**RASQSLG SSYLA**WYQQK PGQAPRLLIY **GASSRA**FGIP*
*DRFSGSGSGT DFTLTISRLE PEDFAVYYQ**Q QYADSPIT**FG QGTRLEIKRT VAAPSVFIFP*
 PSDEQLKSGT ASVVCLLNNF YPREAKVQWK VDNALQSGNS QESVTEQDSK DSTYSLSSTL
 TLSKADYEKH KKYACEVTHQ GLSSPVTKSF NRGEC (SEQ ID NO: 15)

[00126] As described herein, other antibodies, antibody fragments, proteins, or peptides that bind proteins involved in bone formation or bone maintenance may be used.

Example 1: Preparation of chemical conjugates of D10 peptide with mAb1 α -TGF β antibody

[00127] D10 peptide chemical conjugates of the α -TGF β antibody mAb1 were prepared in the manner depicted in FIG. 2. mAb1 (2.0 mg) was exchanged into

degassed borate buffer (25 mM sodium chloride, 1 mM DTPA, 20 mM sodium borate pH 8.0) by three rounds of ultrafiltration over Amicon® Ultra 50 kDa MWCO centrifugal filters (EMD Millipore). The hinge region disulfides were then reduced with 12 mol:mol dithiothreitol (DTT) per mAb for 2 hr at 37°C. The product was desalted over a 4 mL Amicon® Ultra filter with degassed borate buffer. Aliquots (1 nmol, 150 µg) were reacted at 25°C with increasing amounts (1-15 mol:mol) of a D10-maleimide peptide (Ac-D10-C2-PEG12-C6-maleimide, where PEG12 consists of a defined length PEG containing 12 ethylene oxide groups). After 1.5 hr, remaining unreacted thiol groups were blocked by the addition of 12 equivalents of N-ethylmaleimide followed by incubation for 1.5 hr. The products were desalted by ultrafiltration. FIG. 3A depicts SDS-PAGE of 0.5 µg of each product on a 4-12% NuPAGE gel stained with SimplyBlue™ (Thermo Scientific) and imaged by an Odyssey® near IR scanner (LiCor). The lane fluorescence profiles were integrated using AlphaView software (ProteinSimple Corp.) and the peptide to antibody ratio (PAR) determined. The small shift in mobility in each of the heavy or light chain was assumed to represent the addition of a single D10 peptide which is consistent with the maximum of 5 identifiable bands for the heavy chain and 1 for the light chain and matches the number of hinge region cysteines for each. The average number of peptides on the heavy and light chain was separately calculated from the sum of the product of the relative abundance of each minor band times its assigned peptide number. PAR was calculated from the sum of those numbers from the heavy and light chains times two since each chain is represented twice in the whole IgG. The PAR value vs. the peptide-maleimide:mAb ratio in the chemical conjugation reaction is depicted in FIG. 3B which shows a linear increase in the PAR with increasing number of conjugated peptides up to 8 mol:mol.

Example 2: Binding of mAb1-D10 chemical conjugates to TGF-β1

[00128] In this example, a set of chemical conjugates of varying PAR was prepared in the same fashion as described in Example 1 except that the ratio of DTT was varied from 8-10 mol:mol and the maleimide-peptide:mAb was either 3 or 15 mol:mol. As a control, a human IgG1 (Herceptin®) chemical conjugate was prepared by reduction of its hinge disulfides by 3 mol:mol tris(2-carboxyethylphosphine) (TCEP) for 2 hr 37°C

under argon followed by reaction with 15 mol:mol maleimide-peptide overnight at 25°C and purified by desalting using ultrafiltration.

[00129] To assess their ability to bind TGF- β 1, the chemical conjugates were mixed with TGF- β 1 in a 1:1 molar ratio followed by size exclusion chromatography on Superdex 200 (G.E. Healthcare) in phosphate buffered saline (PBS) pH 7.2. The mAb1-D10 chemical conjugate alone yielded a somewhat heterogeneous peak eluting earlier than unmodified mAb1 as shown in FIG. 4A, which is likely due to charge effects produced by the conjugated peptides. Addition of TGF- β 1 to the conjugate produced an earlier-eluting peak than either mAb1 or the mAb1-D10 chemical conjugate, indicating formation of a higher molecular weight complex (FIG. 4B). Similarly, addition of TGF- β 1 to unmodified mAb1 antibody produced a shift to an earlier retention time (FIGS. 4C, 4D). In contrast, although chemical conjugation of D10 to Herceptin® caused a shift in the retention time of the antibody alone as with the mAb1 conjugate (FIGS. 4E, 4F), adding TGF- β 1 (1 mol:mol) to the Herceptin®-D10 conjugate failed to produce any change in its elution time or apparent MW (FIGS. 4F, 4G) indicating binding to the conjugate did not occur as a consequence of the conjugation.

Example 3: Peptide-dependent binding of a mAb1-D10 chemical conjugate to hydroxyapatite

[00130] In this example, a chemical conjugate of D10 with mAb1, such as shown in FIG. 2, was produced by reduction of the hinge region disulfides with 12 eq DTT in 25 mM NaCl, 1 mM DTPA, 20 mM sodium borate pH 8 for 2 hr at 37°C followed by reaction with 2 mol:mol 2,2'-dipyridyl disulfide (Sigma) to convert a portion of the free thiols back to disulfides. This was followed by reaction with D10-maleimide peptide described in Example 1. The final product was purified by ultrafiltration. A portion (25 μ g) was exchanged into 5 mM sodium phosphate pH 7.4 over a spin column and chromatographed over a 100 μ L column of ceramic hydroxyapatite (CHT) Type II (BioRad) and eluted with a gradient of 5-500 mM sodium phosphate pH 7.4 at a flow rate of 0.5 mL/min. Unmodified mAb1 was used as a control. The A_{280} column profile is depicted in FIG. 5A. mAb1 showed only trace binding to the column whereas about half of the conjugate bound and eluted around 0.2 M phosphate. Fractions were

concentrated and analyzed by SDS-PAGE (FIG. 5B). The unbound (flowthrough or “FT”) fraction showed mostly unmodified mAb whereas the major peak 4 contained conjugate with an estimated PAR of 6 by SDS-PAGE.

Example 4: Effect of a range of peptide loading on binding to hydroxyapatite

[00131] In this example, a series of D10 peptide chemical conjugates with varying numbers of peptides described in Example 1 was chromatographed on a CHT type II column as described in Example 3. The A_{280} profiles and a plot of the fraction of conjugate bound and the peak retention times are shown in FIG. 6A. As seen in FIG. 6B, the amount of conjugate bound to the column increased up to PAR 3.8, leveled off, and began to decrease with a greater number of peptides. In contrast, the retention time of the conjugate (indicating the strength of the interaction) with the resin increased with increasing number of peptides up to 9.

Example 5: Effect of D10 peptide chemical conjugation to mAb1 on its potency in neutralizing TGF- β 1 *in vitro*

[00132] In this example, a set of three mAb1-D10 conjugates, such as shown in FIG. 2, was prepared as described in Example 1. A control conjugate was prepared by omitting the D10-maleimide peptide during conjugation. By SDS-PAGE analysis, such as depicted in FIG. 3, the peptide loading (PAR) was determined to be 0, 5 or 9 for these three conjugates. The ability of these conjugates to inactivate TGF- β 1 was then determined by coincubation with TGF- β 1 for 1 hr. Serial dilutions in growth medium were then applied to human A549 cells expressing the human TGF- β 1 receptor followed by overnight incubation. The cellular response to active TGF- β 1 was then determined by release of IL-11 into the growth medium, which was detected by an ELISA assay specific for IL-11. The IL-11 response for the three conjugates and a mAb1 control is depicted in FIG. 7. In all cases, the half-maximal inhibition of IL-11 release (EC_{50}) occurred around 0.1 nM antibody. Both conjugates (PAR=5 and PAR=9) and the mock conjugate lacking peptide (PAR=0) showed slightly better inhibition than mAb1. The number of conjugated peptides had no effect on the EC_{50} .

Example 6: Effect of conjugated D10 peptide on biodistribution of mAb1 administered to mice

[00133] A D10-mAb1 chemical conjugate was prepared in a similar fashion as described in Example 1, such as shown in FIG. 2. mAb1 (19.6 mg) was exchanged into degassed borate buffer, reacted with 10.6 eq (1.06 μ mol) DTT for 1.5 h at 37°C followed by reaction without buffer exchange with 6 eq D10 peptide (Ac-D10-C2-PEG12-C6-maleimide) under argon for 1.5 hr at 25°C. Unconjugated free thiols were blocked by addition of 12 eq N-ethylmaleimide followed by incubation for 30 min at 25°C. The final product was purified by ultrafiltration. The peptide-to-antibody ratio was determined using SDS-PAGE (PAR~4.8). The light chain showed trace amounts of a band corresponding to the addition of a single peptide to a light chain cysteine residue.

[00134] The conjugate and mAb1 antibody control were separately labeled with AlexaFluor® 750 (Thermo Fisher) using conditions as described by the manufacturer. The fluorescent test articles were administered to SKH-1 hairless mice which were imaged with an IVIS instrument (Perkin Elmer) immediately following administration (0.3-1 hr), and after 4 hr, and 1, 2, 3, 4, 7, 8, and 9 days. The images of mice injected with 1 mg/kg labeled mAb1 and conjugate are depicted in FIG. 8A. The fluorescence of labeled mAb1 was uniformly distributed throughout the body, and this pattern was maintained but decreased in intensity over 9 days. In contrast, after 1 day the mAb1-D10 conjugate was concentrated at or near the dorsal midline, limbs and tail, consistent with localization to bone but was at nearly undetectable levels elsewhere in the body. Consistent with the images of FIG. 8A, ratios of distal femur fluorescence compared to heart fluorescence measured in the images of FIG. 8A were significantly elevated ($P < 0.05$) for the mAb1-D10 conjugate compared to control by 24 hr and remained significantly elevated through 168 hr (see FIG. 8B). This distribution was maintained over 9 days with only a minor change in intensity.

Example 7: Preparation of recombinant murine anti-TGFβ-D10 antibody fusion variants

[00135] A set of recombinant anti-TGFβ-D10 peptide fusion variants as depicted in FIGS. 9A and 9B was prepared as described below.

Heavy and Light Chain Expression Vector Constructs

[00136] A panel of plasmids for expressing mAb1 heavy and light chains with D10 peptides at various positions was generated. In addition, two plasmids were also generated for wild type mAb1 heavy and light chain without D10 peptides. All codon-optimized sequences were generated synthetically (GeneArt), flanked with appropriate restriction enzyme sites designed in-frame for the cloning purpose. Three gene fragments, encoding mouse IgG1 constant regions with or without C-terminal D10 peptides and mAb1 wild type complete light chain, were cloned into an empty episomal mammalian expression vector pFF, an analog of the pTT vector described by Durocher *et al.*, (2002, *Nucl. Acids Res.* 30(2): E9) to create “mIgG1_CH123_pFF”, “mIgG1_CH123D10_pFF,” and “mAb1_VLCL_pFF” using ApaLI/HindIII restriction enzymes and subsequent ligation. Gene fragments encoding variable regions with or without N-terminal D10 peptide were cloned into the vectors using ApaLI/EagI for heavy chains and ApaLI/MfeI for the light chain. Gene fragments encoding the constant region of the mouse Ig kappa light chain with C-terminal D10 and different lengths of G4S (SEQ ID NO: 9) spacer were cloned into “mAb1_VLCL_pFF,” using MfeI/HindIII to replace the wild type constant region. Expected correct DNA sequence of each construct was confirmed by DNA sequencing (ACGT, Inc.).

