BMP-6 Antibodies

The present invention relates to the field of medicine. More particularly, the present invention relates to antibodies, or antigen-binding fragments thereof, that bind human BMP-6 and may be useful for treating anemia of chronic disease (ACD), such as anemia of cancer, or anemia of chronic kidney disease (CKD).

BMP-6 is a member of the bone morphogenetic protein (BMP) family; there are more than twenty members in the BMP family. BMP family members are ligands that initiate signaling in the SMAD pathway leading to transcriptional modulation in the cell. BMP-6 knock-out mice are reported to be viable and fertile, and show normal bone and cartilage development, while knock-out mice for the closely related BMP-7 die after birth with kidney, eye, and bone defects. Individual knock-outs of either BMP-6 or BMP-7 have been shown to not alter cardiogenesis, but the double knock-out of BMP-6 and BMP-7 did demonstrate several defects and delays in the heart, and the embryos died due to cardiac insufficiency. The presence of BMP-7 has also been shown in mouse models to be important in preventing progression of chronic heart disease associated with fibrosis. Therefore, when inhibiting human BMP-6 with a BMP-6 antibody, cross-reactivity against BMP-7 is likely not desirable.

Certain chronic diseases, such as cancer, kidney disease, and autoimmune disorders, can lead to ACD when overactive inflammatory cytokines cause dysregulation of iron homeostasis, reduction of erythropoiesis, and a decrease in the life span of red blood cells. Hepcidin has been identified as a key hormone involved in iron homeostasis; high levels of hepcidin have been associated with the iron restricted erythropoiesis seen in ACD. BMP-6 has been shown to increase hepcidin expression.

WO 2010/056981 disclosed administration in mice of a mouse antibody generated to human BMP-6; a decrease in hepcidin and an increase in iron was reported at one time point after a three day regimen with this mouse antibody, MAB507, that was commercially available from R&D Systems. Selectivity towards BMPs was also disclosed, and it was shown that administration of the BMP-6 antibody MAB507 inhibited BMP-7 at certain doses. However, to date, no antibody targeting BMP-6 has been approved for therapeutic use.

There remains a need to provide alternative BMP-6 antibodies. In particular, there remains a need to provide potent BMP-6 antibodies that are selective for BMP-6 over other BMP family members, including BMP-7. There also remains a need to provide potent BMP-6 antibodies that are selective for BMP-6 over other BMP family members, including BMP-7, and produce a prolonged pharmacodynamic response. There also remains a need to provide potent BMP-6 antibodies that are selective for BMP-6 over other BMP family members, including BMP-7, for the treatment of ACD.

Accordingly, the present invention provides an antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising a light chain variable region (LCVR) and a heavy chain variable region (HCVR), wherein the LCVR comprises the complementarity determining regions (CDRs) LCDR1, LCDR2, and LCDR3, and the HCVR comprises the CDRs HCDR1, HCDR2, and HCDR3, wherein the LCDR1 is the polypeptide of RSSENIYRNLA (SEQ ID NO: 2), the LCDR2 is the polypeptide of AATNLAD (SEQ ID NO: 3), the LCDR3 is the polypeptide of QGIWGTPLT (SEQ ID NO: 4), the HCDR1 is the polypeptide of GYTFTSYAMH (SEQ ID NO: 5), the HCDR2 is the polypeptide of YINPYNDGTKYNENFKG (SEQ ID NO: 6) or YINPYNRGTKYNENFKG (SEQ ID NO: 7), and the HCDR3 is the polypeptide of RPFGNAMDI (SEQ ID NO: 8).

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising a light chain variable region (LCVR) and a heavy chain variable region (HCVR), wherein the LCVR comprises the complementarity determining regions (CDRs) LCDR1, LCDR2, and LCDR3, and the HCVR comprises the CDRs HCDR1, HCDR2, and HCDR3, wherein the LCDR1 is the polypeptide of RSSENIYRNLA (SEQ ID NO: 2), the LCDR2 is the polypeptide of AATNLAD (SEQ ID NO: 3), the LCDR3 is the polypeptide of QGIWGTPLT (SEQ ID NO: 4), the HCDR1 is the polypeptide of GYTFTSYAMH (SEQ ID NO: 5), the HCDR2 is the polypeptide of YINPYNDGTKYNENFKG (SEQ ID NO: 6), and the HCDR3 is the polypeptide of RPFGNAMDI (SEQ ID NO: 8).

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising a light chain variable region (LCVR) and a heavy chain variable region (HCVR), wherein the LCVR

comprises the complementarity determining regions (CDRs) LCDR1, LCDR2, and LCDR3, and the HCVR comprises the CDRs HCDR1, HCDR2, and HCDR3, wherein the LCDR1 is the polypeptide of RSSENIYRNLA (SEQ ID NO: 2), the LCDR2 is the polypeptide of AATNLAD (SEQ ID NO: 3), the LCDR3 is the polypeptide of QGIWGTPLT (SEQ ID NO: 4), the HCDR1 is the polypeptide of GYTFTSYAMH (SEQ ID NO: 5), the HCDR2 is the polypeptide of YINPYNRGTKYNENFKG (SEQ ID NO: 7), and the HCDR3 is the polypeptide of RPFGNAMDI (SEQ ID NO: 8).

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 10 or SEQ ID NO: 11. In a further embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 10. In another embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 11.

In an embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 10 or SEQ ID NO: 11. In a further embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 10. In another embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 11.

In an embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising a light chain (LC) and a heavy chain (HC), wherein the LC is the polypeptide of SEQ ID NO: 12, and the HC is the polypeptide of SEQ ID

NO: 13 or SEQ ID NO: 14. In a further embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising a LC and a HC, wherein the LC is the polypeptide of SEQ ID NO: 12, and the HC is the polypeptide of SEQ ID NO: 13. In another embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising a LC and a HC, wherein the LC is the polypeptide of SEQ ID NO: 12, and the HC is the polypeptide of SEQ ID NO: 14.

In an embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising two light chains and two heavy chains, wherein each light chain is the polypeptide of SEQ ID NO: 12, and each heavy chain is the polypeptide of SEQ ID NO: 13. In an embodiment, the present invention provides an antibody that binds to human BMP-6 (SEQ ID NO: 1), comprising two light chains and two heavy chains, wherein each light chain is the polypeptide of SEQ ID NO: 12, and each heavy chain is the polypeptide of SEQ ID NO: 14.

The present invention also relates to polynucleotides encoding the above-described antibodies, or antigen-binding fragments thereof, of the present invention that may be in the form of RNA or in the form of DNA, which DNA includes cDNA, and synthetic DNA. The DNA may be double-stranded or single-stranded. The coding sequences that encode the antibody, or antigen-binding fragment thereof, of the present invention may vary as a result of the redundancy or degeneracy of the genetic code.

In an embodiment, the present invention provides a DNA molecule comprising a polynucleotide sequence encoding a heavy chain polypeptide having the amino acid sequence of SEQ ID NO: 13 or the amino acid sequence of SEQ ID NO: 14. In an embodiment, the present invention provides a DNA molecule comprising a polynucleotide sequence encoding a light chain polypeptide having the amino acid sequence of SEQ ID NO: 12.

In an embodiment, the present invention provides a DNA molecule comprising a polynucleotide sequence encoding a heavy chain polypeptide having the amino acid sequence of SEQ ID NO: 13 and comprising a polynucleotide sequence encoding a light chain polypeptide having the amino acid sequence of SEQ ID NO: 12. In an embodiment, the present invention provides a DNA molecule comprising a polynucleotide sequence encoding a heavy chain polypeptide having the amino acid

sequence of SEQ ID NO: 14 and comprising a polynucleotide sequence encoding a light chain polypeptide having the amino acid sequence of SEQ ID NO: 12.

