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Mature Human BMP-9 and BMP-10

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bmp9     SAGAGSHCQK TSLRVNFEDI GWDSWIIAPK EYEAYECKGG CPFPLADDVT PTKHAIVQTL 60
bmp10    -NAKGNYCKR TPLYIDFKEI GWDSWIIAPP GYEAYECRGV CNYPLAEHLT PTKHAIIQAL 59
           . *.:*:: *.* ::*::* ********* ********:*  * :***:.:* ******:*:*

bmp9     VHLKFPTKVG KACCVPTKLS PISVLYKDDM GVPTLKYHYE GMSVAECGCR 110 (SEQ ID NO:3)
bmp10    VHLKNSQKAS KACCVPTKLE PISILYLD-K GVVTYKFKYE GMAVSECGCR 108 (SEQ ID NO:6)
         **** . *.. *********. ***:** *   ** * *:**  **:*:*****
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Fig. 3

(57) Abstract: In certain aspects, the present invention provides compositions and methods comprising BMP9 or BMP 10 polypeptides or combinations thereof, for increasing red blood cell and/or hemoglobin levels in vertebrates, including rodents and primates, and particularly in humans.

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METHODS AND COMPOSITIONS FOR INCREASING RED BLOOD CELLS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to and the benefit of U.S. provisional patent application serial number 61/621,154 filed on April 6, 2012, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

The mature red blood cell, or erythrocyte, is responsible for oxygen transport in the circulatory systems of vertebrates. Red blood cells contain high concentrations of hemoglobin, a protein that binds oxygen in the lungs at relatively high partial pressure of oxygen (pO_2) and delivers oxygen to areas of the body with a relatively low pO_2.

Mature red blood cells are produced from pluripotent hematopoietic stem cells in a process termed erythropoiesis. Postnatal erythropoiesis occurs primarily in the bone marrow and in the red pulp of the spleen. The coordinated action of various signaling pathways control the balance of cell proliferation, differentiation, survival and death. Under normal conditions, red blood cells are produced at a rate that maintains a constant red cell mass in the body, and production may increase or decrease in response to various stimuli, including increased or decreased oxygen tension or tissue demand. The process of erythropoiesis begins with the formation of lineage committed precursor cells and proceeds through a series of distinct precursor cell types. The final stages of erythropoiesis occur as reticulocytes are released into the bloodstream and lose their mitochondria and ribosomes while assuming the morphology of mature red blood cell. An elevated level of reticulocytes, or an elevated reticulocyte:erythrocyte ratio, in the blood is indicative of increased red blood cell production rates.

Erythropoietin (EPO) is widely recognized as the most significant positive regulator of postnatal erythropoiesis in vertebrates. EPO regulates the compensatory erythropoietic response to reduced tissue oxygen tension (hypoxia) and low red blood cell levels or low hemoglobin levels. In humans, elevated EPO levels promote red blood cell formation by stimulating the generation of erythroid progenitors in the bone marrow and spleen. In the mouse, EPO enhances erythropoiesis primarily in the spleen.

Anemia is a broadly-defined condition characterized by lower than normal levels of hemoglobin or red blood cells in the blood. In some instances, anemia is caused by a primary disorder in the production or survival of red blood cells. More commonly, anemia is secondary to diseases of other systems (Weatherall & Provan (2000) Lancet 355, 1169-1175). Anemia may result from a reduced rate of production or increased rate of destruction of red blood cells or by loss of red blood cells due to bleeding. Anemia may result from a variety of disorders that include, for example, chronic renal failure, chemotherapy treatment, myelodysplastic syndrome, rheumatoid arthritis, and bone marrow transplantation.

Treatment with EPO typically causes a rise in hemoglobins by about 1-3 g/dL in healthy humans over a period of weeks. When administered to anemic individuals, this treatment regimen often provides substantial increases in hemoglobin and red blood cell levels and leads to improvements in quality of life and prolonged survival. EPO is not uniformly effective, and many individuals are refractory to even high doses (Horl et al. (2000) Nephrol Dial Transplant 15, 43-50). Over 50% of patients with cancer have an inadequate response to EPO, approximately 10% with end-stage renal disease are hyporesponsive (Glaspy et al. (1997) J Clin Oncol 15, 1218-1234; Demetri et al. (1998) J Clin Oncol 16, 3412-3425), and less than 10% with myelodysplastic syndrome respond favorably (Estey (2003) Curr Opin Hematol 10, 60-67). Several factors, including inflammation, iron and vitamin deficiency, inadequate dialysis, aluminum toxicity, and hyperparathyroidism may predict a poor therapeutic response. The molecular mechanisms of resistance to EPO are as yet unclear. Recent evidence suggests that higher doses of EPO may be associated with an increased risk of cardiovascular morbidity, tumor growth, and mortality in some patient populations (Krapf et al., 2009, Clin J Am Soc Nephrol 4:470-480; Glaspy, 2009, Annu Rev Med 60:181-192). It has therefore been recommended that EPO-based therapeutic compounds (erythropoietin-stimulating agents, ESAs) be administered at the lowest dose sufficient to avoid the need for red blood cell transfusions (Jelkmann et al., 2008, Crit Rev Oncol. Hematol 67:39-61).

Thus, it is an object of the present disclosure to provide alternative methods and compositions for increasing red blood cell levels in patients.

SUMMARY OF THE INVENTION

In part, the disclosure demonstrates that BMP9 polypeptides or BMP10 polypeptides may be used to increase red blood cell and hemoglobin levels. In particular, the disclosure demonstrates that BMP9, when administered in vivo, causes a profound and rapid increase in red blood cell levels, hematocrit and hemoglobin. BMP10 is closely related to BMP9 and is known to signal through the same set of receptors. Therefore, in certain embodiments, the disclosure provides methods for using BMP9 or BMP10 polypeptides (or a combination thereof) to increase red blood cell and hemoglobin levels in patients and to treat disorders associated with low red blood cell or hemoglobin levels in patients in need thereof.

In certain aspects, the present disclosure provides BMP9 polypeptides. In certain embodiments, a BMP9 polypeptide has an amino acid sequence that comprises, consists of, or consists essentially of, the amino acid sequence of SEQ ID NO: 1, 2, 3, 7, 8 or 16, or an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, or 99% identical to any of the foregoing. A BMP9 polypeptide may comprise an amino acid sequence that is encoded by a nucleic acid of SEQ ID NO:11, including any portion thereof, such as nucleotides 1121-1450 that encode the mature portion of BMP9, and a BMP9 polypeptide may be encoded by a nucleic acid that hybridizes to a nucleic acid that is complementary to the sequence of nucleotides 1121-1450 of SEQ ID NO:11 under less stringent, moderately stringent or highly stringent hybridization conditions.

In certain aspects, the present disclosure provides BMP10 polypeptides. In certain embodiments, a BMP10 polypeptide has an amino acid sequence that comprises, consists of, or consists essentially of, the amino acid sequence of SEQ ID NO: 4, 5, 6, 9, 10 or 17, or an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, or 99% identical to any of the foregoing. A BMP10 polypeptide may comprise an amino acid sequence that is encoded by a nucleic acid of SEQ ID NO:12, including any portion thereof, such as nucleotides 1108-1431 that encode the mature portion of BMP10, and a BMP10 polypeptide may be encoded by a nucleic that hybridizes to a nucleic acid that is complementary to the sequence of nucleotides 1108-1431 of SEQ ID NO:12 under less stringent, moderately stringent or highly stringent hybridization conditions.

In certain aspects, the disclosure provides pharmaceutical preparations comprising a BMP9 or BMP10 polypeptide and a pharmaceutically acceptable carrier. The BMP9 or BMP10 polypeptide may bind to one or more type I (e.g., ALK1, ALK2) or type II (e.g.,

ActRIIA, ActRIIB, BMPRII) receptors with a Kd less than 10 micromolar, less than 1 micromolar, less than 100 nanomolar, less than 10 nanomolar, or less than 1 nanomolar. Typically, a BMP9 or BMP10 polypeptide will bind to both a type I receptor and a type II receptor, although binding to one of the receptors may be at a very weak affinity. Optionally, the BMP9 or BMP10 polypeptide will stimulate expression from a SMAD1- or SMAD5-responsive promoter in a cell, such as a promoter containing the BMP-responsive element (BRE) from the ID1 gene.

A pharmaceutical preparation may further comprise a BMP9 prodomain polypeptide or a BMP10 prodomain polypeptide. In certain embodiments, a BMP9 prodomain polypeptide has an amino acid sequence that comprises, consists of, or consists essentially of, the amino acid sequence of 23-319 of SEQ ID NO: 1 or an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, or 99% identical to same. A BMP9 prodomain polypeptide may comprise an amino acid sequence that is encoded by the sequence of nucleotides 230-1120 of SEQ ID NO:11, including any portion thereof, and a BMP9 prodomain polypeptide may be encoded by a nucleic acid that hybridizes to a nucleic acid that is complementary to the sequence of nucleotides 230-1120 of SEQ ID NO:11 under less stringent, moderately stringent or highly stringent hybridization conditions. In certain embodiments, a BMP10 prodomain polypeptide has an amino acid sequence that comprises, consists of, or consists essentially of, the amino acid sequence of 22-316 of SEQ ID NO: 4 or an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, or 99% identical to same. A BMP10 prodomain polypeptide may comprise an amino acid sequence that is encoded by the sequence of nucleotides 223-1107 of SEQ ID NO:12, including any portion thereof, and a BMP10 prodomain polypeptide may be encoded by a nucleic acid that hybridizes to a nucleic acid that is complementary to the sequence of nucleotides 223-1107 of SEQ ID NO:12 under less stringent, moderately stringent or highly stringent hybridization conditions. A prodomain polypeptide may be covalently or non-covalently associated with a BMP9 or BMP10 polypeptide.

Preferably, a pharmaceutical preparation is substantially pyrogen free. In general, it is preferable that a BMP9 or BMP10 polypeptide be expressed in a mammalian cell line that mediates suitably natural glycosylation so as to diminish the likelihood of an unfavorable immune response in a patient. Human and CHO cell lines have been used successfully, and it is expected that other common mammalian expression vectors will be useful.

In certain aspects, the disclosure provides methods for making a BMP9 or BMP10 polypeptide. Such a method may include expressing any of the nucleic acids (e.g., SEQ ID NO: 11 or 12) disclosed herein in a suitable cell, such as a Chinese hamster ovary (CHO) cell. Such a method may comprise: a) culturing a cell under conditions suitable for expression of the BMP9 or BMP10 polypeptide, wherein said cell is transformed with a BMP9 or BMP10 expression construct; and b) recovering the BMP9 or BMP10 polypeptide so expressed. BMP9 or BMP10 polypeptides may be recovered as crude, partially purified or highly purified fractions using any of the well known techniques for obtaining protein from cell cultures. Purification may be achieved by contacting the BMP9 or BMP10 polypeptide with a ligand binding domain of a receptor protein, such as ALK1, ALK2, ActrIIA, ActRIIB or BMPRII or modified version thereof that binds to BMP9 or BMP10. The ligand binding domain may, for example, be used as a fusion with an Fc portion of an IgG (optionally with an intervening linker) and immobilized on a protein A-coated surface.

In certain aspects, a BMP9 or BMP10 polypeptide, or a pharmaceutical preparation comprising one or more of the foregoing, may be used in a method for promoting red blood cell production or increasing red blood cell levels in a subject. In certain embodiments, the disclosure provides methods for treating a disorder associated with low red blood cell counts or low hemoglobin levels (e.g., an anemia), or to promote red blood cell production, in patients in need thereof. A method may comprise administering to a subject in need thereof an effective amount of a BMP9 or BMP10 polypeptide. In certain aspects, the disclosure provides uses of BMP9 or BMP10 polypeptides for making a medicament for the treatment of a disorder or condition as described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a multiple sequence alignment of human, murine and chicken BMP9 proteins. The alignment was obtained using the Clustal W program.

Figure 2 shows a multiple sequence alignment of human, murine and chicken BMP10 proteins. The alignment was obtained using the Clustal W program.

Figure 3 shows an alignment of the mature portions of BMP9 and BMP10.

DETAILED DESCRIPTION OF THE INVENTION

1. Overview

The transforming growth factor-beta (TGF-beta) superfamily contains a variety of growth factors that share common sequence elements and structural motifs. These proteins are known to exert biological effects on a large variety of cell types in both vertebrates and invertebrates. Members of the superfamily perform important functions during embryonic development in pattern formation and tissue specification and can influence a variety of differentiation processes, including adipogenesis, myogenesis, chondrogenesis, cardiogenesis, hematopoiesis, neurogenesis, and epithelial cell differentiation. By manipulating the activity of a member of the TGF-beta family, it is often possible to cause significant physiological changes in an organism. For example, the Piedmontese and Belgian Blue cattle breeds carry a loss-of-function mutation in the GDF8 (also called myostatin) gene that causes a marked increase in muscle mass. Grobet et al., Nat Genet. 1997, 17(1):71-4. Furthermore, in humans, inactive alleles of GDF8 are associated with increased muscle mass and, reportedly, exceptional strength. Schuelke et al., N Engl J Med 2004, 350:2682-8.