Fusion Variant Assembly and Expression

[00137] The fusion variants were produced by selecting one of each of the heavy and light chain vectors for cotransfection in order to yield the fusion variants and a no-peptide control as described in Table 1. “PAR” (peptide-to-antibody ratio) reflects the total number of peptides expected to be appended to the final expressed antibody on both its heavy and light chains. Fusion variant ID “mAb1 F1” represents a “wildtype” (“wt”) construct that is substantially identical to the mAb1 sequence without modification. “HC” indicates the heavy chain of mAb1, “LC” indicates the light chain of mAb1, “D10”

indicates the D10 peptide (SEQ ID NO: 1), and “G4S” indicates a spacer sequence consisting of gly-gly-gly-gly-ser (SEQ ID NO: 9) incorporated in some constructs.

Table 1 Recombinant fusion variants of mAb1 with D10

Variant ID	Heavy Chain Construct	SEQ ID NO:	Light Chain Construct	SEQ ID NO:	PAR
mAb1 F1	HC	2	LC	6	0
mAb1 F2	HC	2	D10-LC	7	2
mAb1 F3	HC	2	LC-D10	8	2
mAb1 F4	HC	2	LC-(G4S)-D10	11	2
mAb1 F5	HC	2	LC-(G4S) ₂ -D10	12	2
mAb1 F6	HC-D10	3	LC	6	2
mAb1 F7	HC-D10	3	D10-LC	7	4
mAb1 F8	HC-D10	3	LC-D10	8	4
mAb1 F9	HC-D10	3	LC-(G4S)-D10	11	4
mAb1 F10	HC-D10	3	LC-(G4S) ₂ -D10	12	4
mAb1 F11	D10-HC	4	LC	6	2
mAb1 F12	D10-HC	4	D10-LC	7	4
mAb1 F13	D10-HC	4	LC-D10	8	4
mAb1 F14	D10-HC	4	LC-(G4S)-D10	11	4
mAb1 F15	D10-HC	4	LC-(G4S) ₂ -D10	12	4
mAb1 F16	D10-HC-D10	5	LC	6	4
mAb1 F17	D10-HC-D10	5	D10-LC	7	6
mAb1 F18	D10-HC-D10	5	LC-D10	8	6
mAb1 F19	D10-HC-D10	5	LC-(G4S)-D10	11	6
mAb1 F20	D10-HC-D10	5	LC-(G4S) ₂ -D10	12	6

[00138] To assess the ability of the desired recombinant fusion variants to be expressed, sixteen variants from Table 1 were evaluated by cotransfection into Expi293F™ cells (Life Technologies) using conditions as described by the manufacturer. After 4 days, expression was determined by SDS-PAGE of conditioned medium. All of the variants were expressed at levels estimated to be between 10 - 30 µg/mL. Slightly higher levels were observed after 5 and 7 days but expression levels were dependent on the variant. WT (mAb1 F1), HC-D10:LC-D10 (mAb1 F8), and HC-D10: LC-G4S-D10 (mAb1 F9) showed particularly high expression, while D10-HC:D10-LC (mAb1 F12) expressed poorly.

Larger-scale expression

[00139] All twenty recombinant mAb1-D10 fusion variants were expressed in Expi293-F cells at 30 mL scale. Conditioned media (CM) were harvested on day 6 and expression levels assessed by non-reducing SDS-PAGE. Somewhat higher levels of expression (30-150 µg/ml) were observed compared to the initial assessment, but the relative expression levels were consistent with the smaller scale transfections.

Example 8: Recombinant mAb1-D10 fusion variant characterization

Expression level and TGF-β1 binding

[00140] Quantitation of the expression level and the capability of recombinant mAb1-D10 fusion variants to bind TGF-β1 were assessed using an Octet® QK384. Octet® biosensors for murine IgG were dipped into conditioned medium diluted 1:10 in sample diluent (PBS, pH 7.4 containing 0.01% BSA and 0.02% Tween 20) or 2-fold serial dilutions of a purified mAb1 standard over the range of 1.25 to 100 µg/mL. Binding data were collected for 2 min while shaking the samples at 500 rpm. Titters were calculated using a 4-parameter fit of the initial binding rates and comparison to those obtained from the standards. The biosensors were then washed with diluent for 1 min to remove any medium and reestablish a baseline and then dipped into wells containing 40 nM TGF-β1 for 3 min at 1000 rpm to follow binding. This was followed by a dissociation step by transfer of the sensors to diluent for 3 min at 1000 rpm. As seen in Table 2, the concentrations for the fusion variants in the media ranged from 11 to 178 µg/mL (“Octet Conc.”) and generally matched trends observed by SDS-PAGE (“Expression Level”). In

addition, all of the fusion variants were capable of binding TGF- β 1, suggesting the presence of D10 peptide at any of the positions indicated did not seriously affect antigen binding.

Mouse FcRn binding

[00141] Mouse FcRn binding by the recombinant mAb1-D10 fusion variants was assessed using an Octet QK384. All steps were performed at 1000 rpm. Conditioned medium diluted to achieve an antibody concentration of 10 μ g/mL was contacted by anti-murine IgG Fv biosensors for 5 minutes. The biosensors were then dipped into PBSP pH 6.0 (50 mM sodium phosphate pH 6.0, 150 mM sodium chloride, 0.005% surfactant P20) to establish a baseline. The sensors were then transferred to wells containing soluble mouse FcRn diluted to 1 μ M in PBSP pH 6.0 for 3 min followed by 3 min dissociation in wells containing PBSP pH 6.0. As indicated in Table 2, all variants bound mouse FcRn.

Protein G binding

[00142] Binding by the recombinant mAb1-D10 fusion variants to protein G was assessed using an Octet QK384. Protein G biosensors were dipped into wells containing conditioned medium diluted to 10 μ g/mL antibody in sample diluent and signal followed for 3 min at 1000 rpm. As indicated in Table 2, all of the variants bound protein G.

Table 2 Characterization of mAb1-D10 fusion variants

Variant ID	Heavy Chain	Light Chain	PAR	Octet® Conc. (μ g/mL)	Expression Level	TGF- β 1 Binding	Mouse FcRn Binding	Protein G Binding
mAb1 F1	wt-HC	wt-LC	0	85	++	+	+	+++
mAb1 F2	wt-HC	D10-LC	2	53	++	+	+	++
mAb1 F3	wt-HC	LC-D10	2	50	++	+	+	+
mAb1 F4	wt-HC	LC-(G4S)-D10	2	52	++	+	+	+
mAb1 F5	wt-HC	LC-(G4S) ₂ -D10	2	34	+	+	+	+
mAb1	HC-D10	wt-LC	2	178	++++	+	+	++

Variant ID	Heavy Chain	Light Chain	PAR	Octet® Conc. (µg/mL)	Expression Level	TGF-β1 Binding	Mouse FcRn Binding	Protein G Binding
F6								
mAb1 F7	HC-D10	D10-LC	4	46	+	+	+	++
mAb1 F8	HC-D10	LC-D10	4	117	+++	+	+	+
mAb1 F9	HC-D10	LC-(G4S)-D10	4	156	++++	+	+	+
mAb1 F10	HC-D10	LC-(G4S) ₂ -D10	4	100	+++	+	+	+
mAb1 F11	D10-HC	wt-LC	2	36	+	+	+	++
mAb1 F12	D10-HC	D10-LC	4	11	+	+	+	++
mAb1 F13	D10-HC	LC-D10	4	36	+	+	+	+
mAb1 F14	D10-HC	LC-(G4S)-D10	4	34	+	+	+	+
mAb1 F15	D10-HC	LC-(G4S) ₂ -D10	4	27	+	+	+	+
mAb1 F16	D10-HC-D10	wt-LC	4	36	+	+	+	++
mAb1 F17	D10-HC-D10	D10-LC	6	23	+	+	+	++
mAb1 F18	D10-HC-D10	LC-D10	6	31	+	+	+	+
mAb1 F19	D10-HC-D10	LC-(G4S)-D10	6	40	+	+	+	+
mAb1 F20	D10-HC-D10	LC-(G4S) ₂ -D10	6	28	+	+	+	+

SDS-PAGE

[00143] Purified WT construct and recombinant fusion variants mAb1 F2, mAb1 F6, mAb1 F7, mAb1 F11, mAb1 F12, mAb1 F16, and mAb1 F17 were analyzed on 4-20% Tris-Glycine SDS-PAGE gels (Novex, Life Sciences) under reducing and non-reducing conditions and stained with Coomassie Blue. A visible light image collected by a ProteinSimple® imager is depicted in FIG. 10. A small reduction in the mobility of the heavy and/or light chain was observed which matched the expected presence and

number of D10 peptides on each. Impurities and covalent aggregates were not detectable.

Thermal stability by differential scanning fluorimetry (DSF)

[00144] Thermal stabilities of several recombinant mAb1-D10 fusion variants representing all possible combinations of D10 peptides at the termini on the heavy and light chains were determined by differential scanning fluorimetry using SYPRO® Orange (Thermo Scientific) as a reporter dye. It is generally accepted that the stability of proteins at higher temperature is predictive of their stability under typical storage conditions and thus can be used to assess their suitability for manufacture and use as therapeutics. Thermal stability can be assessed with dyes which exhibit an increase in fluorescence upon binding hydrophobic regions exposed by unfolding of protein structure on real-time PCR instruments (Lo *et al.*, 2004, *Anal. Biochem.* 332(1): 153-9). The fluorescence of samples (10 μ L at 0.5 mg/ml protein) containing a 1:1000 dilution of SYPRO® Orange was followed while raising the temperature on a CFX96 Real-time PCR Detection System. Data were analyzed using CFX Manager 3.0 (Bio-Rad Laboratories). FIG. 11 depicts the rate of change of the fluorescence with temperature for several variants. The rate of change is typically used rather than absolute fluorescence in order to separate out the binding of dye to portions of the protein structure which are unaffected by structural transitions. A negative displacement reflects an increase in the rate of fluorescence change and a minimum represents the midpoint of the transition to an unfolded state ("T_m"). Several of the variants tested (mAb1 F6, mAb1 F11, mAb1 F16) showed T_m profiles indistinguishable from the unmodified antibody control ("WT" = mAb1 F1). Two others (mAb1 F2 and mAb1 F7) showed a significant decrease in the T_m for the major transition. Two variants (mAb1 F12 and mAb1 F17) showed the lowest T_m values. Notably, all four of the recombinant mAb1-D10 fusion variants containing a D10 peptide at the N-terminus of the light chain showed a significant decrease in T_m suggesting placement of the peptide at this position on the mAb1 antibody destabilizes its structure. Conversely, placement of the D10 peptide on either terminus of the heavy chain did not correlate with any change in T_m. The T_m values of the predominant transitions for several fusion variants observed as depicted in FIG. 11 are tabulated in Table 3.

Table 3 Differential scanning fluorimetry of expressed recombinant fusion variants

Variant ID ^A	(5'- HC-3'): (5'-LC-3')	PAR	Tm
mAb1 F1 ^B	WT	0	72.5
mAb1 F2	WT-HC:D10-LC	2	64.0
mAb1 F6	HC-D10:WT-LC	2	72.3
mAb1 F7	HC-D10:D10-LC	4	64.0
mAb1 F11	D10-HC: WT-LC	2	72.0
mAb1 F12	D10-HC: D10-LC	4	62.7
mAb1 F16	D10-HC-D10: WT-LC	4	72.0
mAb1 F17	D10-HC-D10: D10-LC	6	62.5

^A see Table 2; ^B mAb1 F1 is a recombinant version of mAb1.

