STABILIZED RECEPTOR POLYPEPTIDES AND USES THEREOF

REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Application Serial No. 61/200,250, filed on November 26, 2008, and U.S. Provisional Application Serial No. 61/259,060, filed on November 6, 2009, the entire disclosures of which are relied upon and incorporated by reference herein.

TECHNICAL FIELD OF THE INVENTION

The technical field of this invention relates to transforming growth factor-β (TGF-β) family members and soluble TGF-β receptors with improved properties, as well as methods of modulating the activities of TGF-β family members for the treatment of various disorders.

BACKGROUND OF THE INVENTION

The transforming growth factor β (TGF-β) family of proteins includes the transforming growth factors-β (TGF-β), activins, bone morphogenic proteins (BMP), nerve growth factors (NGFs), brain-derived neurotrophic factor (BDNF), and growth/differentiation factors (GDFs). These family members are involved in the regulation of a wide range of biological processes including cell proliferation, differentiation, and other functions.

Growth/differentiation factor 8 (GDF-8), also referred to as myostatin, is a TGF-ß family member expressed for the most part in the cells of developing and adult skeletal muscle tissue. Myostatin appears to play an essential role in negatively controlling skeletal muscle growth (McPherron et al., Nature (London) 387, 83-90 (1997), Zimmers et al., Science 296:1486-1488 (2002)). Antagonizing myostatin has been shown to increase lean muscle mass in animals.

Another member of the TGF-β family of proteins is a related growth/differentiation factor, growth/differentiation factor 11 (GDF-11). GDF-11 has approximately 90 % sequence identity to the amino acid sequence of myostatin. GDF-11 has a role in the axial patterning in developing animals (Oh et al., Genes Dev 11:1812-26 (1997)), and also appears to play a role in skeletal muscle development and growth.

Activins A, B and AB are the homodimers and heterdimer respectively of two polypeptide chains, βA and βB (Vale et al., Nature 321, 776-779 (1986), Ling et al., Nature 321, 779-782 (1986)). Activins were originally discovered as gonadal peptides involved in the regulation of follicle stimulating hormone synthesis, and are now believed to be involved in the regulation of a number of biological activities. Activin A is a predominant form of activin.

Activin, myostatin, GDF-11 and other members of the TGF-β superfamily bind and signal through a combination of activin type II and activin type IIB receptors, both of which are transmembrane serine/threonine kinases (Harrison et al., J. Biol. Chem. 279, 28036-28044 (2004)). Cross-linking studies have determined that myostatin is capable of binding the activin type II receptors ActRIIA and ActRIIB *in vitro* (Lee et al., PNAS USA 98:9306-11 (2001)). There is also evidence that GDF-11 binds to both ActRIIA and ActRIIB (Oh et al., Genes Dev 16:2749-54 (2002)).

TGF-β protein expression is known to be associated with a variety of diseases and disorders. Therefore, therapeutic molecules capable of antagonizing several TGF-β proteins simultaneously may be particularly effective for treating these diseases and disorders.

Production of therapeutic proteins on a commercial scale requires proteins that can be efficiently expressed and purified without disruption of the integrity of the protein. Manufacturability can be described as the ability to express and purify a protein in a sufficiently efficient manner to allow for cost-effective production of the protein. In a commercial setting, manufacturability must be determined for each potential therapeutic protein. Although protein expression and purification processes can be optimized for a protein, manufacturability appears to be a function of the intrinsic properties of the protein as well. The present invention provides biologically active therapeutic proteins having improved manufacturability properties, capable of effectively antagonizing TGF-β proteins.

SUMMARY OF THE INVENTION

The present invention provides isolated proteins comprising stabilized human activin receptor IIB (designated svActRIIB) polypeptides capable of binding and inhibiting the activities of activin, GDF-11 and myostatin, and characterized by improved manufacturability properties. The stabilized ActRIIB polypeptides are

characterized by having amino acid substitutions at both positions 28 and 44 with respect to SEQ ID NO: 2.

In one embodiment, the isolated protein comprises a polypeptide having the sequence set forth in SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has the sequence set forth in amino acids 19 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has the sequence set forth in amino acids 23 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has the sequence set forth in amino acids 25 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has an amino acid sequence with at least 80 %, 85 %, 90 %, 95 %, 98 % or 99 % identity to any of the polypeptides above, wherein the polypeptide has single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the substitution of the above polypeptides at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

In another embodiment, the isolated protein comprises a stabilized activin IIB receptor polypeptide, wherein the polypeptide has the sequence set forth in the group consisting of SEQ ID NO: 4, 6, 12 and 14. In another embodiment the protein comprises a polypeptide having at least 80 % sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment the protein comprises a polypeptide having at least 90 %

sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment, the protein comprises a polypeptide having at least 95 % sequence identity to SEQ ID NO: 4, 6, 12, or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the substitution at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

In a further embodiment the svActRIIB protein further comprises a heterologous protein. In one embodiment, the heterologous protein is an Fc domain. In a further embodiment, the Fc domain is a human IgG Fc domain. In a further embodiment the heterologous protein is attached by a linker or a hinge linker peptide. In one embodiment, the linker or hinge linker is selected from group consisting of the amino acid sequences set forth in the group consisting of SEQ ID NO: 25, 27, 38, 40, 42, 44, 45, 46, 48, 49 and 50. In a further embodiment the hinge linkers set forth in SEQ ID NO: 27, 38, 40, 42, 44, 45, or 46 link the human IgG2 Fc (SEQ ID NO: 22) to an svActRIIB polypeptide. In another embodiment, the hinge linkers set forth in SEQ ID NO: 48, 49, or 50 link the human IgG1 Fc (SEQ ID NO: 23) or the modified IgG1 Fc (SEQ ID NO: 47) to an svActRIIB polypeptide.

In a further embodiment, the protein comprises a polypeptide having the sequence set forth in the group consisting of SEQ ID NO: 8, 10, 16 and 18. In another embodiment the protein comprises a polypeptide having at least 80 % sequence identity to SEQ ID NO: 8, 10, 16 or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment the protein comprises a polypeptide having at least 90 % sequence identity to SEQ ID NO: 8, 10, 16 or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment, the protein comprises a polypeptide having at least 95 % sequence identity to SEQ ID NO: 8, 10, 16, or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In a further embodiment, the substitution of

the above polypeptides at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

In a further embodiment, the protein comprises the polypeptides recited above, wherein the amino acid residue at position 64 is alanine.

In another aspect the present invention provides an isolated nucleic acid molecule comprising a polynucleotide encoding a stabilized ActRIIB polypeptide. In one embodiment, the polynucleotide encodes the polypeptide sequence set forth in SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes the polypeptide having the sequence set forth in amino acids 19 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes the polypeptide having the sequence set forth in amino acids 23 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes the polypeptide having the sequence set forth in amino acids 25 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes the a polypeptide having an amino acid sequence at least 80 %, 85 %, 90 %, 95 %, 98 % or 99 % identity to any one of the polypeptides above, wherein the polypeptide has single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the above polynucleotides encode a polypeptide wherein the substitution at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

In one embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having the sequence set forth in the group consisting of SEQ

ID NO: 4, 6, 12 and 14. In another embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having at least 80 % sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having at least 90 % sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having at least 95 % sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the above polynucleotides encode a polypeptide wherein the substitution at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

In another embodiment, the nucleic acid molecule comprises a polynucleotide having a sequence selected from the group consisting of SEQ ID NO: 3, 5, 11 and 13, or its complement.

In another embodiment, the isolated nucleic acid molecule comprises the polynucleotides set forth above, and further comprises a polynucleotide encoding at least one heterologous protein. In one embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having the sequence set forth in the group consisting of SEQ ID NO: 8, 10, 16 and 18. In another embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having at least 80% sequence identity to SEQ ID NO: 8, 10, 16 or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having at least 90% sequence identity to SEQ ID NO: 8, 10, 16 or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In another embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide having at least 95 % sequence identity to SEQ ID NO: 8, 10, 16 or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is

capable of binding myostatin, activin A, or GDF-11. In one embodiment, the above polynucleotides encode a polypeptide wherein the substitution at position 28 is W and the substitution at position S44 is T, wherein the encoded polypeptide is capable of binding myostatin, activin A or GDF-11. In a further embodiment, the nucleic acid molecule comprises a polynucleotide having a sequence selected from the group consisting of SEQ ID NO: 7, 9, 15 and 17, or its complement.

In another embodiment, the nucleic acid molecule further comprises polynucleotides encoding the linkers and hinge linkers set forth in the group consisting of SEQ ID NO: 25, 27, 38, 40, 42, 44, 45, 46, 48, 49 and 50.

In a further embodiment, the nucleic acid molecule further comprises a transcriptional or translational regulatory sequence. In another aspect a recombinant vector comprising a polynucleotide encoding a stabilized ActRIIB protein or polypeptide is provided. In another aspect, host cells comprising the recombinant vectors are provided, and methods of producing the stabilized ActRIIB proteins and polypeptides are provided by culturing the host cells under conditions promoting expression of the proteins or polypeptides.

The present invention further provides a composition containing at least one stabilized ActRIIB polypeptide or protein of the present invention. In one embodiment, the composition is a pharmaceutical composition containing the stabilized ActRIIB polypeptide or protein in admixture with a pharmaceutically acceptable carrier.

In another aspect, the invention provides a method of reducing or blocking myostatin, activin A or GDF-11 activity by administering the svActRIIB proteins and polypeptides, or pharmaceutical compositions containing these, to a subject in need of such treatment.

In another aspect, the invention provides a method of increasing lean muscle mass or increasing the ratio of lean muscle mass to fat mass in a subject in need of such treatment by administering an effective amount of the composition or pharmaceutical composition containing svActRIIB proteins or polypeptides to the subject.

In another aspect, the invention provides a method of treating or preventing a muscle wasting disease in a subject suffering from such a disorder by administering a therapeutic composition containing an svActRIIB polypeptide or protein to the subject. The muscle wasting disease includes, but is not limited to, the following

conditions: cancer cachexia, muscular dystrophy, amyotrophic lateral sclerosis, congestive obstructive pulmonary disease, chronic heart failure, chemical cachexia, cachexia from HIV/AIDS, renal failure, uremia, rheumatoid arthritis, age-related sarcopenia, age-related frailty, organ atrophy, carpal tunnel syndrome, androgen deprivation, and muscle-wasting due to inactivity from prolonged bed rest, spinal chord injury, stroke, bone fracture, burns, aging, insulin resistance, and other disorders. The muscle wasting may also result from weightlessness due to space flight.

In another aspect, the present invention provides a method of treating conditions in which activin is overexpressed in a subject in need of such treatment, by administering an effective amount of a therapeutic composition containing svActRIIB proteins or polypeptides to the subject. In one embodiment, the disease is cancer. In another aspect, the present invention provides a method of treating a metabolic disorder comprising administering a therapeutic composition containing svActRIIB proteins or polypeptides to a subject in need of such treatment, wherein the metabolic disorder is selected from bone loss, diabetes, obesity, impaired glucose tolerance, hyperglycemia, and metabolic syndrome. In another aspect, the present invention provides a method of gene therapy for treating muscle wasting or metabolic or activin-related disorders comprising administering a vector encoding an svActRIIB polypeptide or protein of the present invention to a subject in need thereof, wherein the vector is capable of expressing the svActRIIB protein or polypeptide in the subject.

In another aspect, the present invention provides a method of detecting and quantitating myostatin, activin, or GDF-11 by using any of the svActRIIB proteins or polypeptides as capture or binding agents in any number of assays.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a comparison between ActRIIB-Fc (E28W) and svActRIIB-Fc (E28W, S44T) on an SEC column. svActRIIB-Fc (E28W, S44T) shows a single peak compared with ActRIIB-Fc (E28W), which shows three peaks.

Figure 2 shows the increase in body mass over a 14 day period in 10 C57Bl/6 mice administered a single dose of 10 mg/kg svActRIIB-Fc (E28W, S44T) compared with 10 mice administered 10 mg/kg of PBS.

Figure 3 shows the dose-related change in lean body mass over time for C57Bl/6 receiving a single dose of 0.3 mg/kg, 3 mg/kg, 10 mg/kg, and 30 mg/kg of svActRIIB-Fc (E28W, S44T).

DETAILED DESCRIPTION

The present invention provides an isolated protein comprising a stabilized human activin IIB receptor (svActRIIB) polypeptide. The protein and polypeptide of the invention are characterized by their ability to bind to at least one of three TGF-β proteins, myostatin (GDF-8), activin A, or GDF-11, to inhibit the activities of at least one of these proteins, and to have improved manufacturability properties compared with other ActRIIB soluble receptors. The stabilized human activin IIB receptor polypeptide is characterized by amino acid substitutions at both positions E28 and S44 with reference to the extracellular domain of ActRIIB, as set forth in SEQ ID NO: 2. In one embodiment, a stabilized human activin IIB receptor polypeptide can have a further substitution of alanine at position 64 with respect to SEQ ID NO: 2.

As used herein the term "TGF-β family members" or "TGF-β proteins" refers to the structurally related growth factors of the transforming growth factor family including activins, and growth and differentiation factor (GDF) proteins (Kingsley et al. Genes Dev. 8: 133-146 (1994), McPherron et al., Growth factors and cytokines in health and disease, Vol. 1B, D. LeRoith and C. Bondy. ed., JAI Press Inc., Greenwich, Conn, USA: pp 357-393).