Bone morphogenetic protein 9 (BMP9) and BMP10 are two closely related members of the TGF-beta superfamily. These proteins are thought to be produced as disulfide linked homodimers that can circulate in the blood. BMP signals are mediated by heteromeric complexes of type I and type II serine/threonine kinase receptors, which phosphorylate and activate downstream Smad proteins upon ligand stimulation (Massagué, 2000, Nat. Rev. Mol. Cell Biol. 1:169-178). These type I and type II receptors are transmembrane proteins, composed of a ligand-binding extracellular domain with cysteine-rich region, a transmembrane domain, and a cytoplasmic domain with predicted serine/threonine specificity. Type I receptors are essential for signaling. Type II receptors are required for binding ligands and for expression of Type I receptors. Type I and II activin receptors form a stable complex after ligand binding, resulting in phosphorylation of Type I receptors by Type II receptors. BMP9 and BMP10 are thought to signal through the Type I receptors ALK1 and ALK2 and the Type II receptors ActRIIA, ActRIIB and BMPRII.

As demonstrated herein, a BMP9 polypeptide (and, as inferred by homology and common signaling pathway, a BMP10 polypeptide) is effective at increasing red blood cell levels *in vivo* and is expected to have beneficial effects in a variety of models for anemias. It should be noted that hematopoiesis is a complex process, regulated by a variety of factors,

including erythropoietin, G-CSF and iron homeostasis. The terms "increase red blood cell levels" and "promote red blood cell formation" refer to clinically observable metrics, such as hematocrit, red blood cell counts and hemoglobin measurements, and are intended to be neutral as to the mechanism by which such changes occur.

The terms used in this specification generally have their ordinary meanings in the art, within the context of this invention and in the specific context where each term is used. Certain terms are discussed below or elsewhere in the specification, to provide additional guidance to the practitioner in describing the compositions and methods of the invention and how to make and use them. The scope or meaning of any use of a term will be apparent from the specific context in which the term is used.

"About" and "approximately" shall generally mean an acceptable degree of error for the quantity measured given the nature or precision of the measurements. Typically, exemplary degrees of error are within 20 percent (%), preferably within 10%, and more preferably within 5% of a given value or range of values.

Alternatively, and particularly in biological systems, the terms "about" and "approximately" may mean values that are within an order of magnitude, preferably within 5-fold and more preferably within 2-fold of a given value. Numerical quantities given herein are approximate unless stated otherwise, meaning that the term "about" or "approximately" can be inferred when not expressly stated.

The methods of the invention may include steps of comparing sequences to each other, including wild-type sequence to one or more mutants (sequence variants). Such comparisons typically comprise alignments of polymer sequences, e.g., using sequence alignment programs and/or algorithms that are well known in the art (for example, BLAST, FASTA and MEGALIGN, to name a few). The skilled artisan can readily appreciate that, in such alignments, where a mutation contains a residue insertion or deletion, the sequence alignment will introduce a "gap" (typically represented by a dash, or "A") in the polymer sequence not containing the inserted or deleted residue.

"Homologous," in all its grammatical forms and spelling variations, refers to the relationship between two proteins that possess a "common evolutionary origin," including proteins from superfamilies in the same species of organism, as well as homologous proteins from different species of organism. Such proteins (and their encoding nucleic acids) have

sequence homology, as reflected by their sequence similarity, whether in terms of percent identity or by the presence of specific residues or motifs and conserved positions.

The term "sequence similarity," in all its grammatical forms, refers to the degree of identity or correspondence between nucleic acid or amino acid sequences that may or may not share a common evolutionary origin.

However, in common usage and in the instant application, the term "homologous," when modified with an adverb such as "highly," may refer to sequence similarity and may or may not relate to a common evolutionary origin.

2. BMP9 and BMP10 Polypeptides and Nucleic Acids

In certain aspects, the invention relates to BMP9 polypeptides and BMP10 polypeptides, including, for example, mature human BMP9 and BMP10 proteins as well as BMP9 or BMP10 polypeptides that retain the prodomain, whether covalently or non-covalently attached, and variants and truncations of the foregoing. Such variations and truncations may be selected to retain the ability to stimulate signaling by one or more of the known receptors for BMP9 or BMP10, including ALK1, ALK2, ActRIIA, BMPR2 and ActRIIB. Optionally, a BMP9 or BMP10 polypeptide can increase expression of luciferase in a cell line transfected with a BRE-luciferase reporter gene construct.

As used herein, the terms "BMP-9" or "BMP-10" refer to the family of BMP-9 or BMP-10 proteins, respectively, from any species and variants derived from such proteins by mutagenesis, truncation or other modification. BMP-9 proteins and BMP-10 proteins are well-conserved across vertebrate lineages, particularly in the mature portion of the protein, as shown in Figures 1 and 2. The mature portions of human BMP-9 and BMP-10 also show substantial identity to each other (64%) (Figure 3). Members of the BMP-9 or BMP-10 families are generally secreted proteins, composed of a signal peptide, a pro-domain that binds to the mature portion in a manner that competes with binding to type II receptors (e.g., BMPR2, ActRIIA, ActRIIB) and a mature portion containing a cysteine knot. The mature portion binds to both a type I receptor (e.g., ALK1 or ALK2) and a type II receptor (e.g., BMPR2, ActRIIA or ActRIIB) to form a signaling complex.

The term "BMP9 polypeptide" includes polypeptides comprising any naturally occurring polypeptide of a BMP-9 family member, respectively, as well as any variants thereof (including mutants, fragments, fusions, and peptidomimetic forms) that retain a useful

activity. For example, BMP9 polypeptides may comprise polypeptides derived from the sequence of any known BMP9 protein and may include forms expressed with a signal peptide, as a proprotein form (containing both the prodomain and the mature portion) and as the fully mature form. As shown in Figure 1, vertebrates as diverse as humans, mice and chickens have highly conserved BMP9 proteins, and therefore functional variants may, for example, be selected by reference to amino acids that are less conserved among different vertebrate species as such changes will generally be tolerated. BMP9 polypeptides may comprise, consist essentially of, or consist of, an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, 99%, or 100% identical to the sequence of a naturally occurring BMP9 polypeptide such as any of SEQ. ID. Nos. 1, 2, 3, 7 or 8 or the mature portions of SEQ. ID. Nos. 7 or 8. Numbering of amino acids for all human BMP9 polypeptides described herein is based on the numbering for SEQ ID NO:1, unless specifically designated otherwise.

Examples of BMP9 polypeptides include:

Full-length human BMP9 precursor (including signal sequence, corresponding to amino acids 1 - 22) (Genbank NP_057288):

```
1   MCPGALWVAL PLLSLLAGSL QGKPLQSWGR GSAGGNAHSP LGVPGGGLPE HTFNLKMFLE
61  NVKVDFLRSL NLSGVPSQDK TRVEPPQYMI DLYNRYTSDK STTPASNIVR SFSMEDAISI
121 TATEDFPFQK HILLFNISIP RHEQITRAEL RLYVSCQNHV DPSHDLKGSV VIYDVLDGTD
181 AWDSATETKT FLVSQDIQDE GWETLEVSSA VKRWVRSDST KSKNKLEVTV ESHRKGCDTL
241 DISVPPGSRN LPFFVVFSND HSSGTKETRL ELREMISHEQ ESVLKKLSKD GSTEAGESSH
301 EEDTDGHVAA GSTLARRKRS AGAGSHCQKT SLRVNFEDIG WDSWIIAPKE YEAYECKGGC
361 FFPLADDVTP TKHAIVQTLV HLKFPTKVGK ACCVPTKLSP ISVLYKDDMG VPTLKYHYEG
421 MSVAECGCR  (SEQ. ID. NO:1)
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Full-length human BMP9 proprotein (signal sequence removed but including pro-domain, corresponding to amino acids 23 – 429 of SEQ ID NO:1):

```
KPLQSWGRGS AGGNAHSPLG VPGGGLPEHT FNLKMFLENV KVDFLRSLNL SGVPSQDKTR
VEPPQYMIDL YNRYTSDKST TPASNIVRSF SMEDAISITA TEDFPFQKHI LLFNISIPRH
EQITRAELRL YVSCQNHVDP SHDLKGSVVI YDVLDGTDAW DSATETKTFL VSQDIQDEGW
ETLEVSSAVK RWVRSDSTKS KNKLEVTVES HRKGCDTLDI SVPPGSRNLP FFVVFSNDHS
SGTKETRLEL REMISHEQES VLKKLSKDGS TEAGESSHEE DTDGHVAAGS TLARRKRSAG
AGSHCQKTSL RVNFEDIGWD SWIIAPKEYE AYECKGGCFF PLADDVTPTK HAIVQTLVHL
KFPTKVGKAC CVPTKLSPIS VLYKDDMGVP TLKYHYEGMS VAECGCR (SEQ. ID. NO:2)
```

Mature human BMP9 (both signal sequence and pro-domain removed, corresponding to amino acids 320 – 429 of SEQ ID NO:1):

SAGAGSHCQK TSLRVNFEDI GWDSWIIAPK EYEAYECKGG CFFPLADDVT PTKHAIVQTL VHLKFPTKVG KACCVPTKLS PISVLYKDDM GVPTLKYHYE GMSVAECGCR (SEQ. ID. NO:3)

The term "BMP10 polypeptide" includes polypeptides comprising any naturally occurring polypeptide of a BMP10 family member, respectively, as well as any variants thereof (including mutants, fragments, fusions, and peptidomimetic forms) that retain a useful activity. For example, BMP10 polypeptides may comprise polypeptides derived from the sequence of any known BMP10 protein and may include forms expressed with a signal peptide, as a proprotein form and as the fully mature form. As shown in Figure 2, vertebrates as diverse as humans, mice and chickens have highly conserved BMP10 proteins, and therefore functional variants may, for example, be selected by reference to amino acids that are less conserved among different vertebrate species. BMP10 polypeptides may comprise, consist essentially of, or consist of, an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, 99%, or 100% identical to the sequence of a naturally occurring BMP10 polypeptide such as any of SEQ. ID. Nos. 4, 5, 6, 9 or 10 or the mature portions of SEQ. ID. Nos. 9 or 10. Numbering of amino acids for all human BMP10 polypeptides described herein is based on the numbering for SEQ ID NO:4, unless specifically designated otherwise.

Examples of BMP10 polypeptides include:

Full-length human BMP10 precursor (including signal sequence, corresponding to amino acids 1 - 21) (Genbank NP_055297):

1 MGSLVLTLCA LFCLAAYLVS GSPIMNLEQS PLEEDMSLFG DVFSEQDGVD FNTLLQSMKD
61 EFLKTLNLSD IPTQDSAKVD PPEYMLELYN KFATDRTSMP SANIIRSFKN EDLFSQPVSF
121 NGLRKYPLLF NVSIPHHEEV IMAELRLYTL VQRDRMIYDG VDRKITIFEV LESKGDNEGE
181 RNMLVLVSGE IYGTNSEWET FDVTDAIRRW QKSGSSTHQL EVHIESKHDE AEDASSGRLE
241 IDTSAQNKHN PLLIVFSDDQ SSDKERKEEL NEMISHEQLP ELDNLGLDSF SSGPGEEALL
301 QMRSNIIYDS TARIRRNAKG NYCKRTPLYI DFKEIGWDSW IIAPPGYEAY ECRGVCNYPL
361 AEHLTPTKHA IIQALVHLKN SQKASKACCV PTKLEPISIL YLDKGVVTYK FKYEGMAVSE
421 CGCR (SEQ. ID. NO:4)

Full-length human BMP10 proprotein (signal sequence removed but including pro-domain, corresponding to amino acids 22 – 424 of SEQ ID NO:4):

SPIMNLEQSP LEEDMSLFGD VFSEQDGVDF NTLLQSMKDE FLKTLNLSDI PTQDSAKVDP
PEYMLELYNK FATDRTSMPS ANIIRSFKNE DLFSQPVSFN GLRKYPLLFN VSIPHHEEVI
MAELRLYTLV QRDRMIYDGV DRKITIFEVL ESKGDNEGER NMLVLVSGEI YGTNSEWETF
DVTDAIRRWQ KSGSSTHQLE VHIESKHDEA EDASSGRLEI DTSAQNKHNP LLIVFSDDQS
SDKERKEELN EMISHEQLPE LDNLGLDSFS SGPGEEALLQ MRSNIIYDST ARIRRNAKGN
YCKRTPLYID FKEIGWDSWI IAPPGYEAYE CRGVCNYPLA EHLTPTKHAI IQALVHLKNS
QKASKACCVP TKLEPISILY LDKGVVTYKF KYEGMAVSEC GCR (SEQ. ID. NO:5)

Mature human BMP10 (both signal sequence and pro-domain removed, corresponding to amino acids 317 – 424 of SEQ ID NO:4):

NAKGNYCKRT PLYIDFKEIG WDSWIIAPPG YEAYECRGVC NYPLAEHLTP TKHAIIQALV
HLKNSQKASK ACCVPTKLEP ISILYLDKGV VTYKFKYEGM AVSECGCR (SEQ ID NO:6)

In certain aspects, the disclosure provides isolated and/or recombinant nucleic acids encoding any of the BMP9 or BMP10 polypeptides disclosed herein. Such nucleic acids may be DNA or RNA molecules. These nucleic acids may be used, for example, in methods for making BMP9 or BMP10 polypeptides or as direct therapeutic agents (e.g., in a gene therapy approach).

A nucleic acid sequence encoding a human BMP9 precursor protein is as follows: (Genbank NM_016204)