Example 9: Potency of recombinant mAb1-D10 fusion variants in neutralizing TGF- β 1 *in vitro*

[00145] The potency of recombinant mAb1-D10 fusion variants in neutralizing TGF- β 1 activity was determined by inhibition of the secretion of IL-11 by A549 tumor cells *in vitro* in response to TGF- β 1 added to the medium. The procedure was performed as described in Example 3. Several representative fusion variants from Example 7 were selected on the basis of their affinity for protein G (as an indicator of their ease of purification). The TGF- β 1 inhibition profiles for eight variants (mAb1 F1, mAb1 F2, mAb1 F6, mAb1 F7, mAb1 F11, mAb1 F12, mAb1 F16, and mAb1 F17) are depicted in FIGS. 12A and 12B. All of the fusion proteins showed a similar EC₅₀ as the mAb1 control.

Example 10: Binding of TGF- β 1 by recombinant fusion variants

[00146] Recombinant mAb1-D10 fusion variants of Example 7 were also quantitatively assessed for TGF- β 1 binding using surface plasmon resonance (SPR) as detected by Biacore®. Samples containing purified variants were passed over a sensor chip with amine-coupled TGF- β 1 to determine the equilibrium constant, K_D. A target immobilization level of less than 100 response units (RU) of TGF- β 1 was chosen to minimize the potential for avidity effects arising from binding adjacent TGF- β 1 molecules on the chip. The level of immobilization was determined by the change in response units after NHS/EDC activation of the chip surface, but before quenching with

ethanolamine. The fusion variants, WT fusion variant F1, and mAb1 control were diluted to 30, 10, 3, 1 and 0.37 nM in HBS-EP buffer and passed over the TGF- β 1 chip at 30 μ L/min for 3 min, followed by 5 min dissociation in the same buffer. Between runs, the chip surface was regenerated to remove any bound antibody by passing two 30 sec injections of 40 mM HCl over the chip at a flow rate of 75 μ L/min. As shown in Table 4, the equilibrium constants (K_D) for all of the fusion variants and the WT construct (F1) were within 2.4-fold of the mAb1 control. Unexpectedly, the maximum signal (RU) elicited by the fusion variants decreased with increasing number of peptides, with variant F17 (D10-HC-D10/D10-LC, PAR=6) showing the lowest signal. This is in contrast to the A549 cell potency assay as described in Example 9 which showed all the tested fusion variants to be comparable to or more potent than either mAb1 or the WT construct in neutralizing TGF- β 1. A possible explanation of this decline may reflect electrostatic repulsion between the chip matrix (carboxymethyl dextran) and the negatively charged D10 peptides.

Table 4 Equilibrium constants for mAb1-D10 fusion variants binding to TGF- β 1 by Biacore analysis

Variant ID ^A	Sample	PAR	Kinetic Fit Conc. Range	$K_a(\times 10^5 M^{-1} s^{-1})$	$K_d(\times 10^{-3} s^{-1})$	TGF β 1 K_D (nM)
mAb1	unmodified mAb	0	90-3 nM	1.67	1.00	6.00
mAb1 F1	WT-HC: WT-LC	0	30-3 nM	3.38	0.85	2.51
mAb1 F2	WT-HC: D10-LC	2	90-3 nM	1.66	1.00	6.01
mAb1 F6	HC-D10: WT-LC	2	90-3 nM	1.82	0.84	4.58
mAb1 F7	HC-D10: D10-LC	4	90-3 nM	1.72	0.94	5.43
mAb1 F11	D10-HC: WT-LC	2	90-3 nM	1.64	0.92	5.62
mAb1 F12	D10-HC: D10-LC	4	90-3 nM	1.71	0.93	5.41
mAb1 F16	D10-HC-D10: WT-LC	4	90-3 nM	1.59	1.10	6.88
mAb1 F17	D10-HC-D10: D10-LC	6	90-3 nM	1.91	0.79	4.15

^A see Table 2

Example 11: Binding of recombinant mAb1-D10 fusion variants to hydroxyapatite

[00147] Recombinant mAb1-D10 fusion variants from Example 7 were also tested for binding ceramic hydroxyapatite (CHT) columns as described in Example 3 to assess

their potential for binding to the mineral structure of bone. Recombinant mAb1-D10 fusion variants (25 µg each in 5 mM Na phosphate pH 7.4) were applied to a 100 µL column of hydroxyapatite (CHT type II, BioRad) and eluted using a gradient from 0.005 to 0.5 M Na⁺ phosphate pH 7.4. Protein in the mobile phase eluting from the column was followed by A₂₈₀. A standard (usually a mAb1-D10 chemical conjugate) was run at the beginning and end of each set of runs to insure consistency in column performance. FIG. 13 depicts the A₂₈₀ profiles for each run. The retention time (RT) and fraction bound are shown in Table 5 below. All but one of the recombinant fusion variants were bound nearly quantitatively but showed differences in affinity as reflected in their retention times. The rank order of retention time did not correlate well with the PAR suggesting a significant effect of peptide location on binding. In particular, the strongest binding (highest RT) was observed with variant F7 (PAR4) while variant F17 (PAR6) showed slightly weaker binding. One variant (F6, PAR2) showed weaker binding than most of the PAR4 variants but significantly better than other PAR2 variants (F2 and F11). One variant (F2) with the peptide solely at the N-terminus of the light chains showed only weak binding as reflected in its RT and fraction bound (23%). The mAb1-D10 chemical conjugate ("CC"; PAR~4) yielded two peaks, with 84% eluting at an earlier RT than all of the PAR4 fusion variants.

Table 5 Hydroxyapatite binding by mAb1-D10 recombinant fusion variants and chemical conjugates

Variant ID ^A	Description	PAR	RT (min)
mAb1	Unmodified mAb	0	Nd*
F7	HC-D10 / D10-LC	4	7.58
F16	D10-HC-D10 / wt LC	4	7.53
F17	D10-HC-D10 / D10-LC	6	7.44
F6	HC-D10 / wt-LC	2	7.07
CC ^B	NA ^C	4.8	6.57 (84% [†])
F12	D10-HC / D10-LC	4	6.27
F11	D10-HC / wt LC	2	5.39
F2	wt HC / D10-LC	2	5.17 (23%)
*none detected, [†] fraction bound (if < 100%); ^A see Table 2; ^B mAb1-D10 chemical conjugate (conjugated on hinge region cysteines and light chain C-terminus cysteines, see FIG. 3A); ^C not applicable.			

Example 12: Biodistribution of recombinant fusion variants in mice

[00148] The biodistributions of a selected subset of the recombinant mAb1-D10 fusion variants (F6, F16, and F17) and the mAb1-D10 chemical conjugate produced as described in Example 6 were determined following tail vein injection into CD-1 mice. The recombinant variants were selected on the basis of several factors including expression and purification yield, TGF- β 1 binding affinity, cell based potency, and binding to hydroxyapatite. These variants included examples containing two, four, or six D10 peptides to assess whether targeting recapitulates binding to hydroxyapatite or if it is a function of peptide number. The proteins were expressed in HEK293 cells and purified over protein A. Three recombinant mAb1 fusion variants were characterized in detail *in vitro* and *in vivo*. In these, D10 peptides were recombinantly added either solely to the C-terminus of the heavy chain (mAb1 F6), both the N- and C-termini of the heavy chain (mAb1 F16), or to the N- and C-termini of the heavy chain and C-terminus of the light chains (mAb1 F17). The mAb1 F6, F16 and F17 recombinant variants have peptide to antibody ratios (PAR) of 2, 4, and 6, respectively. The mAb1-D10 peptide chemical conjugate (~4.8 PAR), which showed targeting to bone in the study in Example 6, was chosen as a positive control.

[00149] The recombinant fusion variants and chemical conjugate were labeled by reaction with Dylight® 800-4xPEG NHS ester (Thermo Scientific) in 50 mM sodium borate pH 8.65 and a dye:protein molar ratio of approximately 5:1. The degree of labeling (DOL) was maintained within 20% (~1.2 mol:mol) by adjustment of the dye:protein ratio. The labelled proteins were then administered at 1 mg/kg to CD-1 mice by tail vein injection. Anesthetized animals were subsequently imaged on an IVIS small animal near-infrared imager (Perkin Elmer) at 24, 48, 168, and 504 hours (3 weeks) following administration. Femurs and spine were recovered from an animal from each group at 240 and 504 hr to verify delivery to bone.

[00150] As shown in the dorsal view images in FIG. 14, all of the mAb1-D10 fusion variants and chemical conjugate were concentrated at the dorsal midline near the vertebral column and remained there for 3 weeks (504 hours) although significant differences were observed between the signal intensity for the test articles. A region of interest (ROI) was used for quantitation which included the portion of the spinal column

between the shoulders and pelvis, as shown in FIG. 14. The maximum radiant efficiency within the ROI normalized for the DOL was calculated and plotted as shown in FIG. 15. Recombinant fusion variant F6, which has a D10 peptide on each of the heavy chain C-termini, showed the highest level at the spinal column of all the constructs over the entire course of the study (3 weeks). After 48 hours, the rank order of signal intensity within the ROI was variant F6 > variant F16 > variant F17 $\approx$ chemical conjugate, and this order was maintained throughout the course of study (FIG. 15). The area under the curve (AUC) for the maximum radiant efficiencies within the ROI over time less the background autofluorescence (from vehicle-only control animals) calculated using Phoenix® WinNonlin® software (Pharsight) is shown in Table 6. There was an 8 to 22 fold increase in the bone exposure (AUC) compared to the mAb1 control and modest differences (up to 2.5-fold) between the D10-containing constructs. Variant F6 showed the highest increase compared to mAb1 (21.8-fold, $p < 0.05$). The tissue half-life as calculated using WinNonlin® similarly showed a >10-fold increase in the half-life in bone for variant F6 compared to mAb1 ($p < 0.05$).

[00151] Spines and femurs from representative animals in each cohort were isolated after 240 and 504 hr, separated from surrounding tissue and imaged (FIG. 16). The relative fluorescence intensities of these samples were consistent with the dorsal image signals observed in live animals indicating that they reflect the presence of the recombinant fusion variants and chemical conjugate on bone.

Table 6 Vertebral exposures from fluorescence AUC data

Variant ID	AUC _{inf} (norm) ^A	Tissue t _{1/2} (d) ^A
mAb1	(1.0)	2.3 $\pm$ 0.1
F6	21.8 $\pm$ 9.1*	25.4 $\pm$ 9.9*
F16	10.0 $\pm$ 1.6	14.2 $\pm$ 2.4
F17	9.5 $\pm$ 3.1	19.0 $\pm$ 3.7
CC ^B	7.7 $\pm$ 1.0	17.9 $\pm$ 3.4
^A Mean $\pm$ SEM, adjusted for DOL and normalized to mAb1; ^B mAb1-D10 chemical conjugate * $P < 0.05$ compared to mAb1		

Example 13: Preparation of a recombinant human anti-TGF β -D10 antibody fusion variant

[00152] An expression vector for preparing mAb2 (a human anti-TGF β IgG4 antibody with a hinge mutation S228P) bearing a C-terminal D10 sequence on the heavy chain (*i.e.*, mAb2 HC-D10 / mAb2 wt LC (SEQ ID NO: 14/SEQ ID NO: 15), which has corresponding configuration as in variant F6 (see FIG. 9B), and hereafter referred to as mAb2 F6; see Table 7) was generated in the same fashion as described in Example 7. Expi293F cells were transfected with miniprep DNA and after 6 days, conditioned medium (60 mL) was harvested, and the product protein purified over HiTrap protein A (G.E. Healthcare).