The polynucleotides of the present invention will be expressed in a host cell after the sequences have been operably linked to an expression control sequence. The expression vectors are typically replicable in the host organisms either as episomes or as an integral part of the host chromosomal DNA. Commonly, expression vectors will contain selection markers, e.g., tetracycline, neomycin, and dihydrofolate reductase, to permit detection of those cells transformed with the desired DNA sequences.

The antibody, or antigen-binding fragment thereof, of the present invention may readily be produced in mammalian cells such as CHO, NS0, HEK293 or COS cells; in bacterial cells such as *E. coli, Bacillus subtilis,* or *Pseudomonas fluorescence*; or in fungal or yeast cells. The host cells are cultured using techniques well known in the art.

The vectors containing the polynucleotide sequences of interest (e.g., the polypeptides of the antibody, or antigen-binding fragment thereof, and expression control sequences) can be transferred into the host cell by well-known methods, which vary depending on the type of cellular host. For example, calcium chloride transformation is commonly utilized for prokaryotic cells, whereas calcium phosphate treatment or electroporation may be used for other cellular hosts.

In an embodiment, the present invention provides a mammalian cell comprising a DNA molecule or molecules of the present invention, which cell is capable of expressing an antibody comprising a heavy chain having the amino acid sequence of SEQ ID NO: 13 and a light chain having the amino acid sequence of SEQ ID NO: 12. In an embodiment, the present invention provides a mammalian cell comprising DNA molecules of the present invention, which cell is capable of expressing an antibody comprising a heavy chain having the amino acid sequence of SEQ ID NO: 14 and a light chain having the amino acid sequence of SEQ ID NO: 12.

In an embodiment, the present invention provides a process for producing an antibody of the present invention comprising a heavy chain whose amino acid sequence is SEQ ID NO: 13 and a light chain whose amino acid sequence is SEQ ID NO: 12, comprising cultivating a mammalian cell of the present invention under conditions such that the antibody is expressed, and recovering the expressed antibody. In an embodiment,

the present invention provides a process for producing an antibody of the present invention comprising a heavy chain whose amino acid sequence is SEQ ID NO: 14 and a light chain whose amino acid sequence is SEQ ID NO: 12, comprising cultivating a mammalian cell of the present invention under conditions such that the antibody is expressed, and recovering the expressed antibody. In a further embodiment, the present invention provides an antibody produced by a process of the present invention.

In an embodiment, the present invention provides pharmaceutical compositions comprising an antibody, or antigen-binding fragment thereof, of the present invention, and an acceptable carrier, diluent, or excipient. More particularly, the compositions of the present invention further comprise one or more additional therapeutic agents.

In an embodiment, the present invention provides a method of treating anemia, comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In a further embodiment, the present invention provides a method of treating anemia, comprising administering an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention, wherein the anemia is anemia of chronic disease. In another embodiment, the present invention provides a method of treating anemia, comprising administering an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention, wherein the anemia of chronic disease is selected from the group consisting of anemia of cancer, and anemia of chronic kidney disease.

In an embodiment, the present invention provides a method of treating hepcidin related iron restricted anemia, comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In a further embodiment, the present invention provides a method of treating hepcidin related iron restricted anemia, comprising administering an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention, wherein the hepcidin related iron restricted anemia is selected from the group consisting of anemia of cancer, and anemia of chronic kidney disease.

In an embodiment, the present invention provides a method of treating iron refractory iron deficiency anemia (IRIDA), comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the

present invention. In a further embodiment, the present invention provides a method of treating IRIDA, comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention, wherein IRIDA is caused by a defect in the TMPRSS6 gene.

In an embodiment, the present invention provides a method of treating Sjogren's syndrome, comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention.

In an embodiment, the present invention provides a method of increasing serum iron levels, reticulocyte count, red blood cell count, hemoglobin, and/or hematocrit, comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In another embodiment, the present invention provides a method of increasing serum iron levels comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In another embodiment, the present invention provides a method of increasing reticulocyte count comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In another embodiment, the present invention provides a method of increasing red blood cell count comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In another embodiment, the present invention provides a method of increasing hemoglobin comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention. In another embodiment, the present invention provides a method of increasing hematocrit comprising administering to a patient in need thereof, an effective amount of an antibody, or antigen-binding fragment thereof, of the present invention.

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in therapy. In a further embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of anemia. In another embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of anemia of chronic disease. In another embodiment,

the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of anemia of cancer or anemia of chronic kidney disease.

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of hepcidin related iron restricted anemia. In another embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of hepcidin related iron restricted anemia of cancer. In another embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of hepcidin related iron restricted anemia of chronic kidney disease.

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of IRIDA. In a further embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of IRIDA, wherein IRIDA is caused by a defect in the TMPRSS6 gene.

In an embodiment, the present invention provides an antibody, or antigen-binding fragment thereof, of the present invention for use in the treatment of Sjogren's syndrome.

In an embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament. In a further embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of anemia. In another embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of anemia of chronic disease. In another embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of anemia of chronic kidney disease. In another embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of anemia of cancer.

In an embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of IRIDA. In a further embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of IRIDA, wherein IRIDA is caused by a defect in the TMPRSS6 gene.

In an embodiment, the present invention provides the use of an antibody, or antigen-binding fragment thereof, of the present invention for the manufacture of a medicament for the treatment of Sjogren's syndrome.

The general structure of an "antibody" is very well-known in the art. For an antibody of the IgG type, there are four amino acid chains (two "heavy" chains and two "light" chains) that are cross-linked via intra- and inter-chain disulfide bonds. For an antibody, one of the heavy chains forms an inter-chain disulfide bond with one of the light chains, and the other heavy chain forms an inter-chain disulfide bond with the other light chain, and one of the heavy chains forms two inter-chain disulfide bonds with the other heavy chain. An antigen-binding fragment is a fragment of an antibody, such as a Fab, Fab', $F(ab')_2$, single-chain variable fragment (scFv), or di-scFv.

When expressed in certain biological systems, antibodies having human Fc sequences which are glycosylated in the Fc region. Antibodies may be glycosylated at other positions as well. One of skill in the art will appreciate that antibodies of the present invention may contain such glycosylation. Typically, glycosylation occurs in the Fc region of the antibody at a highly conserved N-glycosylation site. N-glycans typically attach to asparagines. Asparagine 295, by sequential numbering, is predicted to be a glycosylation site for antibodies of the present invention.

An antibody of the present invention is an engineered antibody that has been designed to have frameworks, hinge regions, and constant regions of human origin that are identical with or substantially identical with frameworks and constant regions derived from human genomic sequences. Fully human frameworks, hinge regions, and constant regions are those human germline sequences as well as sequences with naturally-occurring somatic mutations and/or those with engineered mutations. An antibody of the present invention may comprise framework, hinge, or constant regions derived from a

fully human framework, hinge, or constant region containing one or more amino acid substitutions, deletions, or additions therein. Further, an antibody of the present invention is substantially non-immunogenic in humans.

Antibody I comprises two light chains and two heavy chains, wherein each of the light chains consists of the polypeptide of SEQ ID NO: 12 and each of the heavy chains consists of the polypeptide of SEQ ID NO: 13. Antibody II comprises two light chains and two heavy chains, wherein each of the light chains consists of the polypeptide of SEQ ID NO: 12 and each of the heavy chains consists of the polypeptide of SEQ ID NO: 14. A particular DNA molecule encoding each of the heavy chains of Antibody I is SEQ ID NO: 16, and a particular DNA molecule encoding each of the light chains of Antibody I is SEQ ID NO: 15. A particular DNA molecule encoding each of the heavy chains of Antibody II is SEQ ID NO: 17, and a particular DNA molecule encoding each of the light chains of Antibody II is SEQ ID NO: 15.