GDF-8, also referred to as myostatin, is a negative regulator of skeletal muscle tissue (McPherron et al. PNAS USA 94:12457-12461 (1997)). Myostatin is synthesized as an inactive protein approximately 375 amino acids in length, having GenBank Accession No: AAB86694 (SEQ ID NO: 35) for human. The precursor

protein is activated by proteolytic cleavage at a tetrabasic processing site to produce an N-terminal inactive prodomain and an approximately 109 amino acid C-terminal protein which dimerizes to form a homodimer of about 25 kDa. This homodimer is the mature, biologically active protein (Zimmers et al., Science 296, 1486 (2002)).

As used herein, the term "prodomain" or "propeptide" refers to the inactive N-terminal protein which is cleaved off to release the active C-terminal protein. As used herein the term "myostatin" or "mature myostatin" refers to the mature, biologically active C-terminal polypeptide, in monomer, dimer or other form, as well as biologically active fragments or related polypeptides including allelic variants, splice variants, and fusion peptides and polypeptides. The mature myostatin has been reported to have 100% sequence identity among many species including human, mouse, chicken, porcine, turkey, and rat (Lee et al., PNAS 98, 9306 (2001)).

As used herein GDF-11 refers to the BMP (bone morphogenic protein) having Swissprot accession number O95390 (SEQ ID NO: 36), as well as variants and species homologs of that protein. GDF-11 is involved in the regulation of anterior/posterior patterning of the axial skeleton (McPherron et al, Nature Genet. 22 (93): 260-264 (1999); Gamer et al, Dev. Biol. 208 (1), 222-232 (1999)) but postnatal functions are unknown.

Activin A is the homodimer of the polypeptide chains βA. As used herein the term "activin A" refers to the activin protein having GenBank Accession No: NM_002192 (SEQ ID NO: 34). Activins A, B, and AB are the homodimers and heterodimer respectively of two polypeptide chains, βA and βB. As used herein, "activin" refers to activin A, B, and AB, as well as variants and species homologs of that protein.

Receptor Polypeptides

As used herein, the term activin type II B receptors (ActRIIB) refers to human activin receptors having accession number NP_001097 or variants thereof, such as those having the arginine at position 64 substituted with alanine. The term soluble ActRIIB (wild type) refers to the extracellular domain of ActRIIB, amino acids 1 to 134 (with signal sequence), or amino acids 19 through 134 of SEQ ID NO: 2 (without signal sequence).

Stabilized receptor polypeptides

The present invention provides an isolated protein comprising a stabilized ActIIB receptor polypeptide (referred herein as "svActRIIB polypeptide"). As used herein the term "svActRIIB protein" refers to a protein comprising a stabilized ActRIIB polypeptide. As used herein the term "isolated" refers to a protein or polypeptide molecule purified to some degree from endogenous material. These polypeptides and proteins are characterized as having the ability to bind and inhibit the activity of any one of activin A, myostatin, or GDF-11, in addition to having improved manufacturability characteristics.

The stabilized ActRIIB polypeptide is characterized by having an amino acid substitution at both position 28 and 44 with respect to SEQ ID NO: 2. For consistency, the amino acid positions on the stabilized ActRIIB polypeptides and proteins are always referred to with respect to the positions in SEQ ID NO: 2, regardless of whether the polypeptide is mature or truncated. As used herein, the term "mature" refers to a polypeptide or peptide without its signal sequence. As used herein, the term "truncated" refers to polypeptides having N terminal amino acids or C terminal amino acids removed.

In one embodiment, the isolated stabilized activin IIB receptor polypeptide (svActRIIB) has the polypeptide sequence set forth in SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has the sequence set forth in amino acids 19 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has the sequence set forth in amino acids 23 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polypeptide has the sequence set forth in amino acids 25 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the

substitution at position 44 is T. In another embodiment, the polypeptide has an amino acid sequence with at least 80 %, 85 %, 90 %, 95 %, 96 %, 97 %, 98 % or 99 % identity to any one of the polypeptides above, wherein the polypeptide has single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the substitution of the above polypeptides at position 28 is W, and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

In one embodiment, the svActRIIB polypeptide includes a signal sequence, for example, SEQ ID NO: 4, 8, 12, and 16. However, various signal peptides can be used in the preparation of the polypeptides of the instant application. The signal peptides can have the sequence set forth in amino acids 1 to 19 of SEQ ID NO: 4, for example, or the signal sequences set forth in SEQ ID NO: 31 and 32. Any other signal peptides useful for expressing svActRIIB polypeptides may be used. In other embodiments, the signal sequence is removed, leaving the mature peptide. Examples of svActRIIB polypeptides lacking a signal sequence includes, for example, SEQ ID NO: 6, 10, 14 and 18.

In one embodiment, the protein comprises a stabilized activin IIB receptor polypeptide, wherein the polypeptide is selected from the group consisting of polypeptides having the sequence set forth in the group consisting of SEQ ID NO: 4, 6, 12 and 14. These polypeptides represent amino acids 25 to 134 of SEQ ID NO: 2, wherein the polypeptide has single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11, with and without a signal sequence different from that shown in SEQ ID NO: 2. In another embodiment the protein comprises a polypeptide having at least 80 %, 85 %, 90 %, 95 %, 96 %, 97 %, 98 %, or 99 % sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the substitution at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A or GDF-11.

In a further embodiment the svActRIIB protein further comprises a heterologous protein. In one embodiment, the heterologous protein is an Fc domain. In a further embodiment, the Fc domain is a human IgG Fc domain. In one embodiment, the protein comprises a polypeptide having the sequence set forth in the group consisting of SEQ ID NO: 8, 10, 16 and 18. In another embodiment, the protein comprises a polypeptide having at least 80 %, 85 %, 90 %, 95 %, 96 %, 97 %, 98 %, or 99 % sequence identity to SEQ ID NO: 8, 10, 16 or 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the substitution at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A or GDF-11.

In a further embodiment, the protein comprises the any one of the polypeptides described above, wherein the amino acid residue at position 64 is alanine.

In another embodiment, the term svActRIIB polypeptide and protein encompasses proteins comprising fragments of SEQ ID NO: 2, 4, 6, 12 and 14, including N and C terminal truncations, wherein position 28 is W or Y, and position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A or GDF-11.

As used herein the term "derivative" of the svActRIIB polypeptide refers to the attachment of at least one additional chemical moiety, or at least one additional polypeptide to form covalent or aggregate conjugates such as glycosyl groups, lipids, acetyl groups, or C-terminal or N-terminal fusion polypeptides, conjugation to PEG molecules, and other modifications which are described more fully below. Stabilized ActRIIB receptor polypeptides can also include additional modifications and derivatives, including modifications to the C and N termini which arise from processing due to expression in various cell types such as mammalian cells, E. coli, yeasts and other recombinant host cells.

The svActRIIB proteins of the present invention may further comprise heterologous polypeptides attached to the svActRIIB polypeptide either directly or through a linker sequence to form a fusion protein. As used herein the term "fusion protein" refers to a protein having a heterologous polypeptide attached via recombinant DNA techniques. Heterologous polypeptides include but are not limited to Fc polypeptides, his tags, and leucine zipper domains to promote oligomerization

and further stabilization of the stabilized ActRIIB polypeptides as described in, for example, WO 00/29581, which is herein incorporated by reference. In one embodiment, the heterologous polypeptide is an Fc polypeptide or domain. In one embodiment, the Fc domain is selected from a human IgG1 Fc (SEQ ID NO: 23), modified IgG1 Fc (SEQ ID NO: 47), IgG2 Fc (SEQ ID NO: 22), and IgG4 Fc (SEQ ID NO: 24) domain. The svActRIIB protein can further comprise all or a portion of the hinge sequence of the IgG1 (SEQ ID NO: 29), IgG2 (SEQ ID NO: 28), or IgG4 (SEQ ID NO: 30). Exemplary svActRIIB polypeptides are selected from polypeptides consisting of the sequences as set forth in SEQ ID NO: 8, 10, 16 and 18, as well as those polypeptides having substantial similarity to these sequences, wherein the substitutions at positions 28 and 44 are retained. As used herein, "substantial similarity" refers to sequences that are at least 80 % identical, 85 % identical, 90 % identical, 95 % identical, 96 % identical, 97 % identical, 98 % identical, 99 % identical to any of SEQ ID NO: 8, 10, 16, and 18, wherein the polypeptides retain W or Y at position 28 and T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A or GDF-11. In one embodiment, the substitution at position 28 is W and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A or GDF-11.

The svActRIIB polypeptide can optionally further comprise a "linker" sequence. Linkers serve primarily as a spacer between a polypeptide and a second heterologous polypeptide or other type of fusion or between two or more stabilized ActRIIB polypeptides. In one embodiment, the linker is made up of amino acids linked together by peptide bonds, preferably from 1 to 20 amino acids linked by peptide bonds, wherein the amino acids are selected from the 20 naturally occurring amino acids. One or more of these amino acids may be glycosylated, as is understood by those of skill in the art. In one embodiment, the 1 to 20 amino acids may be selected from glycine, alanine, proline, asparagine, glutamine, and lysine. In one embodiment, a linker is made up of a majority of amino acids that are sterically unhindered, such as glycine and alanine. Exemplary linkers are polyglycines (particularly $(Gly)_5$, $(Gly)_8$, poly(Gly-Ala), and polyalanines. One exemplary suitable linker as shown in the Examples below is $(Gly)_4Ser$ (SEQ ID NO: 25). In a further embodiment, svActRIIB can comprise a "hinge linker", that is a linker sequence provided adjacent to a hinge region or a partial hinge region of an IgG, as exemplified

in SEQ ID NO: 27. Hinge sequences include IgG2Fc (SEQ ID NO: 28), IgG1Fc (SEQ ID NO: 29), and IgG4Fc (SEQ ID NO: 30).

Hinge linker sequences may also be designed to improve manufacturability and stability of the svActRIIB-Fc proteins. In one embodiment, the hinge linkers of SEQ ID NO: 27, 38, 40, 42, 44, 45, and 46 are designed to improve manufacturability with the IgG2 Fc (SEQ ID NO: 22) when attached to svActRIIB polypeptides. In one embodiment, the hinge linker sequences is designed to improve manufacturability when attaching svActRIIB polypeptides to a human IgG1 Fc (SEQ ID NO: 23) or a modified human IgG1 Fc (SEQ ID NO: 47), for example, the hinge linkers having SEQ ID NO: 48, SEQ ID NO: 49 and SEQ ID NO: 50. The improved manufacturability of these polypeptides is described below in Example 4.

Linkers may also be non-peptide linkers. For example, alkyl linkers such as -NH-(CH_2)s-C(O)-, wherein s = 2-20 can be used. These alkyl linkers may further be substituted by any non-sterically hindering group such as lower alkyl (e.g., C_1-C_6) lower acyl, halogen (e.g., Cl, Br), CN, NH_2, phenyl, etc.

The svActRIIB polypeptides disclosed herein can also be attached to a non-polypeptide molecule for the purpose of conferring desired properties such as reducing degradation and/or increasing half-life, reducing toxicity, reducing immunogenicity, and/or increasing the biological activity of the svActRIIB polypeptides. Exemplary molecules include but are not limited to linear polymers such as polyethylene glycol (PEG), polylysine, a dextran; a lipid; a cholesterol group (such as a steroid); a carbohydrate, or an oligosaccharide molecule.

The svActRIIB proteins and polypeptides have improved manufacturability properties when compared to other ActRIIB soluble polypeptides. As used herein, the term "manufacturability" refers to the stability of a particular protein during recombinant expression and purification of that protein. Manufacturability is believed to be due to the intrinsic properties of the molecule under conditions of expression and purification. Examples of improved manufacturability characteristics are set forth in the Examples below and include uniform glycosylation of a protein (Example 2), increased cell titer, growth and protein expression during recombinant production of the protein (Example 1), improved purification properties (Example 2), and improved stability at low pH (Example 2). The svActRIIB proteins and polypeptides of the present invention demonstrate the improved manufacturability, along with retention of *in vitro* and *in vivo* activity (Examples 2 and 3), compared with other soluble ActRIIB

polypeptides. Further, additional hinge linker sequences may confer additional manufacturability benefits, as shown in Example 4 below.

As used herein, the term a "svActRIIB polypeptide activity" or "a biological activity of a soluble ActRIIB polypeptide" refers to one or more *in vitro* or *in vivo* activities of the svActRIIB polypeptides including but not limited to those demonstrated in the Example below. Activities of the svActRIIB polypeptides include, but are not limited to, the ability to bind to myostatin or activin A or GDF-11, and the ability to inhibit or neutralize an activity of myostatin or activin A or GDF-11. As used herein, the term "capable of binding" to myostatin, activin A, or GDF-11 refers to binding measured by methods known in the art, such as the KinExA™ method shown in the Examples below. *In vitro* inhibition of myostatin, activin A, or GDF-11 can be measured using, for example, the pMARE C2C12 cell-based assay described in the Examples below. *In vivo* activity, demonstrated in Example 3 below, is demonstrated by increased lean muscle mass in mouse models. *In vivo* activities of the svActRIIB polypeptides and proteins include but are not limited to increasing body weight, increasing lean muscle mass, and increasing the ratio of lean muscle to fat mass. Therapeutic activities further include reducing or preventing cachexia caused by certain types of tumors, preventing the growth of certain types of tumors, and increasing survival of certain animal models. Further discussion of the svActRIIB protein and polypeptide activities is provided below.

In another aspect, the present invention provides an isolated nucleic acid molecule comprising a polynucleotide encoding an svActRIIB polypeptide of the present invention. As used herein the term "isolated" refers to nucleic acid molecules purified to some degree from endogenous material.