```
   1 cggtccagcc cggcagcggg tgagagtggg tgctggccag gacggttcct tcagagcaaa
  61 cagcagggag atgccggccc gctccttccc agctcctccc cgtgcccgct aacacagcac
 121 ggccgcctgc agtctcctct ctgggtgatt gcgcgggcct aagatgtgtc ctggggcact
 181 gtgggtggcc ctgcccctgc tgtccctgct ggctggctcc ctacagggga agccactgca
 241 gagctgggga cgagggtctg ctgggggaaa cgcccacagc ccactggggg tgcctggagg
 301 tgggctgcct gagcacacct tcaacctgaa gatgtttctg gagaacgtga aggtggattt
 361 cctgcgcagc cttaacctga gtggggtccc ttcgcaggac aaaaccaggg tggagccgcc
 421 gcagtacatg attgacctgt acaacaggta cacgtccgat aagtcgacta cgccagcgtc
 481 caacattgtg cggagcttca gcatggaaga tgccatctcc ataactgcca cagaggactt
 541 ccccttccag aagcacatct tgctcttcaa catctccatt cctaggcatg agcagatcac
 601 cagagctgag ctccgactct atgtctcctg tcaaaatcac gtggacccct ctcatgacct
 661 gaaaggaagc gtggtcattt atgatgttct ggatggaaca gatgcctggg atagtgctac
 721 agagaccaag accttcctgg tgtcccagga cattcaggat gagggctggg agaccttgga
 781 agtgtccagc gccgtgaagc gctgggtccg gtccgactcc accaagagca aaaataagct
 841 ggaagtgact gtggagagcc acaggaaggg ctgcgacacg ctggacatca gtgtcccccc
 901 aggttccaga aacctgccct tctttgttgt cttctccaat gaccacagca gtgggaccaa
 961 ggagaccagg ctggagctga gggagatgat cagccatgaa caagagagcg tgctcaagaa
1021 gctgtccaag gacggctcca cagaggcagg tgagagcagt cacgaggagg acacggatgg
1081 ccacgtggct gcggggtcga ctttagccag gcggaaaagg agcgccgggg ctggcagcca
1141 ctgtcaaaag acctccctgc gggtaaactt cgaggacatc ggctgggaca gctggatcat
1201 tgcacccaag gagtatgaag cctacgagtg taagggcggc tgcttcttcc ccttggctga
1261 cgatgtgacg ccgacgaaac acgctatcgt gcagaccctg gtgcatctca agttccccac
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1321 aaaggtgggc aaggcctgct gtgtgcccac caaactgagc cccatctccg tcctctacaa
1381 ggatgacatg ggggtgccca ccctcaagta ccattacgag ggcatgagcg tggcagagtg
1441 tgggtgcagg tag (SEQ. ID. NO:11)
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The coding region for BMP9 (signal peptide, prodomain and mature portion) runs from position 164 – 1453 of SEQ. ID. No. 11. The signal peptide is encoded by nucleotides 164 – 229, the prodomain by nucleotides 230 – 1120 and the mature peptide by positions 1121 – 1450.

The nucleic acid sequence encoding a human BMP10 precursor protein is as follows (Genbank NM_014482):

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   1 ggggagagga agagtggtag ggggagggag agagagagga agagtttcca aacttgtctc
  61 cagtgacagg agacatttac gttccacaag ataaaactgc cacttagagc ccagggaagc
 121 taaaccttcc tggcttggcc taggagctcg agcggagtca tgggctctct ggtcctgaca
 181 ctgtgcgctc ttttctgcct ggcagcttac ttggtttctg gcagccccat catgaaccta
 241 gagcagtctc ctctggaaga agatatgtcc ctctttggtg atgttttctc agagcaagac
 301 ggtgtcgact ttaacacact gctccagagc atgaaggatg agtttcttaa gacactaaac
 361 ctctctgaca tccccacgca ggattcagcc aaggtggacc caccagagta catgttggaa
 421 ctctacaaca aatttgcaac agatcggacc tccatgccct ctgccaacat cattaggagt
 481 ttcaagaatg aagatctgtt ttcccagccg gtcagtttta atgggctccg aaaatacccc
 541 ctcctcttca atgtgtccat tcctcaccat gaagaggtca tcatggctga acttaggcta
 601 tacacactgg tgcaaaggga tcgtatgata tacgatggag tagaccggaa aattaccatt
 661 tttgaagtgc tggagagcaa aggggataat gagggagaaa gaaacatgct ggtcttggtg
 721 tctggggaga tatatggaac caacagtgag tgggagactt ttgatgtcac agatgccatc
 781 agacgttggc aaaagtcagg ctcatccacc caccagctgg aggtccacat tgagagcaaa
 841 cacgatgaag ctgaggatgc cagcagtgga cggctagaaa tagataccag tgcccagaat
 901 aagcataacc ctttgctcat cgtgttttct gatgaccaaa gcagtgacaa ggagaggaag
 961 gaggaactga atgaaatgat ttcccatgag caacttccag agctggacaa cttgggcctg
1021 gatagctttt ccagtggacc tggggaagag gctttgttgc agatgagatc aaacatcatc
1081 tatgactcca ctgcccgaat cagaaggaac gccaaaggaa actactgtaa gaggaccccg
1141 ctctacatcg acttcaagga gattgggtgg gactcctgga tcatcgctcc gcctggatac
1201 gaagcctatg aatgccgtgg tgtttgtaac tacccctgg cagagcatct cacacccaca
1261 aagcatgcaa ttatccaggc cttggtccac ctcaagaatt cccagaaagc ttccaaagcc
1321 tgctgtgtgc ccacaaagct agagcccatc tccatcctct atttagacaa aggcgtcgtc
1381 acctacaagt ttaaatacga aggcatggcc gtctccgaat gtggctgtag atagaagaag
1441 agtcctatgg cttatttaat aactgtaaat gtgtatattt ggtgttccta tttaatgaga
1501 ttatttaata agggtgtaca gtaatagagg cttgctgcct tcaggaaatg gacaggtcag
1561 tttgttgtag gaaatgcata tttt (SEQ. ID. NO:12)
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The coding region for BMP10 (signal peptide, prodomain and mature portion) runs from position 160 – 1434 of SEQ. ID. No. 12. The signal peptide is encoded by nucleotides 160 – 222, the prodomain by nucleotides 223 – 1107 and the mature peptide by positions 1108 – 1431.

In certain aspects, the subject nucleic acids encoding BMP9 or BMP10 polypeptides are further understood to include nucleic acids that are variants of SEQ ID NOs: 11 or 12. Variant nucleotide sequences include sequences that differ by one or more nucleotide substitutions, additions or deletions, such as allelic variants; and will, therefore, include

coding sequences that differ from the nucleotide sequence of the coding sequence designated in SEQ ID NOs: 11 or 12.

In certain embodiments, the disclosure provides isolated or recombinant nucleic acid sequences that are at least 63%, 70%. 80%, 85%, 90%, 95%, 97%, 98%, 99% or 100% identical to SEQ ID NO: 11 or 12 or the portions thereof that encode the prodomain or mature portion. One of ordinary skill in the art will appreciate that nucleic acid sequences complementary to SEQ ID NO: 11 or 12, and variants of SEQ ID NO: 11 or 12, are also within the scope of this invention. In further embodiments, the nucleic acid sequences of the invention can be isolated, recombinant, and/or fused with a heterologous nucleotide sequence, or in a DNA library.

In other embodiments, nucleic acids of the invention also include nucleotide sequences that hybridize under stringent conditions to the nucleotide sequence designated in SEQ ID NO: 11 or 12, including the portions thereof that encode the prodomain or mature portion, complement sequence of SEQ ID NO: 11 or 12, including the portions thereof that encode the prodomain or mature portion thereof. In a particular embodiment, the disclosure provides nucleic acids that hybridize under stringent conditions to a complement to the nucleic acid of 1121 – 1450 of SEQ ID NO:11 or a complement of the nucleic acid of 1108 – 1431 of SEQ ID NO:12, and BMP9 or BMP10 polypeptides encoded by the foregoing. As discussed above, one of ordinary skill in the art will understand readily that appropriate stringency conditions which promote DNA hybridization can be varied. For example, one could perform the hybridization at 6.0 x sodium chloride/sodium citrate (SSC) at about 45 °C, followed by a wash of 2.0 x SSC at 50 °C. For example, the salt concentration in the wash step can be selected from a low stringency of about 2.0 x SSC at 50 °C to a high stringency of about 0.2 x SSC at 50 °C. In addition, the temperature in the wash step can be increased from low stringency conditions at room temperature, about 22 °C, to high stringency conditions at about 65 °C. Both temperature and salt may be varied, or temperature or salt concentration may be held constant while the other variable is changed. In one embodiment, the disclosure provides nucleic acids which hybridize under low stringency conditions of 6 x SSC at room temperature followed by a wash at 2 x SSC at room temperature.

Isolated nucleic acids which differ from the nucleic acids as set forth in SEQ ID NO: 11 or 12 due to degeneracy in the genetic code are also within the scope of the invention. For example, a number of amino acids are designated by more than one triplet. Codons that

specify the same amino acid, or synonyms (for example, CAU and CAC are synonyms for histidine) may result in "silent" mutations which do not affect the amino acid sequence of the protein. In certain embodiments, the BMP9 or BMP10 polypeptide will be encoded by an alternative nucleotide sequence. Alternative nucleotide sequences are degenerate with respect to the native BMP9 or BMP10 nucleic acid sequence but still encode for the same fusion protein.

In certain embodiments, the recombinant nucleic acids of the invention may be operably linked to one or more regulatory nucleotide sequences in an expression construct. Regulatory nucleotide sequences will generally be appropriate to the host cell used for expression. Numerous types of appropriate expression vectors and suitable regulatory sequences are known in the art for a variety of host cells. Typically, said one or more regulatory nucleotide sequences may include, but are not limited to, promoter sequences, leader or signal sequences, ribosomal binding sites, transcriptional start and termination sequences, translational start and termination sequences, and enhancer or activator sequences. Constitutive or inducible promoters as known in the art are contemplated by the invention. The promoters may be either naturally occurring promoters, or hybrid promoters that combine elements of more than one promoter. An expression construct may be present in a cell on an episome, such as a plasmid, or the expression construct may be inserted in a chromosome. In a preferred embodiment, the expression vector contains a selectable marker gene to allow the selection of transformed host cells. Selectable marker genes are well known in the art and will vary with the host cell used.

In certain aspects of the disclosure, the subject nucleic acid is provided in an expression vector comprising a nucleotide sequence encoding a BMP9 or BMP10 polypeptide and operably linked to at least one regulatory sequence. Regulatory sequences are art-recognized and are selected to direct expression of the BMP9 or BMP10 polypeptide. Accordingly, the term regulatory sequence includes promoters, enhancers, and other expression control elements. Exemplary regulatory sequences are described in Goeddel; *Gene Expression Technology*: *Methods in Enzymology*, Academic Press, San Diego, CA (1990). For instance, any of a wide variety of expression control sequences that control the expression of a DNA sequence when operatively linked to it may be used in these vectors to express DNA sequences encoding a BMP9 or BMP10 polypeptide. Such useful expression control sequences, include, for example, the early and late promoters of SV40, tet promoter, adenovirus or cytomegalovirus immediate early promoter, RSV promoters, the lac system,

the trp system, the TAC or TRC system, T7 promoter whose expression is directed by T7 RNA polymerase, the major operator and promoter regions of phage lambda, the control regions for fd coat protein, the promoter for 3-phosphoglycerate kinase or other glycolytic enzymes, the promoters of acid phosphatase, e.g., Pho5, the promoters of the yeast α-mating factors, the polyhedron promoter of the baculovirus system and other sequences known to control the expression of genes of prokaryotic or eukaryotic cells or their viruses, and various combinations thereof. It should be understood that the design of the expression vector may depend on such factors as the choice of the host cell to be transformed and/or the type of protein desired to be expressed. Moreover, the vector's copy number, the ability to control that copy number and the expression of any other protein encoded by the vector, such as antibiotic markers, should also be considered.

A recombinant nucleic acid for production of BMP9 or BMP10 polypeptides can be produced by ligating the cloned gene, or a portion thereof, into a vector suitable for expression in either prokaryotic cells, eukaryotic cells (yeast, avian, insect or mammalian), or both. Expression vehicles for production of a recombinant BMP9 or BMP10 polypeptide include plasmids and other vectors. For instance, suitable vectors include plasmids of the types: pBR322-derived plasmids, pEMBL-derived plasmids, pEX-derived plasmids, pBTac-derived plasmids and pUC-derived plasmids for expression in prokaryotic cells, such as *E. coli*.