An antibody, or antigen-binding fragment thereof, of the present invention can be produced using techniques well known in the art, e.g., recombinant technologies, phage display technologies, synthetic technologies, or combinations of such technologies or other technologies readily known in the art. Methods for producing and purifying antibodies are well known in the art and can be found, for example, in Harlow and Lane (1988) *Antibodies, A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, chapters 5-8 and 15, ISBN 0-87969-314-2.

Anemia of CKD is anemia that is an early and common complication in patients suffering with CKD. Anemia of cancer is anemia caused by hematological malignancies and some solid tumors; whereas, chemotherapy-induced anemia is anemia caused by the treatment of cancer patients with chemotherapeutic agents. Anemia in CKD exacerbates diabetic neuropathy, cardiovascular disease, and retinopathy, among other conditions. Cancer-related anemia is associated with an increased relative risk of death. Current treatment options for cancer-related anemia are limited to blood transfusions, as erythropoiesis-stimulating agents are only indicated for chemotherapy-induced anemia.

"Binds" as used herein in reference to the affinity of a BMP-6 antibody, or antigen-binding fragment thereof, for human BMP-6, is intended to mean, unless indicated otherwise, a K_D of less than about 1×10^{-8} M, preferably, less than about $1 \times 10^{-}$

^{9} M as determined by common methods known in the art, including by use of a surface plasmon resonance (SPR) biosensor at 37°C essentially as described herein. The term "selective" used herein in reference to an antibody of the present invention refers to an antibody that binds human BMP-6 with a K_D about 1000-, 500-, 200-, 100-, 50-, 10-, or about 5-fold lower than the antibody binds at least one member of the BMP family, including, but not limited to, human BMP-5 or human BMP-7, as measured by surface plasmon resonance at 37°C. Additionally, or alternatively, a BMP-6 selective antibody, or antigen-binding fragment thereof, of the present invention binds human BMP-6 but does not bind or only minimally binds to at least one member of the human BMP family, including, but not limited to human BMP-5 or human BMP-7, when assayed by the methods described in Examples 2 – 3 herein below.

"Effective amount" means the amount of an antibody of the present invention or pharmaceutical composition comprising an antibody of the present invention that will elicit the biological or medical response of or desired therapeutic effect on a tissue, system, animal, mammal or human that is being sought by the researcher, medical doctor, or other clinician. An effective amount of the antibody may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the antibody to elicit a desired response in the individual. An effective amount is also one in which any toxic or detrimental effect of the antibody is outweighed by the therapeutically beneficial effects.

The terms "treatment," "treat," "treating," and the like, are meant to include slowing or reversing the progression of a disorder. These terms also include alleviating, ameliorating, attenuating, eliminating, or reducing one or more symptoms of a disorder or condition, even if the disorder or condition is not actually eliminated and even if progression of the disorder or condition is not itself slowed or reversed. A patient refers to a mammal, preferably a human with a disease, disorder or condition that would benefit from inhibition of BMP-6 activity.

An antibody, or antigen-binding fragment thereof, of the present invention, or pharmaceutical composition comprising the same, may be administered by parenteral routes (e.g., subcutaneous, intravenous, intraperitoneal, intramuscular, or transdermal). An antibody, or antigen-binding fragment thereof, of the present invention may be

administered to a patient alone or in combination with a pharmaceutically acceptable carrier and/or diluent in single or multiple doses. Pharmaceutical compositions of the present invention can be prepared by methods well known in the art (e.g., *Remington: The Science and Practice of Pharmacy*, 19th ed. (1995), A. Gennaro et al., Mack Publishing Co.) and comprise an antibody, as disclosed herein, and one or more pharmaceutically acceptable carriers, diluents, or excipients.

Example 1: Antibody expression and purification

The polypeptides of the variable regions of the heavy chain and light chain, the complete heavy chain and light chain amino acid sequences of Antibody I and II, and the nucleotide sequences encoding the same, are listed below in the section entitled "Amino Acid and Nucleotide Sequences." In addition, the light chain and heavy chain CDR polypeptides are shown in Table 1.

The antibodies, or antigen-binding fragments thereof, of the present invention, including, but not limited to, Antibodies I and II, can be made and purified essentially as follows. An appropriate host cell, such as HEK 293 EBNA or CHO, can be either transiently or stably transfected with an expression system for secreting antibodies using an optimal predetermined HC:LC vector ratio or a single vector system encoding both HC and LC. Clarified media, into which the antibody has been secreted, may be purified using any of many commonly-used techniques. For example, the medium may be conveniently applied to a MabSelect column (GE Healthcare), or KappaSelect column (GE Healthcare) for Fab fragment, that has been equilibrated with a compatible buffer, such as phosphate buffered saline (pH 7.4). The column may be washed to remove nonspecific binding components. The bound antibody may be eluted, for example, by pH gradient (such as 20 mM Tris buffer pH 7 to 10 mM sodium citrate buffer pH 3.0, or phosphate buffered saline pH 7.4 to 100 mM glycine buffer pH 3.0). Antibody fractions may be detected, such as by SDS-PAGE, and then may be pooled. Further purification is optional, depending on the intended use. The antibody may be concentrated and/or sterile filtered using common techniques. Soluble aggregate and multimers may be effectively removed by common techniques, including size exclusion, hydrophobic interaction, ion exchange, multimodal, or hydroxyapatite chromatography. The purity of the antibody

after these chromatography steps is greater than 95%. The product may be immediately frozen at -70°C or may be lyophilized.

Table 1: SEQ ID NOs

Antibody	Light Chain	Heavy Chain	LCVR	HCVR
I	12	13	9	10
II	12	14	9	11

Antibody	LCDR1	LCDR2	LCDR3
I	RSSENIYRNLA (SEQ ID NO: 2)	AATNLAD (SEQ ID NO: 3)	QGIWGTPLT (SEQ ID NO: 4)
II	RSSENIYRNLA (SEQ ID NO: 2)	AATNLAD (SEQ ID NO: 3)	QGIWGTPLT (SEQ ID NO: 4)

Antibody	HCDR1	HCDR2	HCDR3
I	GYTFTSYAMH (SEQ ID NO: 5)	YINPYNDGTKYNENFKG (SEQ ID NO: 6)	RPFGNAMDI (SEQ ID NO: 8)
II	GYTFTSYAMH (SEQ ID NO: 5)	YINPYNRGTKYNENFKG (SEQ ID NO: 7)	RPFGNAMDI (SEQ ID NO: 8)

Example 2: Binding kinetics, affinity, and specificity of anti-BMP6 antibodies

The binding kinetics, affinity, and selectivity to human BMP-6, as well as human BMP-5 and human BMP-7, for antibodies, or antigen-binding fragments thereof, of the present invention, may be determined by use of a surface plasmon resonance (SPR) biosensor such as a BIAcore® 2000, BIAcore® 3000, or a BIAcore® T100 (GE HealthCare) according to methods known in the art.

Human BMP-5, human BMP-6, human BMP-7, and MAB507 may be purchased from R&D Systems (Minneapolis, MN). MAB507 is a commercial antibody that is purported to be specific for BMP-6. Cynomolgus monkey BMP-6 and rat BMP-6 may be made using standard procedures. Immobilization of ligands on a CM4 chip (BIAcore # BR-1005-34) may be prepared using EDC/NHS amine coupling method (BIAcore # BR-1000-50). Briefly, the surfaces of all four flow cells may be activated by injecting a 1:1 mixture of EDC/NHS for 7 minutes at 10 µL/minute. Human BMP-5, BMP -6, and BMP -7 may be diluted to 1-2 µg/mL in 10 mM acetate buffer, pH 4.5, and immobilized for approximately 200 resonance units (RU) onto flow cell (Fc) 2, 3 or 4 at a flow rate of 10 µL/minute. Fc1 may be left blank. Un-reacted sites may be blocked with a 7 minute injection of ethanolamine at 10 µL/minute. Injections of 3 x 30 sec of glycine pH 1.5 at 30 µL/minute may be used to remove any non-covalently associated protein. All measurements may be performed at 25 and 37°C. Running buffer may be HBS-EP+ (BIAcore # BR-1006-69). BIAcore T100 Evaluation Software Version 2.0.3 may be used for the analysis.