In one embodiment, the polynucleotide encodes a polypeptide having the sequence set forth in SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes a polypeptide having the sequence set forth in amino acids 19 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes a polypeptide having the sequence set forth in amino acids 23 through 134 of SEQ ID

NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes a polypeptide having the sequence set forth in amino acids 25 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T. In another embodiment, the polynucleotide encodes the a polypeptide having an amino acid sequence at least 80 %, 85 %, 90 %, 95 %, 98 % or 99 % identity to any one of the polypeptides above, wherein the polypeptide has single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from W or Y, and the substitution at position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11. In one embodiment, the polynucleotide of the above embodiments encodes a polypeptide wherein the substitution at position 28 is W and the substitution at position 44 is T.

In one embodiment, the isolated nucleic acid molecule of the present invention comprises a polynucleotide encoding a polypeptide having the sequence set forth in the group consisting of SEQ ID NO: 4, 6, 12, and 14. In another embodiment, the nucleic acid comprises a polynucleotide encoding a polypeptide having at least 80 %, 90 %, 95 %, 96 %, 97 %, 98 %, 99 % sequence identity to SEQ ID NO: 4, 6, 12 or 14, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding activin A, GDF-11, or myostatin. In one embodiment, the polynucleotide of the above embodiments encodes a polypeptide wherein the substitution at position 28 is W and the substitution at position 44 is T, and wherein the polypeptide is capable of binding activin A, GDF-11 or myostatin.

In another embodiment, the isolated nucleic acid molecule further comprises a polynucleotide encoding at least one heterologous protein. In one embodiment, the heterologous protein is an Fc domain, in a further embodiment, the Fc domain is a human IgG Fc domain. In another embodiment, the nucleic acid molecule further comprises polynucleotides encoding the linkers and hinge linkers set forth in SEQ ID NO: 25, 27, 38, 40, 42, 44, 45, 46, 48, 49 or 50. In a further embodiment, such polynucleotides have sequences selected from the group consisting of SEQ ID NO: 26, 37, 39, 41, and 43.

In one embodiment, the nucleic acid molecule comprises a polynucleotide encoding a polypeptide consisting of the sequence set forth in the group consisting of SEQ ID NO: 8, 10, 16 and 18. In another embodiment, the nucleic acid comprises a polynucleotide encoding a polypeptide having at least 80 %, 90 %, 95 %, 96 %, 97 %, 98 %, 99 % sequence identity to the group consisting of SEQ ID NO: 8, 10, 16 and 18, wherein the polypeptide has a W or Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding activin A, GDF-11, or myostatin. In one embodiment, the polynucleotide of the above embodiments encodes a polypeptide wherein the substitution at position 28 is W and the substitution at position 44 is T, and wherein the polypeptide is capable of binding myostatin, activin A or GDF-11.

In one embodiment, the isolated nucleic acid molecule comprises a polynucleotide having the sequence selected from the group consisting of SEQ ID NO: 3, 5, 11 or 13, or its complement. In another embodiment, the isolated nucleic acid molecule comprises a polynucleotide having the sequence selected from the group consisting of the sequence SEQ ID NO: 7, 9, 15 and 17, or its complement. In a further embodiment the isolated nucleic acid molecule hybridizes under stringent or moderate conditions with SEQ ID NO: 3, 5, 7, 9, 11, 13, 15 or 17 wherein the encoded polypeptide is substantially similar to SEQ ID NO: 4, 6, 8, 10, 12, 14, 16, or 18, wherein the polypeptide comprises an amino acid sequence having W or Y at position 28, and T at position 44, and wherein the encoded polypeptide is capable of binding or inhibiting activin A, myostatin or GDF-11.

Nucleic acid molecules of the invention include DNA in both single-stranded and double-stranded form, as well as the RNA complement thereof. DNA includes, for example, cDNA, genomic DNA, synthetic DNA, DNA amplified by PCR, and combinations thereof. Genomic DNA may be isolated by conventional techniques, such as by using the DNA of SEQ ID NO: 3, 5, 11 or 13, or a suitable fragment thereof, as a probe. Genomic DNA encoding ActRIIB polypeptides is obtained from genomic libraries which are available for a number of species. Synthetic DNA is available from chemical synthesis of overlapping oligonucleotide fragments followed by assembly of the fragments to reconstitute part or all of the coding regions and flanking sequences. RNA may be obtained from procaryotic expression vectors which direct high-level synthesis of mRNA, such as vectors using T7 promoters and RNA polymerase. cDNA is obtained from libraries prepared from mRNA isolated from various tissues that express ActRIIB. The DNA molecules of the invention

include full length genes as well as polynucleotides and fragments thereof. The full length gene may also include sequences encoding the N-terminal signal sequence.

The invention further provides the nucleic acid molecule describe above, wherein the polynucleotide is operably linked to a transcriptional or translational regulatory sequence.

Exemplary polynucleotide and polypeptide sequences.

svActRIIB (E28W, S44T) with signal sequence
atggagtttgggctgagctgggttttcctcgttgctcttttaagaggtgtccagtgtgagacacggtggtgcatctactacaac
gccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaaggcgagcaggacaagcggctgcact
gctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggctgctggctagatgacttcaactgctacg
ataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgctgtgagggcaacttctgcaacgagcgc
ttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccgacagcccccacc (SEQ ID NO: 3)

svActRIIB (E28W, S44T) with signal sequence
mefglswvflvallrgvqcetrwciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfn
cydrqecvateenpqvyfcccegnfcnerfthlpeaggpevtyeppptapt (SEQ ID NO: 4)

svActRIIB (E28W, S44T) without signal sequence
gagacacggtggtgcatctactacaacgccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaa
ggcgagcaggacaagcggctgcactgctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggc
tgctggctagatgacttcaactgctacgataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgct
gtgagggcaacttctgcaacgagcgcttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccc
gacagcccccacc (SEQ ID NO: 5)

svActRIIB (E28W, S44T) without signal sequence
etrwciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfncydrqecvateenpqvyfc
ccegnfcnerfthlpeaggpevtyeppptapt (SEQ ID NO: 6)

svActRIIB-Fc (E28W, S44T) polynucleotide sequence with signal sequence
atggagtttgggctgagctgggttttcctcgttgctcttttaagaggtgtccagtgtgagacacggtggtgcatctactacaac
gccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaaggcgagcaggacaagcggctgcact
gctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggctgctggctagatgacttcaactgctacg
ataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgctgtgagggcaacttctgcaacgagcgc
ttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccgacagcccccaccggaggggggagga
tctgtcgagtgcccaccgtgcccagcaccacctgtggcaggaccgtcagtcttcctcttcccccaaaacccaaggacacc
ctcatgatctcccggacccctgaggtcacgtgcgtggtggtggacgtgagccacgaagaccccgaggtccagttcaactg
gtacgtggacggcgtggaggtgcataatgccaagacaaagccacgggaggagcagttcaacagcacgttccgtgtggtc
agcgtcctcaccgttgtgcaccaggactggctgaacggcaaggagtacaagtgcaaggtctccaacaaaggcctcccag
ccccatcgagaaaaccatctccaaaaccaaagggcagccccgagaaccacaggtgtacaccctgccccatcccggg
aggagatgaccaagaaccaggtcagcctgacctgcctggtcaaaggcttctatcccagcgacatcgccgtggagtggga
gagcaatgggcagccggagaacaactacaagaccacacctcccatgctggactccgacggctccttcttcctctacagca
agctcaccgtggacaagagcaggtggcagcaggggaacgtcttctcatgctccgtgatgcatgaggctctgcacaaccac
tacacgcagaagagcctctccctgtctccgggtaaa (SEQ ID NO: 7)

svActRIIB-Fc (E28W, S44T) polypeptide sequence with signal sequence

mefglswvflvallrgvqcetrwciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfn
cydrqecvateenpqvyfcccegnfcnerfthlpeaggpevtyeppptaptggggsvecppcpappvagpsvflfpp
kpkdtlmisrtpevtcvvvdvshedpevqfnwyvdgvevhnaktkpreeqfnstfrvvsvltvvhqdwlngkeykc
kvsnkglpapiektisktkgqprepqvytlppsreemtknqvsltclvkgfypsdiavewesngqpennykttppml
dsdgsfflyskltvdksrwqqgnvfscsvmhealhnhytqkslslspgk (SEQ ID NO: 8)

svActRIIB-Fc (E28W, S44T) polynucleotide sequence without signal sequence
gagacacggtggtgcatctactacaacgccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaa
ggcgagcaggacaagcggctgcactgctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggc
tgctggctagatgacttcaactgctacgataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgct
gtgagggcaacttctgcaacgagcgcttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccc
gacagcccccaccggaggggggaggatctgtcgagtgcccaccgtgcccagcaccacctgtggcaggaccgtcagtctt
cctcttcccccccaaaacccaaggacaccctcatgatctcccggacccctgaggtcacgtgcgtggtggtggacgtgagcc
acgaagaccccgaggtccagttcaactggtacgtggacggcgtggaggtgcataatgccaagacaaagccacgggagg
agcagttcaacagcacgttccgtgtggtcagcgtcctcaccgttgtgcaccaggactggctgaacggcaaggagtacaag
tgcaaggtctccaacaaaggcctcccagccccatcgagaaaaccatctccaaaaccaaagggcagccccgagaacca
caggtgtacaccctgccccatcccgggaggagatgaccaagaaccaggtcagcctgacctgcctggtcaaaggcttcta
tcccagcgacatcgccgtggagtgggagagcaatgggcagccggagaacaactacaagaccacacctcccatgctgga
ctccgacggctccttcttcctctacagcaagctcaccgtggacaagagcaggtggcagcaggggaacgtcttctcatgctc
cgtgatgcatgaggctctgcacaaccactacacgcagaagagcctctccctgtctccgggtaaa (SEQ ID NO: 9)

svActRIIB-Fc (E28W, S44T), polypeptide sequence without signal sequence
etrwciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfncydrqecvateenpqvyfc
ccegnfcnerfthlpeaggpevtyeppptaptggggsvecppcpappvagpsvflfppkpkdtlmisrtpevtcvvvd
vshedpevqfnwyvdgvevhnaktkpreeqfnstfrvvsvltvvhqdwlngkeykckvsnkglpapiektisktkg
qprepqvytlppsreemtknqvsltclvkgfypsdiavewesngqpennykttppmldsdgsfflyskltvdksrwq
qgnvfscsvmhealhnhytqkslslspgk (SEQ ID NO: 10)

svActRIIB (E28Y, S44T) with signal sequence
atggagtttgggctgagctgggttttcctcgttgctcttttaagaggtgtccagtgtgagacacggtactgcatctactacaac
gccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaaggcgagcaggacaagcggctgcact
gctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggctgctggctagatgacttcaactgctacg
ataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgctgtgagggcaacttctgcaacgagcgc
ttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccgacagcccccacc (SEQ ID NO:
11)

svActRIIB (E28Y,S44T) with signal sequence
mefglswvflvallrgvqcetryciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfnc
ydrqecvateenpqvyfcccegnfcnerfthlpeaggpevtyeppptapt (SEQ ID NO: 12)

svActRIIB (E28Y,S44T) without signal sequence
gagacacggtactgcatctactacaacgccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaa
ggcgagcaggacaagcggctgcactgctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggc
tgctggctagatgacttcaactgctacgataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgct
gtgagggcaacttctgcaacgagcgcttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccc
gacagcccccacc (SEQ ID NO: 13)

svActRIIB (E28Y,S44T) without signal sequence
etryciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfncydrqecvateenpqvyfc
ccegnfcnerfthlpeaggpevtyeppptapt (SEQ ID NO: 14)

svActRIIB-Fc (E28Y, S44T) polynucleotide sequence with signal sequence
atggagtttgggctgagctgggttttcctcgttgctcttttaagaggtgtccagtgtgagacacggtactgcatctactacaac
gccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaaggcgagcaggacaagcggctgcact
gctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggctgctggctagatgacttcaactgctacg
ataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgctgtgagggcaacttctgcaacgagcgc
ttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccgacagcccccaccggaggggggagga
tctgtcgagtgcccaccgtgcccagcaccacctgtggcaggaccgtcagtcttcctcttcccccccaaaacccaaggacacc
ctcatgatctcccggacccctgaggtcacgtgcgtggtggtggacgtgagccacgaagaccccgaggtccagttcaactg
gtacgtggacggcgtggaggtgcataatgccaagacaaagccacgggaggagcagttcaacagcacgttccgtgtggtc
agcgtcctcaccgttgtgcaccaggactggctgaacggcaaggagtacaagtgcaaggtctccaacaaaggcctcccag
ccccatcgagaaaaccatctccaaaaccaaagggcagccccgagaaccacaggtgtacaccctgccccccatcccgggg
aggagatgaccaagaaccaggtcagcctgacctgcctggtcaaaggcttctatcccagcgacatcgccgtggagtggga
gagcaatgggcagccggagaacaactacaagaccacacctcccatgctggactccgacggctccttcttcctctacagca
agctcaccgtggacaagagcaggtggcagcaggggaacgtcttctcatgctccgtgatgcatgaggctctgcacaaccac
tacacgcagaagagcctctccctgtctccgggtaaa (SEQ ID NO: 15)

