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(54) Titre : HETEROMULTIMERES ALK4:ACTRIIB ET LEURS UTILISATIONS
(54) Title: ALK4:ACTRIIB HETEROMULTIMERS AND USES THEREOF

ActRIIa ILGRSETQEC LFFNANWEKD RTNQTGVEPC YGDKDKRRHC FATWKNISGS
ActRIIb GRGEAETREC IYYNANWELE RTNQSGLERC EGEQDKRLHC YASWRNSSGT

IEIVKQGOWL DDINCYDRID CVEKKDSPEV YFCCCEGNMC NEKFSYFPEN
IELVKKGOWL DDFNCDYDRQE CVATEENPQV YFCCCEGNFC NERFTHLPEA

EVTQPTSNPV TPKPPT
GGPEVTYEPP PTAPT

FIGURE 1

(57) Abrégé/Abstract:

In certain aspects, the disclosure provides soluble heteromeric polypeptide complexes comprising an extracellular domain of an ALK4 receptor and an extracellular domain of ActRIIB. In certain aspects, such soluble ALK4:ActRIIB complexes may be used to

(57) **Abrégé(suite)/Abstract(continued):**

regulate (promote or inhibit) growth of tissues or cells including, for example, muscle, bone, cartilage, fat, neural tissue, tumors, and/or cancerous cells. In certain aspects, such ALK4:ActRIIB complexes are can be used to improve muscle formation, bone formation, metabolic parameters, and disorders associated with these tissues, cellular networks, kidney, and endocrine systems.

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(54) Title: **ALK4:ACTRIIB HETEROMULTIMERS AND USES THEREOF**

(57) Abstract: In certain aspects, the disclosure provides soluble heteromeric polypeptide complexes comprising an extracellular do-
main of an ALK4 receptor and an extracellular domain of ActRIIB. In certain aspects, such soluble ALK4:ActRIIB complexes may
be used to regulate (promote or inhibit) growth of tissues or cells including, for example, muscle, bone, cartilage, fat, neural tissue,
tumors, and/or cancerous cells. In certain aspects, such ALK4:ActRIIB complexes are can be used to improve muscle formation, bone
formation, metabolic parameters, and disorders associated with these tissues, cellular networks, kidney, and endocrine systems.

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ALK4:ACTRIIB HETEROMULTIMERS AND USES THEREOF**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application claims the benefit of priority from U.S. Provisional Application No. 62/404,727, filed October 5, 2016, and U.S. Provisional Application No. 62/510,417, filed May 24, 2017. The specifications of the foregoing applications are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

The transforming growth factor-beta (TGF-beta) superfamily contains a variety of growth factors that share common sequence elements and structural motifs. These proteins are known to exert biological effects on a large variety of cell types in both vertebrates and invertebrates. Members of the superfamily perform important functions during embryonic development in pattern formation and tissue specification and can influence a variety of differentiation processes, including adipogenesis, myogenesis, chondrogenesis, cardiogenesis, hematopoiesis, neurogenesis, and epithelial cell differentiation. The family is divided into two general phylogenetic clades: the more recently evolved members of the superfamily, which includes TGF-betas, activins, and nodal and the clade of more distantly related proteins of the superfamily, which includes a number of BMPs and GDFs [Hinck (2012) FEBS Letters 586:1860-1870]. TGF-beta family members have diverse, often complementary biological effects. By manipulating the activity of a member of the TGF-beta family, it is often possible to cause significant physiological changes in an organism. For example, the Piedmontese and Belgian Blue cattle breeds carry a loss-of-function mutation in the GDF8 (also called myostatin) gene that causes a marked increase in muscle mass [Grobet *et al.* (1997) Nat Genet 17(1):71-4]. Furthermore, in humans, inactive alleles of GDF8 are associated with increased muscle mass and, reportedly, exceptional strength [Schuelke *et al.* (2004) N Engl J Med 350:2682-8].

Changes in fibrosis, muscle, bone, fat, and other tissues may be achieved by enhancing or inhibiting intracellular signaling (e.g., SMAD 1, 2, 3, 5, and/or 8) that is mediated by ligands of the TGF-beta family. Thus, there is a need for agents that regulate the activity of various ligands of the TGF-beta superfamily.