Some mammalian expression vectors contain both prokaryotic sequences to facilitate the propagation of the vector in bacteria, and one or more eukaryotic transcription units that are expressed in eukaryotic cells. The pcDNAI/amp, pcDNAI/neo, pRc/CMV, pSV2gpt, pSV2neo, pSV2-dhfr, pTk2, pRSVneo, pMSG, pSVT7, pko-neo and pHyg derived vectors are examples of mammalian expression vectors suitable for transfection of eukaryotic cells. Some of these vectors are modified with sequences from bacterial plasmids, such as pBR322, to facilitate replication and drug resistance selection in both prokaryotic and eukaryotic cells. Alternatively, derivatives of viruses such as the bovine papilloma virus (BPV-1), or Epstein-Barr virus (pHEBo, pREP-derived and p205) can be used for transient expression of proteins in eukaryotic cells. Examples of other viral (including retroviral) expression systems can be found below in the description of gene therapy delivery systems. The various methods employed in the preparation of the plasmids and in transformation of host organisms are well known in the art. For other suitable expression systems for both prokaryotic and eukaryotic cells, as well as general recombinant procedures, see *Molecular Cloning A*

Laboratory Manual, 2nd Ed., ed. by Sambrook, Fritsch and Maniatis (Cold Spring Harbor Laboratory Press, 1989) Chapters 16 and 17. In some instances, it may be desirable to express the recombinant polypeptides by the use of a baculovirus expression system. Examples of such baculovirus expression systems include pVL-derived vectors (such as pVL1392, pVL1393 and pVL941), pAcUW-derived vectors (such as pAcUW1), and pBlueBac-derived vectors (such as the ß-gal containing pBlueBac III).

In a preferred embodiment, a vector will be designed for production of the subject BMP9 or BMP10 polypeptides in CHO cells, such as a Pcmv-Script vector (Stratagene, La Jolla, Calif.), pcDNA4 vectors (Invitrogen, Carlsbad, Calif.) and pCI-neo vectors (Promega, Madison, Wisc.). As will be apparent, the subject gene constructs can be used to cause expression of the subject BMP9 or BMP10 polypeptides in cells propagated in culture, e.g., to produce proteins, including fusion proteins or variant proteins, for purification.

This disclosure also pertains to a host cell transfected with a recombinant gene including a coding sequence for one or more of the subject BMP9 or BMP10 polypeptides. The host cell may be any prokaryotic or eukaryotic cell. For example, a BMP9 or BMP10 polypeptide of the invention may be expressed in bacterial cells such as *E. coli*, insect cells (e.g., using a baculovirus expression system), yeast, or mammalian cells. Other suitable host cells are known to those skilled in the art.

The above-described nucleic acids may be used to express BMP9 or BMP10 polypeptides in suitable cells, including, for example, HEK cells, COS cells and CHO cells. The signal sequence can be a native signal sequence of BMP9 or BMP10, or a signal sequence from another protein, such as a tissue plasminogen activator (TPA) signal sequence or a honey bee melittin (HBM) signal sequence. The prodomain sequences of BMP9 and BMP10 may be interchanged, such that a BMP10 mature portion is expressed with a BMP9 prodomain or vice versa. The protein PACE (or Furin) mediates cleavage of the proprotein into two peptides, the proprotein and the mature portion, and thus it is useful to express a PACE transgene in a cell that is intended to produce a BMP9 or BMP10 polypeptide if such cleavage is desired. It is generally accepted that members of the GDF or BMP families need to dissociate from their prodomains in order to become fully active. In the case of BMP9 or BMP10, the prodomain remains associated with the mature portion, thus it may be desirable to separate the mature portion to generate the administrable pharmaceutical form. Alternatively, it is recognized here that the prodomain may confer desirable pharmaceutical properties, including, for example, longer serum half-life and greater bioavailability, and thus

in certain embodiments the disclosure provides pharmaceutical preparations comprising the mature portion of a BMP9 or BMP10 polypeptide that is covalently or non-covalently associated with a prodomain polypeptide. A "prodomain polypeptide" is a polypeptide comprising, consisting essentially of, or consisting of, an amino acid sequence that is at least 63%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, 99%, or 100% identical to the sequence of a naturally occurring BMP9 or BMP10 prodomain such as amino acids 23 – 319 of SEQ ID No. 1 or amino acids 22 – 316 of SEQ ID No. 4. It will be apparent that a prodomain polypeptide should not generally include more than 30, 20, 10 or 5 amino acids of the corresponding mature portion. In certain embodiments, a prodomain polypeptide will bind to the mature portion of a BMP9 or BMP10 polypeptide with a KD of no greater than 10^{-6}M, 10^{-7}M, 10^{-8}M or 10^{-9}M, or less.

In certain embodiments, the present disclosure contemplates making functional variants by modifying the structure of a BMP9 or BMP10 polypeptide for such purposes as enhancing therapeutic efficacy, or stability (e.g., ex vivo shelf life and resistance to proteolytic degradation *in vivo*). BMP9 or BMP10 polypeptides can also be generated by amino acid substitution, deletion, or addition. For instance, it is reasonable to expect that an isolated replacement of a leucine with an isoleucine or valine, an aspartate with a glutamate, a threonine with a serine, or a similar replacement of an amino acid with a structurally related amino acid (e.g., conservative mutations) will not have a major effect on the biological activity of the resulting molecule. Conservative replacements are those that take place within a family of amino acids that are related in their side chains. Whether a change in the amino acid sequence of a BMP9 or BMP10 polypeptide results in a functional variant can be readily determined by assessing the ability of the BMP9 or BMP10 polypeptide to produce a response in cells relative to the unmodified BMP9 or BMP10 polypeptide, or to bind to one or more receptors. In the case of variations in a prodomain polypeptide, the functional activity of a variant may be assessed by measuring the ability of the prodomain to bind to a mature BMP9 or BMP10 polypeptide.

In certain embodiments, the present invention contemplates BMP9 or BMP10 polypeptides having specific mutations so as to alter the glycosylation of the BMP9 or BMP10 polypeptide. Alterations in amino acid sequence may be made so as to introduce one or more N-linked glycosylation sites, which are generally an NXS or NXT sequence. Mutations may also be selected so as to eliminate one or more glycosylation sites, such as O-linked or N-linked glycosylation sites. The alteration may also be made by the addition of, or

substitution by, one or more asparagine, serine or threonine residues to the sequence of a BMP9 or BMP10 polypeptide. A variety of amino acid substitutions or deletions at one or both of the first or third amino acid positions of a glycosylation recognition site (and/or amino acid deletion at the second position) results in non-glycosylation at the modified tripeptide sequence. Another means of increasing the number of carbohydrate moieties on a BMP9 or BMP10 polypeptide is by chemical or enzymatic coupling of glycosides to the BMP9 or BMP10 polypeptide. Depending on the coupling mode used, the sugar(s) may be attached to (a) arginine and histidine; (b) free carboxyl groups; (c) free sulfhydryl groups such as those of cysteine; (d) free hydroxyl groups such as those of serine, threonine, or hydroxyproline; (e) aromatic residues such as those of phenylalanine, tyrosine, or tryptophan; or (f) the amide group of glutamine. These methods are described in WO 87/05330 and in Aplin and Wriston (1981) CRC Crit. Rev. Biochem., pp. 259-306, incorporated by reference herein. Removal of one or more carbohydrate moieties present on a BMP9 or BMP10 polypeptide may be accomplished chemically and/or enzymatically. Chemical deglycosylation may involve, for example, exposure of the BMP9 or BMP10 polypeptide to the compound trifluoromethanesulfonic acid, or an equivalent compound. This treatment results in the cleavage of most or all sugars except the linking sugar (N-acetylglucosamine or N-acetylgalactosamine), while leaving the amino acid sequence intact. Chemical deglycosylation is further described by Hakimuddin et al. (1987) Arch. Biochem. Biophys. 259:52 and by Edge et al. (1981) Anal. Biochem. 118:131. Enzymatic cleavage of carbohydrate moieties on BMP9 or BMP10 polypeptides can be achieved by the use of a variety of endo- and exo-glycosidases as described by Thotakura et al. (1987) Meth. Enzymol. 138:350. The sequence of a BMP9 or BMP10 polypeptide may be adjusted, as appropriate, depending on the type of expression system used, as mammalian, yeast, insect and plant cells may all introduce differing glycosylation patterns that can be affected by the amino acid sequence of the peptide. In general, BMP9 or BMP10 polypeptides for use in humans will be expressed in a mammalian cell line that provides proper glycosylation, such as HEK293 or CHO cell lines, although other mammalian expression cell lines are expected to be useful as well.

This disclosure further contemplates a method of generating variants, particularly sets of combinatorial variants of a BMP9 or BMP10 polypeptide, including, optionally, truncation variants; pools of combinatorial mutants are especially useful for identifying BMP9 or BMP10 sequences. The purpose of screening such combinatorial libraries may be to

generate, for example, BMP9 or BMP10 polypeptide variants which have altered properties, such as altered pharmacokinetics, or altered receptor binding. A variety of screening assays are provided below, and such assays may be used to evaluate variants. For example, a BMP9 or BMP10 polypeptide variant may be screened for the ability to bind to an ALK1, ActRIIA or ActRIIB polypeptide.

The activity of a BMP9 or BMP10 polypeptide or its variants may also be tested in a cell-based or *in vivo* assay. For example, the effect of a BMP9 or BMP10 polypeptide variant on the expression of genes involved in hematopoiesis may be assessed. Likewise, a BMP9 or BMP10 polypeptide may be administered to a mouse or other animal, and one or more blood measurements, such as an RBC count, hemoglobin levels, hematocrit levels, iron stores, or reticulocyte count may be assessed using art recognized methods. The BMP-responsive element (BRE) element, generally obtained from the promoter region of the ID1 gene is widely recognized as an appropriate reporter gene for members of the BMP/GDF family that stimulate SMAD 1/5/8 signaling. See, e.g., Logeart-Avramoglou D, et al., Anal Biochem. 2006 Feb 1;349(1):78-86. BMP9 or BMP10 polypeptide may also be measured by induction of alkaline phosphatase by ATDC5 mouse chondrogenic cells or MC3T3-E1 mouse osteoblastic cells. Nakamura, K. et al. (1999) Exp. Cell Res. 250:351.

In certain embodiments, the BMP9 or BMP10 polypeptides may further comprise post-translational modifications in addition to any that are naturally present in the BMP9 or BMP10 polypeptides. Such modifications include, but are not limited to, acetylation, carboxylation, glycosylation, phosphorylation, lipidation, acylation and modification with polyethylene glycol (PEG). As a result, BMP9 or BMP10 polypeptides may contain non-amino acid elements, such as polyethylene glycols, lipids, poly- or mono-saccharide, and phosphates. Effects of such non-amino acid elements on the functionality of a BMP9 or BMP10polypeptide may be tested as described herein for other BMP9 or BMP10 polypeptide variants. When a BMP9 or BMP10 polypeptide is produced in cells by cleaving a nascent form of BMP9 or BMP10 polypeptide, post-translational processing may also be important for correct folding and/or function of the protein. Different cells (such as CHO, HeLa, MDCK, 293, WI38, NIH-3T3 or HEK293) have specific cellular machinery and characteristic mechanisms for such post-translational activities and may be chosen to ensure the correct modification and processing of the BMP9 or BMP10 polypeptides.

In certain aspects, BMP9 or BMP10 polypeptides include fusion proteins having at least a portion of a BMP9 or BMP10 polypeptide and one or more fusion domains. Well

known examples of such fusion domains include, but are not limited to, polyhistidine, Glu-Glu, glutathione S transferase (GST), thioredoxin, protein A, protein G, an immunoglobulin heavy chain constant region (e.g., an Fc), maltose binding protein (MBP), or human serum albumin. A fusion domain may be selected so as to confer a desired property. For example, some fusion domains are particularly useful for isolation of the fusion proteins by affinity chromatography. For the purpose of affinity purification, relevant matrices for affinity chromatography, such as glutathione-, amylase-, and nickel- or cobalt- conjugated resins are used. Many of such matrices are available in "kit" form, such as the Pharmacia GST purification system and the QIAexpress™ system (Qiagen) useful with (HIS_6) fusion partners. As another example, a fusion domain may be selected so as to facilitate detection of the BMP9 or BMP10 polypeptides. Examples of such detection domains include the various fluorescent proteins (e.g., GFP) as well as "epitope tags," which are usually short peptide sequences for which a specific antibody is available. Well known epitope tags for which specific monoclonal antibodies are readily available include FLAG, influenza virus haemagglutinin (HA), and c-myc tags. In some cases, the fusion domains have a protease cleavage site, such as for Factor Xa or Thrombin, which allows the relevant protease to partially digest the fusion proteins and thereby liberate the recombinant proteins therefrom. The liberated proteins can then be isolated from the fusion domain by subsequent chromatographic separation. In certain preferred embodiments, a BMP9 or BMP10 polypeptide is fused with a domain that stabilizes the BMP9 or BMP10 polypeptide *in vivo* (a "stabilizer" domain). By "stabilizing" is meant anything that increases serum half life, regardless of whether this is because of decreased destruction, decreased clearance by the kidney, or other pharmacokinetic effect. Fusions with the Fc portion of an immunoglobulin are known to confer desirable pharmacokinetic properties on a wide range of proteins. Likewise, fusions to human serum albumin can confer desirable properties. Other types of fusion domains that may be selected include multimerizing (e.g., dimerizing, tetramerizing) domains and functional domains (that confer an additional biological function, such as further increasing red blood cell levels).