svActRIIB-Fc (E28Y, S44T) polypeptide sequence with signal sequence
mefglswvflvallrgvqcetryciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfnc
ydrqecvateenpqvyfcccegnfcnerfthlpeaggpevtyeppptaptggggsvecppcpappvagpsvflfppk
pkdtlmisrtpevtcvvvdvshedpevqfnwyvdgvevhnaktkpreeqfnstfrvvsvltvvhqdwlngkeykck
vsnkglpapiektisktkgqprepqvytlppsreemtknqvsltclvkgfypsdiavewesngqpennykttppmlds
dgsfflyskltvdksrwqqgnvfscsvmhealhnhytqkslslspgk (SEQ ID NO: 16)

svActRIIB-Fc (E28Y, S44T) polynucleotide sequence without signal sequence
gagacacggtactgcatctactacaacgccaactgggagctggagcgcaccaaccagaccggcctggagcgctgcgaa
ggcgagcaggacaagcggctgcactgctacgcctcctggcgcaacagctctggcaccatcgagctcgtgaagaagggc
tgctggctagatgacttcaactgctacgataggcaggagtgtgtggccactgaggagaacccccaggtgtacttctgctgct
gtgagggcaacttctgcaacgagcgcttcactcatttgccagaggctgggggcccggaagtcacgtacgagccacccccc
gacagcccccaccggaggggggaggatctgtcgagtgcccaccgtgcccagcaccacctgtggcaggaccgtcagtctt
cctcttcccccccaaaacccaaggacaccctcatgatctcccggacccctgaggtcacgtgcgtggtggtggacgtgagcc
acgaagaccccgaggtccagttcaactggtacgtggacggcgtggaggtgcataatgccaagacaaagccacgggagg
agcagttcaacagcacgttccgtgtggtcagcgtcctcaccgttgtgcaccaggactggctgaacggcaaggagtacaag
tgcaaggtctccaacaaaggcctcccagccccatcgagaaaaccatctccaaaaccaaagggcagccccgagaacca
caggtgtacaccctgccccccatcccgggaggagatgaccaagaaccaggtcagcctgacctgcctggtcaaaggcttcta
tcccagcgacatcgccgtggagtgggagagcaatgggcagccggagaacaactacaagaccacacctcccatgctgga
ctccgacggctccttcttcctctacagcaagctcaccgtggacaagagcaggtggcagcaggggaacgtcttctcatgctc
cgtgatgcatgaggctctgcacaaccactacacgcagaagagcctctccctgtctccgggtaaa (SEQ ID NO: 17)

svActRIIB-Fc (E28Y, S44T) polypeptide sequence without signal sequence
etryciyynanwelertnqtglercegeqdkrlhcyaswrnssgtielvkkgcwlddfncydrqecvateenpqvyfc
ccegnfcnerfthlpeaggpevtyeppptaptggggsvecppcpappvagpsvflfppkpkdtlmisrtpevtcvvvd
vshedpevqfnwyvdgvevhnaktkpreeqfnstfrvvsvltvvhqdwlngkeykckvsnkglpapiektisktkg
qprepqvytlppsreemtknqvsltclvkgfypsdiavewesngqpennykttppmldsdgsfflyskltvdksrwq
qgnvfscsvmhealhnhytqkslslspgk (SEQ ID NO: 18)

In another aspect of the present invention, expression vectors containing the nucleic acid molecules and polynucleotides of the present invention are also provided,

and host cells transformed with such vectors, and methods of producing the svActRIIB polypeptides are also provided. The term "expression vector" refers to a plasmid, phage, virus or vector for expressing a polypeptide from a polynucleotide sequence. Vectors for the expression of the svActRIIB polypeptides contain at a minimum sequences required for vector propagation and for expression of the cloned insert. An expression vector comprises a transcriptional unit comprising an assembly of (1) a genetic element or elements having a regulatory role in gene expression, for example, promoters or enhancers, (2) a sequence that encodes svActRIIB polypeptides and proteins to be transcribed into mRNA and translated into protein, and (3) appropriate transcription initiation and termination sequences. These sequences may further include a selection marker. Vectors suitable for expression in host cells are readily available and the nucleic acid molecules are inserted into the vectors using standard recombinant DNA techniques. Such vectors can include promoters which function in specific tissues, and viral vectors for the expression of svActRIIB polypeptides in targeted human or animal cells. An exemplary expression vector suitable for expression of svActRIIB is the pDSRa, (described in WO 90/14363, herein incorporated by reference) and its derivatives, containing svActRIIB polynucleotides, as well as any additional suitable vectors known in the art or described below.

The invention further provides methods of making svActRIIB polypeptides. A variety of other expression/host systems may be utilized. These systems include but are not limited to microorganisms such as bacteria transformed with recombinant bacteriophage, plasmid or cosmid DNA expression vectors; yeast transformed with yeast expression vectors; insect cell systems infected with virus expression vectors (e.g., baculovirus); plant cell systems transfected with virus expression vectors (e.g., cauliflower mosaic virus, CaMV; tobacco mosaic virus, TMV) or transformed with bacterial expression vectors (e.g., Ti or pBR322 plasmid); or animal cell systems. Mammalian cells useful in recombinant protein production include but are not limited to VERO cells, HeLa cells, Chinese hamster ovary (CHO) cell lines, or their derivatives such as Veggie CHO and related cell lines which grow in serum-free media (see Rasmussen et al., 1998, Cytotechnology 28:31) or CHO strain DX-B11, which is deficient in DHFR (see Urlaub et al., 1980, Proc. Natl. Acad. Sci. USA 77:4216-20) COS cells such as the COS-7 line of monkey kidney cells (ATCC CRL 1651) (see Gluzman et al., 1981, Cell 23:175), W138, BHK, HepG2, 3T3 (ATCC

CCL 163), RIN, MDCK, A549, PC12, K562, L cells, C127 cells, BHK (ATCC CRL 10) cell lines, the CV1/EBNA cell line derived from the African green monkey kidney cell line CV1 (ATCC CCL 70) (see McMahan et al., 1991, EMBO J. 10:2821), human embryonic kidney cells such as 293, 293 EBNA or MSR 293, human epidermal A431 cells, human Colo205 cells, other transformed primate cell lines, normal diploid cells, cell strains derived from in vitro culture of primary tissue, primary explants, HL-60, U937, HaK or Jurkat cells. Mammalian expression allows for the production of secreted or soluble polypeptides which may be recovered from the growth medium.

Using an appropriate host-vector system, svActRIIB polypeptides are produced recombinantly by culturing a host cell transformed with an expression vector containing the nucleic acid molecules of the present invention under conditions allowing for production. Transformed cells can be used for long-term, high-yield polypeptide production. Once such cells are transformed with vectors that contain selectable markers as well as the desired expression cassette, the cells can be allowed to grow in an enriched media before they are switched to selective media, for example. The selectable marker is designed to allow growth and recovery of cells that successfully express the introduced sequences. Resistant clumps of stably transformed cells can be proliferated using tissue culture techniques appropriate to the cell line employed. An overview of expression of recombinant proteins is found in Methods of Enzymology, v. 185, Goeddell, D.V., ed., Academic Press (1990).

In some cases, such as in expression using procaryotic systems, the expressed polypeptides of this invention may need to be "refolded" and oxidized into a proper tertiary structure and disulfide linkages generated in order to be biologically active. Refolding can be accomplished using a number of procedures well known in the art. Such methods include, for example, exposing the solubilized polypeptide to a pH usually above 7 in the presence of a chaotropic agent. The selection of chaotrope is similar to the choices used for inclusion body solubilization, however a chaotrope is typically used at a lower concentration. Exemplary chaotropic agents are guanidine and urea. In most cases, the refolding/oxidation solution will also contain a reducing agent plus its oxidized form in a specific ratio to generate a particular redox potential which allows for disulfide shuffling to occur for the formation of cysteine bridges. Some commonly used redox couples include cysteine/cystamine, glutathione/dithiobisGSH, cupric chloride, dithiothreitol DTT/dithiane DTT, and 2-

mercaptoethanol (bME)/dithio-bME. In many instances, a co-solvent may be used to increase the efficiency of the refolding. Commonly used cosolvents include glycerol, polyethylene glycol of various molecular weights, and arginine.

In addition, the polypeptides can be synthesized in solution or on a solid support in accordance with conventional techniques. Various automatic synthesizers are commercially available and can be used in accordance with known protocols. See, for example, Stewart and Young, Solid Phase Peptide Synthesis, 2d.Ed., Pierce Chemical Co. (1984); Tam et al., J Am Chem Soc, 105:6442, (1983); Merrifield, Science 232:341-347 (1986); Barany and Merrifield, The Peptides, Gross and Meienhofer, eds, Academic Press, New York, 1-284; Barany et al., Int J Pep Protein Res, 30:705-739 (1987).

The polypeptides and proteins of the present invention can be purified according to protein purification techniques are well known to those of skill in the art. These techniques involve, at one level, the crude fractionation of the proteinaceous and non-proteinaceous fractions. Having separated the peptide polypeptides from other proteins, the peptide or polypeptide of interest can be further purified using chromatographic and electrophoretic techniques to achieve partial or complete purification (or purification to homogeneity). The term "isolated polypeptide" or "purified polypeptide" as used herein, is intended to refer to a composition, isolatable from other components, wherein the polypeptide is purified to any degree relative to its naturally-obtainable state. A purified polypeptide therefore also refers to a polypeptide that is free from the environment in which it may naturally occur. Generally, "purified" will refer to a polypeptide composition that has been subjected to fractionation to remove various other components, and which composition substantially retains its expressed biological activity. Where the term "substantially purified" is used, this designation will refer to a peptide or polypeptide composition in which the polypeptide or peptide forms the major component of the composition, such as constituting about 50 %, about 60 %, about 70 %, about 80 %, about 85 %, or about 90 % or more of the proteins in the composition.

Various techniques suitable for use in purification will be well known to those of skill in the art. These include, for example, precipitation with ammonium sulphate, PEG, antibodies (immunoprecipitation) and the like or by heat denaturation, followed by centrifugation; chromatography such as affinity chromatography (Protein-A columns), ion exchange, gel filtration, reverse phase, hydroxylapatite, hydrophobic

interaction chromatography, isoelectric focusing, gel electrophoresis, and combinations of these techniques. As is generally known in the art, it is believed that the order of conducting the various purification steps may be changed, or that certain steps may be omitted, and still result in a suitable method for the preparation of a substantially purified polypeptide. Exemplary purification steps are provided in the Examples below.

Various methods for quantifying the degree of purification of polypeptide will be known to those of skill in the art in light of the present disclosure. These include, for example, determining the specific binding activity of an active fraction, or assessing the amount of peptide or polypeptide within a fraction by SDS/PAGE analysis. A preferred method for assessing the purity of a polypeptide fraction is to calculate the binding activity of the fraction, to compare it to the binding activity of the initial extract, and to thus calculate the degree of purification, herein assessed by a "-fold purification number." The actual units used to represent the amount of binding activity will, of course, be dependent upon the particular assay technique chosen to follow the purification and whether or not the polypeptide or peptide exhibits a detectable binding activity.

Stabilized activin type IIB polypeptides bind to ligands that activate muscle-degradation cascades. svActRIIB polypeptides capable of binding and inhibiting the activity of the ligands activin A, myostatin, and/or GDF-11, and have the ability to treat diseases that involve muscle atrophy, as well as the treatment of certain cancers, and other diseases.

The Examples below show improved properties for svActRIIB polypeptides and proteins having the amino acid substitutions described herein, while retaining the ability to bind and neutralize myostatin, activin A, or GDF-11 in *in vitro* assays, as well as retaining *in vivo* activity. These properties result in proteins and polypeptides having improved manufacturability in comparison to other soluble receptors.

Antibodies

The present invention further includes antibodies which bind to stabilized ActRIIB polypeptides, including those that specifically bind to the svActRIIB polypeptides of the present invention. As used herein the term "specifically binds" refers to antibodies having a binding affinity (K_a) for svActRIIB polypeptides of 10^6 M^{-1} or greater. As used herein, the term "antibody" refers to intact antibodies

including polyclonal antibodies (see, for example Antibodies: A Laboratory Manual, Harlow and Lane (eds), Cold Spring Harbor Press, (1988)), and monoclonal antibodies (see, for example, U.S. Patent Nos. RE 32,011, 4,902,614, 4,543,439, and 4,411,993, and Monoclonal Antibodies: A New Dimension in Biological Analysis, Plenum Press, Kennett, McKearn and Bechtol (eds.) (1980)). As used herein, the term "antibody" also refers to a fragment of an antibody such as F(ab), F(ab'), $F(ab')_2$, Fv, Fc, and single chain antibodies which are produced by recombinant DNA techniques or by enzymatic or chemical cleavage of intact antibodies. The term "antibody" also refers to bispecific or bifunctional antibodies, which are an artificial hybrid antibody having two different heavy/light chain pairs and two different binding sites. Bispecific antibodies can be produced by a variety of methods including fusion of hybridomas or linking of Fab' fragments. (See Songsivilai et al, Clin. Exp. Immunol. 79:315-321 (1990), Kostelny et al., J. Immunol.148:1547-1553 (1992)).