SUMMARY OF THE INVENTION

As described herein, it has been discovered that an ALK4:ActRIIB heterodimer protein is a unique antagonist of ligands of the TGF-beta superfamily, exhibiting a different ligand-binding profile/selectivity compared to corresponding ActRIIB and ALK4 homodimers. In particular, an exemplary ALK4:ActRIIB heterodimer displays enhanced binding to activin B compared to either homodimer, retains strong binding to activin A, GDF8, and GDF11 as observed with ActRIIB homodimer, and exhibits substantially reduced binding to BMP9, BMP10, and GDF3. In fact, the ALK4:ActRIIB heterodimer displays low to no observable affinity for BMP9, whereas this ligand binds strongly to ActRIIB homodimer. See Figure 4. These results therefore demonstrate that ALK4:ActRIIB heterodimers are a more selective antagonists (inhibitors) of certain ligands of the TGF-beta superfamily compared to ActRIIB homodimers. Accordingly, an ALK4:ActRIIB heterodimer will be more useful than an ActRIIB homodimer in certain applications where such selective antagonism is advantageous. Examples include therapeutic applications where it is desirable to antagonize one or more of activin (e.g., activin A, activin B, activin AB, activin AC), GDF8, and GDF11 with decreased antagonism of one or more of BMP9, BMP10, and GDF3.

Moreover, ALK4:ActRIIB heterodimer produced certain biological effects strikingly similar to those of an ActRIIB homodimer despite differential ligand selectivity of the two complexes. For example, ALK4:ActRIIB heterodimer exerts beneficial anabolic effects on skeletal muscle and bone as well as catabolic effects on adipose tissue, very similar to those of an ActRIIB-Fc homodimer. However, unlike ActRIIB homodimer, ActRIIB:ALK4 heterodimer exhibits only low-affinity or transient binding to BMP9 and BMP10 and so should have little to no concurrent inhibition on processes mediated by those ligands, such as angiogenesis. This novel selectivity may be useful, for example, in treating patients in need of stimulatory effects on muscle and bone, and/or inhibitory effects on fat, but not in need of altered angiogenesis. In addition, ALK4:ActRIIB heterodimer had various beneficial effects in a mouse model of kidney disease, particularly on treating or preventing kidney damage, inflammation, and fibrosis. Therefore, while not wishing to be bound to a particular mechanisms of action, it is expected that ALK4:ActRIIB heteromultimers, as well as variants thereof, that bind to/inhibit at least one or more of activin (e.g., activin A, activin B, activin AB, and activin AC), GDF8, and/or GDF11 will be useful agents for promoting beneficial

anabolic effects on skeletal muscle and bone, catabolic effects on adipose tissue, and beneficial effects on kidney disease.

Therefore, the present disclosure relates, in part, to heteromultimer complexes (heteromultimers) comprising at least one ALK4 polypeptide and at least one ActRIIB polypeptide (ALK4:ActRIIB heteromultimers). Preferably, ALK4 polypeptides comprise a ligand-binding domain of an ALK4 receptor, for example, a portion of the ALK4 extracellular domain. Similarly, ActRIIB polypeptides generally comprise a ligand-binding domain of an ActRIIB receptor, for example, a portion of the ActRIIB extracellular domain. Preferably, such ALK4 and ActRIIB polypeptides, as well as resultant heteromultimers thereof, are soluble. Preferably, such ALK4 and ActRIIB polypeptides, as well as resultant heteromultimers thereof, are recombinant proteins. Preferably, such ALK4 and ActRIIB polypeptides, as well as resultant heteromultimers thereof, are isolated proteins.

In certain aspects, an ALK4:ActRIIB heteromultimer comprises an ALK4 domain comprising an amino acid sequence that is at least 70% identical to a polypeptide that begins at any one of amino acids 24-34 of SEQ ID NO: 9 (e.g., amino acids 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, and 34) and ends at any one of amino acids 101-126 of SEQ ID NO: 9 (e.g., amino acids 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, and 126). For example, ALK4:ActRIIB heteromultimers may comprise an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 34-101 of SEQ ID NO: 9. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 24-126 of SEQ ID NO: 9. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an ALK4 amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 10.