To determine specificity of Antibody I and MAB 507 between different BMP family members, the antibodies may be prepared at final concentration of 1000, 100, 10, 1, 0.1, 0.01, 0.001, and 0 (blank) nM into the running buffer HBS-EP+. Each cycle may consist of an injection of diluted antibody at 50 µL/minute for 300 seconds over all flow cells, followed by dissociation at 50 µL/minute for 1200 seconds. The chip surface may be regenerated by injecting 10 mM glycine pH 1.5 for 60 seconds at 50 µL/minute and HBS-EP buffer for 30 seconds at 30 µL/minute. Reference-subtracted data may be collected, and the on-rate (k_{on}) and off-rate (k_{off}) for each ligand may be evaluated using a 1:1 binding model in the BIAevaluation analysis software. The affinity (K_D) may be calculated from the binding kinetics according to the relationship $K_D = k_{off}/k_{on}$.

In experiments performed essentially as described in this Example 2, Antibody I binds to human BMP-6 with 0.020 nM affinity. With no detectable binding to human BMP-5 and human BMP-7 at 37°C, Antibody I shows selectivity over the two members of the BMP family that are closest in sequence homology to BMP-6.

The R&D antibody MAB507 binds human BMP-6 with 1 nM affinity, and unlike Antibody I, MAB507 has an affinity of 23 nM towards human BMP-7 (Table 2). MAB507 has no detectable binding to human BMP-5 at 37°C (Table 2).

Fabs of Antibody I and Antibody II bind to human BMP-6 with similar affinities ranging from 0.08 – 0.09 nM at 37°C (Table 3). The Fab of MAB507, Fab507, binds to human BMP-6 with an affinity of 12.2 nM at 37°C (Table 3).

Antibody I and II Fabs exhibit a 135-150-fold higher affinity toward human BMP-6 than the Fab of MAB507. Antibody I exhibits a 50-fold higher affinity to human BMP-6 when comparing to MAB507.

The Fab of Antibody I binds to human, cynomolgus monkey, and rat BMP-6 with similar affinities ranging from 79.6 to 88.0 pM at 37°C (Table 4). The high affinity of Antibody I toward cynomolgus monkey BMP-6 and rat BMP-6 allows Antibody I to be used directly in cynomolgus monkey and rat animal models without the need to resort to a surrogate antibody.

Table 2: Selectivity of Antibody I and MAB507 Measured by Using SPR

mAb	Ligands	On Rate (K_{on}, $M^{-1}S^{-1}$)	Off Rate (K_{off}, S^{-1})	Affinity (K_D, nM)	Temperature (°C)
Antibody I	Human BMP-5	No binding			37
	Human BMP-6	1.73×10^{6}	4.05×10^{-5}	0.02	
	Human BMP-7	No binding			
MAB507	Human BMP-5	No binding			37
	Human BMP-6	1.87×10^{5}	1.87×10^{-4}	1	
	Human BMP-7	3.42×10^{4}	7.93×10^{-4}	23.2	

Table 3: Binding Kinetics and Affinity of BMP6 Antibodies to Human BMP-6 Measured by Using SPR

Fab	On Rate (K_{on}, $M^{-1}S^{-1}$)	Off Rate (K_{off}, S^{-1})	Affinity (K_D, nM)	Temperature (°C)
Fab of Antibody I	$2.5\pm0.1 \times 10^{6}$	$2.3\pm0.1 \times 10^{-4}$	0.09 ± 0.01	37
Fab of Antibody II	$3.0\pm0.4 \times 10^{6}$	$2.5\pm0.1 \times 10^{-4}$	0.08 ± 0.01	37
Fab507	$3.6\pm0.7 \times 10^{5}$	$4.3\pm0.1 \times 10^{-3}$	12.2 ± 2.0	37

Table 4: Binding Kinetics and Affinity of Antibody I to Human, Cynomolgus Monkey, and Rat BMP-6 Measured by Using SPR

Fab	BMP-6 Ligands	On Rate (K_{on}, $M^{-1}S^{-1}$) (±SD)	Off Rate (K_{off}, S^{-1}) (±SD)	Affinity (K_D, pM) (±SD)	Temperature (°C)
Fab of Antibody I	Human	$3.7\pm1.5 \times 10^6$	$2.8\pm0.3 \times 10^{-4}$	84.5 ± 24.9	37
	Cyno Monkey	$4.1\pm2.2 \times 10^6$	$2.8\pm0.5 \times 10^{-4}$	79.6 ± 29.9	
	Rat	$4.1\pm2.3 \times 10^6$	$3.0\pm0.7 \times 10^{-4}$	88.0 ± 33.1	

Example 3: Anti-BMP6 antibodies inhibit BMP-6 induction of hepcidin expression

The *in vitro* cell-based inhibition of human BMP-6 by an antibody, or antigen-binding fragment thereof, of the present invention may be measured in a cell-based assay where BMP-6 induces hepcidin expression. The *in vitro* cell-based assay may also be used to evaluate the selectivity of BMP-6 antibodies against induction of hepcidin by other BMPs, such as BMP-2, BMP-4, BMP-5, BMP-7, BMP-9, and BMP-10. In the aforementioned *in vitro* cell-based assay, the binding of BMP ligands to the BMP responsive elements on the hepcidin promoter induces luciferase reporter activity in HepProm_Luc cells. The assay is extremely sensitive, and as such is not appropriate for showing which BMP family members are involved in iron homeostasis. The assay is effective, although, for showing the selectivity of inhibitors against different BMP family members in a cell environment.

The HepProm_Luc cell line may be generated by stable transfection of Hep3B2.1-7 cells (ATCC, Manassas, VA, #HB-8064) with a luciferase reporter vector, containing a cloned hepcidin promoter DNA sequence (HepProm 0.3 + 1.0kb). HepProm_Luc cells may be maintained in complete medium of DMEM/high glucose (Hyclone, Logan, UT, #SH30243.01) plus 5% heat inactivated FBS (Invitrogen, Grand Island, NY, #10082-147) with 1X MEM NEAA (Invitrogen, Carlsbad, CA) and 200 µg/ml G418 Sulfate (Invitrogen, Grand Island, NY, #30-234-CI).

For the assay, HepProm_Luc cells may be resuspended to 150,000 cells/mL in complete medium containing no antibiotic. 0.1 mL of the resuspended HepProm_Luc cells may be added to 96-well microtiter plates (Corning, Lowell, MA, #3917) at 15,000 cells/well, and the cells may then be incubated for 24 hours at 37°C under 5% (v/v) CO_2.

The culture medium may then be removed and the cells starved in 80 µL of OptiMEM I (Invitrogen, Grand Island,NY, #31985) with 0.1% (w/v) BSA (Invitrogen, Grand Island, NY, #15260) for 5 hours at 37°C under 5% (v/v) CO_2.