Table 7 Recombinant fusion variants of mAb2 with D10

Variant ID	Heavy Chain Construct	SEQ ID NO:	Light Chain Construct	SEQ ID NO:
mAb2 F1	HC	13	LC	15
mAb2 F2	HC	13	D10-LC	18
mAb2 F3	HC	13	LC-D10	19
mAb2 F4	HC	13	LC-(G4S)-D10	21
mAb2 F5	HC	13	LC-(G4S) ₂ -D10	22
mAb2 F6	HC-D10	14	LC	15
mAb2 F7	HC-D10	14	D10-LC	18
mAb2 F8	HC-D10	14	LC-D10	19
mAb2 F9	HC-D10	14	LC-(G4S)-D10	21
mAb2 F10	HC-D10	14	LC-(G4S) ₂ -D10	22
mAb2 F11	D10-HC	16	LC	15
mAb2 F12	D10-HC	16	D10-LC	18
mAb2 F13	D10-HC	16	LC-D10	19
mAb2 F14	D10-HC	16	LC-(G4S)-D10	21
mAb2 F15	D10-HC	16	LC-(G4S) ₂ -D10	22
mAb2 F16	D10-HC-D10	17	LC	15
mAb2 F17	D10-HC-D10	17	D10-LC	18
mAb2 F18	D10-HC-D10	17	LC-D10	19
mAb2 F19	D10-HC-D10	17	LC-(G4S)-D10	21
mAb2 F20	D10-HC-D10	17	LC-(G4S) ₂ -D10	22

Example 14: Biodistribution of human anti-TGF β -D10 antibody fusion protein in mice

[00153] The recombinant mAb2 variant F6 (mAb2 F6) and mAb2 control antibodies were labeled with AlexaFluor® 647 (Thermo Scientific) and administered

intraperitoneally to C57BL/6 mice at a dose of 1 mg/kg. After 24 and 96 hours, some mice were sacrificed and spines and femurs resected and imaged on an IVIS instrument. A sample of serum (10 μ L) obtained at sacrifice was imaged in parallel. The average total radiant efficiency for the distal femur (trabecular) ROI and lumbar spine is shown in FIGS. 17A and 17B. The relative intensities are tabulated in Table 8. These results show a large increase in the amount of antibody in the lumbar spine and femur with significantly less in serum after 96 hours as a result of recombinant addition of D10 to mAb2.

Table 8 Relative bone exposure in mice for human anti-TGF β -D10 fusion proteins in C57BL/6

Bone/serum Signal Ratio*			
	Bone	24 h	96 h
mAb2 F1	Lumbar	(1.00)	1.2
	D. Femur	0.82	0.70
mAb2 F6	Lumbar	12.6	189
	D. Femur	19.0	147
*normalized to mAb2 lumbar at 24 h			

Example 15: Single dose serum and bone pharmacokinetics of murine anti-TGF β -D10 antibody fusion protein in mice

[00154] In this example, the pharmacokinetics of murine anti-TGF β -D10 antibody fusion proteins was measured in mice.

[00155] A single dose of mAb1 or recombinant mAb1 F6 (see Table 2) was administered intraperitoneally to G610C mice (an osteogenesis imperfecta animal model; n=12 per time point) and blood samples were collected at 4 hr or 2, 7, 15, 22, and 43 days post-dose. An ELISA optimized for detecting and quantifying serum concentrations of relevant antibodies was utilized.

[00156] For bone imaging, a single dose of fluorophore-labeled mAb1, recombinant mAb1 F6 or various other D10 alternatives was administered intravenously to nude CD-1 mice (n=3 per time point) and *in vivo* optical imaging performed at 4 hr or 1, 2, 4, 7, 10, and 21 days post-dose. Fluorescent images of mouse spinal column were

generated which allowed for relative test article comparisons between mAb1 and mAb1 F6 in the bone (not shown).

[00157] Pharmacokinetic profiles in the serum and bone, respectively, can be seen in FIGS. 18A and 18B and resulting pharmacokinetic parameters in Table 9 below.

[00158] The results demonstrated fundamental contrasts in pharmacokinetics between mAb1 and mAb1 F6 in the serum and bone following a single dose. mAb1 F6 exhibited 13-fold less AUC (exposure) in the serum and 22-fold higher exposure in the bone compared to mAb1. Additionally, mAb1 F6 exhibited a 14-fold shorter $t_{1/2}$ in serum than mAb1 and commensurately 13-fold faster clearance. And lastly for bone, mAb1 F6 exhibited an 11-fold longer $t_{1/2}$ than mAb1 and commensurately 17-fold slower clearance. These attributes may be advantageous for a human form of mAb1-D10 in the clinical realm where peripheral (serum) inhibition of TGF β may not be desired from a safety standpoint, while higher exposure in the bone may enhance efficacy.

Table 9 Single Dose PK Parameters

Test Article	Method/Analyte	AUC	$t_{1/2}$ (day)	Clearance
mAb1	ELISA/Serum	740 $\pm$ 91.6	12.6 $\pm$ 2.51	0.14 $\pm$ 0.034
mAb1 F6		56.3 $\pm$ 13.1*	0.91 $\pm$ 0.21*	1.78 $\pm$ 0.27*
mAb1	Imaging/Bone	(1.0) [#]	2.3 $\pm$ 0.1	1.82 $\pm$ 0.08
mAb1 F6		21.8 $\pm$ 9.1*	25.4 $\pm$ 9.9*	0.11 $\pm$ 0.03*

* $p < 0.05$ compared to mAb1; [#]AUC normalized to 1.0 for mAb1

Example 16: Multiple dose peak trough serum pharmacokinetics of murine anti-TGF β -D10 antibody fusion protein in mice

[00159] In this example, a multiple dose peak-trough pharmacokinetic study was performed in an animal model of osteogenesis imperfecta.

[00160] mAb1 and mAb1 F6 (see Table 2) were dosed intraperitoneally at a concentration of 0.3 mg/kg and 1 mg/kg, 3 x weekly for 8 weeks (24 total doses) to G610C mice (n=10) and blood samples were collected at 24 and 48 hr post dose following dose 1 and 23 (beginning and end of study). Results are shown only for the 1

mg/kg dose (see FIG. 19). A Mass Spec assay, optimized for detecting and quantifying serum concentrations of relevant antibodies, was utilized.

[00161] Results are quantified in Table 10 below. The results demonstrated fundamental contrasts in pharmacokinetics between mAb1 and mAb1 F6 in the serum following both dose 1 and 23. Significantly lower serum concentrations were observed for mAb1 F6 compared to mAb1 at both 24 and 48 hr post dose on both dose 1 and 23. Additionally, the slope between 24 and 48 hr post dose for mAb1 F6 was steeper compared to mAb1 at both dose 1 and 23, suggesting that mAb1 F6 is leaving the serum (systemic circulation) at a faster rate than mAb1, likely due to its high affinity for bone (hydroxyapatite). Lastly, both mAb1 F6 and mAb1 appear to be accumulating in the serum from dose 1 to 23, but mAb1 F6 appears to accumulate at a decreased concentration compared to mAb1 (mAb1 F6: 2.5 to 3.5 fold accumulation and mAb1: 4 to 5.5 fold accumulation from dose 1 to 23). These attributes may be advantageous for a human form of mAb1 F6 in the clinical realm where peripheral (serum) inhibition of TGF β may not be desired from a safety standpoint.

Table 10 mAb1 dosing study results

<i>Dose Groups (1 mg/kg)</i>	<i>Avg. Serum (μg/mL)</i>	
	<i>24 hr</i>	<i>48 hr</i>
<i>mAb1 F6 Dose 1</i>	<i>3.24 $\pm$ 1.25*</i>	<i>1.60 $\pm$ 0.68*</i>
<i>mAb1 Dose 1</i>	<i>9.60 $\pm$ 1.72</i>	<i>9.03 $\pm$ 1.51</i>
<i>mAb1 F6 Dose 23</i>	<i>8.52 $\pm$ 2.61*</i>	<i>4.86 $\pm$ 1.85*</i>
<i>mAb1 Dose 23</i>	<i>40.07 $\pm$ 5.43</i>	<i>44.95 $\pm$ 7.58</i>

* $p \leq 0.05$ compared to mAb1

Example 17: Multiple dose efficacy study in lumbar bone with mAb1 and mAb1 F6

[00162] In this example, a multiple dose efficacy study was performed in an animal model of osteogenesis imperfecta to determine effectiveness of bone targeted (mAb1 F6) versus untargeted mAb1 on bone density and strength.

[00163] mAb1 and mAb1 F6 were dosed intraperitoneally 3 x weekly at 0.3, 1, and 5 mg/kg for 8 weeks to G610C mice. Following the final dose, mice were necropsied and the 6th lumbar bone was imaged via μ CT to determine bone volume over total volume (BV/TV) and subjected to biomechanical testing to ascertain maximum force to failure (bone strength).

[00164] Results are shown in FIGS. 20 and 21. Significant changes of BV/TV (%) compared to 13C4 treated G610C mice were observed at 1 and 5 mg/kg for both treatments. Significant changes of maximum force to failure compared to 13C4 treated G610C mice were observed at 1 and 5 mg/kg for mAb1 F6 and 1 mg/kg only for mAb1. G610C mice treated with an antibody control (13C4) exhibited significant decreases in both BV/TV and maximum force to failure compared to WT background strain. These results demonstrate that both treatments induce similar dose related changes in BV/TV and maximum force to failure in the G610C mouse at this regimen of 3 x weekly dosing. Trends did exist for enhanced efficacy for mAb1 F6 on bone strength, as half of the cohort of mice at 5 mg/kg exhibited substantially higher maximum force to failure values (40 Newtons or higher) than mice treated with mAb1 at 1 mg/kg or 5 mg/kg.

Example 18: Dosing frequency study in lumbar bone with mAb1 and mAb1 F6

[00165] In this example, a dosing frequency study was performed in an animal model of osteogenesis imperfecta to determine the appropriate frequency of dosing for mAb1 F6 to achieve its optimal effectiveness of bone targeted antibodies.

[00166] mAb1 and mAb1 F6 were dosed intraperitoneally at various frequencies (3 x weekly, 1 x weekly, 1 x every 2 weeks, or 1 x every 4 weeks) at 5 mg/kg for 12 weeks to G610C mice. Pharmacokinetic (PK) serum samples were taken at the beginning and end of study to ascertain Peak and Trough values for both mAb1 and mAb1 F6. Following the final dose, mice were necropsied and the 6th lumbar bone was imaged via μ CT to determine bone volume over total volume (BV/TV) and subjected to biomechanical testing to ascertain maximum force to failure (bone strength).

[00167] Results are shown in FIGS. 22, 23, and 24. Significant changes of BV/TV (%) compared to 13C4-treated G610C mice were observed for mAb1 at 3 x weekly, 1 x weekly, 1 x every 2 weeks, and 1 x every 4 weeks. Significant changes of BV/TV (%)

compared to 13C4-treated G610C mice were observed for mAb1 F6 at 3 x weekly and 1 x weekly. mAb1 treatment exhibited significantly higher BV/TV compared to mAb1 F6 treatment at 1 x every 2 weeks and 1 x every 4 weeks dosing frequency. Significant changes of maximum force to failure compared to 13C4-treated G610C mice were observed for mAb1 at 3 x weekly, 1 x weekly and 1 x every 2 weeks. Significant changes of maximum force to failure compared to 13C4-treated G610C mice were observed for mAb1 F6 at 3 x weekly and 1 x weekly. G610C mice treated with a control antibody (13C4) exhibited significant decreases in BV/TV and a trend of lower maximum force to failure, compared to WT background strain.