In other aspects, an ALK4:ActRIIB heteromultimer comprises an ALK4 domain comprising an amino acid sequence that is at least 70% identical to a polypeptide that begins at any one of amino acids 24-34 of SEQ ID NO: 19 (e.g., amino acids 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, and 34) and ends at any one of amino acids 101-126 of SEQ ID NO: 19 (e.g., amino acids 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, and 126). For example, ALK4:ActRIIB heteromultimers may comprise an amino acid sequence that is at least 70%, 75%, 80%, 85%,

86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 34-101 of SEQ ID NO: 19. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100%

5 identical to amino acids 24-126 of SEQ ID NO: 19. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an ALK4 amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 20.

In certain aspects, an ALK4:ActRIIB heteromultimer comprises an ActRIIB domain
10 comprising an amino acid sequence that is at least 70% identical to a polypeptide that begins at any one of amino acids 20-29 of SEQ ID NO: 1 (e.g., amino acids 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29) and ends at any one of amino acids 109-134 (109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, and 134) of SEQ ID NO: 1. For example, ALK4:ActRIIB heteromultimers may comprise an
15 amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 29-109 of SEQ ID NO: 1. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 25-131 of
20 SEQ ID NO: 1. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an ActRIIB amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 2. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an ActRIIB amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%,
25 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 3. In some embodiments, ALK4:ActRIIB heteromultimers do not comprise an ActRIIB polypeptide comprising an acidic amino acid (e.g., the naturally occurring amino acids E or D or an artificial acidic amino acid) at the position corresponding to L79 of SEQ ID NO: 1.

In other aspects, an ALK4:ActRIIB heteromultimer comprises an ActRIIB domain
30 comprising an amino acid sequence that is at least 70% identical to a polypeptide that begins at any one of amino acids 20-29 of SEQ ID NO: 4 (e.g., amino acids 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29) and ends at any one of amino acids 109-134 (109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, and 134) of SEQ ID NO: 4. For example, ALK4:ActRIIB heteromultimers may comprise an

amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 29-109 of SEQ ID NO: 4. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 25-131 of SEQ ID NO: 4. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an ActRIIB amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 5. In some embodiments, ALK4:ActRIIB heteromultimers may comprise an ActRIIB amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 6. In some embodiments, ALK4:ActRIIB heteromultimers do not comprise an ActRIIB polypeptide comprising an acidic amino acid (e.g., the naturally occurring amino acids E or D or an artificial acidic amino acid) at the position corresponding to L79 of SEQ ID NO: 1.

As described herein, ALK4:ActRIIB heteromultimer structures include, for example, heterodimers, heterotrimers, heterotetramers, heteropentamers, and higher order heteromultimer complexes. See, e.g., Figure 6. In certain preferred embodiments, ALK4:ActRIIB heteromultimers are heterodimers.

In certain aspects, ALK4 and/or ActRIIB polypeptides may be fusion proteins. For example, in some embodiments, an ALK4 polypeptide may be a fusion protein comprising an ALK4 polypeptide domain and one or more heterologous (non-ALK4) polypeptide domains (e.g., ALK4-Fc fusion proteins). Similarly, in some embodiments, an ActRIIB polypeptide may be a fusion protein comprising an ActRIIB polypeptide domain and one or more heterologous (non-ActRIIB) polypeptide domains (ActRIIB-Fc fusion proteins).

In some embodiments, ALK4 polypeptides are fusion proteins that comprise an Fc domain of an immunoglobulin. Similarly, in some embodiments, ActRIIB polypeptides are fusion proteins that comprise an Fc domain of an immunoglobulin. Traditional Fc fusion proteins and antibodies are examples of unguided interaction pairs, whereas a variety of engineered Fc domains have been designed as asymmetric interaction pairs [Spiess et al (2015) Molecular Immunology 67(2A): 95-106]. Therefore, a first member and/or a second member of an interaction pair described herein may comprise a constant domain of an immunoglobulin, including, for example, the Fc portion of an immunoglobulin. For example, a first member of an interaction pair may comprise an amino acid sequence that is derived from an Fc domain of an IgG (IgG1, IgG2, IgG3, or IgG4), IgA (IgA1 or IgA2), IgE, or IgM

immunoglobulin. Such immunoglobulin domains may comprise one or more amino acid modifications (e.g., deletions, additions, and/or substitutions) that promote ALK4:ActRIIB heteromultimer formation. Similarly, a second member of an interaction pair may comprise an amino acid sequence that is derived from an Fc domain of an IgG (IgG1, IgG2, IgG3, or IgG4), IgA (IgA1 or IgA2), IgE, or IgM. Such immunoglobulin domains may comprise one or more amino acid modifications (e.g., deletions, additions, and/or substitutions) that promote ALK4:ActRIIB heteromultimer formation. For example, the second member of an interaction pair may comprise, consist essentially of, or consist of an amino acid sequence that is at least 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% identical to any one of SEQ ID NOs: 23-37. In some embodiments, a first member and a second member of an interaction pair comprise Fc domains derived from the same immunoglobulin class and subtype. In other embodiments, a first member and a second member of an interaction pair comprise Fc domains derived from different immunoglobulin classes or subtypes.