10 µL of BMP6 antibodies (10X the final concentration) in OptiMEM I with 0.1% (w/v) BSA may be added to the cells for a final dosage range of 0.2 nM to 20 nM for BMP-6 induction; final dosage range of 7.8 nM to 1000 nM for BMP-5 and BMP-7 induction, and up to 1000 nM, single point dose for BMP-2, BMP-4, BMP-9 and BMP-10 induction. 10 µL of BMP ligand (10X final concentration) may then be added for a final concentration of BMP-2 (3.8nM), BMP-4 (3.8nM), BMP-5 (12.8nM), BMP-6 (3.4 nM), BMP-7 (3.2 nM), BMP-9 (0.8 nM) or BMP-10 (4.1nM) in each well; the cells may be incubated for 22-24 hours at 37°C under 5% (v/v) CO_2. The culture medium may be removed from the cells, and 50 µL of Glo Lysis Buffer (Promega, Madison, WI, #E2661) may be added to the cells and incubated at room temperature for 5 minutes after 2 minutes of shaking. 50 µL of Bright Glo™ Luciferase Reagent (Promega, Madison,WI, #E2620) may then be added to the cells and incubated at room temperature for 5 minutes after 30 seconds of shaking. Luminescence may be measured for 1sec/well on a Wallac Victor instrument.

For calculating the percentage of inhibition by the BMP-6 antibody, 0% inhibition may be set at the average luminescence for BMP ligand treatment without BMP-6 antibody addition, and 100% inhibition may be set at the average luminescence of no BMP ligand treatment without BMP-6 antibody addition. Three or four parameter curve fit analysis may be performed using GraphPad Prism software (San Diego, CA).

In experiments performed essentially as described in this Example 3, Antibodies I and II potently inhibit BMP-6-induced hepcidin promoter luciferase activity of HepProm_Luc cells (Table 5); this inhibition is approximately 22-fold more potent than MAB507.

The data in Table 6 shows that Antibodies I and II do not inhibit BMP-2, BMP-4, BMP-5, BMP-7, BMP-9 and BMP-10 induction of hepcidin promoter luciferase activity significantly when tested at a single point concentration of 1000 nM compared to human IgGPAA4 control. Antibodies I and II in this assay show selectivity over the panel of BMPs tested. MAB507, however, does not show selectivity for BMP-6, and has a mean

of 54.2% inhibition at 1000 nM (N=2) against BMP-7 compared to human IgGPAA4 control which has a mean of -1.7% inhibition at 1000 nM (N=6).

Table 5: IC_{50} of BMP-6 antibodies in BMP-6 induced Hep_Luc Assay

Antibody	N	Geometric Mean IC50 (nM)
I	5	0.99
II	4	0.94
MAB507	5	22.08

Table 6: Selectivity of BMP-6 antibodies tested at 1000 nM in BMP-2, BMP-4, BMP-5, BMP-7, BMP-9, BMP-10 induced Hep_Luc Assay

BMP ligand	Antibody	N	Mean% Inh at 1000nM	Stdev
BMP2	I	4	8.5	14.1
	II	3	6.6	5.1
	MAB507	3	-50.6	40.5
	Control	6	7.8	10.5
BMP4	I	4	0.3	9.0
	II	3	-2.8	6.9
	MAB507	3	-65.4	52.7
	Control	6	4.2	7.9
BMP5	I	4	3.9	8.8
	II	3	1.9	9.3
	MAB507	3	-43.5	34.8
	Control	5	2.5	6.7
BMP7	I	4	-12.0	28.1
	II	3	-8.2	18.0
	MAB507	2	54.2	0.8
	Control	6	-1.7	11.5
BMP9	I	4	-1.7	5.5
	II	3	-2.7	6.6
	MAB507	3	-76.1	47.8
	Control	6	2.8	8.7
BMP10	I	4	-6.7	6.9
	II	3	0.9	10.8
	MAB507	3	-87.2	80.1
	Control	6	5.4	9.4

Example 4: Pharmacokinetic/Pharmacodynamic Studies of BMP-6 Antibodies Following a Single Intravenous Dose to Male Cynomolgus Monkeys

The serum pharmacokinetics/pharmacodynamics (PK/PD) of an antibody, or antigen-binding fragment thereof, of the present invention may be tested following single intravenous doses to normal male cynomolgus monkeys. Male cynomolgus monkeys may be injected with a single intravenous (IV) bolus dose of antibody in a dose volume of 1 mL/kg. From serum samples taken at different time points, the serum iron concentration, the BMP-6 antibody level, and hepcidin level may be measured.

For pharmacokinetics, serum hepcidin, and BMP-6 quantification, approximately 1.5 mL blood may be collected at time points from each animal in tubes without anticoagulant. The samples may be allowed to clot under ambient conditions prior to centrifugation to obtain serum; samples may be maintained on wet ice prior to storage at approximately -70°C. For clinical pathology analysis, approximately 0.5 mL blood may be collected at time points from each animal via a femoral vein into tubes containing no anticoagulant. The blood may be used to measure serum iron, unsaturated iron binding capacity, total iron binding capacity, percent iron saturation, and standard hematology measurements using standard methods. Hepcidin concentration may be measured as described in Murphy et al., Blood, 110(3):1048 (2007).

Serum samples may be analyzed for concentrations of BMP-6 antibody using a total human IgG ELISA. BMP-6 antibody in serum may be bound to anti-human kappa light chain antibody coated wells of a 96 well microtiter plate (Nunc Immobilizer Amino Cat. #436006) and detected with anti-human IgG4-HRP conjugate antibody (Southern Biotech, #9200-05). The upper and lower limits of detection in the assay may be 200 and 10 ng/mL, respectively. The concentration of immunoreactive BMP-6 antibody may be determined from standard curves prepared from known amounts of the compound in rat serum using a 4/5-parameter algorithm (StatLIA, version 3.2). Pharmacokinetic parameters may be calculated using Watson (Version 7.4 Bioanalytical LIMS) software package (Thermo Scientific). The parameters calculated may include the area under the curve ($AUC_{0-\infty}$), apparent clearance (Cl), and elimination half-life.

In an experiment performed essentially as described in this Example 4, Study I has doses of 0.3, 1.0, 3.0, and 10 mg/kg of Antibody I administered as a single intravenous bolus. Control human IgG4 is dosed at 10 mg/kg. The vehicle in Study I is phosphate buffered-saline (pH 7.4). Data for the pharmacokinetics, serum iron and serum hepcidin responses after administration of Antibody I are measured from each animal pre-dose (day -1) and at 1, 6, 12, 24, 48, 72, 120, 168, 240, 336, 432, 528, and 672 hours post-dose and on study days 36, 43, 50, and 57 for pharmacokinetics, serum hepcidin, and BMP-6 quantification.

In an experiment performed essentially as described in this Example 4, Study II has doses of 0.05, 0.3, and 3.0 mg/kg of Antibody I administered as a single intravenous bolus. Control human IgG4 was dosed at 3 mg/kg. The vehicle in Study II is phosphate buffered-saline (pH 7.4) plus 0.02% Tween80. Data for the pharmacokinetics, serum iron and serum hepcidin responses after administration of Antibody I are measured from each animal pre-dose (day -1) and at 1, 6, 12, 24, 48, 72, 120, 168, 240, 336, 432, 528, 672, 840, 1008, 1176, 1344, 1512, 1680, and 1848 hours post-dose.

In Studies I and II, the maximal serum concentrations (C_{max}) of Antibody I increases in an approximately dose proportional fashion over the 0.05- to 10-mg/kg examined. Over the dose range examined, Antibody I displays nonlinear pharmacokinetics with clearance decreasing and elimination half-life increasing with increasing dose. The clearance decreases from ~0.57 to ~0.17 mL/hr/kg over the dose range examined. Over the time frame and dose range studied, the half-life ranges from ~58 to ~295 hours.

Pharmacodynamic data in Tables 8 and 9 show that administration of Antibody I is associated with an initial immediate increase in serum iron that peaks at 24 hours before returning to near-baseline (pre-dose) levels at 120-240 hours after dosing. In the 3 and 10 mg/kg dose groups, serum iron elevates again after 240 hours in a more dose-dependent fashion; prolonged serum iron elevation to the end of the study is observed.