It is understood that different elements of the fusion proteins may be arranged in any manner that is consistent with the desired functionality. For example, a BMP9 or BMP10 polypeptide may be placed C-terminal to a heterologous domain, or, alternatively, a heterologous domain may be placed C-terminal to a BMP9 or BMP10 polypeptide. The BMP9 or BMP10 polypeptide domain and the heterologous domain need not be adjacent in a

fusion protein, and additional domains or amino acid sequences may be included C- or N-terminal to either domain or between the domains.

In certain embodiments, the present invention makes available isolated and/or purified forms of the BMP9 or BMP10 polypeptides, which are isolated from, or otherwise substantially free of, other proteins.

In certain embodiments, BMP9 or BMP10 polypeptides (unmodified or modified) of the invention can be produced by a variety of art-known techniques. For example, polypeptides can be synthesized using standard protein chemistry techniques such as those described in Bodansky, M. Principles of Peptide Synthesis, Springer Verlag, Berlin (1993) and Grant G. A. (ed.), Synthetic Peptides: A User's Guide, W. H. Freeman and Company, New York (1992). In addition, automated peptide synthesizers are commercially available (e.g., Advanced ChemTech Model 396; Milligen/Biosearch 9600). Alternatively, the BMP9 or BMP10 polypeptides, fragments or variants thereof may be recombinantly produced using various expression systems (e.g., E. coli, Chinese Hamster Ovary (CHO) cells, COS cells, baculovirus) as is well known in the art, followed by protein purification. BMP9 and BMP10 are also commercially available from R&D Systems (Minneapolis,Minnesota).

Accordingly, the disclosure provides methods of producing the subject BMP9 or BMP10 polypeptides. For example, a host cell transfected with an expression vector encoding a BMP9 or BMP10 polypeptide can be cultured under appropriate conditions to allow expression of the polypeptide to occur. The BMP9 or BMP10 polypeptide may be secreted and isolated from a mixture of cells and medium containing the BMP9 or BMP10 polypeptide. Alternatively, the polypeptide may be retained cytoplasmically or in a membrane fraction and the cells harvested, lysed and the protein isolated. A cell culture includes host cells, media and other byproducts. Suitable media for cell culture are well known in the art. The subject BMP9 or BMP10 polypeptides can be isolated from cell culture medium, host cells, or both, using techniques known in the art for purifying proteins, including ion-exchange chromatography, gel filtration chromatography, ultrafiltration, electrophoresis, and immunoaffinity purification with antibodies specific for particular epitopes of the BMP9 or BMP10 polypeptides.

The disclosure further provides novel methods for purification of BMP9 or BMP10 polypeptides by using the affinity of these proteins for one or more of their receptors, including ALK1, ALK2, BMPR2, ActRIIA or ActRIIB. A solid matrix (e.g.,

chromatography resin) may be joined to a ligand-binding portion of any of the foregoing to create an affinity matrix that will bind selectively to BMP9 or BMP10 polypeptides. The extracellular domain of the receptor may be fused to an Fc portion of an immunoglobulin and joined to a matrix containing an Fc binding protein, such as protein A. Surprisingly, a variant of an ActRIIB extracellular domain which contains an aspartic acid or glutamic acid rather than a leucine at position 79 is a particularly effective reagent for affinity purification of BMP9 or BMP10 polypeptides. Notably, this variant has reduced affinity for BMP9 or BMP10 relative to wild-type ActRIIB. See the following published PCT patent applications for examples of receptors and receptor-Fc fusion constructs that are useful in the production of BMP9 or BMP10 polypeptides: WO 2011/020045, WO 2010/151426, WO 2010/019261, WO 2009/139891, WO 2009/134428, WO 2008/097541, WO 2008/076437, WO 2007/062188 and WO 2006/012627, the receptor and receptor-Fc sequences of which are incorporated by reference. ActRIIA, BMPR2 and ActRIIB reagents are useful for purifying BMP9 or BMP10 mature proteins, as these proteins will compete with the propeptide for binding to the mature portion. ALK1 or ALK2 reagents are useful for purifying BMP9 or BMP10 polypeptides as complexes with the prodomain, as these bind at a site that is distinct and non-competitive relative to the propeptide.

In another embodiment, a fusion gene coding for a purification leader sequence, such as a poly-(His)/enterokinase cleavage site sequence at the N-terminus of the desired portion of the recombinant BMP9 or BMP10 polypeptide, can allow purification of the expressed fusion protein by affinity chromatography using a Ni^{2+} metal resin. The purification leader sequence can then be subsequently removed by treatment with enterokinase to provide the purified BMP9 or BMP10 polypeptide (e.g., see Hochuli et al., (1987) *J. Chromatography* 411:177; and Janknecht et al., *PNAS USA* 88:8972).

Techniques for making fusion genes are well known. Essentially, the joining of various DNA fragments coding for different polypeptide sequences is performed in accordance with conventional techniques, employing blunt-ended or stagger-ended termini for ligation, restriction enzyme digestion to provide for appropriate termini, filling-in of cohesive ends as appropriate, alkaline phosphatase treatment to avoid undesirable joining, and enzymatic ligation. In another embodiment, the fusion gene can be synthesized by conventional techniques including automated DNA synthesizers. Alternatively, PCR amplification of gene fragments can be carried out using anchor primers which give rise to complementary overhangs between two consecutive gene fragments which can subsequently

be annealed to generate a chimeric gene sequence (see, for example, *Current Protocols in Molecular Biology*, eds. Ausubel et al., John Wiley & Sons: 1992).

3. Exemplary Therapeutic Uses

In certain embodiments, the BMP9 or BMP10 polypeptides of the present disclosure can be used to increase red blood cell levels in mammals such as rodents and primates, and particularly human patients. Additionally, BMP9 or BMP10 polypeptides may be used in combination with EPO receptor activators to achieve an increase in red blood cells at lower dose ranges or to achieve an overall higher level of RBCs or a greater response rate. This may be beneficial in reducing the known off-target effects and risks associated with high doses of EPO receptor activators. In certain embodiments, the present invention provides methods of treating or preventing anemia in an individual in need thereof by administering to the individual a therapeutically effective amount of a BMP9 or BMP10 polypeptide or a combination (or concomitant therapy) of a BMP9 or BMP10 polypeptide and a EPO receptor activator. These methods may be used for therapeutic and prophylactic treatments of mammals, and particularly humans.

The BMP9 or BMP10 polypeptides may be used in combination with EPO receptor activators to reduce the required dose of these activators in patients that are susceptible to adverse effects of EPO. The primary adverse effects of EPO are an excessive increase in the hematocrit or hemoglobin levels and polycythemia. Elevated hematocrit levels can lead to hypertension (more particularly aggravation of hypertension) and vascular thrombosis. Other adverse effects of EPO which have been reported, some of which related to hypertension, are headaches, influenza-like syndrome, obstruction of shunts, myocardial infarctions and cerebral convulsions due to thrombosis, hypertensive encephalopathy, and red cell blood cell applasia (Singibarti, (1994) J. Clin Investig 72(suppl 6), S36-S43; Horl et al. (2000) Nephrol Dial Transplant 15(suppl 4), 51-56; Delanty et al. (1997) Neurology 49, 686-689; Bunn (2002) N Engl J Med 346(7), 522-523).

The rapid effect on red blood cell levels of the BMP9 or BMP10 polypeptides disclosed herein indicate that these agents act by a different mechanism than EPO. Accordingly, these antagonists may be useful for increasing red blood cell and hemoglobin levels in patients that do not respond well to EPO. For example, a BMP9 or BMP10 polypeptide may be beneficial for a patient in which administration of a normal to increased

(>300 IU/kg/week) dose of EPO does not result in the increase of hemoglobin level up to the target level. Patients with an inadequate EPO response are found for all types of anemia, but higher numbers of non-responders have been observed particularly frequently in patients with cancers and patients with end-stage renal disease. An inadequate response to EPO can be either constitutive (i.e. observed upon the first treatment with EPO) or acquired (e.g. observed upon repeated treatment with EPO).

As used herein, a therapeutic that "prevents" a disorder or condition refers to a compound that, in a statistical sample, reduces the occurrence of the disorder or condition in the treated sample relative to an untreated control sample, or delays the onset or reduces the severity of one or more symptoms of the disorder or condition relative to the untreated control sample. The term "treating" as used herein includes prophylaxis of the named condition or amelioration or elimination of the condition once it has been established. In either case, prevention or treatment may be discerned in the diagnosis provided by a physician or other health care provider and the intended result of administration of the therapeutic agent.

As shown herein, BMP9 or BMP10 polypeptides, optionally combined with an EPO receptor activator, may be used to increase red blood cell, hemoglobin or reticulocyte levels in healthy individuals, and such BMP9 or BMP10 polypeptides may be used in selected patient populations. Examples of appropriate patient populations include those with undesirably low red blood cell or hemoglobin levels, such as patients having an anemia, and those that are at risk for developing undesirably low red blood cell or hemoglobin levels, such as those patients that are about to undergo major surgery or other procedures that may result in substantial blood loss. In one embodiment, a patient with adequate red blood cell levels is treated with a BMP9 or BMP10 polypeptide to increase red blood cell levels, and then blood is drawn and stored for later use in transfusions.

BMP9 or BMP10 polypeptides, optionally combined with an EPO receptor activator, disclosed herein may be used to increase red blood cell levels in patients having an anemia. When observing hemoglobin levels in humans, a level of less than normal for the appropriate age and gender category may be indicative of anemia, although individual variations are taken into account. For example, a hemoglobin level of 12 g/dl is generally considered the lower limit of normal in the general adult population. Potential causes include blood-loss, nutritional deficits, medication reaction, various problems with the bone marrow and many diseases. More particularly, anemia has been associated with a variety of disorders that

include, for example, chronic renal failure, myelodysplastic syndrome, rheumatoid arthritis, bone marrow transplantation. Anemia may also be associated with the following conditions: solid tumors (e.g. breast cancer, lung cancer, colon cancer); tumors of the lymphatic system (e.g. chronic lymphocyte leukemia, non-Hodgkins and Hodgkins lymphomas); tumors of the hematopoietic system (e.g. leukemia, myelodysplastic syndrome, multiple myeloma); radiation therapy; chemotherapy (e.g. platinum containing regimens); inflammatory and autoimmune diseases, including, but not limited to, rheumatoid arthritis, other inflammatory arthritides, systemic lupus erythematosis (SLE), acute or chronic skin diseases (e.g. psoriasis), inflammatory bowel disease (e.g. Crohn's disease and ulcerative colitis); acute or chronic renal disease or failure including idiopathic or congenital conditions; acute or chronic liver disease; acute or chronic bleeding; situations where transfusion of red blood cells is not possible due to patient allo- or auto-antibodies and/or for religious reasons (e.g. some Jehovah's Witnesses); infections (e.g. malaria, osteomyelitis); hemoglobinopathies, including, for example, sickle cell disease, thalassemias; drug use or abuse, e.g. alcohol misuse; pediatric patients with anemia from any cause to avoid transfusion; and elderly patients or patients with underlying cardiopulmonary disease with anemia who cannot receive transfusions due to concerns about circulatory overload.

BMP9 or BMP10 polypeptides, optionally combined with an EPO receptor activator, would be appropriate for treating anemias of hypoproliferative bone marrrow, which are typically associated with little change in red blood cell (RBC) morphology. Hypoproliferative anemias include: 1) anemia of chronic disease, 2) anemia of kidney disease, and 3) anemia associated with hypometabolic states. In each of these types, endogenous erythropoietin levels are *inappropriately low* for the degree of anemia observed. Other hypoproliferative anemias include: 4) early-stage iron-deficient anemia, and 5) anemia caused by damage to the bone marrow. In these types, endogenous erythropoietin levels are *appropriately elevated* for the degree of anemia observed.

The most common type of anemia is anemia of chronic disease, which encompasses inflammation, infection, tissue injury, and conditions such as cancer, and is distinguished by both low erythropoietin levels and an inadequate response to erythropoietin in the bone marrow (Adamson, 2008, Harrison's Principles of Internal Medicine, 17th ed.; McGraw Hill, New York, pp 628-634). Many factors can contribute to cancer-related anemia. Some are associated with the disease process itself and the generation of inflamatory cytokines such as interleukin-1, interferon-gamma, and tumor necrosis factor (Bron et al., 2001, Semin Oncol

28(Suppl 8):1-6). Among its effects, inflammation induces the key iron-regulatory peptide hepcidin, thereby inhibiting iron export from macrophages and generally limiting iron availability for erythropoiesis (Ganz, 2007, J Am Soc Nephrol 18:394-400). Blood loss through various routes can also contribute to cancer-related anemia. The prevalence of anemia due to cancer progression varies with cancer type, ranging from 5% in prostate cancer up to 90% in multiple myeloma. Cancer-related anemia has profound consequences for patients, including fatigue and reduced quality of life, reduced treatment efficacy, and increased mortality.