[00168] These results demonstrate that both mAb1 and mAb1 F6 can induce similar maximum effects in BV/TV and maximum force to failure in the G610C mice. mAb1 appears to have an advantage in durability of efficacy compared to mAb1 F6, maintaining significant efficacy when dosed once every 4 weeks for BV/TV and once every 2 weeks for maximum force to failure. However, PK serum sample averages at equivalently efficacious dosing regimens (mAb1, 1 x every 2 weeks and mAb1 F6, 1 x weekly) resulted in approximately 38 µg/mL and 8 µg/mL for mAb1 and mAb1 F6, respectively. This suggests that serum exposure may be less with mAb 1 F6, which may offer safety advantages to OI patients.

Example 19: Dosing frequency study in lumbar bone with mAb1 F16

[00169] In this example, a dosing frequency study was performed in an animal model of osteogenesis imperfecta to determine the appropriate dosing frequency for mAb1 F16 to achieve its optimal impact on bone density.

[00170] mAb1 and mAb1 F16 were dosed intraperitoneally 3 x weekly at 5 mg/kg for 8 weeks in G610C mice. Following the final dose, mice were necropsied and the 6th lumbar bone was imaged via µCT to determine bone volume over total volume (BV/TV).

[00171] Results are shown in FIG. 25. Significant changes of BV/TV (%) compared to 13C4-treated G610C mice were observed at 5 mg/kg for both mAb1 and mAb F16. G610C mice treated with the control antibody (13C4) exhibited significant decreases in BV/TV compared to WT background strain. These results demonstrate that both mAb1

and mAb F16 induce similar dose-related changes in BV/TV in the G610C mice under this dosing regimen.

Example 20: Dosing frequency study in bone with mAb1 F11

[00172] In this example, a dosing frequency study was performed in wild type mice to determine the appropriate frequency of dosing for mAb1 F11 to achieve its optimal impact on bone density.

[00173] mAb1 and mAb1 F11 were dosed intraperitoneally 3 x weekly at 5 mg/kg for 11 weeks in wild type mice. Several *in vivo* μ CT time points were taken during the in life portion of the study. Data is shown only at 9 weeks post dose for bone volume over total volume (BV/TV%).

[00174] Results are shown in FIG. 26. Significant changes of BV/TV (%) compared to 13C4-treated wild type mice were observed at 5 mg/kg for both treatments. These results demonstrate that both mAb1 and mAb1 F11 induce similar dose related changes in BV/TV in wild type mice at this dosing regimen.

Example 21: Biodistribution of mouse and human bone targeting anti-TGF β antibodies mAb1 F6 and mAb2 F6 in mice

[00175] In this example, a study was conducted to compare the biodistribution of fluorescently labeled mAb1, mAb1 F6, mAb2, and mAb2 D10 (D10 conjugated to the heavy chain C-terminus of mAb2; mAb2 F6) in wild type mice. A single intraperitoneal dose of each test article and vehicle was administered to the mice, which were euthanized at various time points for tissue collection. Among other tissues harvested (data not shown), lumbar vertebrae, heart, liver, and intestines were collected at 1, 4, 10, 20, 43, and 98 days post dosing with mAb1 and mAb1 F6. Tissues were also sampled following dosing with mAb2 and mAb2 D10 at 24 and 96 hrs.

[00176] Results are shown in FIGS. 27-33. FIGS. 27-30 show total radiant efficiencies (TREs) in tissues from mice dosed with mAb1, mAb1 F6, or vehicle at 1-98 days post dose. Lumbar vertebrae exhibits robust persistent presence of mAb1 F6 compared to mAb1, with significantly higher total radiant efficiency (TRE) at every time point. In the heart and liver, mAb1 F6 exhibits much lower TRE relative to mAb1.

Lastly, no significant differences were noted between vehicle and either test article in the intestines.

[00177] These results demonstrate that mAb1 F6 is characterized by high bone affinity that conversely leads to lower exposure in other tissues (e.g., heart and liver). The results also indicate the safety advantage of targeting the site of TGF- β inhibition in the bone while limiting systemic TGF- β inhibition and reducing adverse side effects. The lack of any TRE relative to vehicle in the intestines demonstrates that the fluorophore maintained its labeling on the respective antibodies. Previous data have shown if the fluorophore did not maintain its label on the antibodies, it would be detected in the intestines.

[00178] FIGS. 31-33 show TREs in tissues from mice dosed with either mAb2 or mAb2 D10. FIG. 31 demonstrates the high bone affinity of mAb2 D10 compared to mAb2. Significantly, higher TRE is observed in the femur for mAb2 D10 compared to mAb2. The same overall trend was observed in the lumbar. The lumbar/serum and femur/serum ratios in mAb2 D10 dosed mice as compared to those in mAb2 dosed mice also strongly support the bone targeting capability of mAb2 D10 (FIGS. 32 and 33).

[00179] Having described the invention in detail and by reference to specific embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims. More specifically, although some aspects of the present invention are identified herein as particularly advantageous, it is contemplated that the present invention is not necessarily limited to these particular aspects of the invention. In some embodiments, values disclosed herein may alternatively vary in amount by ± 10 , 20, or 30% from values disclosed and remain within the scope of the contemplated invention.

[00180] Unless otherwise defined herein, scientific and technical terms used in connection with the present invention shall have the meanings that are commonly understood by those of ordinary skill in the art. Exemplary methods and materials are described below, although methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present invention. All

publications and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. Although a number of documents are cited herein, this citation does not constitute an admission that any of these documents forms part of the common general knowledge in the art. Further, unless otherwise required by context, singular terms shall include pluralities and plural terms shall include the singular. Generally, nomenclature used in connection with, and techniques of, cell and tissue culture, molecular biology, immunology, microbiology, genetics, analytical chemistry, synthetic organic chemistry, medicinal and pharmaceutical chemistry, and protein and nucleic acid chemistry and hybridization described herein are those well-known and commonly used in the art. Enzymatic reactions and purification techniques are performed according to manufacturer's specifications, as commonly accomplished in the art or as described herein. Throughout this specification and embodiments, the words "have" and "comprise," or variations such as "has," "having," "comprises," or "comprising," will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers. Further, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. For example, reference to "an antibody" means one or more antibodies.

[00181] For the purposes of describing and defining the present invention it is noted that the term "substantially" is utilized herein to represent the inherent degree of uncertainty that can be attributed to any quantitative comparison, value, measurement, or other representation. The term "substantially" is also utilized herein to represent the degree by which a quantitative representation can vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

[00182] As used herein, the term "about" refers to $\pm 10\%$ of a given quantity, however whenever the quantity in question refers to an indivisible object, such as an amino acid or other object that would lose its identity is subdivided, then "about" refers to ± 1 of the indivisible object. For example, about 2% water refers to 1.8% to 2.2% water, whereas about 6 amino acid residues refers to 5-7 amino acid residues.

[00183] As used herein, the terms "or" and "and/or" are utilized to describe multiple components in combination or exclusive of one another. For example, "x, y, and/or z"

can refer to “x” alone, “y” alone, “z” alone, “x, y, and z,” “(x and y) or z,” “x or (y and z),” or “x or y or z.”

[00184] Sequences referred to in the specification are provided in Table 11 below as well as in the Sequence Listing.

Table 11 Sequences

Amino acid sequence for D10 (SEQ ID NO: 1)	DDDDDDDDDD
Amino acid sequence for mAb1 Heavy Chain (WT HC) (SEQ ID NO: 2)	HVQLQQSGPELVRPGASVKLSCKASGYIFITYWMNWVKQR PGQGLEWIGQIFPASGSTNYNEMFEGKATLTVDTSSTAYM QLSSLTSEDSAVYYCARGDGNALDAMDYWGQGTSTVTVSS AKTTPPSVYPLAPGSAAQTNSMVTLGCLVKGYFPEPVTVTW NSGSLSSGVHTFPAVLQSDLYTLSSSVTVPSSTWPSQTVTC NVAHPASSTKVDKKIVPRDCGCKPCICTVPEVSSVFIFPPKP KDVLTITLTPKVTCVVVDISKDDPEVQFSWFVDDDEVHTAQT KPREEQFNSTFRSVSELPIMHQDWLNGKEFKCRVNSAAFP PIEKTISKTKGRPKAPQVYTIPPPKEQMAKDKVSLTCMITDFF PEDITVEWQWNGQPAENYKNTQPIMDTDGSYFVYSKLNQ KSNWEAGNTFTCSVLHEGLHNHHTKSLSHSPGK
Amino acid sequence for mAb1 Heavy Chain with C-terminal D10 (HC-D10) (SEQ ID NO: 3)	HVQLQQSGPELVRPGASVKLSCKASGYIFITYWMNWVKQR PGQGLEWIGQIFPASGSTNYNEMFEGKATLTVDTSSTAYM QLSSLTSEDSAVYYCARGDGNALDAMDYWGQGTSTVTVSS AKTTPPSVYPLAPGSAAQTNSMVTLGCLVKGYFPEPVTVTW NSGSLSSGVHTFPAVLQSDLYTLSSSVTVPSSTWPSQTVTC NVAHPASSTKVDKKIVPRDCGCKPCICTVPEVSSVFIFPPKP KDVLTITLTPKVTCVVVDISKDDPEVQFSWFVDDDEVHTAQT KPREEQFNSTFRSVSELPIMHQDWLNGKEFKCRVNSAAFP PIEKTISKTKGRPKAPQVYTIPPPKEQMAKDKVSLTCMITDFF PEDITVEWQWNGQPAENYKNTQPIMDTDGSYFVYSKLNQ KSNWEAGNTFTCSVLHEGLHNHHTKSLSHSPGKDDDDDD DDDD
Amino acid sequence for mAb1 Heavy Chain with N-terminal D10 (D10-HC) (SEQ ID NO: 4)	DDDDDDDDDDHVQLQQSGPELVRPGASVKLSCKASGYIFIT YWMNWVKQRPGQGLEWIGQIFPASGSTNYNEMFEGKATLT VDTSSSTAYMQLSSLTSEDSAVYYCARGDGNALDAMDYW GQGTSTVTVSSAKTTPPSVYPLAPGSAAQTNSMVTLGCLVKG YFPEPVTVTWNSGSLSSGVHTFPAVLQSDLYTLSSSVTVPS STWPSQTVTCNVAHPASSTKVDKKIVPRDCGCKPCICTVPE VSSVFIFPPKPKDVLTITLTPKVTCVVVDISKDDPEVQFSWFV DDDEVHTAQTKPREEQFNSTFRSVSELPIMHQDWLNGKEF KCRVNSAAFPPIEKTISKTKGRPKAPQVYTIPPPKEQMAK KVSLTCMITDFFPEDITVEWQWNGQPAENYKNTQPIMDTDG SYFVYSKLNQKSNWEAGNTFTCSVLHEGLHNHHTKSLSH HSPGK
Amino acid sequence for mAb1 Heavy Chain with N- and C-termini D10 (D10-HC-D10)	DDDDDDDDDDHVQLQQSGPELVRPGASVKLSCKASGYIFIT YWMNWVKQRPGQGLEWIGQIFPASGSTNYNEMFEGKATLT VDTSSSTAYMQLSSLTSEDSAVYYCARGDGNALDAMDYW GQGTSTVTVSSAKTTPPSVYPLAPGSAAQTNSMVTLGCLVKG