Antibody I administration is also associated with an acute decrease in cynomolgus serum hepcidin that occurs as early as 6 to 12 hours post dose. Serum hepcidin returns to baseline in a dose dependent fashion in Study II, but this dose dependency of hepcidin return to baseline is not as apparent in Study I. The human IgG4 control antibody in

Study I shows a decrease in serum hepcidin that is not replicated in Study II. Both studies also show significant changes in serum iron levels in the presence of Antibody I that does not correlate with low observed serum hepcidin levels.

Table 8: Study I

	Mean serum iron concentrations, ug/dL (2 subjects)									
Sample	**Control**		**Antibody I**							
Dose	10 mg/kg		0.3 mg/kg		1.0 mg/kg		3.0 mg/kg		10 mg/kg	
	µg/dL	SD	µg/dL	SD	µg/dL	SD	µg/dL	SD	µg/dL	SD
Time, h										
0	103	15.6	119.5	16.3	93	8.5	126	26.9	112	12.7
1	97	0	130	9.9	86.5	10.6	110	8.5	114.5	7.8
6	81	15.6	111.5	21.9	87	14.1	96.5	2.1	95.5	20.5
12	135.5	6.4	189.5	19.1	176	45.3	217	49.5	181.5	20.5
24	70.5	10.6	290	2.8	221	83.4	296	52.3	230.5	62.9
48	87	2.8	257	49.5	200	62.2	266	12.7	257.5	14.8
72	77	14.1	153.5	19.1	120.5	47.4	156	33.9	207	73.5
120	61.5	12	118.5	10.6	118	36.8	133.5	31.8	142	9.9
168	75.5	7.8	155	22.6	80	11.3	206.5	3.5	200	45.3
240	67	15.6	123.5	12	103	35.4	155	43.8	137.5	0.7
336	65.5	0.7	133.5	26.2	102.5	17.7	168.5	20.5	222	41
432	58	1.4	141.5	16.3	104.5	23.3	224	52.3	204.5	29
528	62.5	3.5	163.5	21.9	145	14.1	265	22.6	239.5	12
672	83.5	6.4	110.5	3.5	99.5	31.8	184	39.6	193.5	24.7
864	82	12.7	115	12.7	92	5.7	193.5	37.5	187	17
1032	75	9.9	99	32.5	75	2.8	136	1.4	173.5	48.8
1200	84	7.1	114	18.4	84.5	9.2	179.5	6.4	185	14.1
1368	86	7.1	117	1.4	76	11.3	158.5	4.9	198	18.4

Table 9: Study II

	Mean serum iron concentrations, ug/dL (3 subjects for Antibody I)							
Sample	**Control**		**Antibody I**					
Dose	3 mg/kg		0.05 mg/kg		0.3 mg/kg		3.0 mg/kg	
	µg/dL	SD	µg/dL	SD	µg/dL	SD	µg/dL	SD
Time, h								
0	120.5	3.5	137.7	30.5	149.3	23.4	96.3	10.7
1	119	28.3	152.3	34.8	121.3	31	95.3	13.6
6	91	14.1	134.7	13.3	115	32	79.7	14.6
12	121	5.7	193	37.4	201	37.3	147.3	7.6
24	128.5	2.1	276.3	27.5	305	45.6	283.7	7.5
48	118.5	9.2	182.7	52.2	275.7	54.4	263.3	32
72	85.5	0.7	165.7	56.5	192.7	36.1	163.7	45.3
120	81.5	3.5	149	61	168	32.8	153.3	13.9
168	96.5	9.2	138.7	38.6	189.3	22.6	143.3	10.1
240	108.5	20.5	105	31.5	140.3	16.7	146.7	19.4
336	119.5	4.9	111.3	35.4	170	24.6	159	80.3
432	96.5	4.9	179.3	40.5	249.7	24	235.7	47.4
528	83	28.3	109.3	30.4	152.7	32.6	176.3	60.1
672	151	15.6	125	27.9	118	21	184.7	25.1
840	106.5	37.5	134	44.8	114	20	161	8.5
1008	106.5	23.3	132	32.1	126	28.8	188.7	50.6
1176	117.5	0.7	133.7	35.2	125.3	20.6	199.3	69.5
1344	111	14.1	121.3	24.4	108.7	10.5	166.7	11.6
1512	139.5	3.5	137.3	40.1	118.7	13.1	121.7	11.8
1680	141	9.9	135.7	25.1	123.7	11.4	125.7	16.4
1848	142	11.3	141.3	43	132.7	14.6	107	19.3

Pharmacokinetic/Pharmacodynamic Studies of HuA507 Following a Single Intravenous Dose to Male Cynomolgus Monkeys

In an experiment performed essentially as described in this Example 4, the serum PK/PD of HuA507 is tested following a single intravenous dose to normal male cynomolgus monkeys. HuA507 is a chimeric antibody made by replacing the mouse constant regions of the MAB507 antibody from R&D Systems with a human IgG4PAA backbone. A single intravenous bolus 10 mg/kg dose of HuA507 antibody or control human IgG4 is given in a volume of 1 mL/kg. The vehicle in the study is phosphate buffered-saline (pH 7.4). Blood is collected from each animal pre-dose (Day 1) and at 1, 6, 12, 24, 48, 72, 96, 168, 264, 336, 432, 528, and 624 hours post-dose for analyses. With

the 10 mg/kg dose of HuA507 antibody, the mean serum iron concentration increases from approximately 150 μg/ml at pre-dose to approximately 210 μg/ml at 12 hours post-dose, but then falls back to baseline by 48 hours. Unlike the prolonged pharmacodynamic effect for Antibody I shown in this Example 4, treatment with HuA507 only shows a short, initial increase in serum iron concentration out to 48 hours, but not the prolonged response seen with Antibody I.

Example 5: Efficacy in rat ACD model

The efficacy of antibodies, or antigen-binding fragments thereof, of the present invention can be measured in a rat ACD model. In female Lewis rats, 8 to 10 weeks old, inflammation may be induced by one intraperitoneal dose of 5 mg/kg of gram-positive bacterial cell wall extract (Lee Labs, #PG-PS 10S) at day 0. Without any further treatment, reduced hemoglobin concentrations may be seen in this model within 10 days of treatment with the cell wall extract. Treatment with 10 mg/kg of an antibody of the present invention may be started with an IV dose at day 8 and continued weekly IV doses of the antibody. Hemoglobin, serum iron, and hepcidin concentrations may be measured and compared to the values seen with treatment by a HuIgG4 control.

For clinical pathology analysis, approximately 0.2 mL blood may be collected at time points from each animal via a tail clip into tubes containing EDTA. The blood may be used to measure serum iron, unsaturated iron binding capacity, total iron binding capacity, percent iron saturation, and standard hematology measurements using standard methods. For all other analysis, approximately 0.75 mL blood may be collected at time points from each animal via a tail clip into tubes containing no anti-coagulant.

In an experiment performed essentially as described in this Example 5, Antibody I shows a prolonged pharmacodynamic response with statistically significant higher hemoglobin and iron than the hIgG4 isotype control on most days to the end of the study at day 60. Compared to the control, the hemoglobin concentration increase is approximately 0.82-1.5 g/dL. Erythrocytes in the treated group become less microcytic and less hypochromic once Antibody I treatment is initiated. Based on the change in erythrocyte characteristics, the increase in hemoglobin observed in the study can be concluded to derive

from increased normalization of erythrocyte size and cellular hemoglobin level rather than increased production of red cells.