As used herein the term "antibody" also refers to chimeric antibodies, that is, antibodies having a human constant antibody immunoglobin domain coupled to one or more non-human variable antibody immunoglobin domain, or fragments thereof (see, for example, U.S. Patent No. 5,595,898 and U.S. Patent No. 5,693,493). Antibodies also refers to "humanized" antibodies (see, for example, U.S. Pat. No. 4,816,567 and WO 94/10332), minibodies (WO 94/09817), maxibodies, and antibodies produced by transgenic animals, in which a transgenic animal containing a proportion of the human antibody producing genes but deficient in the production of endogenous antibodies are capable of producing human antibodies (see, for example, Mendez et al., Nature Genetics 15:146-156 (1997), and U.S. Patent No. 6,300,129). The term "antibodies" also includes multimeric antibodies, or a higher order complex of proteins such as heterdimeric antibodies, and anti-idiotypic antibodies. "Antibodies" also includes anti-idiotypic antibodies. The antibodies against sv ActRIIB polypeptides can be used, for example, to identify and quantitate svActRIIB *in vitro* and *in vivo*.

Also included are polyclonal antibodies from any mammal, for example mouse and rat antibodies, and rabbit antibodies, that bind specifically to the svActRIIB polypeptides described herein.

Such antibodies find use as research tools and in quantitative assays for detecting and assaying the polypeptides disclosed herein. Such antibodies are made using methods described above and as known in the art.

Pharmaceutical Compositions

Pharmaceutical compositions containing the svActRIIB proteins and polypeptides of the present invention are also provided. Such compositions comprise a therapeutically or prophylactically effective amount of the polypeptide or protein in admixture with pharmaceutically acceptable materials, and physiologically acceptable formulation materials. The pharmaceutical composition may contain formulation materials for modifying, maintaining or preserving, for example, the pH, osmolarity, viscosity, clarity, color, isotonicity, odor, sterility, stability, rate of dissolution or release, adsorption or penetration of the composition. Suitable formulation materials include, but are not limited to, amino acids (such as glycine, glutamine, asparagine, arginine or lysine); antimicrobials; antioxidants (such as ascorbic acid, sodium sulfite or sodium hydrogen-sulfite); buffers (such as borate, bicarbonate, Tris-HCl, citrates, phosphates, other organic acids); bulking agents (such as mannitol or glycine), chelating agents (such as ethylenediamine tetraacetic acid (EDTA)); complexing agents (such as caffeine, polyvinylpyrrolidone, beta-cyclodextrin or hydroxypropyl-beta-cyclodextrin); fillers; monosaccharides; disaccharides and other carbohydrates (such as glucose, mannose, or dextrins); proteins (such as serum albumin, gelatin or immunoglobulins); coloring; flavoring and diluting agents; emulsifying agents; hydrophilic polymers (such as polyvinylpyrrolidone); low molecular weight polypeptides; salt-forming counterions (such as sodium); preservatives (such as benzalkonium chloride, benzoic acid, salicylic acid, thimerosal, phenethyl alcohol, methylparaben, propylparaben, chlorhexidine, sorbic acid or hydrogen peroxide); solvents (such as glycerin, propylene glycol or polyethylene glycol); sugar alcohols (such as mannitol or sorbitol); suspending agents; surfactants or wetting agents (such as pluronics, PEG, sorbitan esters, polysorbates such as polysorbate 20, polysorbate 80, triton, tromethamine, lecithin, cholesterol, tyloxapal); stability enhancing agents (sucrose or sorbitol); tonicity enhancing agents (such as alkali metal halides (preferably sodium or potassium chloride, mannitol sorbitol); delivery vehicles; diluents; excipients and/or pharmaceutical adjuvants. (Remington's Pharmaceutical Sciences, 18th Edition, A.R. Gennaro, ed., Mack Publishing Company, 1990).

The optimal pharmaceutical composition will be determined by one skilled in the art depending upon, for example, the intended route of administration, delivery format, and desired dosage. See for example, Remington's Pharmaceutical Sciences,

supra. Such compositions may influence the physical state, stability, rate of *in vivo* release, and rate of *in vivo* clearance of the polypeptide. For example, suitable compositions may be water for injection, physiological saline solution for parenteral administration.

The primary vehicle or carrier in a pharmaceutical composition may be either aqueous or non-aqueous in nature. For example, a suitable vehicle or carrier may be water for injection, physiological saline solution or artificial cerebrospinal fluid, possibly supplemented with other materials common in compositions for parenteral administration. Neutral buffered saline or saline mixed with serum albumin are further exemplary vehicles. Other exemplary pharmaceutical compositions comprise Tris buffers, or acetate buffers, which may further include sorbitol or a suitable substitute thereof. In one embodiment of the present invention, compositions may be prepared for storage by mixing the selected composition having the desired degree of purity with optional formulation agents (Remington's Pharmaceutical Sciences, supra) in the form of a lyophilized cake or an aqueous solution. Further, the therapeutic composition may be formulated as a lyophilizate using appropriate excipients such as sucrose.

The formulations can be delivered in a variety of methods, for example, by inhalation therapy, orally, or by injection. When parenteral administration is contemplated, the therapeutic compositions for use in this invention may be in the form of a pyrogen-free, parenterally acceptable aqueous solution comprising the desired polypeptide in a pharmaceutically acceptable vehicle. A particularly suitable vehicle for parenteral injection is sterile distilled water in which a polypeptide is formulated as a sterile, isotonic solution, properly preserved. Yet another preparation can involve the formulation of the desired molecule with an agent, such as injectable microspheres, bio-erodible particles, polymeric compounds (polylactic acid, polyglycolic acid), beads, or liposomes, that provides for the controlled or sustained release of the product which may then be delivered via a depot injection. Hyaluronic acid may also be used, and this may have the effect of promoting sustained duration in the circulation. Other suitable means for the introduction of the desired molecule include implantable drug delivery devices.

In another aspect, pharmaceutical formulations suitable for injectable administration may be formulated in aqueous solutions, preferably in physiologically compatible buffers such as Hanks' solution, Ringer's solution, or physiologically

buffered saline. Aqueous injection suspensions may contain substances that increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol, or dextran. Additionally, suspensions of the active compounds may be prepared as appropriate oily injection suspensions. Suitable lipophilic solvents or vehicles include fatty oils, such as sesame oil, or synthetic fatty acid esters, such as ethyl oleate, triglycerides, or liposomes. Non-lipid polycationic amino polymers may also be used for delivery. Optionally, the suspension may also contain suitable stabilizers or agents to increase the solubility of the compounds and allow for the preparation of highly concentrated solutions. In another embodiment, a pharmaceutical composition may be formulated for inhalation. Inhalation solutions may also be formulated with a propellant for aerosol delivery. In yet another embodiment, solutions may be nebulized. Pulmonary administration is further described in PCT Application No. PCT/US94/001875, which describes pulmonary delivery of chemically modified proteins.

It is also contemplated that certain formulations may be administered orally. In one embodiment of the present invention, molecules that are administered in this fashion can be formulated with or without those carriers customarily used in the compounding of solid dosage forms such as tablets and capsules. For example, a capsule may be designed to release the active portion of the formulation at the point in the gastrointestinal tract when bioavailability is maximized and pre-systemic degradation is minimized. Additional agents can be included to facilitate absorption of the therapeutic molecule. Diluents, flavorings, low melting point waxes, vegetable oils, lubricants, suspending agents, tablet disintegrating agents, and binders may also be employed. Pharmaceutical compositions for oral administration can also be formulated using pharmaceutically acceptable carriers well known in the art in dosages suitable for oral administration. Such carriers enable the pharmaceutical compositions to be formulated as tablets, pills, dragees, capsules, liquids, gels, syrups, slurries, suspensions, and the like, for ingestion by the patient.

Pharmaceutical preparations for oral use can be obtained through combining active compounds with solid excipient and processing the resultant mixture of granules (optionally, after grinding) to obtain tablets or dragee cores. Suitable auxiliaries can be added, if desired. Suitable excipients include carbohydrate or protein fillers, such as sugars, including lactose, sucrose, mannitol, and sorbitol; starch from corn, wheat, rice, potato, or other plants; cellulose, such as methyl

cellulose, hydroxypropylmethyl-cellulose, or sodium carboxymethylcellulose; gums, including arabic and tragacanth; and proteins, such as gelatin and collagen. If desired, disintegrating or solubilizing agents may be added, such as the cross-linked polyvinyl pyrrolidone, agar, and alginic acid or a salt thereof, such as sodium alginate.

Dragee cores may be used in conjunction with suitable coatings, such as concentrated sugar solutions, which may also contain gum arabic, talc, polyvinylpyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for product identification or to characterize the quantity of active compound, *i.e.*, dosage.

Pharmaceutical preparations that can be used orally also include push-fit capsules made of gelatin, as well as soft, sealed capsules made of gelatin and a coating, such as glycerol or sorbitol. Push-fit capsules can contain active ingredients mixed with fillers or binders, such as lactose or starches, lubricants, such as talc or magnesium stearate, and, optionally, stabilizers. In soft capsules, the active compounds may be dissolved or suspended in suitable liquids, such as fatty oils, liquid, or liquid polyethylene glycol with or without stabilizers.

Additional pharmaceutical compositions will be evident to those skilled in the art, including formulations involving polypeptides in sustained- or controlled-delivery formulations. Techniques for formulating a variety of other sustained- or controlled-delivery means, such as liposome carriers, bio-erodible microparticles or porous beads and depot injections, are also known to those skilled in the art. See for example, PCT/US93/00829 that describes controlled release of porous polymeric microparticles for the delivery of pharmaceutical compositions. Additional examples of sustained-release preparations include semipermeable polymer matrices in the form of shaped articles, e.g. films, or microcapsules. Sustained release matrices may include polyesters, hydrogels, polylactides (U.S. 3,773,919, EP 58,481), copolymers of L-glutamic acid and gamma ethyl-L-glutamate (Sidman et al., Biopolymers, 22:547-556 (1983), poly (2-hydroxyethyl-methacrylate) (Langer et al., J. Biomed. Mater. Res., 15:167-277, (1981); Langer et al., Chem. Tech.,12:98-105(1982)), ethylene vinyl acetate (Langer et al., supra) or poly-D(-)-3-hydroxybutyric acid (EP 133,988). Sustained-release compositions also include liposomes, which can be prepared by any of several methods known in the art. See e.g., Eppstein *et al.*, PNAS (USA), 82:3688 (1985); EP 36,676; EP 88,046; EP 143,949.

The pharmaceutical composition to be used for *in vivo* administration typically must be sterile. This may be accomplished by filtration through sterile filtration membranes. Where the composition is lyophilized, sterilization using this method may be conducted either prior to or following lyophilization and reconstitution. The composition for parenteral administration may be stored in lyophilized form or in solution. In addition, parenteral compositions generally are placed into a container having a sterile access port, for example, an intravenous solution bag or vial having a stopper pierceable by a hypodermic injection needle.

Once the pharmaceutical composition has been formulated, it may be stored in sterile vials as a solution, suspension, gel, emulsion, solid, or a dehydrated or lyophilized powder. Such formulations may be stored either in a ready-to-use form or in a form (e.g., lyophilized) requiring reconstitution prior to administration.

In a specific embodiment, the present invention is directed to kits for producing a single-dose administration unit. The kits may each contain both a first container having a dried protein and a second container having an aqueous formulation. Also included within the scope of this invention are kits containing single and multi-chambered pre-filled syringes (*e.g.*, liquid syringes and lyosyringes).

An effective amount of a pharmaceutical composition to be employed therapeutically will depend, for example, upon the therapeutic context and objectives. One skilled in the art will appreciate that the appropriate dosage levels for treatment will thus vary depending, in part, upon the molecule delivered, the indication for which the polypeptide is being used, the route of administration, and the size (body weight, body surface or organ size) and condition (the age and general health) of the patient. Accordingly, the clinician may titer the dosage and modify the route of administration to obtain the optimal therapeutic effect. A typical dosage may range from about 0.1mg/kg to up to about 100 mg/kg or more, depending on the factors mentioned above. Polypeptide compositions may be preferably injected or administered intravenously. Long-acting pharmaceutical compositions may be administered every three to four days, every week, or biweekly depending on the half-life and clearance rate of the particular formulation. The frequency of dosing will depend upon the pharmacokinetic parameters of the polypeptide in the formulation used. Typically, a composition is administered until a dosage is reached that achieves the desired effect. The composition may therefore be administered as a single dose, or as multiple doses (at the same or different concentrations/dosages) over time, or as

a continuous infusion. Further refinement of the appropriate dosage is routinely made. Appropriate dosages may be ascertained through use of appropriate dose-response data.

The route of administration of the pharmaceutical composition is in accord with known methods, e.g. orally, through injection by intravenous, intraperitoneal, intracerebral (intra-parenchymal), intracerebroventricular, intramuscular, intra-ocular, intraarterial, intraportal, intralesional routes, intramedullary, intrathecal, intraventricular, transdermal, subcutaneous, or intraperitoneal; as well as intranasal, enteral, topical, sublingual, urethral, vaginal, or rectal means, by sustained release systems or by implantation devices. Where desired, the compositions may be administered by bolus injection or continuously by infusion, or by implantation device. Alternatively or additionally, the composition may be administered locally via implantation of a membrane, sponge, or another appropriate material on to which the desired molecule has been absorbed or encapsulated. Where an implantation device is used, the device may be implanted into any suitable tissue or organ, and delivery of the desired molecule may be via diffusion, timed-release bolus, or continuous administration.