(SEQ ID NO: 5)	YFPEPVTVTWNSGSLSSGVHTFPAVLQSDLYTLSSSVTVPS STWPSQTVTCNVAHPASSTKVDKKIVPRDCGCKPCICTVPE VSSVFIFPPKPKDVLTLTPKVTVCVVVDISKDDPEVQFSWFV DDVEVHTAQTKPREEQFNSTFRSVSELPIMHQDWLNGKEF KCRVNSAAFPAPIEKTISKTKGRPKAPQVYTIPPPKEQMAKD KVSLTCMITDFFPEDITVEWQWNGQPAENYKNTQPIMDTDG SYFVYSKLVQKSNWEAGNTFTCSVLHEGLHNHHTKSLS HSPGKDDDDDDDDDD
Amino acid sequence for mAb1 Light Chain (WT LC) (SEQ ID NO: 6)	NIVLTQSPASLAVSLGQRATISCRASESVDSYGNSFMHWYQ QKSGQPPKLLIYLASNLESGVPARFSGSGSRTDFTLTIDPVE ADDAATYYCQQNNEDPLTFGAGTKLELKRADAAPTVSIFPP SSEQLTSGGASVVCFLNNFYPKDINVKWKIDGSERQNGVLN SWTDQDSKDSYSTSMSSTLTLTKDEYERHNSYTCEATHKTST SPIVKSFNRECE
Amino acid sequence for mAb1 Light Chain with N- terminal D10 (D10-LC) (SEQ ID NO: 7)	DDDDDDDDDDNIVLTQSPASLAVSLGQRATISCRASESVDS YGNSFMHWYQQKSGQPPKLLIYLASNLESGVPARFSGSGS RTDFTLTIDPVEADDAATYYCQQNNEDPLTFGAGTKLELKRA DAAPTVSIFPPSSEQLTSGGASVVCFLNNFYPKDINVKWKID GSERQNGVLNSWTDQDSKDSYSTSMSSTLTLTKDEYERHNS YTCEATHKTSTSPIVKSFNRECE
Amino acid sequence for mAb1 Light Chain with C- terminal D10 (LC-D10) (SEQ ID NO: 8)	NIVLTQSPASLAVSLGQRATISCRASESVDSYGNSFMHWYQ QKSGQPPKLLIYLASNLESGVPARFSGSGSRTDFTLTIDPVE ADDAATYYCQQNNEDPLTFGAGTKLELKRADAAPTVSIFPP SSEQLTSGGASVVCFLNNFYPKDINVKWKIDGSERQNGVLN SWTDQDSKDSYSTSMSSTLTLTKDEYERHNSYTCEATHKTST SPIVKSFNRECEDDDDDDDDDD
Amino acid sequence for: 1X peptide linker (G4S) (SEQ ID NO: 9)	GGGGS
Amino acid sequence for: 2X peptide linker ((G4S)x2) (SEQ ID NO: 10)	GGGGS
Amino acid sequence for mAb1 Light Chain with 1X Linker and C-terminal D10 (LC-G4S-D10) (SEQ ID NO: 11)	NIVLTQSPASLAVSLGQRATISCRASESVDSYGNSFMHWYQ QKSGQPPKLLIYLASNLESGVPARFSGSGSRTDFTLTIDPVE ADDAATYYCQQNNEDPLTFGAGTKLELKRADAAPTVSIFPP SSEQLTSGGASVVCFLNNFYPKDINVKWKIDGSERQNGVLN SWTDQDSKDSYSTSMSSTLTLTKDEYERHNSYTCEATHKTST SPIVKSFNRECEGGGGSDDDDDDDDD
Amino acid sequence for mAb1 Light Chain with 2X Linker and C-terminal D10 (LC-(G4S)2-D10) (SEQ ID NO: 12)	NIVLTQSPASLAVSLGQRATISCRASESVDSYGNSFMHWYQ QKSGQPPKLLIYLASNLESGVPARFSGSGSRTDFTLTIDPVE ADDAATYYCQQNNEDPLTFGAGTKLELKRADAAPTVSIFPP SSEQLTSGGASVVCFLNNFYPKDINVKWKIDGSERQNGVLN SWTDQDSKDSYSTSMSSTLTLTKDEYERHNSYTCEATHKTST SPIVKSFNRECEGGGGSGGGGSDDDDDDDDDD
Amino acid sequence for mAb2 Heavy Chain WT (WT HC) (SEQ ID NO: 13)	QVQLVQSGAEVKKPGSSVKVSKASGYTFSSNVISWVRQA PGQGLEWMGGVPIVDIANYAQRFKGRVTITADESTSTTYME LSSLRSEDYAVYYCASTLGLVLDAMDYWGQGTLVTVSSAST KGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTVSWNSG ALTSGVHTFPAVLQSSGLYSLSSVTVPSSSLGKTYTCNVD

	HKPSNTKVDKRVESKYGPPCPPCPAPEFLGGPSVFLFPPKP KDTLMISRTPEVTCVVVDVSQEDPEVQFNWYVDGVEVHNA KTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKG LPSSIEKTISKAKGQPREPQVYTLPPSQEEMTKNQVSLTCLV KGFYPVDIAVEWESNGQPENNYKTTTPVLDSGDSFFLYSRL TVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLGLGK
Amino acid sequence for mAb2 Heavy Chain with C-terminal D10 (HC-D10) (SEQ ID NO: 14)	QVQLVQSGAEVKKPGSSVKVSCKASGYTFSSNVISWVRQA PGQGLEWMGGVPIVDIANYAQRFKGRVTITADESTSTTYME LSSLRSEDTAVYYCASTLGLVLDAMDYWGQGTTLTVSSAST KGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTVSWNSG ALTSGVHTFPAVLQSSGLYSLSSVTVPSSSLGKTYTCNV HKPSNTKVDKRVESKYGPPCPPCPAPEFLGGPSVFLFPPKP KDTLMISRTPEVTCVVVDVSQEDPEVQFNWYVDGVEVHNA KTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKG LPSSIEKTISKAKGQPREPQVYTLPPSQEEMTKNQVSLTCLV KGFYPVDIAVEWESNGQPENNYKTTTPVLDSGDSFFLYSRL TVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLGLGKDDDD DDDDDDDD
Amino acid sequence for mAb2 Light Chain WT (WT LC) (SEQ ID NO: 15)	ETVLTQSPGTLSLSPGERATLSCRASQSLGSSYLAWYQQKP GQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPED FAVYYCQQYADSPITFGQGTREIKRTVAAPSVFIFPPSDEQ LKSGTASVCLLNFPYFREAKVQWKVDNALQSGNSQESVT EQDSKDYSTYSLSTLTLSKADYEKHKVYACEVTHQGLSSPV TKSFNRGEC
Amino acid sequence for mAb2 Heavy Chain with N-terminal D10 (D10-HC) (SEQ ID NO: 16)	DDDDDDDDDDQVQLVQSGAEVKKPGSSVKVSCKASGYTFS SNVISWVRQAPGQGLEWMGGVPIVDIANYAQRFKGRVTITA DESTSTTYMELSSLRSEDTAVYYCASTLGLVLDAMDYWGQ GTLTVSSASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFP EPVTVSWNSGALTSGVHTFPAVLQSSGLYSLSSVTVPS LGKTYTCNVDPKPSNTKVDKRVESKYGPPCPPCPAPEFLG GPSVFLFPPKPKDTLMISRTPEVTCVVVDVSQEDPEVQFNW YVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGK EYKCKVSNKGLPSSIEKTISKAKGQPREPQVYTLPPSQEEMT KNQVSLTCLVKGFYPVDIAVEWESNGQPENNYKTTTPVLDS DGSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHYTQKS LSLGLGK
Amino acid sequence for mAb2 Heavy Chain with N-terminal D10 and C- terminal D10 (D10-HC- D10) (SEQ ID NO: 17)	DDDDDDDDDDQVQLVQSGAEVKKPGSSVKVSCKASGYTFS SNVISWVRQAPGQGLEWMGGVPIVDIANYAQRFKGRVTITA DESTSTTYMELSSLRSEDTAVYYCASTLGLVLDAMDYWGQ GTLTVSSASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFP EPVTVSWNSGALTSGVHTFPAVLQSSGLYSLSSVTVPS LGKTYTCNVDPKPSNTKVDKRVESKYGPPCPPCPAPEFLG GPSVFLFPPKPKDTLMISRTPEVTCVVVDVSQEDPEVQFNW YVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGK EYKCKVSNKGLPSSIEKTISKAKGQPREPQVYTLPPSQEEMT KNQVSLTCLVKGFYPVDIAVEWESNGQPENNYKTTTPVLDS DGSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHYTQKS LSLGLGKDDDDDDDDDD
Amino acid sequence for	DDDDDDDDDDDETTLTQSPGTLSLSPGERATLSCRASQSLG

mAb2 Light Chain with N-terminal D10 (D10-LC) (SEQ ID NO: 18)	SSYLAWYQQKPGQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPEDFAVYYCQQYADSPITFGQGTRLEIKRTVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDYSLSSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGEC
Amino acid sequence for mAb2 Light Chain with C-terminal D10 (LC-D10) (SEQ ID NO: 19)	ETVLTQSPGTLSLSPGERATLSCRASQSLGSSYLAWYQQKPGQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPEDFAVYYCQQYADSPITFGQGTRLEIKRTVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDYSLSSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGECDDDDDDDDDDDD
Amino acid sequence for mAb2 Light Chain with N-terminal D10 and C-terminal D10 (D10-LC-D10) (SEQ ID NO: 20)	DDDDDDDDDDDETULTQSPGTLSLSPGERATLSCRASQSLGSSYLAWYQQKPGQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPEDFAVYYCQQYADSPITFGQGTRLEIKRTVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDYSLSSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGECDDDDDDDDDDDD
Amino acid sequence for mAb2 Light Chain with 1X Linker and C-terminal D10 (LC-G4S-D10) (SEQ ID NO: 21)	ETVLTQSPGTLSLSPGERATLSCRASQSLGSSYLAWYQQKPGQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPEDFAVYYCQQYADSPITFGQGTRLEIKRTVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDYSLSSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGECGGGGSGDDDDDDDDDDDD
Amino acid sequence for mAb2 Light Chain with 2X Linker and C-terminal D10 (LC-(G4S)2-D10) (SEQ ID NO: 22)	ETVLTQSPGTLSLSPGERATLSCRASQSLGSSYLAWYQQKPGQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPEDFAVYYCQQYADSPITFGQGTRLEIKRTVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDYSLSSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGECGGGGSGGGGSGDDDDDDDDDDDD
Nucleic acid sequence for mAb2 Heavy Chain WT (WT HC) (SEQ ID NO: 23)	CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAA GCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTTCTGG ATACACCTTCAGTAGCAATGTTATCAGCTGGGTGCGCCA GGCCCCTGGACAAGGGCTCGAGTGGATGGGGGGGGTCA TCCCTATTGTTGATATTGCGAACTACGCACAGAGATTCAA GGGCAGAGTCACGATTACCGCGGACGAATCCACTAGTAC AACTTACATGGAGTTGAGCAGCCTGAGGTCTGAGGACAC GGCCGTGTATTACTGTGCGAGCACACTTGGTCTCGTCCT GGATGCTATGGACTACTGGGGTCAGGGTACGTTAGTGAC GGTCTCGAGTGCTTCCACCAAGGGCCCATCCGTCTTCCC CCTGGCGCCCTGCTCCAGGAGCACCTCCGAGAGCACAG CCGCCCTGGGCTGCCTGGTCAAGGACTACTTCCCCGAAC CGGTGACGGTGTCTGTGGAACCTCAGGCGCCCTGACCAGC GGCGTGACACCTTCCCGGCTGTCTACAGTCCTCAGGA CTCTACTCCCTCAGCAGCGTGGTGACCGTGCCCTCCAGC AGCTTGGGCACGAAGACCTACACCTGCAACGTAGATCAC AAGCCCAGCAACACCAAGGTCGACAAGAGAGTTGAGTCC AAATATGGTCCCCCATGCCACCATGCCAGCACCTGAG TTCCTGGGGGGGACCATCAGTCTTCTGTTCCCCCAAAA CCCAAGGACACTCTCATGATCTCCCGGACCCCTGAGGTC ACGTGCGTGGTGGTGGACGTGAGCCAGGAAGACCCCGA