In certain aspects, the disclosure relates to ALK4:ActRIIB heteromultimers comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein wherein the ALK4-Fc fusion protein comprises one or more amino acid modifications (e.g., amino acid substitution, cationization, deamination, carboxyl-terminal amino acid heterogeneity, phosphorylation, and glycosylation) that alter the isoelectric point (pI) of the ALK4-Fc fusion protein and/or the ActRIIB-Fc fusion protein comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the one or more amino acid modifications in the ALK4-Fc fusion protein confers increased difference in pIs between the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein. In other embodiments, the one or more amino acid modifications in the ActRIIB-Fc fusion protein confers increased difference in pIs between the ActRIIB-Fc fusion protein and the ALK4-Fc fusion protein. In still other embodiments the one or more amino acid modifications in the ALK4-Fc fusion protein confers increased difference in pIs between the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein, and the one or more amino acid modifications in the ActRIIB-Fc fusion protein confers increased difference in pIs between the ActRIIB-Fc fusion protein and the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein comprises one or more amino acid modifications that alter pI by at least 0.1 (e.g., by at least 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.8, 0.9, 1.0, 1.3, 1.5, 1.7, 2.0, 2.3, 2.5, 2.7, 3.0, 3.3, 3.5, 3.7, or at least by 4.0). In some embodiments, the ActRIIB-Fc fusion protein comprises one or more amino acid modifications that alter pI by at least 0.1 (e.g., by

at least 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.8, 0.9, 1.0, 1.3, 1.5, 1.7, 2.0, 2.3, 2.5, 2.7, 3.0, 3.3, 3.5, 3.7, or at least by 4.0). In some embodiments, the ALK4-Fc fusion protein comprises one or more amino acid modifications that alter pI by at least 0.1 (e.g., by at least 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.8, 0.9, 1.0, 1.3, 1.5, 1.7, 2.0, 2.3, 2.5, 2.7, 3.0, 3.3, 3.5, 3.7, or at least by 4.0) and the ActRIIB-Fc fusion protein comprises one or more amino acid modifications that alter pI by at least 0.1 (e.g., by at least 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.8, 0.9, 1.0, 1.3, 1.5, 1.7, 2.0, 2.3, 2.5, 2.7, 3.0, 3.3, 3.5, 3.7, or at least by 4.0). In some embodiments, the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein have at least a 0.7 difference in pI (e.g., at least 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, or at least 4.0 or more difference in pI).

In certain aspects, an ALK4:ActRIIB heteromultimer of the disclosure comprises an ALK4-Fc fusion protein comprising one or more amino acid modifications that increase the pI of the ALK4-Fc fusion protein; and an ActRIIB-Fc fusion protein comprising one or more amino acid modifications that decrease the pI of the ActRIIB-Fc fusion protein. For example, an ALK4-Fc fusion protein may be modified by substituting one or more neutral or negatively charged amino acids with one or more positively charged amino acids [e.g., an arginine (R), lysine (K), or histidine (H)]. Similarly, an ActRIIB-Fc fusion protein may be modified by substituting one or more neutral or positively charged amino acids with one or more negatively charged amino acids [e.g., aspartic acid (E) or glutamic acid (D)]. In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG1 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31; b) an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31; and c) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31. In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H); b) an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H); and c) an arginine, lysine, or histidine substitution at

the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H) and an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H). In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R); b) an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R); and c) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R) and an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG2 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ALK4-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32; b) an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32; and c) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32. In some embodiments, the ALK4-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H); b) an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H); and c) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H) and an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG3 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33. In some embodiments, the ALK4-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33; b) an amino acid substitution at the position corresponding to D186 of SEQ ID NO:

33; and c) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to D186 of SEQ ID NO: 33. In some embodiments, the ALK4-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H); b) an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H); and c) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H) and an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG4 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ALK4-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35; b) an amino acid substitution at the position corresponding to D183 of SEQ ID NO: 35; and c) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35 and an amino acid substitution at the position corresponding to D183 of SEQ ID NO: 35. In some embodiments, the ALK4-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H); b) an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 35 (D183R, D183K, or D183H); and c) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H) and an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 32 (D183R, D183K, or D183H). In some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG1 Fc domain that comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the

position corresponding to K138 of SEQ ID NO: 31; b) an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31; and c) an amino acid substitution at the position corresponding to K138 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

5 a) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D); b) an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31

10 (K138E or K138D) and an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D). In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E); b) an aspartic acid substitution at the position corresponding to K217 of

15 SEQ ID NO: 31 (K217D); and c) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E) and an aspartic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217D). In some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG2 Fc domain that comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the

20 ActRIIB-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein IgG2 fusion Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to K136 of SEQ ID

25 NO: 32; b) an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32; and c) an amino acid substitution at the position corresponding to K136 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the

30 position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D); b) an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D) and an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D). In

some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG3 Fc domain that comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 5 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33. In some embodiments, the ActRIIB-Fc fusion protein IgG3 fusion Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to K145 of SEQ ID NO: 33; b) an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33; and c) an amino acid substitution at the position 10 corresponding to K145 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33. In some embodiments, the modified ActRIIB-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D); b) an aspartic acid or glutamic acid substitution at the 15 position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D) and an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D). In some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG4 Fc domain that comprises one or more 20 amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein IgG4 fusion Fc domain comprises one or more amino acid 25 substitutions selected from: a) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35; b) an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35; and c) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35 and an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein IgG4 Fc domain 30 comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D); b) an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D) and

an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D).

In certain aspects, an ALK4:ActRIIB heteromultimer of the disclosure comprises an ActRIIB-Fc fusion protein comprising one or more amino acid modifications that increase the pI of the ActRIIB-Fc fusion protein; and an ALK4-Fc fusion protein comprising one or more amino acid modifications that decrease the pI of the ALK-Fc fusion protein. For example, an ActRIIB-Fc fusion protein may be modified by substituting one or more neutral or negatively charged amino acids with one or more positively charged amino acids [e.g., an arginine (R), lysine (K), or histidine (H)]. Similarly, an ALK4-Fc fusion protein may be modified by substituting one or more neutral or positively charged amino acids with one or more negatively charged amino acids [e.g., aspartic acid (E) or glutamic acid (D)]. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG1 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31; b) an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31; and c) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H); b) an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H); and c) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H) and an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H). In some embodiments, the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R); b) an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R); and c) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R) and an arginine substitution at the

position corresponding to D179 of SEQ ID NO: 31 (D179R). In some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG2 Fc domain that comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG2 Fc domain comprises an amino acid

5 sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32; b) an amino acid substitution at the position corresponding to D177

10 of SEQ ID NO: 32; and c) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R,

15 N160K, or N160H); b) an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H); and c) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H) and an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H). In some

20 embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG3 Fc domain that comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33. In some embodiments,

25 the ActRIIB-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33; b) an amino acid substitution at the position corresponding to D186 of SEQ ID NO: 33; and c) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to D186 of SEQ

30 ID NO: 33. In some embodiments, the modified ActRIIB-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H); b) an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H); and c) an arginine,

lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H) and an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H). In some embodiments, the ActRIIB-Fc fusion protein Fc domain is an IgG4 Fc domain that comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein. In some embodiments, the ActRIIB-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35; b) an amino acid substitution at the position corresponding to D183 of SEQ ID NO: 35; and c) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35 and an amino acid substitution at position D183 of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from: a) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H); b) an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 35 (D183R, D183K, or D183H); and c) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H) and an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 35 (D183R, D183K, or D183H). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG1 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ALK4-Fc fusion protein IgG1 fusion Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to K138 of SEQ ID NO: 31; b) an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31; and c) an amino acid substitution at the position corresponding to K138 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31. In some embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D); b) an aspartic acid or glutamic acid

substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D) and an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D). In some

5 embodiments, the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from: a) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E); b) an aspartic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217D); and c) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E) and an aspartic acid substitution