In some cases, the svActRIIB polypeptides of the present invention can be delivered by implanting certain cells that have been genetically engineered, using methods such as those described herein, to express and secrete the polypeptide. Such cells may be animal or human cells, and may be autologous, heterologous, or xenogeneic. Optionally, the cells may be immortalized. In order to decrease the chance of an immunological response, the cells may be encapsulated to avoid infiltration of surrounding tissues. The encapsulation materials are typically biocompatible, semi-permeable polymeric enclosures or membranes that allow the release of the polypeptide product(s) but prevent the destruction of the cells by the patient's immune system or by other detrimental factors from the surrounding tissues.

svActRIIB gene therapy *in vivo* is also envisioned wherein a nucleic acid molecule encoding svActRIIB, or a derivative of svActRIIB is introduced directly into the subject. For example, a nucleic acid sequence encoding a svActRIIB is introduced into target cells via local injection of a nucleic acid construct with or without an appropriate delivery vector, such as an adeno-associated virus vector. Alternative viral vectors include, but are not limited to, retroviruses, adenovirus, herpes simplex, virus and papilloma virus vectors. Physical transfer of the virus

vector may be achieved *in vivo* by local injection of the desired nucleic acid construct or other appropriate delivery vector containing the desired nucleic acid sequence, liposome-mediated transfer, direct injection (naked DNA), or microparticle bombardment (gene-gun).

The compositions of the present disclosure may be used alone or in combination with other therapeutic agents to enhance their therapeutic effects or decrease potential side effects.

Uses of svActRIIB Compositions

The present invention provides methods and pharmaceutical compositions for reducing or neutralizing the amount or activity of myostatin, activin A, or GDF-11 *in vivo* and *in vitro*. svActRIIB polypeptides have a high binding affinity for myostatin, activin A, and GDF-11, and are capable of reducing and inhibiting the biological activities of at least one of myostatin, activin A and GDF-11.

In one aspect, the present invention provides methods and reagents for treating myostatin-related and/or activin A related disorders in a subject in need of such a treatment by administering an effective dosage of an svActRIIB composition to the subject. As used herein the term "subject" refers to any animal, such as mammals including humans.

The compositions of the present invention are useful for increasing lean muscle mass in a subject. The compositions may also be useful to increase lean muscle mass in proportion to fat mass, and thus decrease fat mass as percentage of body weight in a subject. Example 3 demonstrates that the svActRIIB polypeptides and proteins of the invention can increase lean muscle mass in animals.

The disorders that can be treated by an svActRIIB composition include but are not limited to various forms of muscle wasting, as well as metabolic disorders such as diabetes and related disorders, and bone degenerative diseases such as osteoporosis.

Muscle wasting disorders also include dystrophies such as Duchenne's muscular dystrophy, progressive muscular dystrophy, Becker's type muscular dystrophy, Dejerine-Landouzy muscular dystrophy, Erb's muscular dystrophy, and infantile neuroaxonal muscular dystrophy. Additional muscle wasting disorders arise from chronic diseases or disorders such as amyotrophic lateral sclerosis, congestive obstructive pulmonary disease, cancer, AIDS, renal failure, organ atrophy, androgen deprivation, and rheumatoid arthritis.

Over-expression of myostatin and/or activin may contribute to cachexia, a severe muscle wasting syndrome. Cachexia results from cancers, and also arises due to rheumatoid arthritis, diabetic nephropathy, renal failure, chemotherapy, injury due to burns, as well as other causes. In another example, serum and intramuscular concentrations of myostatin-immunoreactive protein was found to be increased in men exhibiting AIDS-related muscle wasting and was inversely related to fat-free mass (Gonzalez-Cadavid et al., PNAS USA 95: 14938-14943 (1998)). Myostatin levels have also been shown to increase in response to burns injuries, resulting in a catabolic muscle effect (Lang et al, FASEB J 15, 1807-1809 (2001)). Additional conditions resulting in muscle wasting may arise from inactivity due to disability such as confinement in a wheelchair, prolonged bed rest due to stroke, illness, spinal chord injury, bone fracture or trauma, and muscular atrophy in a microgravity environment (space flight). For example, plasma myostatin immunoreactive protein was found to increase after prolonged bed rest (Zachwieja et al. J Gravit Physiol. 6(2):11(1999). It was also found that the muscles of rats exposed to a microgravity environment during a space shuttle flight expressed an increased amount of myostatin compared with the muscles of rats which were not exposed (Lalani et al., J.Endocrin 167 (3):417-28 (2000)).

In addition, age-related increases in fat to muscle ratios, and age-related muscular atrophy appear to be related to myostatin. For example, the average serum myostatin-immunoreactive protein increased with age in groups of young (19-35 yr. old), middle-aged (36-75 yr. old), and elderly (76-92 yr old) men and women, while the average muscle mass and fat-free mass declined with age in these groups (Yarasheski et al. J Nutr Aging 6(5):343-8 (2002)). In addition, myostatin has now been found to be expressed at low levels in heart muscle and expression is upregulated in cardiomyocytes after infarct (Sharma et al., J Cell Physiol. 180 (1):1-9 (1999)). Therefore, reducing myostatin levels in the heart muscle may improve recovery of heart muscle after infarct.

Myostatin also appears to influence metabolic disorders including type 2 diabetes, noninsulin-dependent diabetes mellitus, hyperglycemia, and obesity. For example, lack of myostatin has been shown to improve the obese and diabetic phenotypes of two mouse models (Yen *et al. FASEB J. 8*:479 (1994). The svActRIIB polypeptides of the present disclosure are suitable for treating such metabolic disorders. Therefore, administering the compositions of the present invention will

improve diabetes, obesity, and hyperglycemic conditions in suitable subjects. In addition, compositions containing the svActRIIB polypeptides may decrease food intake in obese individuals.

Administering the stabilized ActRIIB polypeptides of the present invention may improve bone strength and reduce osteoporosis and other degenerative bone diseases. It has been found, for example, that myostatin-deficient mice showed increased mineral content and density of the mouse humerus and increased mineral content of both trabecular and cortical bone at the regions where the muscles attach, as well as increased muscle mass (Hamrick et al. Calcif Tissue Int 71(1):63-8 (2002)). In addition, the svActRIIB compositions of the present invention can be used to treat the effects of androgen deprivation in cases such as androgen deprivation therapy used for the treatment of prostate cancer, for example.

The present invention also provides methods and compositions for increasing muscle mass in food animals by administering an effective dosage of the svActRIIB proteins to the animal. Since the mature C-terminal myostatin polypeptide is similar or identical in all species tested, svActRIIB polypeptides would be expected to be effective for increasing lean muscle mass and reducing fat in any agriculturally important species including cattle, chicken, turkeys, and pigs.

The svActRIIB polypeptides and compositions of the present invention also antagonize the activity of activin A, as shown in the *in vitro* assays below. Activin A is known to be expressed in certain types of cancers, particularly gonadal tumors such as ovarian carcinomas, and to cause severe cachexia. (Ciprano et al. Endocrinol 141 (7):2319-27 (2000), Shou et al., Endocrinol 138 (11):5000-5 (1997); Coerver et al, Mol Endocrinol 10(5):534-43 (1996); Ito et al. British J Cancer 82(8):1415-20 (2000), Lambert-Messerlian, et al, Gynecologic Oncology 74:93-7 (1999). Therefore, the compositions of the present disclosure may be used to treat conditions related to activin A overexpression, as well as myostatin expression, such as cachexia from certain cancers and the treatment of certain gonadal type tumors.

In addition, the svActRIIB polypeptides of the present invention are useful for detecting and quantitating myostatin, activin A, or GDF-11 in any number of assays. In general, the stabilized ActRIIB polypeptides of the present invention are useful as capture agents to bind and immobilize myostatin, activin A, or GDF-11 in a variety of assays, similar to those described, for example, in Asai, ed., Methods in Cell Biology, 37, Antibodies in Cell Biology, Academic Press, Inc., New York (1993). The

polypeptides may be labeled in some manner or may react with a third molecule such as an antibody which is labeled to enable myostatin to be detected and quantitated. For example, a polypeptide or a third molecule can be modified with a detectable moiety, such as biotin, which can then be bound by a fourth molecule, such as enzyme-labeled streptavidin, or other proteins. (Akerstrom, *J Immunol* 135:2589 (1985); Chaubert, *Mod Pathol* 10:585 (1997)).

The invention having been described, the following examples are offered by way of illustration, and not limitation.

Example 1

Expression and Purification of svActRIIB Polypeptides

The following methods were used for expressing and purifying the stabilized ActRIIB polypeptides.

The cDNA of the human activin type IIB receptor was isolated from a cDNA library of human testis origin (Clontech, Inc.) and cloned as described in U.S. application serial no: 11/590,962, U.S. application publication No: 2007/0117130, which is herein incorporated by reference.

The following method was used to produce the svActRIIB-Fc (E28W, S44T) polypeptide (SEQ ID NO: 10), and the ActRIIB-Fc (E28W) (SEQ ID NO: 21). Polynucleotides encoding the svActRIIB, (E28W, S44T) (SEQ ID NO: 5), or polynucleotides encoding ActRIIB (E28W) (SEQ ID NO: 19) were fused to polynucleotides encoding the human IgG2 Fc (SEQ ID NO: 22), via polynucleotides encoding hinge linker sequence (SEQ ID NO: 26) using PCR overlap extension using primers containing the mutation resulting in the amino acid substitutions at position 28 of E to W, and at position 44 of S to T. The full polynucleotide sequence is SEQ ID NO: 9 for svActRIIB-IgG Fc (E28W, S44T), and SEQ ID NO: 20 for ActRIIB-ActRIIB-IgG Fc (E28W). Double stranded DNA fragments were subcloned into vectors pTT5 (Biotechnology Research Institute, National Research Council Canada (NRCC), 6100 Avenue Royalmount, Montréal (Québec) Canada H4P 2R2), pDSRα described in WO/9014363) and/or derivatives of pDSRα.

Transient expression of stabilized ActRIIB-Fc polypeptides was carried out as follows.

The svActRIIB-IgG Fc (E28W, S44T) (SEQ ID NO: 10), and ActRIIB-IgG Fc (E28W) (SEQ ID NO: 21) polypeptides were expressed transiently in serum-free

suspension adapted 293-6E cells (National Research Council of Canada, Ottawa, Canada) maintained in FreeStyle™ medium (Invitrogen Corporation, Carlsbad, CA) supplemented with 250 μg/ml geneticin (Invitrogen) and 0.1% Pluronic F68 (Invitrogen). Transfections were performed as 1L cultures. Briefly, the cell inoculum was grown to 1.1×10^6 cells/ml in a 4L fernbach shake flask (Corning, Inc.). The shake flask culture was maintained on an Innova 2150 shaker platform (News Brunswick Scientific, Edison, NJ) at 65 RPM which was placed in a humidified incubator maintained at 37°C and 5% CO_2. At the time of transfection, the 293-6E cells were diluted to 1.0×10^6 cells/ml.

The transfection complexes were formed in 100 ml FreeStyle™ 293 Media (Invitrogen). 1 mg plasmid DNA was first added to the medium followed by 3 ml of FuGene HD transfection reagent (Roche Applied Science, Indianapolis, IN). The transfection complex was incubated at room temperature for approximately 15 minutes and then added to the cells in the shake flask. Twenty hours post transfection, 20% (w/v) of peptone TN1 (OrganoTechnie S.A., TeknieScience, QC, Canada) was added to reach a final concentration of 0.5% (w/v). The transfection/expression was performed for 4-7 days, after which the conditioned medium was harvested by centrifugation at 4,000 RPM for 60 minutes at 4°C.

Stable transfection and expression was carried out as follows. The svActRIIB-IgG-Fc cell lines were created by transfecting stable CHO host cells with the expression plasmids containing polynucleotides encoding svActRIIB-IgG Fc (E28W, S44T) (SEQ ID NO: 9) or ActRIIB-IgG Fc (E28W) (SEQ ID NO: 20) using a standard electroporation procedure. After transfection of the host cell line with the expression plasmids the cells were grown in serum-free selection medium without GHT for 2-3 weeks to allow for selection of the plasmid and recovery of the cells. Cells are selected until they achieved greater than 85% viability. This pool of transfected cells was then cultured in medium containing 150 nM methotrexate.

In a six-day expression assay, pools of svActRIIB-Fc (E28W, S44T) expressing cells showed higher cell titer, growth performance, and improved specific productivity (picogram/cell/day) of protein produced compared with pools of ActRIIB-Fc (E28W) expressing cells. Select pools, for example, produced about 1.2 g/liter for svActRIIB-Fc (E28W, S44T) compared with 0.9 g/liter for ActRIIB-Fc (E28W).

Each of an svActRIIB-Fc (E28W, S44T) and an ActRIIB-Fc (E28W) expressing cell line was scaled up using a typical fed-batch process. Cells were inoculated into a Wave bioreactor (Wave Biotech LLC). Cultures were fed three times with bolus feeds. 10 L were harvested on day 10, the remainder was harvested on day 11; both harvests underwent depth filtration followed by sterile filtration. The conditioned media was filtered through a 10 inch 0.45/0.2 micron pre filter, followed by a filtration through a 6 inch 0.2 micron filter.

Protein Purification

Approximately 5 L of conditioned media was directly loaded onto a 220mL MabSelect™ column Protein A column (GE Healthcare). The column was pre-equilibrated in PBS (phosphate-buffered saline: 2.67 mM potassium chloride, 138 mM sodium chloride, 1.47 mM potassium phosphate monobasic, 8.1 mM sodium phosphate dibasic, pH 7.4). The column was washed with the equilibration buffer until the reading at OD280 was approximately zero, and then the protein was eluted with 0.1M acetic acid.

The Mabselect™ Pool was applied to a 300mL SP-HP column (GE Healthcare) (5 x 15 cm). The column was pre-equilibrated with 10mM NaOAC, pH 5. The column was then washed with the equilibration buffer until the reading at OD280 was approximately 0. The column was eluted with 20 column volumes of a gradient buffer from 0-150 mM NaCl in 10 mM NaOAC, pH 5. The SP-HP pool was concentrated, and filtered with a 0.2uM cellulose acetate (Corning) filter.