	GGTCCAGTTCAACTGGTACGTGGATGGCGTGGAGGTGCA TAATGCCAAGACAAAGCCGCGGGAGGAGCAGTTCAACAG CACGTACCGTGTGGTCAGCGTCCTCACCGTCCTGCACCA GGACTGGCTGAACGGCAAGGAGTACAAGTGCAAGGTCTC CAACAAAGGCCTCCCGTCCTCCATCGAGAAAACCATCTC CAAAGCCAAAGGGCAGCCCCGAGAGCCACAGGTGTACA CCCTGCCCCCATCCCAGGAGGAGATGACCAAGAACCAG GTCAGCCTGACCTGCCTGGTCAAAGGCTTCTACCCCAGC GACATCGCCGTGGAGTGGGAGAGCAATGGGCAGCCGGA GAACAACTACAAGACCACGCCTCCCGTGCTGGACTCCGA CGGCTCCTTCTTCTCTACAGCAGGCTAACCGTGGACAA GAGCAGGTGGCAGGAGGGGAATGTCTTCTCATGCTCCGT GATGCATGAGGCTCTGCACAACCACTACACACAGAAGAG CCTCTCCCTGTCTCTGGGGAAATGA
Nucleic acid sequence for mAb2 Heavy Chain with N-terminal D10 (D10-HC) (SEQ ID NO: 24)	GACGACGATGATGACGATGACGACGACGATCAGGTGCAG CTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTC CTCGGTGAAGGTCTCCTGCAAGGCTTCTGGATACACCTT CAGTAGCAATGTTATCAGCTGGGTGCGCCAGGCCCTGG ACAAGGGCTCGAGTGGATGGGGGGGGTTCATCCCTATTGT TGATATTGCGAACTACGCACAGAGATTCAAGGGCAGAGT CACGATTACCGCGGACGAATCCACTAGTACAACCTTACATG GAGTTGAGCAGCCTGAGGTCTGAGGACACGGCCGTGTAT TACTGTGCGAGCACACTTGGTCTCGTCCTGGATGCTATG GACTACTGGGGTCAGGGTACGTTAGTGACGGTCTCGAGT GCTTCCACCAAGGGGCCATCCGTCTTCCCCCTGGCGCCC TGCTCCAGGAGCACCTCCGAGAGCACAGCCGCCCTGGG CTGCCTGGTCAAGGACTACTTCCCCGAACCGGTGACGGT GTCGTGGAACCTCAGGCGCCCTGACCAGCGGCGTGCACA CCTTCCCGGCTGTCTTACAGTCCTCAGGACTCTACTCCCT CAGCAGCGTGGTGACCGTGCCCTCCAGCAGCTTGGGCA CGAAGACCTACACCTGCAACGTAGATCACAAGCCCAGCA ACACCAAGGTGACAAGAGAGTTGAGTCCAAATATGGTC CCCCATGCCACCATGCCCAGCACCTGAGTTCCTGGGGG GACCATCAGTCTTCTGTTCCTCCCCCAAAACCCAAGGACA CTCTCATGATCTCCCGGACCCCTGAGGTACAGTGCGTGG TGGTGGACGTGAGCCAGGAAGACCCCGAGGTCCAGTTC AACTGGTACGTGGATGGCGTGGAGGTGCATAATGCCAAG ACAAAGCCGCGGGAGGAGCAGTTCAACAGCACGTACCGT GTGGTCAGCGTCCTCACCGTCCTGCACCAGGACTGGCTG AACGGCAAGGAGTACAAGTGCAAGGTCTCCAACAAAGGC CTCCCGTCCTCCATCGAGAAAACCATCTCCAAAGCCAAA GGGCAGCCCCGAGAGCCACAGGTGTACACCCTGCCCCC ATCCCAGGAGGAGATGACCAAGAACCAGGTGAGCCTGAC CTGCCTGGTCAAAGGCTTCTACCCCAGCGACATCGCCGT GGAGTGGGAGAGCAATGGGCAGCCGGAGAACAACCTACA AGACCACGCCTCCCGTGCTGGACTCCGACGGCTCCTTCT TCCTCTACAGCAGGCTAACCGTGGACAAGAGCAGGTGGC AGGAGGGGAATGTCTTCTCATGCTCCGTGATGCATGAGG CTCTGCACAACCACTACACACAGAAGAGCCTCTCCCTGT CTCTGGGGAAATGA
Nucleic acid sequence	CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAA

for mAb2 Heavy Chain with C-terminal D10 (HC- D10) (SEQ ID NO: 25)	GCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTTCTGG ATACACCTTCAGTAGCAATGTTATCAGCTGGGTGCGCCA GGCCCCTGGACAAGGGCTCGAGTGGATGGGGGGGGTCA TCCCTATTGTTGATATTGCGAACTACGCACAGAGATTCAA GGGCAGAGTCACGATTACCGCGGACGAATCCACTAGTAC AACTTACATGGAGTTGAGCAGCCTGAGGTCTGAGGACAC GGCCGTGTATTACTGTGCGAGCACACTTGGTCTCGTCCT GGATGCTATGGACTACTGGGGTCAGGGTACGTTAGTGAC GGTCTCGAGTGCTTCCACCAAGGGCCCATCCGTCTTCCC CCTGGCGCCCTGCTCCAGGAGCACCTCCGAGAGCACAG CCGCCCTGGGCTGCCTGGTCAAGGACTACTTCCCCGAAC CGGTGACGGTGTCTGTGGAACCTCAGGCGCCCTGACCAGC GGCGTGACACACCTTCCCGGCTGTCTACAGTCCTCAGGA CTCTACTCCCTCAGCAGCGTGGTGACCGTGCCCTCCAGC AGCTTGGGCACGAAGACCTACACCTGCAACGTAGATCAC AAGCCCAGCAACACCAAGGTGACAAAGAGAGTTGAGTCC AAATATGGTCCCCCATGCCACCATGCCAGCACCTGAG TTCCTGGGGGGACCATCAGTCTTCTGTTCCCCCAAAA CCCAAGGACACTCTCATGATCTCCCGGACCCCTGAGGTC ACGTGCGTGGTGGTGGACGTGAGCCAGGAAGACCCCGA GGTCCAGTTCAACTGGTACGTGGATGGCGTGGAGGTGCA TAATGCCAAGACAAAGCCGCGGGAGGAGCAGTTCAACAG CACGTACCGTGTGGTCAGCGTCCTCACCGTCCTGCACCA GGACTGGCTGAACGGCAAGGAGTACAAGTGCAAGGTCTC CAACAAAGGCCTCCCGTCTCCATCGAGAAAACCATCTC CAAAGCCAAAGGGCAGCCCCGAGAGCCACAGGTGTACA CCCTGCCCCCATCCCAGGAGGAGATGACCAAGAACCAG GTCAGCCTGACCTGCCTGGTCAAAGGCTTCTACCCCAGC GACATCGCCGTGGAGTGGGAGAGCAATGGGCAGCCGGA GAACAACTACAAGACCACGCCTCCCGTGCTGGACTCCGA CGGCTCCTTCTTCTCTACAGCAGGCTAACCGTGGAACA GAGCAGGTGGCAGGAGGGGAATGTCTTCTCATGCTCCGT GATGCATGAGGCTCTGCACAACCACTACACACAGAAGAG CCTCTCCCTGTCTCTGGGGAAAGACGACGATGATGACGA TGACGACGACGATTGA
Nucleic acid sequence for mAb2 Heavy Chain with N-terminal D10 and C-termina (D10-HC-D10) (SEQ ID NO: 26)	GACGACGATGATGACGATGACGACGACGATCAGGTGCAG CTGGTGAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTG CTCGGTGAAGGTCTCCTGCAAGGCTTCTGGATACACCTT CAGTAGCAATGTTATCAGCTGGGTGCGCCAGGCCCTGG ACAAGGGCTCGAGTGGATGGGGGGGGTTCATCCCTATTGT TGATATTGCGAACTACGCACAGAGATTCAAGGGCAGAGT CACGATTACCGCGGACGAATCCACTAGTACAACCTACATG GAGTTGAGCAGCCTGAGGTCTGAGGACACGGCCGTGTAT TACTGTGCGAGCACACTTGGTCTCGTCCTGGATGCTATG GACTACTGGGGTCAGGGTACGTTAGTGACGGTCTCGAGT GCTTCCACCAAGGGCCCATCCGTCTTCCCCCTGGCGCCC TGCTCCAGGAGCACCTCCGAGAGCACAGCCGCCCTGGG CTGCCTGGTCAAGGACTACTTCCCCGAACCGGTGACGGT GTCGTGGAACCTCAGGCGCCCTGACCAGCGGCGTGCACA CCTTCCCGGCTGTCTTACAGTCCTCAGGACTCTACTCCCT CAGCAGCGTGGTGACCGTGCCCTCCAGCAGCTTGGGCA