Amino Acid and Nucleotide Sequences

SEQ ID NO: 1 (human BMP-6)
PPPLRPPLPAAAAAAAGGQLLGDGGSPGRTEQPPPSPQSSSGFLYRRLKTQEKRE
MQKEILSVLGLPHRPRPLHGLQQPQPPALRQQEEQQQQQQLPRGEPPPGRLKSAP
LFMLDLYNALSADNDEDGASEGERQQSWPHEAASSSQRRQPPPGAAHPLNRKSL
LAPGSGSGGASPLTSAQDSAFLNDADMVMSFVNLVEYDKEFSPRQRHHKEFKFN
LSQIPEGEVVTAAEFRIYKDCVMGSFKNQTFLISIYQVLQEHQHRDSDLFLLDTRV
VWASEEGWLEFDITATSNLWVVTPQHNMGLQLSVVTRDGVHVHPRAAGLVGR
DGPYDKQPFMVAFFKVSEVHVRTTRSASSRRRQQSRNRSTQSQDVARVSSASDY
NSSELKTACRKHELYVSFQDLGWQDWIIAPKGYAANYCDGECSFPLNAHMNAT
NHAIVQTLVHLMNPEYVPKPCCAPTKLNAISVLYFDDNSNVILKKYRNMVVRAC
GCH

SEQ ID NO: 2 (LCDR1 – Antibody I and Antibody II)
RSSENIYRNLA

SEQ ID NO: 3 (LCDR2 - Antibody I and Antibody II)
AATNLAD

SEQ ID NO: 4 (LCDR3 - Antibody I and Antibody II)
QGIWGTPLT

SEQ ID NO: 5 (HCDR1 - Antibody I and Antibody II)
GYTFTSYAMH

SEQ ID NO: 6 (HCDR2 - Antibody I)
YINPYNDGTKYNENFKG

SEQ ID NO: 7 (HCDR2 – Antibody II)
YINPYNRGTKYNENFKG

SEQ ID NO: 8 (HCDR3 - Antibody I and Antibody II)
RPFGNAMDI

SEQ ID NO: 9 (LCVR - Antibody I and Antibody II)
DIQMTQSPSSLSASVGDRVTITCRSSENIYRNLAWYQQKPGKAPKLLIYAATNLA
DGVPSRFSGSGSGTDFTLTISSLQPEDFATYYCQGIWGTPLTFGGGTKVEIK

SEQ ID NO: 10 (HCVR - Antibody I)
QVQLVQSGAEVKKPGSSVKVSCKASGYTFTSYAMHWVRQAPGQGLEWMGYIN
PYNDGTKYNENFKGRVTITADESTSTAYMELSSLRSEDTAVYYCARRPFGNAMD
IWGQGTLVTVSS

SEQ ID NO: 11 (HCVR – Antibody II)

QVQLVQSGAEVKKPGSSVKVSCKASGYTFTSYAMHWVRQAPGQGLEWMGYIN
PYNRGTKYNENFKGRVTITADESTSTAYMELSSLRSEDTAVYYCARRPFGNAMDI
WGQGTLVTVSS

SEQ ID NO: 12 (LC - Antibody I and Antibody II)
DIQMTQSPSSLSASVGDRVTITCRSSENIYRNLAWYQQKPGKAPKLLIYAATNLA
DGVPSRFSGSGSGTDFTLTISSLQPEDFATYYCQGIWGTPLTFGGGTKVEIKRTVA
APSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQ
DSKDSTYSLSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGEC

SEQ ID NO: 13 (HC - Antibody I)
QVQLVQSGAEVKKPGSSVKVSCKASGYTFTSYAMHWVRQAPGQGLEWMGYIN
PYNDGTKYNENFKGRVTITADESTSTAYMELSSLRSEDTAVYYCARRPFGNAMD
IWGQGTLVTVSSASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTVSWNS
GALTSGVHTFPAVLQSSGLYSLSSVVTVPSSSLGTKTYTCNVDHKPSNTKVDKRV
ESKYGPPCPPCPAPEAAGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSQEDPEVQ
FNWYVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNK
GLPSSIEKTISKAKGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWE
SNGQPENNYKTTPPVLDSDGSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHY
TQKSLSLSLG

SEQ ID NO: 14 (HC - Antibody II)
QVQLVQSGAEVKKPGSSVKVSCKASGYTFTSYAMHWVRQAPGQGLEWMGYIN
PYNRGTKYNENFKGRVTITADESTSTAYMELSSLRSEDTAVYYCARRPFGNAMDI
WGQGTLVTVSSASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTVSWNSG
ALTSGVHTFPAVLQSSGLYSLSSVVTVPSSSLGTKTYTCNVDHKPSNTKVDKRVE
SKYGPPCPPCPAPEAAGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSQEDPEVQF
NWYVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKG
LPSSIEKTISKAKGQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWES
NGQPENNYKTTPPVLDSDGSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHYT
QKSLSLSLG

SEQ ID NO: 15 (LC DNA - Antibody I and Antibody II)
GACATCCAGATGACCCAGTCTCCATCCTCCCTGTCTGCATCTGTAGGAGACAG
AGTCACCATCACTTGCCGATCTTCCGAAAATATTTACCGTAATTTAGCATGGT
ATCAGCAGAAACCAGGGAAAGCCCCTAAGCTCCTGATCTATGCTGCAACAAA
CTTAGCAGATGGGGTCCCATCAAGGTTCAGTGGCAGTGGATCTGGGACAGAT
TTCACTCTCACCATCAGCAGTCTGCAACCTGAAGATTTTGCAACTTACTACTG
TCAAGGCATTTGGGGTACTCCGCTCACTTTCGGCGGAGGGACCAAGGTGGAG
ATCAAACGAACTGTGGCTGCACCATCTGTCTTCATCTTCCCGCCATCTGATGA
GCAGTTGAAATCTGGAACTGCCTCTGTTGTGTGCCTGCTGAATAACTTCTATC
CCAGAGAGGCCAAAGTACAGTGGAAGGTGGATAACGCCCTCCAATCGGGTAA
CTCCCAGGAGAGTGTCACAGAGCAGGACAGCAAGGACAGCACCTACAGCCTC
AGCAGCACCCTGACGCTGAGCAAAGCAGACTACGAGAAACACAAAGTCTAC
GCCTGCGAAGTCACCCATCAGGGCCTGAGCTCGCCCGTCACAAAGAGCTTCA
ACAGGGGAGAGTGC