The sequences of the proteins used are set forth in the Table below.

ActRIIB-Fc	ActRIIB sequence	Linker— Hinge	IgG2 Fc
svActRIIB-IgG_2Fc (E28W, S44T) (SEQ ID NO: 10)	ETRWCIYYNANWELERT NQTGLERCEGEQDKRLH CYASWRNSSGTIELVKKG CWLDDFNCYDRQECVAT EENPQVYFCCCEGNFCNE RFTHLPEAGGPEVTYEPP PTAPT (SEQ ID NO: 6)	GGGGSV ECPPCP (SEQ ID NO: 27)	APPVAGPSVFLFPPKPKDTLMISR TPEVTCVVVDVSHEDPEVQFNWY VDGVEVHNAKTKPREEQFNSTFR VVSVLTVVHQDWLNGKEYKCKV SNKGLPAPIEKTISKTKGQPREPQ VYTLPPSREEMTKNQVSLTCLVK GFYPSDIAVEWESNGQPENNYKT TPPMLDSDGSFFLYSKLTVDKSR WQQGNVFSCSVMHEALHNHYTQ KSLSLSPGK (SEQ ID NO:22)

ActRIIB-IgG_2Fc (E28W) (SEQ ID NO: 21)	ETRWCIYYNANWELERT NQSGLERCEGEQDKRLH CYASWRNSSGTIELVKKG CWLDDFNCYDRQECVAT EENPQVYFCCCEGNFCNE RFTHLPEAGGPEVTYEPP PTAPT (SEQ ID NO: 19)	GGGGSV ECPPCP (SEQ ID NO: 27)	APPVAGPSVFLFPPKPKDTLMISR TPEVTCVVVDVSHEDPEVQFNWY VDGVEVHNAKTKPREEQFNSTFR VVSVLTVVHQDWLNGKEYKCKV SNKGLPAPIEKTISKTKGQPREPQ VYTLPPSREEMTKNQVSLTCLVK GFYPSDIAVEWESNGQPENNYKT TPPMLDSDGSFFLYSKLTVDKSR WQQGNVFSCSVMHEALHNHYTQ KSLSLSPGK (SEQ ID NO: 22)

Example 2

Characterization of polypeptides

Samples of the svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10) purified through the MabSelect™ step, and ActRIIB-Fc (E28W) (SEQ ID NO: 21) polypeptides purified through the SP-HP column step, as described above, were diluted with PBS, pH 7.4 to 0.2 mg/ml. The glycosylation profile of the polypeptides were then determined using SEC as described below.

Size exclusion chromatography (SEC). Experiments were performed on an Agilent 1100 HPLC system with two columns (TOSOHAAS G3000swxl, 7.8 x 300 mm) in tandem. 2x PBS was used as the mobile phase at 0.5 ml/minute.

Figure 1 shows a comparison between ActRIIB-Fc (E28W) and svActRIIB-Fc (E28W, S44T) on an SEC column using the protocols described above. svActRIIB-Fc (E28W, S44T) shows a single peak compared with ActRIIB-Fc (E28W), which shows three peaks. These correspond to the degree of N-linked glycosylation at the N42 position of the Fc dimers of both proteins. The single peak of the svActRIIB-Fc (E28W, S44T) polypeptide corresponds to fully glycosylated N-linked asparagines at position N42 of the dimer. The three peaks of ActRIIB-Fc (E28W) corresponds to (from left to right), fully glycosylated asparagines at N42, partially glycosylated asparagines at N42, and non-glycosylated asparagines at N42. Therefore, this demonstrates that the svActRIIB-Fc (E28W, S44T) molecule is fully glycosylated compared to ActRIIB-Fc (E28W), which is heterogeneous with respect to this glycosylation site, and thus more difficult to purify. In addition, preliminary studies indicate that the svActRIIB-Fc (E28W, S44T) molecule has addition improved manufacturability properties as set forth below. Additional studies also demonstrated

that the least glycosylated peak of the ActRIIB-Fc (E28W) has lower physical and thermal stability than partially and fully glycosylated molecules.

Determination of K_D and IC_{50} values of the receptor polypeptides for activin A, myostatin, and GDF-11 were obtained as described below.

KinEx A™ Equilibrium Assays

Solution-based equilibrium-binding assays using KinExA™ technology (Sapidyne Instruments, Inc.) were used to determine the dissociation equilibrium (K_D) of ligand binding to ActRIIB-Fc polypeptides. UltraLink Biosupport beads (Pierce) was pre-coated with about 100 μg/ml each of myostatin, GDF-11, and activin A overnight, and then blocked with BSA. 1 pM and 3 pM of ActRIIB-Fc (E28W) (SEQ ID NO: 21) and svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10) samples were incubated with various concentrations (0.7 fM to 160 pM) of myostatin, activin A, and GDF-11 respectively in sample buffer at room temperature for 8 hours before being run through the ligand-coated beads. The amount of the bead-bound soluble receptor was quantified by fluorescent (Cy5) labeled goat anti-human-Fc antibody at 1 mg/ml in superblock. The binding signal is proportional to the concentration of free soluble receptor at equilibrium with a given myostatin, activin A, or GDF-11 concentration. K_D was obtained from the nonlinear regression of the competition curves using a dual-curve one-site homogeneous binding model provided in the KinEx A™ software (Sapidyne Instruments, Inc.). The K_D values obtained for each are given in the table below.

	Myostatin	GDF-11	Activin A
ActRIIB-Fc (E28W)	0.1 pM	0.1 pM	0.2 pM
svActRIIB-Fc (E28W, S44T)	0.1pM	0.1 pM	0.1 pM

C2C12 Cell Based Activity Assay

The ability of ActRIIB-Fc (E28W) (SEQ ID NO: 21) and svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10) to inhibit the binding of activin A, GDF-11, or myostatin to the wild type activin IIB receptor-Fc was tested using a cell based activity assay as described below.

A myostatin/activin/GDF-11-responsive reporter cell line was generated by transfection of C2C12 myoblast cells (ATCC No: CRL-1772) with a pMARE-luc

construct. The pMARE-luc construct is made by cloning twelve repeats of the CAGA sequence, representing the myostatin/activin response elements (Dennler et al. EMBO 17: 3091-3100 (1998)) into a pLuc-MCS reporter vector (Stratagene cat # 219087) upstream of the TATA box. The C2C12 cells naturally express activin receptor IIB on their cell surface. When myostatin/activinA/GDF-11 binds the cell receptors, the Smad pathway is activated, and phosphorylated Smad binds to the response element (Macias-Silva et al. Cell 87:1215 (1996)), resulting in the expression of the luciferase gene. Luciferase activity was then measured using a commercial luciferase reporter assay kit (cat # E4550, Promega, Madison, WI) according to manufacturer's protocol. A stable line of C2C12 cells that has been transfected with pMARE-luc (C2C12/pMARE) was used to measure activity according to the following procedure. Reporter cells were plated into 96 well cultures. Screening using dilutions of the ActRIIB-IgG2 Fc fusions constructed as described above was performed with the concentration fixed at 4 nM activin A, myostatin, and GDF-11. Each of these ligands was pre-incubated with the receptors at several concentrations. Activity was measured by determining the luciferase activity in the treated cultures. The IC_{50} values were determined for each polypeptide. These are shown in the Table below. These values are given in Table below.

	Myostatin	GDF-11	Activin A
ActRIIB-Fc (E28W)	0.95 nM	2.4 nM	3.2 nM
svActRIIB-Fc (E28W, S44T)	1.07 nM	2.4 nM	3.6 nM

Thus the cell based activities are approximately the same for ActRIIB-Fc (E28W) and svActRIIB-Fc (E28W, S44T).

Stability at low pH

Stability of a protein at low pH is a useful parameter in considering the manufacturability of the protein, since the viral inactivation step of a commercial production process typically is carried out at low pH, such as between about pH 3.0 to 4.0.

To assess the short term protein stability effects at low pH experienced during the viral inactivation step of commercial protein purification the following test was

performed. Each protein was diluted to 10 mg/ml of 100 mM sodium acetate, pH 3.5. This was stored at 25 °C and analyzed at time 0, at 2 hours and at 24 hours using SEC analysis. SEC analysis was performed as described above, and percentage of high molecular weight aggregates was determined.

% HMW aggregate

	T = 0	T = 2 hours	T = 4 hours
ActRIIB-Fc (E28W)	1.53	1.36	13.74
svActRIIB-Fc (E28W, S44T)	1.66	2.17	8.93

Thus the percentage of high molecular weight aggregates produced at pH 3.5 is substantially less for svActRIIB-Fc (E28W, S44T) than ActRIIB-Fc (E28W) at 4 hours.

Additional studies showed that svActRIIB-Fc (E28W, S44T) showed better reversibility than ActRIIB-Fc (E28W) from exposure to pH 3.0, 3.5 and 5.0, and that svActRIIB-Fc (E28, S44T) was more homogeneous that ActRIIB-Fc (E28W) at all pHs.

Thus, the svActRIIB-Fc (E28W, S44T) polypeptides are demonstrated to have improved manufacturability characteristics, in particular, improved stability at low pH, and greater homogeneity at all pHs compared with ActRIIB-Fc (E28W) while retaining the ability to inhibit activin A, myostatin, and GDF-11 activity.

Example 3

Determination of *in vivo* efficacy

11-week-old female C57Bl/6 mice were purchased from Charles River Laboratories. The mice (ten mice per group) were administered a single dose (10 mg/kg) of svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10) or vehicle (PBS). Lean body mass was determined by NMR (PIXImus, GE LUNAR Corporation) at 3, 7, 10 and 14 days after dose administration for the ten animals in each group. The results for each set of mice are shown in Figure 2. It can be seen that a single dose of svActRIIB-Fc (E28W, S44T) significantly increased lean body mass in the animals. ($P<0.001$, based on repeated measurement ANOVA. n=10 animals per group).

A study to determine dose-response efficacy was carried out as follows. Escalating single doses of 0, 0.3, 3, 10, and 30 mg/kg of svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10) in PBS was administered subcutaneously to female 10-12 week old C57Bl/6 mice (Charles River Laboratories). Six animals were initially in each dosage group including the PBS control group. Lean body mass was determined by NMR (PIXImus, GE LUNAR Corporation) every two to four days for the forty-two days of the study. At the end of each week, one animal from each group was sacrificed to obtain additional data (six in total each week from all six groups), and the lean body mass determined for the remaining animals in subsequent weeks. The results are set out in Figure 3. It can be seen that the svActRIIB-Fc (E28W, S44T) polypeptide at all doses significantly increased muscle mass in the animals, in a dose-dependent manner.

In further studies, head to head comparisons between ActRIIB-Fc (E28W) (SEQ ID NO: 21) and svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10) were performed on female C57Bl/6 mice (Charles River Laboratories, 10 animals per group) to measure the increase in lean muscle mass and body weight changes after a single dose of 10 mg/kg of each soluble receptor compared with a control group (administered PBS). Lean body mass was determined by NMR (PIXImus, GE LUNAR Corporation), and body weight change was determined by weighing the animals periodically for 37 days. The results at the end of this comparative study was that ActRIIB-Fc (E28W) (SEQ ID NO: 21) showed an increase of 24% in lean muscle mass and 25% in increase of body weight compared with an increase of 25% in lean muscle mass and 20% increase in body weight for svActRIIB-Fc (E28W, S44T) (SEQ ID NO: 10), compared with an increase of 5% lean muscle mass and 9% increase body weight for the control group.

Therefore, it can be seen that svActRIIB-Fc (E28W, S44T) retains comparable *in vivo* efficacy compared with ActRIIB-Fc (E28W) while having improved manufacturability characteristics.

Example 4

Improved Manufacturability with Modified Hinge Linkers

Additional linkers and modified hinge regions were constructed to test for further improvement of protein expression and manufacturability of the stabilized

ActRIIB (E28W, S44T) polypeptides. Modified linker/hinge sequences based on modifications of hinge linker #1 were generated using overlap extension PRC mutagenesis methods, according to Mikaelian et al., Methods in Molecular Biology, 57, 193-202 (1996), and well known methodology.