Chronic kidney disease is associated with hypoproliferative anemia that varies in severity with the degree of renal impairment. Such anemia is primarily due to inadequate production of erythropoietin and reduced survival of red blood cells. Chronic kidney disease usually proceeds gradually over a period of years or decades to end-stage (Stage-5) disease, at which point dialysis or kidney transplantation is required for patient survival. Anemia often develops early in this process and worsens as disease progresses. The clinical consequences of anemia of kidney disease are well-documented and include development of left ventricular hypertrophy, impaired cognitive function, reduced quality of life, and altered immune function (Levin et al., 1999, Am J Kidney Dis 27:347-354; Nissenson, 1992, Am J Kidney Dis 20(Suppl 1):21-24; Revicki et al., 1995, Am J Kidney Dis 25:548-554; Gafter et al., 1994, Kidney Int 45:224-231). A BMP9 or BMP10 polypeptide, optionally combined with an EPO receptor activator, can be used to treat anemia of kidney disease.

Many conditions resulting in a hypometabolic rate can produce a mild-to-moderate hypoproliferative anemia. Among such conditions are endocrine deficiency states. For example, anemia can occur in Addison's disease, hypothyroidism, hyperparathyroidism, or males who are castrated or treated with estrogen. Mild-to-moderate anemia can also occur with reduced dietary intake of protein, a condition particularly prevalent in the elderly. Finally, anemia can develop in patients with chronic liver disease arising from nearly any cause (Adamson, 2008, Harrison's Principles of Internal Medicine, 17th ed.; McGraw Hill, New York, pp 628-634).

Anemia resulting from acute blood loss of sufficient volume, such as from trauma or postpartum hemorrhage, is known as acute post-hemorrhagic anemia. Acute blood loss initially causes hypovolemia without anemia since there is proportional depletion of RBCs along with other blood constituents. However, hypovolemia will rapidly trigger physiologic mechanisms that shift fluid from the extravascular to the vascular compartment, which results

in hemodilution and anemia. If chronic, blood loss gradually depletes body iron stores and eventually leads to iron deficiency. A BMP9 or BMP10 polypeptide, optionally combined with an EPO receptor activator, can be used to speed recovery from anemia of acute blood loss.

Iron-deficiency anemia is the final stage in a graded progression of increasing iron deficiency which includes negative iron balance and iron-deficient erythropoiesis as intermediate stages. Iron deficiency can result from increased iron demand, decreased iron intake, or increased iron loss, as exemplified in conditions such as pregnancy, inadequate diet, intestinal malabsorption, acute or chronic inflammation, and acute or chronic blood loss. With mild-to-moderate anemia of this type, the bone marrow remains hypoproliferative, and RBC morphology is largely normal; however, even mild anemia can result in some microcytic hypochromic RBCs, and the transition to severe iron-deficient anemia is accompanied by *hyper*proliferation of the bone marrow and increasingly prevalent microcytic and hypochromic RBCs (Adamson, 2008, Harrison's Principles of Internal Medicine, 17th ed.; McGraw Hill, New York, pp 628-634). Appropriate therapy for iron-deficiency anemia depends on its cause and severity, with oral iron preparations, parenteral iron formulations, and RBC transfusion as major conventional options. A BMP9 or BMP10 polypeptide, optionally combined with an EPO receptor activator, could be used to treat chronic iron-deficiency anemias alone or in combination with conventional therapeutic approaches, particularly to treat anemias of multifactorial origin.

Hypoproliferative anemias can result from primary dysfunction or failure of the bone marrow, instead of dysfunction secondary to inflammation, infection, or cancer progression. Prominent examples would be myelosuppression caused by cancer chemotherapeutic drugs or cancer radiation therapy. A broad review of clinical trials found that mild anemia can occur in 100% of patients after chemotherapy, while more severe anemia can occur in up to 80% of such patients (Groopman et al., 1999, J Natl Cancer Inst 91:1616-1634). Myelosuppressive drugs include: 1) alkylating agents such as nitrogen mustards (e.g., melphalan) and nitrosoureas (e.g., streptozocin); 2) antimetabolites such as folic acid antagonists (e.g., methotrexate), purine analogs (e.g., thioguanine), and pyrimidine analogs (e.g., gemcitabine); 3) cytotoxic antibotics such as anthracyclines (e.g., doxorubicin); 4) kinase inhibitors (e.g., gefitinib); 5) mitotic inhibitors such as taxanes (e.g., paclitaxel) and vinca alkaloids (e.g., vinorelbine); 6) monoclonal antibodies (e.g., rituximab); and 7) topoisomerase inhibitors (e.g., topotecan and etoposide). A BMP9 or BMP10 polypeptide, optionally combined with

an EPO receptor activator, can be used to treat anemia caused by chemotherapeutic agents and/or radiation therapy.

BMP9 or BMP10 polypeptides, optionally combined with an EPO receptor activator, would also be appropriate for treating anemias of disordered RBC maturation, which are characterized in part by undersized (microcytic), oversized (macrocytic), misshapen, or abnormally colored (hypochromic) RBCs.

Patients may be treated with a dosing regimen intended to restore the patient to a target hemoglobin level, usually between about 10 g/dl and about 12.5 g/dl, and typically about 11.0 g/dl (see also Jacobs et al. (2000) Nephrol Dial Transplant 15, 15-19), although lower target levels may cause fewer cardiovascular side effects. Alternatively, hematocrit levels (percentage of the volume of a blood sample occupied by the cells) can be used as a measure for the condition of red blood cells. Hematocrit levels for healthy individuals range from 41 to 51% for adult males and from 35 to 45% for adult females. Target hematocrit levels are usually around 30-33%. Moreover, hemoglobin/hematocrit levels vary from person to person. Thus, optimally, the target hemoglobin/hematocrit level can be individualized for each patient.

In certain embodiments, the present invention provides methods for managing a patient that has been treated with, or is a candidate to be treated with, a BMP9 or BMP10 polypeptide by measuring one or more hematologic parameters in the patient. The hematologic parameters may be used to evaluate appropriate dosing for a patient who is a candidate to be treated with a BMP9 or BMP10 polypeptide, to monitor the hematologic parameters during treatment with a BMP9 or BMP10 polypeptide, to evaluate whether to adjust the dosage during treatment with a BMP9 or BMP10 polypeptide, and/or to evaluate an appropriate maintenance dose of a BMP9 or BMP10 polypeptide. If one or more of the hematologic parameters are outside the normal level, dosing with a BMP9 or BMP10 polypeptide may be reduced, delayed or terminated.

Hematologic parameters that may be measured in accordance with the methods provided herein include, for example, red blood cell levels, blood pressure, iron stores, and other agents found in bodily fluids that correlate with increased red blood cell levels, using art recognized methods. Such parameters may be determined using a blood sample from a patient. Increases in red blood cell levels, hemoglobin levels, and/or hematocrit levels may cause increases in blood pressure.

In one embodiment, if one or more hematologic parameters are outside the normal range, or on the high side of normal, in a patient who is a candidate to be treated with a BMP9 or BMP10 polypeptide then onset of administration of the polypeptide may be delayed until the hematologic parameters have returned to a normal or acceptable level either naturally or via therapeutic intervention. For example, if a candidate patient is hypertensive or prehypertensive, then the patient may be treated with a blood pressure lowering agent in order to reduce the patient's blood pressure. Any blood pressure lowering agent appropriate for the individual patient's condition may be used including, for example, diuretics, adrenergic inhibitors (including alpha blockers and beta blockers), vasodilators, calcium channel blockers, angiotensin-converting enzyme (ACE) inhibitors, or angiotensin II receptor blockers. Blood pressure may alternatively be treated using a diet and exercise regimen. Similarly, if a candidate patient has iron stores that are lower than normal, or on the low side of normal, then the patient may be treated with an appropriate regimen of diet and/or iron supplements until the patient's iron stores have returned to a normal or acceptable level. For patients having higher than normal red blood cell levels and/or hemoglobin levels, then administration of the BMP9 or BMP10 polypeptide may be delayed until the levels have returned to a normal or acceptable level.

In certain embodiments, if one or more hematologic parameters are outside the normal range, or on the high side of normal, in a patient who is a candidate to be treated with a BMP9 or BMP10 polypeptide then the onset of administration may be delayed. However, the dosage amount or frequency of dosing of the BMP9 or BMP10 polypeptide may be set at an amount that would reduce the risk of an unacceptable increase in the hematologic parameters arising upon administration of the BMP9 or BMP10 polypeptide. Alternatively, a therapeutic regimen may be developed for the patient that combines a BMP9 or BMP10 polypeptide with a therapeutic agent that addresses the undesirable level of the hematologic parameter. For example, if the patient has elevated blood pressure, or the BMP9 or BMP10 polypeptide appears to be causing elevated blood pressure, then a therapeutic regimen involving administration of a BMP9 or BMP10 polypeptide and a blood pressure lowering agent may be designed. For a patient having lower than desired iron stores, a therapeutic regimen of a BMP9 or BMP10 polypeptide and iron supplementation may be developed.

In one embodiment, baseline parameter(s) for one or more hematologic parameters may be established for a patient who is a candidate to be treated with a BMP9 or BMP10 polypeptide and an appropriate dosing regimen establish for that patient based on the baseline

value(s). Alternatively, established baseline parameters based on a patient's medical history could be used to inform an appropriate BMP9 or BMP10 polypeptide dosing regimen for a patient. For example, if a healthy patient has an established baseline blood pressure reading that is above the defined normal range it may not be necessary to bring the patient's blood pressure into the range that is considered normal for the general population prior to treatment with the BMP9 or BMP10 polypeptide. A patient's baseline values for one or more hematologic parameters prior to treatment with a BMP9 or BMP10 polypeptide may also be used as the relevant comparative values for monitoring any changes to the hematologic parameters during treatment with the BMP9 or BMP10 polypeptide.

In certain embodiments, one or more hematologic parameters are measured in patients who are being treated with a BMP9 or BMP10 polypeptide. The hematologic parameters may be used to monitor the patient during treatment and permit adjustment or termination of the dosing with the BMP9 or BMP10 polypeptide or additional dosing with another therapeutic agent. For example, if administration of a BMP9 or BMP10 polypeptide results in an increase in blood pressure, red blood cell level, or hemoglobin level, or a reduction in iron stores, then the dose of the BMP9 or BMP10 polypeptide may be reduced in amount or frequency in order to decrease the effects of the BMP9 or BMP10 polypeptide on the one or more hematologic parameters. If administration or a BMP9 or BMP10 polypeptide results in a change in one or more hematologic parameters that is adverse to the patient, then the dosing of the BMP9 or BMP10 polypeptide may be terminated either temporarily, until the hematologic parameter(s) return to an acceptable level, or permanently. Similarly, if one or more hematologic parameters are not brought within an acceptable range after reducing the dose or frequency of administration of the BMP9 or BMP10 polypeptide then the dosing may be terminated. As an alternative, or in addition to, reducing or terminating the dosing with the BMP9 or BMP10 polypeptide, the patient may be dosed with an additional therapeutic agent that addresses the undesirable level in the hematologic parameter(s), such as, for example, a blood pressure lowering agent or an iron supplement. For example, if a patient being treated with a BMP9 or BMP10 polypeptide has elevated blood pressure, then dosing with the BMP9 or BMP10 polypeptide may continue at the same level and a blood pressure lowering agent is added to the treatment regimen, dosing with the BMP9 or BMP10 polypeptide may be reduce (e.g., in amount and/or frequency) and a blood pressure lowering agent is added to the treatment regimen, or dosing with the BMP9 or BMP10 polypeptide may be terminated and the patient may be treated with a blood pressure lowering agent.

4. Pharmaceutical Preparations

In certain embodiments, BMP9 or BMP10 polypeptides of the present invention are formulated with a pharmaceutically acceptable carrier. For example, a BMP9 or BMP10 polypeptide can be administered alone or as a component of a pharmaceutical preparation. The subject compounds may be formulated for administration in any convenient way for use in human or veterinary medicine. As noted above, it may be desirable to prepare a BMP9 or BMP10 polypeptide in a formulation comprising a prodomain polypeptide.

In certain embodiments, the therapeutic method of the invention includes administering the preparation systemically, or locally as an implant or device. When administered, the pharmaceutical preparation for use in this invention is, of course, in a pyrogen-free, physiologically acceptable form. Therapeutically useful agents other than the BMP9 or BMP10 polypeptides which may also optionally be included in the preparation as described above, may be administered simultaneously or sequentially with the subject BMP9 or BMP10 polypeptides.

Typically, compounds will be administered parenterally. Pharmaceutical preparations suitable for parenteral administration may comprise one or more BMP9 or BMP10 polypeptides in combination with one or more pharmaceutically acceptable sterile isotonic aqueous or nonaqueous solutions, dispersions, suspensions or emulsions, or sterile powders (e.g., lyophilates) which may be reconstituted into sterile injectable solutions or dispersions just prior to use, which may contain antioxidants, buffers, bacteriostats, solutes which render the formulation isotonic with the blood of the intended recipient or suspending or thickening agents. Examples of suitable aqueous and nonaqueous carriers which may be employed in the pharmaceutical compositions of the invention include water, sugars, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), and suitable mixtures thereof, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate.