SEQ ID NO: 16 (HC DNA - Antibody I)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGG
TGAAGGTCTCCTGCAAGGCTTCTGGATATACATTCACTAGCTATGCTATGCAC
TGGGTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGATGGGATATATTAATC
CTTATAATGATGGTACTAAGTACAATGAGAACTTCAAAGGCAGAGTCACGAT
TACCGCGGACGAATCCACGAGCACAGCCTACATGGAGCTGAGCAGCCTGAGA
TCTGAGGACACGGCCGTGTATTACTGTGCGAGAAGGCCCTTTGGTAACGCTAT
GGACATTTGGGGCCAGGGCACCCTGGTCACCGTCTCCTCAGCCTCCACCAAG
GGCCCATCGGTCTTCCCGCTAGCGCCCTGCTCCAGGAGCACCTCCGAGAGCAC
AGCCGCCCTGGGCTGCCTGGTCAAGGACTACTTCCCCGAACCGGTGACGGTG
TCGTGGAACTCAGGCGCCCTGACCAGCGGCGTGCACACCTTCCCGGCTGTCCT
ACAGTCCTCAGGACTCTACTCCCTCAGCAGCGTGGTGACCGTGCCCTCCAGCA
GCTTGGGCACGAAGACCTACACCTGCAACGTAGATCACAAGCCCAGCAACAC
CAAGGTGGACAAGAGAGTTGAGTCCAAATATGGTCCCCCATGCCCACCCTGC
CCAGCACCTGAGGCCGCCGGGGGACCATCAGTCTTCCTGTTCCCCCCAAAACC
CAAGGACACTCTCATGATCTCCCGGACCCCTGAGGTCACGTGCGTGGTGGTG
GACGTGAGCCAGGAAGACCCCGAGGTCCAGTTCAACTGGTACGTGGATGGCG
TGGAGGTGCATAATGCCAAGACAAAGCCGCGGGAGGAGCAGTTCAACAGCA
CGTACCGTGTGGTCAGCGTCCTCACCGTCCTGCACCAGGACTGGCTGAACGGC
AAGGAGTACAAGTGCAAGGTCTCCAACAAAGGCCTCCCGTCCTCCATCGAGA
AAACCATCTCCAAAGCCAAAGGGCAGCCCCGAGAGCCACAGGTGTACACCCT
GCCCCCATCCCAGGAGGAGATGACCAAGAACCAGGTCAGCCTGACCTGCCTG
GTCAAAGGCTTCTACCCCAGCGACATCGCCGTGGAGTGGGAAAGCAATGGGC
AGCCGGAGAACAACTACAAGACCACGCCTCCCGTGCTGGACTCCGACGGCTC
CTTCTTCCTCTACAGCAGGCTAACCGTGGACAAGAGCAGGTGGCAGGAGGGG
AATGTCTTCTCATGCTCCGTGATGCATGAGGCTCTGCACAACCACTACACACA
GAAGAGCCTCTCCCTGTCTCTGGGT

SEQ ID NO: 17 (HC DNA – Antibody II)
CAGGTGCAGCTGGTGCAGTCTGGGGCTGAGGTGAAGAAGCCTGGGTCCTCGG
TGAAGGTCTCCTGCAAGGCTTCTGGATATACATTCACTAGCTATGCTATGCAC
TGGGTGCGACAGGCCCCTGGACAAGGGCTTGAGTGGATGGGATATATTAATC
CTTATAATCGTGGTACTAAGTACAATGAGAACTTCAAAGGCAGAGTCACGAT
TACCGCGGACGAATCCACGAGCACAGCCTACATGGAGCTGAGCAGCCTGAGA
TCTGAGGACACGGCCGTGTATTACTGTGCGAGAAGGCCCTTTGGTAACGCTAT
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GCTTGGGCACGAAGACCTACACCTGCAACGTAGATCACAAGCCCAGCAACAC
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AATGTCTTCTCATGCTCCGTGATGCATGAGGCTCTGCACAACCACTACACACA
GAAGAGCCTCTCCCTGTCTCTGGGT

WE CLAIM:

1. An antibody, or antigen-binding fragment thereof, that binds to human BMP-6 (SEQ ID NO: 1), comprising a light chain variable region (LCVR) and a heavy chain variable region (HCVR), wherein the LCVR comprises the complementarity determining regions (CDRs) LCDR1, LCDR2, and LCDR3, and the HCVR comprises the CDRs HCDR1, HCDR2, and HCDR3, wherein the LCDR1 is the polypeptide of RSSENIYRNLA (SEQ ID NO: 2), the LCDR2 is the polypeptide of AATNLAD (SEQ ID NO: 3), the LCDR3 is the polypeptide of QGIWGTPLT (SEQ ID NO: 4), the HCDR1 is the polypeptide of GYTFTSYAMH (SEQ ID NO: 5), the HCDR2 is the polypeptide of YINPYNDGTKYNENFKG (SEQ ID NO: 6) or YINPYNRGTKYNENFKG (SEQ ID NO: 7), and the HCDR3 is the polypeptide of RPFGNAMDI (SEQ ID NO: 8).
2. The antibody, or antigen-binding fragment thereof, of Claim 1, wherein the LCDR1 is the polypeptide of RSSENIYRNLA (SEQ ID NO: 2), the LCDR2 is the polypeptide of AATNLAD (SEQ ID NO: 3), the LCDR3 is the polypeptide of QGIWGTPLT (SEQ ID NO: 4), the HCDR1 is the polypeptide of GYTFTSYAMH (SEQ ID NO: 5), the HCDR2 is the polypeptide of YINPYNDGTKYNENFKG (SEQ ID NO: 6), and the HCDR3 is the polypeptide of RPFGNAMDI (SEQ ID NO: 8).
3. The antibody, or antigen-binding fragment thereof, of Claim 1, wherein the LCDR1 is the polypeptide of RSSENIYRNLA (SEQ ID NO: 2), the LCDR2 is the polypeptide of AATNLAD (SEQ ID NO: 3), the LCDR3 is the polypeptide of QGIWGTPLT (SEQ ID NO: 4), the HCDR1 is the polypeptide of GYTFTSYAMH (SEQ ID NO: 5), the HCDR2 is the polypeptide of YINPYNRGTKYNENFKG (SEQ ID NO: 7), and the HCDR3 is the polypeptide of RPFGNAMDI (SEQ ID NO: 8).
4. The antibody, or antigen-binding fragment thereof, of Claim 1, comprising an LCVR and an HCVR, wherein the LCVR is the polypeptide

of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 10 or SEQ ID NO: 11.

5. The antibody, or antigen-binding fragment thereof, of Claim 4, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 10.

6. The antibody, or antigen-binding fragment thereof, of Claim 4, wherein the LCVR is the polypeptide of SEQ ID NO: 9, and the HCVR is the polypeptide of SEQ ID NO: 11.

7. The antibody of Claim 1 or 4, comprising a light chain (LC) and a heavy chain (HC), wherein the LC is the polypeptide of SEQ ID NO: 12, and the HC is the polypeptide of SEQ ID NO: 13 or SEQ ID NO: 14.

8. The antibody of Claim 7, wherein the LC is the polypeptide of SEQ ID NO: 12, and the HC is the polypeptide of SEQ ID NO: 13.

9. The antibody of Claim 7, wherein the LC is the polypeptide of SEQ ID NO: 12, and the HC is the polypeptide of SEQ ID NO: 14.

10. The antibody of any one of Claim 1, 4, or 7, comprising two light chains and two heavy chains, wherein each light chain is the polypeptide of SEQ ID NO: 12, and each heavy chain is the polypeptide of SEQ ID NO: 13.

11. The antibody of any one of Claim 1, 4, or 7, comprising two light chains and two heavy chains, wherein each light chain is the polypeptide of SEQ ID NO: 12, and each heavy chain is the polypeptide of SEQ ID NO: 14.

12. A pharmaceutical composition comprising an antibody, or antigen-binding fragment thereof, of any one of Claims 1-11, and an acceptable carrier, diluent, or excipient.

13. A method of treating anemia, comprising administering to a patient in need thereof, an effective amount of the antibody, or antigen-binding fragment thereof, of any one of Claims 1-11.

14. The method according to Claim 13, wherein the anemia is anemia of chronic disease.

15. The method according to Claim 14, wherein the anemia of chronic disease is selected from the group consisting of anemia of cancer, and anemia of chronic kidney disease.
16. A method of increasing serum iron levels, reticulocyte count, red blood cell count, hemoglobin, and/or hematocrit, comprising administering an effective amount of the antibody, or antigen-binding fragment thereof, of any one of Claims 1-11.
17. The antibody, or antigen-binding fragment thereof, of any one of Claims 1-11, for use in therapy.
18. The antibody, or antigen-binding fragment thereof, of any one of Claims 1-11, for use in the treatment of anemia.
19. The antibody, or antigen-binding fragment thereof, of Claim 18, wherein the anemia is anemia of chronic disease.
20. The antibody, or antigen-binding fragment thereof, of Claim 19, wherein the anemia of chronic disease is selected from the group consisting of anemia of cancer, and anemia of chronic kidney disease.