The modified hinge linkers designed to perform well with IgG2 Fc fusions are hinge linker #2-7 set forth below (in comparison to hinge linker #1 sequences).

hinge linker #1 polynucleotide
ggaggggaggatctgtcgagtgcccaccgtgccca (SEQ ID NO: 26).

hinge linker #1 polypeptide
GGGGSVECPPCP (SEQ ID NO: 27)

hinge linker #2 polynucleotide
ggaggggaggatctgagcgcaaatgttgtgtcgagtgcccaccgtgc (SEQ ID NO: 37)

hinge linker #2 peptide
GGGGSERKCCVECPPC (SEQ ID NO: 38)

hinge linker #3 polynucleotide
ggaggggaggatctggtggaggtggttcaggtccaccgtgc (SEQ ID NO: 39)

hinge linker #3 peptide
GGGGSGGGGSGPPC (SEQ ID NO: 40)

hinge linker #4 polynucleotide
ggaggggaggatctggtggaggtggttcaggtccaccggga (SEQ ID NO: 41)

hinge linker #4 peptide
GGGGSGGGGSGPPG (SEQ ID NO: 42)

hinge linker #5 polynucleotide
ggaggggaggatctgagcgcaaatgtccaccttgtgtcgagtgcccaccgtgc (SEQ ID NO: 43)

hinge linker #5 peptide
GGGGSERKCPPCVECPPC (SEQ ID NO: 44)

hinge linker #6 peptide
GPASGGPASGPPCP (SEQ ID NO: 45)

hinge linker #7 peptide
GPASGGPASGCPPCVECPPCP (SEQ ID NO: 46)

The following hinge linkers #8 to #10 below were designed to perform well with an IgG1Fc (SEQ ID NO: 23) or the modified IgG1Fc given below (SEQ ID NO: 47 below).

modified IgG1 Fc

APELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEV
HNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISK
AKGQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENN
YKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLS
PGK (SEQ ID NO: 47)

hinge linker #8 peptide
GGGGSVDKTHTCPPCP (SEQ ID NO: 48)

hinge linker #9 peptide
GGGGSVDKTHTGPPCP (SEQ ID NO: 49)

hinge linker #10 peptide
GGGGSGGGGSVDKTHTGPPCP (SEQ ID NO: 50)

Testing of modified hinge linker sequences with svActRIIB-Fc (28W, S44T) was performed as follows. Polynucleotides encoding svActRIIB (E28W, S44T) (SEQ ID NO: 5), polynucleotides encoding the modified hinge linkers shown above, and polynucleotides encoding IgG2 Fc (SEQ ID NO: 22) or polynucleotides encoding IgG1 Fc (SEQ ID NO: 23) or modified IgG1 Fc (SEQ ID NO: 47) were subcloned into vectors as described in Example 1 and expressed using the transient 293-6E expression system as described in Example 1, except for the following changes: F17 media (Invitrogen) supplemented with 1.1 mg/ml Pluronic, 6 mM L-glutamine and 25 μg/ml geneticin (Invitrogen) was used in place of Freestyle 293 medium as described in Durocher et al., Nucleic Acids Research 30, No. 3, e9 (2002)). The cultures were grown for seven days at 37 °C after transfection. Aliquots were centrifuged to remove cells, and the supernatant was mixed with loading buffer before being heated and loaded onto a 4-20% tris-glycine gel for analysis by Western Blot. After the protein was transferred to a nitrocellulose membrane, samples were probed with a hydrogen peroxidase conjugated anti-human Fc antibody (Pierce #31423) at a dilution of 1:1000.

Protein purification was performed using the following procedure. Approximately 0.25 L of the conditioned media containing the svActRIIB-Fc variants were concentrated using a 5 ft^2 10K membrane tangential flow filter. The concentrated material was applied to a 5 mL Protein A High Performance Column™ (GE Heathcare) which had been equilibrated with PBS (Dulbecco's with no magnesium chloride or calcium chloride). After washing the column with the equilibration buffer until the absorbance at 280 nm (OD_{280}) was less than 0.1, the

bound protein was eluted with 0.1 M glycine-HCl, pH 2.7, and immediately neutralized with 1 M Tris-HCl, pH 8.5.

The portion of aggregate in percent and the portion of half molecule in percent were determined by the following method. Denaturing size exclusion chromatography experiments were performed by injecting a 50 µl aliquot of each sample onto an HPLC system with two size exclusion columns (TOSOHAAS G3000swxl) in tandem. The mobile phase contains 5 M GuHCl in phosphate buffered saline (PBS). All samples were diluted to 1 mg/mL in PBS with 7 M GuHCl. The portion of aggregate in percent is determined from the total peak areas of the peaks eluted before the main peak, whereas the portion of half-molecule in percent is determined from the total peak areas of the peaks eluted after the main peak. The half-molecule are believed to represent inactive half-molecules.

Aggregate and half-molecule distribution of svActRIIB-Fc (E28W, S44T) with the various hinge linkers are set forth in the following table.

Hinge linker sequence	% aggregate	% half molecule
GGGGSVECPPC (SEQ ID NO: 27)	0.63	15.12
GGGGSERKCCVECPPC (SEQ ID NO: 38)	15.01	7.19
GGGGSGGGGSGPPC (SEQ ID NO: 40)	0.56	3.83
GGGGSGGGGSGPPG (SEQ ID NO: 42)	0.00	99.03
GGGGSERKCPPCVECPPC (SEQ ID NO: 44)	1.09	3.81

Thus certain linkers may improve manufacturability of the stabilized ActRIIB-Fc (E28W, S44T) according to these preliminary tests by reducing the percentage of inactive half-molecules produced.

The table below identifies the sequences as listed in the sequence listing.

SEQ ID NO	Description
1	ActRIIB extracellular domain, polynucleotide
2	ActRIIB extracellular domain, polypeptide

3	svActRIIB (E28W, S44T) polynucleotide with signal sequence
4	svActRIIB (E28W, S44T) polypeptide with signal sequence
5	svActRIIB (E28W, S44T) polynucleotide without signal sequence
6	svActRIIB (E28W, S44T) polypeptide without signal sequence
7	svActRIIB-Fc (E28W, S44T) polynucleotide with signal sequence
8	svActRIIB-Fc (E28W, S44T) polypeptide with signal sequence
9	svActRIIB-Fc (E28W, S44T) polynucleotide without signal sequence
10	svActRIIB-Fc (E28W, S44T) polypeptide without signal sequence
11	svActRIIB (E28Y, S44T) polynucleotide with signal sequence
12	svActRIIB (E28Y, S44T) polypeptide with signal sequence
13	svActRIIB (E28Y, S44T) polynucleotide without signal sequence
14	svActRIIB (E28Y, S44T) polypeptide without signal sequence
15	svActRIIB-Fc (E28Y, S44T) polynucleotide with signal sequence
16	svActRIIB-Fc (E28Y, S44T) polypeptide with signal sequence
17	svActRIIB-Fc (E28Y, S44T) polynucleotide without signal sequence
18	svActRIIB-Fc (E28Y, S44T) polypeptide without signal sequence
19	ActRIIB (E28W) polypeptide, without signal sequence
20	ActRIIB-Fc (E28W) polynucleotide, without signal sequence
21	ActRIIB-Fc (E28W) polypeptide, without signal sequence
22	IgG2Fc polypeptide sequence
23	IgG1Fc polypeptide sequence
24	IgG4 Fc polypeptide sequence
25	Linker amino acid sequence
26	Hinge linker #1 polynucleotide sequence
27	Hinge linker #1 peptide sequence
28	Hinge region IgG2
29	Hinge region IgG1
30	Hinge region IgG4
31	Alternative signal sequence, polypeptide
32	Signal sequence, polypeptide
33	Wild type ActRIIB accession NP_001097
34	Activin polypeptide sequence
35	Myostatin polypeptide sequence
36	GDF-11 polypeptide sequence
37	Hinge linker sequence #2 polynucleotide
38	Hinge linker sequence #2 peptide
39	Hinge linker sequence #3 polynucleotide
40	Hinge linker sequence #3 peptide
41	Hinge linker sequence #4 polynucleotide
42	Hinge linker sequence #4 peptide
43	Hinge linker sequence #5 polynucleotide
44	Hinge linker sequence #5 peptide
45	Hinge linker sequence #6 peptide
46	Hinge linker sequence #7 peptide
47	Modified IgG1 Fc polypeptide sequence
48	Hinge linker sequence #8 peptide
49	Hinge linker sequence #9 peptide
50	Hinge linker sequence #10 peptide

The present invention is not to be limited in scope by the specific embodiments described herein, which are intended as single illustrations of individual aspects of the invention, and functionally equivalent methods and components are within the scope of the invention. Indeed, various modifications of the invention, in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

CLAIMS

What is claimed is:

1. An isolated protein comprising a stabilized activin IIB receptor polypeptide, wherein said polypeptide is selected from the group consisting of:

(a) a polypeptide consisting of the sequence set forth in the group consisting of SEQ ID NO: 4, 6, 12 and 14;

(b) a polypeptide having at least 90 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11, and

(c) polypeptides having at least 95 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

2. The protein of claim 1, wherein the polypeptide is connected to at least one heterologous protein.

3. The protein of claim 2, wherein the heterologous polypeptide is an IgG Fc domain.

4. The protein of claim 2, wherein the heterologous polypeptide is connected to the polypeptide by a linker sequence.

5. The protein of claim 4, wherein the linker is selected from the group consisting of: SEQ ID NO: 25, SEQ ID NO: 27, SEQ ID NO: 38, SEQ ID NO: 40, SEQ ID NO: 42, SEQ ID NO: 44, SEQ ID NO: 45, SEQ ID NO: 46, SEQ ID NO: 48, SEQ ID NO: 49 and SEQ ID NO: 50.

6. The protein of claim 3, wherein the protein comprises a polypeptide selected from the group consisting of:

(a) a polypeptide consisting of the sequence set forth in the group consisting of SEQ ID NO: 8, 10, 16 and 18;

(b) a polypeptide having at least 90 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11, and

(c) polypeptides having at least 95 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

7. The protein of claim 1, wherein the amino acid residue at position 64 is alanine.

8. An isolated protein comprising a stabilized activin IIB receptor polypeptide (svActRIIB) wherein said polypeptide is selected from the group consisting of:

(a) a polypeptide consisting of the sequence set forth in SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from the group consisting of W and Y, and the substitution at position 44 is T;

(b) a polypeptide consisting of the sequence set forth in amino acids 19 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from the group consisting of W and Y, and the substitution at position 44 is T;

(c) a polypeptide consisting of the sequence set forth in amino acids 23 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from the group consisting of W and Y, and the substitution at position 44 is T;

(d) a polypeptide consisting of the sequence set forth in amino acids 25 through 134 of SEQ ID NO: 2, except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from the group consisting of W and Y, and the substitution at position 44 is T;

(e) a polypeptide having at least 80 % sequence identity to any one of (a) through (d), except for a single amino acid substitution at position 28, and a single amino acid substitution at position 44, wherein the substitution at position 28 is selected from the group consisting of W and Y, and the substitution at position 44 is T, wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

9. An isolated nucleic acid molecule comprising a polynucleotide encoding the polypeptide of claim 8.

10. An isolated nucleic acid molecule comprising a polynucleotide selected from the group consisting of:

(a) a polynucleotide encoding a polypeptide consisting of the sequence set forth in the group consisting of SEQ ID NO: 4, 6, 12, and 14;

(b) a polynucleotide encoding a polypeptide having at least 90 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44; and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11; and

(c) a polynucleotide encoding a polypeptide having at least 95 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

11. The nucleic acid molecule of claim 10, wherein the polynucleotide has the sequence selected from the group consisting of SEQ ID NO: 3, 5, 11 and 13 or its complement.

12. The nucleic acid molecule of claim of claim 10, wherein the polynucleotide further comprises polynucleotides encoding at least one heterologous protein.

13. The nucleic acid molecule of claim 12, comprising a polynucleotide selected from the group consisting of:

(a) a polynucleotide encoding a polypeptide consisting of the sequence set forth in the group consisting of SEQ ID NO: 8, 10, 16, and 18;

(b) a polynucleotide encoding a polypeptide having at least 90 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11; and

(c) a polynucleotide encoding a polypeptide having at least 95 % sequence identity to (a), wherein the polypeptide has a W or a Y at position 28 and a T at position 44, and wherein the polypeptide is capable of binding myostatin, activin A, or GDF-11.

14. The nucleic acid molecule of claim 13, wherein the polynucleotide has the sequence selected from the group consisting of SEQ ID NO: 7, 9, 15 and 17, or it complement.

15. The nucleic acid molecule of claim 10, wherein the polynucleotide is operably linked to a transcriptional or translational regulatory sequence.

16. A recombinant vector comprising the nucleic acid molecule of claim 10.

17. A host cell comprising the recombinant vector of claim 16.

18. The host cell of claim 17, wherein the host cell is a mammalian cell.

19. A method of producing an svActRIIB protein comprising culturing the host cell of claim 17 under conditions promoting the expression of the protein, and recovering the protein.

20. A pharmaceutical composition comprising an effective amount of the protein of claim 1 in admixture with a pharmaceutically acceptable carrier.

21. A method of inhibiting myostatin activity or activin activity in a subject in need of such treatment comprising administering a therapeutically effective amount of the composition of claim 20 to the subject.

22. A method of increasing lean muscle mass or increasing the ratio of lean muscle mass to fat mass in a subject in need of such treatment comprising administering a therapeutically effective amount of the composition of claim 20 to the subject.

23. A method of treating a muscle-wasting disease or metabolic disorder in a subject in need of such treatment comprising administering a therapeutically effective amount of the composition of claim 20 to the subject.

24. The method of claim 23, wherein the muscle-wasting disease is selected from muscular dystrophy, amyotrophic lateral sclerosis, congestive obstructive pulmonary disease, chronic heart failure, cancer cachexia, AIDS, renal failure, uremia, rheumatoid arthritis, age-related sarcopenia, organ atrophy, carpal tunnel syndrome, androgen deprivation, burn injury, diabetes, and muscle-wasting due to prolonged bed rest, spinal chord injury, stroke, bone fracture, aging or exposure to micro-gravity.

25. The method of claim 23, wherein the metabolic disorder is selected from diabetes, obesity, hyperglycemia, and bone loss.

26. A method of treating a disease in which activin is over-expressed in a subject in need of such treatment comprising administering a therapeutically effective amount of the composition of claim 20 to said subject.

27. The method of claim 26, wherein the disease is cancer.

28. A method of treating a muscle wasting or metabolic or activin related disorder in a subject in need of such a treatment comprising administering the vector of claim 16 to the subject, wherein the vector is capable of directing expression of an svActRIIB polypeptide in the subject.