Further, the preparation may be encapsulated or injected in a form for delivery to a target tissue site. In certain embodiments, preparations of the present invention may include a matrix capable of delivering one or more therapeutic compounds (e.g., BMP9 or BMP10 polypeptides) to a target tissue site, providing a structure for the developing tissue and optimally capable of being resorbed into the body. For example, the matrix may provide

slow release of the BMP9 or BMP10 polypeptides. Such matrices may be formed of materials presently in use for other implanted medical applications.

The choice of matrix material is based on biocompatibility, biodegradability, mechanical properties, cosmetic appearance and interface properties. The particular application of the subject compositions will define the appropriate formulation. Potential matrices for the compositions may be biodegradable and chemically defined calcium sulfate, tricalciumphosphate, hydroxyapatite, polylactic acid and polyanhydrides. Other potential materials are biodegradable and biologically well defined, such as bone or dermal collagen. Further matrices are comprised of pure proteins or extracellular matrix components. Other potential matrices are non-biodegradable and chemically defined, such as sintered hydroxyapatite, bioglass, aluminates, or other ceramics. Matrices may be comprised of combinations of any of the above mentioned types of material, such as polylactic acid and hydroxyapatite or collagen and tricalciumphosphate. The bioceramics may be altered in composition, such as in calcium-aluminate-phosphate and processing to alter pore size, particle size, particle shape, and biodegradability.

It is understood that the dosage regimen will be determined by the attending physician considering various factors which modify the action of the BMP9 or BMP10 polypeptides. The various factors include, but are not limited to, the patient's red blood cell count, hemoglobin level, systolic or diastolic blood pressure or other diagnostic assessments, the desired target red blood cell count, the patient's age, sex, and diet, the severity of any disease that may be contributing to a depressed red blood cell level, time of administration, and other clinical factors. The addition of other known growth factors to the final composition may also affect the dosage. Progress can be monitored by periodic assessment of red blood cell and hemoglobin levels, as well as assessments of reticulocyte levels and other indicators of the hematopoietic process.

In certain embodiments, the present invention also provides gene therapy for the *in vivo* production of BMP9 or BMP10 polypeptides. Such therapy would achieve its therapeutic effect by introduction of the BMP9 or BMP10 polynucleotide sequences into cells or tissues having the disorders as listed above. Delivery of BMP9 or BMP10 polynucleotide sequences can be achieved using a recombinant expression vector such as a chimeric virus or a colloidal dispersion system. Preferred for therapeutic delivery of BMP9 or BMP10 polynucleotide sequences is the use of targeted liposomes.

Various viral vectors which can be utilized for gene therapy as taught herein include adenovirus, herpes virus, vaccinia, or an RNA virus such as a retrovirus. The retroviral vector may be a derivative of a murine or avian retrovirus. Examples of retroviral vectors in which a single foreign gene can be inserted include, but are not limited to: Moloney murine leukemia virus (MoMuLV), Harvey murine sarcoma virus (HaMuSV), murine mammary tumor virus (MuMTV), and Rous Sarcoma Virus (RSV). A number of additional retroviral vectors can incorporate multiple genes. All of these vectors can transfer or incorporate a gene for a selectable marker so that transduced cells can be identified and generated. Retroviral vectors can be made target-specific by attaching, for example, a sugar, a glycolipid, or a protein. Preferred targeting is accomplished by using an antibody. Those of skill in the art will recognize that specific polynucleotide sequences can be inserted into the retroviral genome or attached to a viral envelope to allow target specific delivery of the retroviral vector containing the BMP9 or BMP10 polynucleotide.

EXEMPLIFICATION

The invention now being generally described, it will be more readily understood by reference to the following examples, which are included merely for purposes of illustration of certain embodiments and embodiments of the present invention, and are not intended to limit the invention.

Example 1. Generation of a BMP9 or BMP10 Polypeptide

BMP9 or BMP10 may be purchased from a commercial supplier, such as R&D Systems (Minneapolis, Minnesota). Alternatively, a protocol such as the following may be followed:

A human BMP-9 (bBMP9) cDNA construct was generated by replacing the native signal sequence of BMP-9 with the signal sequence of tissue plasminogen activator (tPA) or another signal sequence. Examples of leader sequences:

(i) Honey bee melittin (HBML): MKFLVNVALVFMVVYISYIYA (SEQ ID NO: 14)

(ii) Tissue Plasminogen Activator (TPA): MDAMKRGLCCVLLLCGAVFVSP (SEQ ID NO: 15)

The DNA sequence encoding the tPA signal sequence was fused in-frame with the DNA sequence encoding the propeptide/mature region of BMP-9. This cDNA sequence was cloned into the pAID4 vector to encode a protein with the following unprocessed sequence:

```
1       MDAMKRGLCC VLLLCGAVFV SPGAKPLQSW GRGSAGGNAH SPLGVPGGGL
51      PEHTFNLKMF LENVKVDFLR SLNLSGVPSQ DKTRVEPPQY MIDLYNRYTS
101     DKSTTPASNI VRSFSMEDAI SITATEDFPF QKHILLFNIS IPRHEQITRA
151     ELRLYVSCQN HVDPSHDLKG SVVIYDVLDG TDAWDSATET KTFLVSQDIQ
201     DEGWETLEVS SAVKRWVRSD STKSKNKLEV TVESHRKGCD TLDISVPPGS
251     RNLPFFVVFS NDHSSGTKET RLELREMISH EQESVLKKLS KDGSTEAGES
301     SHEEDTDGHV AAGSTLARRK RSAGAGSHCQ KTSLRVNFED IGWDSWIIAP
351     KEYEAYECKG GCFFPLADDV TPTKHAIVQT LVHLKFPTKV GKACCVPTKL
401     SPISVLYKDD MGVPTLKYHY EGMSVAECGC R (SEQ ID NO:16)
```

A BMP10 polypeptide expression cassette may be similarly produced:

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1       MDAMKRGLCC VLLLCGAVFV SPGASPIMNL EQSPLEEDMS LFGDVFSEQD GVDFNTLLQS
61      MKDEFLKTLN LSDIPTQDSA KVDPPEYMLE LYNKFATDRT SMPSANIIRS FKNEDLFSQP
121     VSFNGLRKYP LLFNVSIPHH EEVIMAELRL YTLVQRDRMI YDGVDRKITI FEVLESKGDN
181     EGERNMLVLV SGEIYGTNSE WETFDVTDAI RRWQKSGSST HQLEVHIESK HDEAEDASSG
241     RLEIDTSAQN KHNPLLIVFS DDQSSDKERK EELNEMISHE QLPELDNLGL DSFSSGPGEE
301     ALLQMRSNII YDSTARIRRN AKGNYCKRTP LYIDFKEIGW DSWIIAPPGY EAYECRGVCN
361     YPLAEHLTPT KHAIIQALVH LKNSQKASKA CCVPTKLEPI SILYLDKGVV TYKFKYEGMA
421    VSECGCR  (SEQ. ID. NO:17)
```

BMP-9 constructs were be transfected into a CHO DUKX B11 cell line that has been engineered to express a soluble (secreted) form of PACE (Furin)(Genbank No. P09958). Co-expression of PACE facilitates propeptide cleavage of BMPs. Clones were selected in 10nM methotrexate (MTX) followed by amplification in 50nM MTX to increase expression. A high expressing clone was identified by dilution cloning and adapted to serum-free suspension growth to generate conditioned media for purification. Optionally, a ubiquitous chromatin opening element (UCOE) may be included in the vector to facilitate expression. See, e.g., Cytotechnology. 2002 Jan;38(1-3):43-6.

Affinity purification was achieved by passage over an affinity column prepared by loading and cross-linking a protein A column (MAb SelectSure, GE Healthcare Life Sciences) with an altered ActRIIb-Fc fusion protein having the following sequence:

```
1   ETRECIYYNA NWELERTNQS GLERCEGEQD KRLHCYASWR NSSGTIELVK
51  KGCWDDDFNC YDRQECVATE ENPQVYFCCC EGNFCNERFT HLPEAGGPEV
```

101 TYEPPPTGGG THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV

151 VVDVSHEDPE VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD

201 WLNGKEYKCK VSNKALPAPI EKTISKAKGQ PREPQVYTLP PSREEMTKNQ

251 VSLTCLVKGF YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV

301 DKSRWQQGNV FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 18)

BMP-9 protein was eluted from the column with 0.1M glycine, pH 3.0. BMP10 may be prepared in the same manner. In the event that BMP9 or BMP10 is purified as a mixed solution of covalent and non-covalent dimers, the covalent and non-covalent forms may be separated using a reverse phase HPLC, such as a Vydac C4 column eluted with a gradient of 0 to 100% acetonitrile in the presence of 0.1% trifluoroacetic acid. Covalent/non-covalent dimer content may be assessed by comparison of reducing and non-reducing SDS-PAGE.

Example 2. Administration of BMP9 to Wild-type Mice

To explore the effects of BMP9 on erythropoiesis, 10 C57BL/6 mice were randomized (2 groups, 5 animals per group) to receive two doses of vehicle control (TBS containing 0.8mM HCl and 0.1%BSA), or BMP9 (10 mg/kg) once daily for two days by intraperitoneal injection. Blood samples were taken via tail vein on the study termination date. At 48 hours post treatment whole blood was obtained to determine complete blood counts (CBCs).

BMP9 increased RBC number, Hemoglobin (HGB) level and Hematocrit (HCT) by 32%, 34% and 31%, respectively, compared to vehicle control suggesting that BMP9 treatments results in increased red blood cells. There were no substantial effects on white blood cells or other blood parameters.

This study demonstrated that BMP9 has a profound, selective and rapid effect in increasing levels of red blood cells in the bloodstream, as measured by erythrocyte count, hemoglobin level and hematocrit.

INCORPORATION BY REFERENCE

All publications and patents mentioned herein are hereby incorporated by reference in their entirety as if each individual publication or patent was specifically and individually indicated to be incorporated by reference.

While specific embodiments of the subject matter have been discussed, the above specification is illustrative and not restrictive. Many variations will become apparent to those skilled in the art upon review of this specification and the claims below. The full scope of the invention should be determined by reference to the claims, along with their full scope of equivalents, and the specification, along with such variations.

We Claim:

1. A method for increasing red blood cell levels or treating anemia in a patient, the method comprising administering to a patient in need thereof a polypeptide selected from the group consisting of a BMP9 polypeptide and a BMP10 polypeptide.

2. The method of claim 1, wherein the polypeptide is a BMP9 polypeptide.

3. The method of claim 2, wherein the BMP9 polypeptide comprises an amino acid sequence that is at least 63% identical to the sequence of SEQ ID NO. 3.

4. The method of claim 2, wherein the BMP9 polypeptide comprises an amino acid sequence that is encoded by a nucleic acid that hybridizes under stringent hybridization conditions to the a nucleic acid that is complementary to the sequence of nucleotides 1121-1450 of SEQ ID NO: 11.

5. The method of claim 2, wherein the BMP9 polypeptide comprises an amino acid sequence that is identical to the sequence of SEQ ID NO.3.

6. The method of claim 1, wherein the polypeptide is a BMP10 polypeptide.

7. The method of claim 6, wherein the BMP10 polypeptide comprises an amino acid sequence that is at least 63% identical to the sequence of SEQ ID NO. 6.

8. The method of claim 6, wherein the BMP10 polypeptide comprises an amino acid sequence that is encoded by a nucleic acid that hybridizes under stringent hybridization conditions to the a nucleic acid that is complementary to the sequence of nucleotides 1108-1431 of SEQ ID NO: 12.

9. The method of claim 6, wherein the BMP10 polypeptide comprises an amino acid sequence that is identical to the sequence of SEQ ID NO.6.

10. The method of any of claims 1-9, wherein the BMP9 polypeptide or BMP10 polypeptide is administered in a pharmaceutical preparation.

11. The method of claim 10, wherein the pharmaceutical preparation comprises a prodomain polypeptide selected from the group consisting of a BMP9 prodomain polypeptide and a BMP10 prodomain polypeptide.

12. The method of claim 11, wherein the prodomain polypeptide is a BMP9 prodomain polypeptide.

13. The method of claim 12, wherein the prodomain polypeptide comprises an amino acid sequence that is at least 80% identical to the sequence of amino acids 23-319 of SEQ ID NO. 1.

14. The method of claim 12, wherein the prodomain polypeptide comprises the amino acid sequence of amino acids 23-319 of SEQ ID NO. 1.

15. The method of claim 12, wherein the pharmaceutical preparation comprises a BMP9 polypeptide noncovalently associated with the BMP9 prodomain polypeptide.

16. The method of claim 12, wherein the pharmaceutical preparation comprises a BMP10 polypeptide noncovalently associated with the BMP9 prodomain polypeptide.

17. The method of claim 11, wherein the prodomain polypeptide is a BMP10 prodomain polypeptide.

18. The method of claim 17, wherein the prodomain polypeptide comprises an amino acid sequence that is at least 80% identical to the sequence of amino acids 22-316 of SEQ ID NO. 4.

19. The method of claim 17, wherein the prodomain polypeptide comprises the amino acid sequence of amino acids 22-316 of SEQ ID NO. 4.

20. The method of any of claims 1-19, wherein the patient has anemia associated with chronic kidney disease.

21. The method of any of claims 1-19, wherein the patient has anemia associated with a chemotherapy treatment.

22. The method of any of claims 1-19, wherein the chemotherapy treatment is a taxane.

23. The method of any of claims 1-19, wherein the patient has anemia as a consequence of blood loss.

24. A pharmaceutical preparation comprising a BMP polypeptide and a prodomain polypeptide, wherein the BMP polypeptide is selected from the group consisting of: a

BMP9 polypeptide and a BMP10 polypeptide, and wherein the prodomain polypeptide is selected from the group consisting of a BMP9 prodomain polypeptide and a BMP10 prodomain polypeptide.

25. The pharmaceutical preparation of claim 24, wherein a substantial portion of the BMP polypeptide is noncovalently associated with the prodomain polypeptide.

26. The pharmaceutical preparation of claim 24, wherein the BMP polypeptide is a BMP9 polyepeptide.

27. The pharmaceutical preparation of claim 26, wherein the BMP9 polypeptide comprises an amino acid sequence that is at least 63% identical to the sequence of SEQ ID NO. 3.

28. The pharmaceutical preparation of claim 26, wherein the BMP9 polypeptide comprises an amino acid sequence that is encoded by a nucleic acid that hybridizes under stringent hybridization conditions to the a nucleic acid that is complementary to the sequence of nucleotides 1121-1450 of SEQ ID NO: 11.

29. The pharmaceutical preparation of claim 26, wherein the BMP9 polypeptide comprises an amino acid sequence that is identical to the sequence of SEQ ID NO.3.

30. The pharmaceutical preparation of claim 24, wherein the polypeptide is a BMP10 polypeptide.

31. The pharmaceutical preparation of claim 30, wherein the BMP10 polypeptide comprises an amino acid sequence that is at least 63% identical to the sequence of SEQ ID NO. 6.

32. The pharmaceutical preparation of claim 30, wherein the BMP10 polypeptide comprises an amino acid sequence that is encoded by a nucleic acid that hybridizes under stringent hybridization conditions to the a nucleic acid that is complementary to the sequence of nucleotides 1108-1431 of SEQ ID NO: 12.

33. The pharmaceutical preparation of claim 30, wherein the BMP10 polypeptide comprises an amino acid sequence that is identical to the sequence of SEQ ID NO.6.

34. The pharmaceutical preparation of any of claims 25-33, wherein the prodomain polypeptide is a BMP9 prodomain polypeptide.

35. The pharmaceutical preparation of claim 34, wherein the prodomain polypeptide comprises an amino acid sequence that is at least 80% identical to the sequence of amino acids 23-319 of SEQ ID NO. 1.

36. The pharmaceutical preparation of claim 34, wherein the prodomain polypeptide comprises the amino acid sequence of amino acids 23-319 of SEQ ID NO. 1.

37. The pharmaceutical preparation of any of claims 25-33, wherein the prodomain polypeptide is a BMP10 prodomain polypeptide.

38. The pharmaceutical preparation of claim 37, wherein the prodomain polypeptide comprises an amino acid sequence that is at least 80% identical to the sequence of amino acids 22-316 of SEQ ID NO. 4.

39. The pharmaceutical preparation of claim 37, wherein the prodomain polypeptide comprises the amino acid sequence of amino acids 22-316 of SEQ ID NO. 4.

BMP9 Multiple Sequence Alignment