	CGAAGACCTACACCTGCAACGTAGATCACAAGCCCAGCA ACACCAAGGTGACACAAGAGAGTTGAGTCCAAATATGGTC CCCCATGCCACCATGCCAGCACCTGAGTTCCTGGGGG GACCATCAGTCTTCCTGTTCCCCCAAAACCCAAGGACA CTCTCATGATCTCCCGGACCCCTGAGGTCACGTGCGTGG TGGTGGACGTGAGCCAGGAAGACCCCGAGGTCCAGTTC AACTGGTACGTGGATGGCGTGGAGGTGCATAATGCCAAG ACAAAGCCGCGGGAGGAGCAGTTCAACAGCACGTACCGT GTGGTCAGCGTCCTCACCCTCCTGCACCAGGACTGGCTG AACGGCAAGGAGTACAAGTGCAAGGTCTCCAACAAAGGC CTCCCGTCCCTCCATCGAGAAAACCATCTCCAAAGCCAAA GGGCAGCCCCGAGAGCCACAGGTGTACACCCTGCCCCC ATCCCAGGAGGAGATGACCAAGAACCAGGTGAGCCTGAC CTGCCTGGTCAAAGGCTTCTACCCCAGCGACATCGCCGT GGAGTGGGAGAGCAATGGGCAGCCGAGACAACACTACA AGACCACGCCTCCCGTGCTGGACTCCGACGGCTCCTTCT TCCTCTACAGCAGGCTAACCCTGGACAAGAGCAGGTGGC AGGAGGGGAATGTCTTCTCATGCTCCGTGATGCATGAGG CTCTGCACAACCACTACACACAGAAGAGCCTCTCCCTGT CTCTGGGGAAAGACGACGATGATGACGATGACGACGACG ATTGA
Nucleic acid sequence for mAb2 Light Chain WT (WT LC) (SEQ ID NO: 27)	GAAACGGTACTCACGCAGTCTCCAGGTACCCTGTCTTTGT CTCCAGGGGAAAGAGCCACCCTCTCCTGCAGGGCCAGT CAGAGTCTTGGCAGCAGCTACTTAGCCTGGTATCAGCAG AAACCTGGTCAGGCTCCCAGGCTCCTCATCTATGGTGCA TCCAGCAGGGCACCTGGCATCCCAGACAGGTTCAAGTGGC AGTGGGTCTGGTACCGACTTCACTCTCACCATCAGCCGA CTGGAGCCTGAAGATTTTGCAGTTTATTACTGTCAGCAGT ATGCTGACTCACCGATCACCTTCGGCCAAGGGACACGAC TGGAGATTAAACGTACGGTGGCTGCACCATCTGTCTTCAT CTTCCCGCCATCTGATGAGCAGTTGAAATCTGGAAGTGC CTCTGTTGTGTGCCTGCTGAATAACTTCTATCCCAGAGAG GCCAAAGTACAGTGGAAGGTGGATAACGCCCTCCAATCG GGTAACTCCCAGGAGAGTGTACAGAGCAGGACAGCAAG GACAGCACCTACAGCCTCAGCAGCACCCCTGACGCTGAGC AAAGCAGACTACGAGAAACACAAAGTCTACGCCTGCGAA GTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGC TTCAACAGGGGAGAGTGTTAG
Nucleic acid sequence for mAb2 Light Chain with N-terminal D10 (D10-LC) (SEQ ID NO: 28)	GACGACGATGATGACGATGACGACGACGATGAAACGGTA CTCACGCAGTCTCCAGGTACCCTGTCTTTGTCTCCAGGG GAAAGAGCCACCCTCTCCTGCAGGGCCAGTCAGAGTCTT GGCAGCAGCTACTTAGCCTGGTATCAGCAGAAACCTGGT CAGGCTCCCAGGCTCCTCATCTATGGTGCATCCAGCAGG GCACCTGGCATCCCAGACAGGTTCAAGTGGCAGTGGGTCT GGTACCGACTTCACTCTCACCATCAGCCGACTGGAGCCT GAAGATTTTGCAGTTTATTACTGTCAGCAGTATGCTGACT CACCGATCACCTTCGGCCAAGGGACACGACTGGAGATTA AACGTACGGTGGCTGCACCATCTGTCTTCATCTTCCCGC CATCTGATGAGCAGTTGAAATCTGGAAGTGCCTCTGTTGT GTGCCTGCTGAATAACTTCTATCCCAGAGAGGCCAAAGTA CAGTGGAAGGTGGATAACGCCCTCCAATCGGGTAACTCC

	CAGGAGAGTGTACAGAGCAGGACAGCAAGGACAGCAC CTACAGCCTCAGCAGCACCCCTGACGCTGAGCAAAGCAGA CTACGAGAAACACAAAGTCTACGCCTGCGAAGTCACCCA TCAGGGCCTGAGCTCGCCCGTCACAAAGAGCTTCAACAG GGGAGAGTGTTAG
Nucleic acid sequence for mAb2 Light Chain with C-terminal D10 (LC- D10) (SEQ ID NO: 29)	GAAACGGTACTCACGCAGTCTCCAGGTACCCTGTCTTTGT CTCCAGGGGAAAGAGCCACCCTCTCCTGCAGGGCCAGT CAGAGTCTTGGCAGCAGCTACTTAGCCTGGTATCAGCAG AAACCTGGTCAGGCTCCCAGGCTCCTCATCTATGGTGCA TCCAGCAGGGCACCTGGCATCCCAGACAGGTTCAAGTGGC AGTGGGTCTGGTACCGACTTCACTCTCACCATCAGCCGA CTGGAGCCTGAAGATTTTGCAGTTTATTACTGTCAGCAGT ATGCTGACTCACCGATCACCTTCGGCCAAGGGACACGAC TGGAGATTAAACGTACGGTGGCTGCACCATCTGTCTTCAT CTTCCCGCCATCTGATGAGCAGTTGAAATCTGGAAGTGC CTCTGTTGTGTGCCTGCTGAATAACTTCTATCCCAGAGAG GCCAAAGTACAGTGGAAGGTGGATAACGCCCTCCAATCG GGTAACTCCCAGGAGAGTGTACAGAGCAGGACAGCAAG GACAGCACCTACAGCCTCAGCAGCACCCCTGACGCTGAGC AAAGCAGACTACGAGAAACACAAAGTCTACGCCTGCGAA GTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGC TTCAACAGGGGAGAGTGTGACGACGATGATGACGATGAC GACGACGATTAG
Nucleic acid sequence for mAb2 Light Chain with N-terminal D10 and C-terminal D10 (D10-LC- D10) (SEQ ID NO: 30)	GACGACGATGATGACGATGACGACGACGATGAAACGGTA CTCACGCAGTCTCCAGGTACCCTGTCTTTGTCTCCAGGG GAAAGAGCCACCCTCTCCTGCAGGGCCAGTCAGAGTCTT GGCAGCAGCTACTTAGCCTGGTATCAGCAGAAACCTGGT CAGGCTCCCAGGCTCCTCATCTATGGTGCATCCAGCAGG GCACCTGGCATCCCAGACAGGTTCAAGTGGCAGTGGGTCT GGTACCGACTTCACTCTCACCATCAGCCGACTGGAGCCT GAAGATTTTGCAGTTTATTACTGTCAGCAGTATGCTGACT CACCGATCACCTTCGGCCAAGGGACACGACTGGAGATTA AACGTACGGTGGCTGCACCATCTGTCTTCATCTTCCCGC CATCTGATGAGCAGTTGAAATCTGGAAGTGCCTCTGTTGT GTGCCTGCTGAATAACTTCTATCCCAGAGAGGGCCAAAGTA CAGTGGAAGGTGGATAACGCCCTCCAATCGGGTAACTCC CAGGAGAGTGTACAGAGCAGGACAGCAAGGACAGCAC CTACAGCCTCAGCAGCACCCCTGACGCTGAGCAAAGCAGA CTACGAGAAACACAAAGTCTACGCCTGCGAAGTCACCCA TCAGGGCCTGAGCTCGCCCGTCACAAAGAGCTTCAACAG GGGAGAGTGTGACGACGATGATGACGATGACGACGACG ATTAG
Nucleic acid sequence for mAb2 Light Chain with 1X Linker and C- terminal D10 (LC-G4S-D10) (SEQ ID NO: 31)	GAAACGGTACTCACGCAGTCTCCAGGTACCCTGTCTTTGT CTCCAGGGGAAAGAGCCACCCTCTCCTGCAGGGCCAGT CAGAGTCTTGGCAGCAGCTACTTAGCCTGGTATCAGCAG AAACCTGGTCAGGCTCCCAGGCTCCTCATCTATGGTGCA TCCAGCAGGGCACCTGGCATCCCAGACAGGTTCAAGTGGC AGTGGGTCTGGTACCGACTTCACTCTCACCATCAGCCGA CTGGAGCCTGAAGATTTTGCAGTTTATTACTGTCAGCAGT ATGCTGACTCACCGATCACCTTCGGCCAAGGGACACGAC TGGAGATTAAACGTACGGTGGCTGCACCATCTGTCTTCAT

	CTTCCCGCCATCTGATGAGCAGTTGAAATCTGGAAGTGC CTCTGTTGTGTGCCTGCTGAATAACTTCTATCCCAGAGAG GCCAAAGTACAGTGGAAGGTGGATAACGCCCTCCAATCG GGTAACTCCCAGGAGAGTGTACAGAGCAGGACAGCAAG GACAGCACCTACAGCCTCAGCAGCACCTGACGCTGAGC AAAGCAGACTACGAGAAACACAAAGTCTACGCCTGCGAA GTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGC TTCAACAGGGGAGAGTGTGGCGGAGGCGGCAGCGACGA CGATGATGACGATGACGACGACGATTAG
Nucleic acid sequence for mAb2 Light Chain with 2X Linker and C- terminal D10 (LC-(G4S)2-D10) (SEQ ID NO: 32)	GAAACGGTACTCACGCAGTCTCCAGGTACCCTGTCTTTGT CTCCAGGGGAAAGAGCCACCCTCTCCTGCAGGGCCAGT CAGAGTCTTGGCAGCAGCTACTTAGCCTGGTATCAGCAG AAACCTGGTCAGGCTCCCAGGCTCCTCATCTATGGTGCA TCCAGCAGGGCACCTGGCATCCCAGACAGGTTCAAGTGGC AGTGGGTCTGGTACCGACTTCACTCTCACCATCAGCCGA CTGGAGCCTGAAGATTTTGCAGTTTATTACTGTCAGCAGT ATGCTGACTCACCGATCACCTTCGGCCAAGGGACACGAC TGGAGATTAAACGTACGGTGGCTGCACCATCTGTCTTCAT CTTCCCGCCATCTGATGAGCAGTTGAAATCTGGAAGTGC CTCTGTTGTGTGCCTGCTGAATAACTTCTATCCCAGAGAG GCCAAAGTACAGTGGAAGGTGGATAACGCCCTCCAATCG GGTAACTCCCAGGAGAGTGTACAGAGCAGGACAGCAAG GACAGCACCTACAGCCTCAGCAGCACCTGACGCTGAGC AAAGCAGACTACGAGAAACACAAAGTCTACGCCTGCGAA GTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGC TTCAACAGGGGAGAGTGTGGCGGAGGCGGCAGCGGCGG AGGCGGCAGCGACGACGATGATGACGATGACGACGACG ATTAG
mAb2 HCDR1 (SEQ ID NO: 33)	SNVIS
mAb2 HCDR2 (SEQ ID NO: 34)	GVIPIVDIANYAQRFKG
mAb2 HCDR3 (SEQ ID NO: 35)	TLGLVLDAMDY
mAb2 LCDR1 (SEQ ID NO: 36)	RASQSLGSSYLA
mAb2 LCDR2 (SEQ ID NO: 37)	GASSRAP
mAb2 LCDR3 (SEQ ID NO: 38)	QQYADSPIT
mAb2 HCVD (SEQ ID NO: 39)	QVQLVQSGAEVKKPGSSVKVSCKASGYTFSSNVISWVRQA PGQGLEWMGGVPIVDIANYAQRFKGRVTITADESTSTTYME LSSLRSEDYAVYYCASTLGLVLDAMDYWGQGTLVTVSS
mAb2 LCVD (SEQ ID NO: 40)	ETVLTQSPGTLTSLSPGERATLSCRASQSLGSSYLAHWYQQK PQAPRLLIYGASSRAPGIPDRFSGSGSGTDFTLTISRLEPED FAVYYCQQYADSPITFGQGTRLEIK

CLAIMS

1. An IgG₄ antibody that binds human TGFβ1, TGFβ2, and TGFβ3, wherein the heavy chain of the antibody comprises the amino acid sequence of SEQ ID NO: 14, and the light chain comprises the amino acid sequence of SEQ ID NO: 15.
2. An IgG₄ antibody that binds human TGFβ1, TGFβ2, and TGFβ3, wherein the heavy chain of the antibody comprises the amino acid sequence of SEQ ID NO: 17, and the light chain comprises the amino acid sequence of SEQ ID NO: 15.
3. A pharmaceutical composition comprising an antibody of claim 1 and a pharmaceutically acceptable excipient.
4. A pharmaceutical composition comprising an antibody of claim 2 and a pharmaceutically acceptable excipient.
5. A method of producing a bone-targeting pharmaceutical composition, comprising:

providing an antibody of claim 1, and

admixing the antibody with a pharmaceutically acceptable carrier.
6. A method of producing a bone-targeting pharmaceutical composition, comprising:

providing an antibody of claim 2, and

admixing the antibody with a pharmaceutically acceptable carrier.