```
human      MCPGALWVALPLLSLLAGSLQGKPLQSWGRGSAGGNAHSPLGVPGGGLPEHTFNLKMFLE 60
murine     MSPGAFRVALLPLFLLVCVTQQKPLQNWEQASPGENAHSSLGLSGAGE-EGVFDLQMFLE 59
chicken    MHYFGVLAALSVFNIIACLTRGKPLENWKKLPVMEESDAFFHDPGEVEHDTHFDFKSFLE 60
           *    .. .**  : ::.   : ***:.* : .   ::.: :  .*    :  *::: ***

human      NVKVDFLRSLNLSGVPSQDKTRVEPPQYMIDLYNRYTSDKSTTPASNIVRSFSMEDAISI 120
murine     NMKVDFLRSLNLSGIPSQDKTRAEPPQYMIDLYNRYTTDKSSTPASNIVRSFSVEDAIST 119
chicken    NMKTDLLRSLNLSRVPSQVKTKEEPPQFMIDLYNRYTADKSSIPASNIVRSFSTEDVVSL 120
           *:*.*:******* :*** **: ****:*********:***: ********** **.:*

human      TATEDFPFQKHILLFNISIPRHEQITRAELRLYVSCQNHVDPSHDLKGSVVIYDVLDGTD 180
murine     AATEDFPFQKHILIFNISIPRHEQITRAELRLYVSCQNDVDSTHGLEGSMVVYDVLEDSE 179
chicken    ISPEEHSFQKHILLFNISIPRYEEVTRAELRIFISCHKEVGSPSRLEGNMVIYDVLDG-D 179
            :.*:..*****:*******:*:******:::**::.*...  *:*.:*:****:. :

human      AWDSATETKTFLVSQDIQDEGWETLEVSSAVKRWVRSDSTKSKNKLEVTVESHRKG---C 237
murine     TWDQATGTKTFLVSQDIRDEGWETLEVSSAVKRWVRADSTTNKNKLEVTVQSHRES---C 236
chicken    HWENKESTKSLLVSHSIQDCGWEMFEVSSAVKRWVKADKMKTKNKLEVVIESKDLSGFPC 239
            *:.    **::***:.*:* *** :*********::*. ..******.::*:  .   *

human      DTLDISVPPGSRNLPFFVVFSNDHSSGTKETRLELREMISHEQESVLKKLSKDGSTEAGE 297
murine     DTLDISVPPGSKNLPFFVVFSNDRSNGTKETRLELKEMIGHEQETMLVKTAKNAYQVAGE 296
chicken    GKLDITVTHDTKNLPLLIVFSNDRSNGTKETKVELREMIVHEQESVLNKLGKNDSSSEEE 299
           ..***:*. .::***:::****:*.*****::**:*** ****::* * .*:      *

human      SSHEEDTDGHVAAGSTLARRKRSAGAGSHCQKTSLRVNFEDIGWDSWIIAPKEYEAYECK 357
murine     SQEEEGLDGYTAVGPLLARRKRSTGASSHCQKTSLRVNFEDIGWDSWIIAPKEYDAYECK 356
chicken    QREEKAIARPRQHS---SRSKRSIGAN-HCRRTSLHVNFKEIGWDSWIIAPKDYEAFECK 355
           . .*:          .    :* *** **. **::***:***::***********:*:*:***

human      GGCFFPLADDVTPTKHAIVQTLVHLKFPTKVGKACCVPTKLSPISVLYKDDMGVPTLKYH 417
murine     GGCFFPLADDVTPTKHAIVQTLVHLKFPTKVGKACCVPTKLSPISILYKDDMGVPTLKYH 416
chicken    GGCFFPLTDNVTPTKHAIVQTLVHLQNPKKASKACCVPTKLDAISILYKDDAGVPTLIYN 415
           *******:*:**************: *.*..*********..**:***** ***** *:

human      YEGMSVAECGCR 429(SEQ. ID. NO:1)
murine     YEGMSVAECGCR 428(SEQ. ID. NO:7)
chicken    YEGMKVAECGCR 427(SEQ. ID. NO:8)
           ****.*******
```

Fig. 1

BMP10 Multiple Sequence Alignment

```
Human_BMP10       MGSLVLTLCALFCLAAYLVSGSPIMNLEQSPLEEDMSLFGDVFSEQDGVDFNTLLQSMKD
Murine_BMP10      MGSLVLPLSAVFCLVAHSASGSPIMGLEQSPLEEDMPFFDDIFTEQDGIDFNTLLQSMKN
Chicken_BMP10     MDSIVLQLWAGLCLLVHLATCSPILSLEHSSLEEGEPLFDEFLSEQDGVDFNTLLQNMKN
                  *.*:** * * :** .: .: ***:.**:*.***. .:*.:.::****:*******.**:

Human_BMP10       EFLKTLNLSDIPTQDSAKVDPPEYMLELYNKFATDRTSMPSANIIRSFKNEDLFSQPVSF
Murine_BMP10      EFLKTLNLSDIPVQDTGRVDPPEYMLELYNKFATDRTSMPSANIIRSFKNEDLFSQPVTF
Chicken_BMP10     EFLKTLNLSDIPLHESAKVDPPEYMLELYNKFATDRTSMPSANIIRSFKNEDLASHPVGV
                  ************ :::.:************************************ *:** .

Human_BMP10       NGLRKYPLLFNVSIPHHEEVIMAELRLYTLVQRDRMIYDGVDRKITIFEVLE-SKGDNEG
Murine_BMP10      NGLRKYPLLFNVSIPHHEEVVMAELRLYTLVQRDRMMYDGVDRKITIFEVLE-SADGSEE
Chicken_BMP10     IGVRKYPLLFNVSIPHHEEITMAELRLYTLVERDQMLYEGLDRKVTIFEVLENDHMGVGE
                   *:****************: **********:**:*:*:*:***:*******  .   .

Human_BMP10       ERNMLVLVSGEIYGTNSEWETFDVTDAIRRWQKSGSSTHQLEVHIESKHDEAEDASSGRL
Murine_BMP10      ERSMLVLVSTEIYGTNSEWETFDVTDATRRWQKSGPSTHQLEIHIESRQNQAEDTGRGQL
Chicken_BMP10     ERKIVALASRQIYGTSSEWESFEVTEAIRRWRRAGLTTHRLEVHIESREG-EEQNGEGKL
                  **.::.*.* :****.****:*:**:* ***:::* :**:**:****:..  *: . *:*

Human_BMP10       EIDTSAQNKHNPLLIVFSDDQSSD-KERKEELNEMISHEQLPELDNLGLDSFSSGPGEEA
Murine_BMP10      EIDMSAQNKHDPLLVVFSDDQSND-KEQKEELNELITHEQDLDLD---SDAFFSGPDEEA
Chicken_BMP10     DIDINSEAKHVPLLIVFSDDQSNDQKEEKQELNEMIDHEQLLDLENLEVGNFHGHPGEEA
                  :** .:: ** ***:*******.* **.*:****:* ***  :*:    . * . *.***

Human_BMP10       LLQMRSNIIYDSTARIRRNAKGNYCKRTPLYIDFKEIGWDSWIIAPPGYEAYECRGVCNY
Murine_BMP10      LLQMRSNMIDDSSARIRRNAKGNYCKKTPLYIDFKEIGWDSWIIAPPGYEAYECRGVCNY
Chicken_BMP10     LLQMRSNIIYDSTARIRRNAKGNYCKKTPLYIDFKEIGWDSWIIAPAGYEAYECHGVCAY
                  *******:* **:*************:******************.*******:*** *

Human_BMP10       PLAEHLTPTKHAIIQALVHLKNSQKASKACCVPTKLEPISILYLDKGVVTYKFKYEGMAV
Murine_BMP10      PLAEHLTPTKHAIIQALVHLKNSQKASKACCVPTKLDPISILYLDKGVVTYKFKYEGMAV
Chicken_BMP10     PLTEHVTPTKHAIVQTLVHLKNPQKASKACCVPTKLDPISILYMDAGVVTYKFKYEGMVV
                  **:**:*******:*:******.*************:******:* ************.*

Human_BMP10       SECGCR   (SEQ. ID. NO:4)
Murine_BMP10      SECGCR   (SEQ. ID. NO:9)
Chicken_BMP10     SECGCR   (SEQ. ID. NO:10)
                  ******
```

Fig. 2

Mature Human BMP-9 and BMP-10

```
bmp9    SAGAGSHCQK TSLRVNFEDI GWDSWIIAPK EYEAYECKGG CFFPLADDVT PTKHAIVQTL 60
bmp10   -NAKGNYCKR TPLYIDFKEI GWDSWIIAPP GYEAYECRGV CNYPLAEHLT PTKHAIIQAL 59
           . *.:*::: *.* ::*:*:* ********** *  :***:.:* ********:*:*

bmp9    VHLKFPTKVG KACCVPTKLS PISVLYKDDM GVPTLKYHYE GMSVAECGCR 110 (SEQ ID NO:3)
bmp10   VHLKNSQKAS KACCVPTKLE PISILYLD-K GVVTYKFKYE GMAVSECGCR 108 (SEQ ID NO:6)
        ***** . *.. ********** ***:** *    ** * *::*** **:*:******
```

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/035305

A. CLASSIFICATION OF SUBJECT MATTER

A61K 38/19 (2006.01) A61P 7/06 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPOQUE: databases EPODOC, WPID, Medline. Keywords: Bone morphogenetic protein [9,10], BMP_9, BMP_10, growth differentiation factor_2, GDF2, NP_057288, NP_055297, Red blood [cell, corpuscle], erythrocyte, an[ae,e]mia

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 June 2013	04 June 2013

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INTERNATIONAL SEARCH REPORT C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		International application No. **PCT/US2013/035305**
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/015383 A2 (UNIVERSITY COLLEGE CARDIFF CONSULTANTS LIMITED) 07 February 2008 see claims and SEQ ID NOs. 3 and 4	24 and 26-39
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INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/US2013/035305**

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INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/US2013/035305**

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End of Annex

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