10 at the position corresponding to K217 of SEQ ID NO: 31 (K217D). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG2 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%,

15 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ALK4-Fc fusion protein IgG2 fusion Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to K136 of SEQ ID NO: 32; b) an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32; and c) an amino acid substitution at the position corresponding to K136

20 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32. In some embodiments, the ALK4-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D); b) an aspartic acid or glutamic acid substitution at the position corresponding to

25 K215 of SEQ ID NO: 32 (K215E or K215D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D) and an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG3 Fc domain that comprises one or more amino acid modifications that alter

30 the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33. In some embodiments, the ALK4-Fc fusion protein IgG3 fusion Fc domain comprises one or more amino acid substitutions selected from: a) an amino

acid substitution at the position corresponding to K145 of SEQ ID NO: 33; b) an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33; and c) an amino acid substitution at the position corresponding to K145 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33. In some embodiments,

5 the ALK4-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D); b) an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of

10 SEQ ID NO: 33 (K145E or K145D) and an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D). In some embodiments, the ALK4-Fc fusion protein Fc domain is an IgG4 Fc domain that comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein. In some embodiments, the ALK4-Fc fusion protein IgG4 Fc domain comprises an amino acid

15 sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ALK4-Fc fusion protein IgG4 fusion Fc domain comprises one or more amino acid substitutions selected from: a) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35; b) an amino acid substitution at the position corresponding to K221

20 of SEQ ID NO: 35; and c) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35 and an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35. In some embodiments, the ALK4-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from: a) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or

25 K142D); b) an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D); and c) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D) and an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D).

30 As described herein, ALK4-Fc fusion proteins and/or ActRIIB-Fc fusion proteins may comprise one or more modifications that promote heteromultimer formation (e.g., ALK4-Fc:ActRIIB-Fc heterodimerization). Similarly, ALK4-Fc fusion proteins and/or ActRIIB-Fc fusion proteins may comprise one or more modifications that inhibit homomultimer formation (e.g., ALK4-Fc:ActRIIB-Fc homodimerization). In some embodiments, ALK4-Fc

fusion proteins and/or ActRIIB-Fc fusion proteins may comprise one or more modifications that promote heteromultimer formation and comprise one or more modifications that inhibit homomultimer formation. For example, in some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ALK4-Fc fusion protein having an IgG1 Fc domain comprising a cysteine substitution at position S132 of SEQ ID NO: 31 (S132C) and a tryptophan substitution at position T144 of SEQ ID NO: 31 (T144W); and b) an ActRIIB-Fc fusion protein having an IgG1 Fc domain comprising a cysteine substitution at position Y127 of SEQ ID NO: 31 (Y127C), a serine substitution at position T144 of SEQ ID NO: 31 (T144S), an alanine substitution at position L146 of SEQ ID NO: 31 (L146A), and a valine substitution at position Y185 of SEQ ID NO: 31 (Y185V). In some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ActRIIB-Fc fusion protein having an IgG1 Fc domain comprising a cysteine substitution at position S132 of SEQ ID NO: 31 (S132C) and a tryptophan substitution at position T144 of SEQ ID NO: 31 (T144W); and b) an ALK4-Fc fusion protein having an IgG1 Fc domain comprising a cysteine substitution at position Y127 of SEQ ID NO: 31 (Y127C), a serine substitution at position T144 of SEQ ID NO: 31 (T144S), an alanine substitution at position L146 of SEQ ID NO: 31 (L146A), and a valine substitution at position Y185 of SEQ ID NO: 31 (Y185V). In some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ALK4-Fc fusion protein having an IgG2 Fc domain comprising a cysteine substitution at position S130 of SEQ ID NO: 32 (S130C) and a tryptophan substitution at position T142 of SEQ ID NO: 32 (T142W); and b) an ActRIIB-Fc fusion protein having an IgG2 Fc domain comprising a cysteine substitution at position Y125 of SEQ ID NO: 32 (Y125C), a serine substitution at position T142 of SEQ ID NO: 32 (T142S), an alanine substitution at position L144 of SEQ ID NO: 32 (L144A), and a valine substitution at position Y183 of SEQ ID NO: 32 (Y183V). In some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ActRIIB-Fc fusion protein having an IgG2 Fc domain comprising a cysteine substitution at position S130 of SEQ ID NO: 32 (S130C) and a tryptophan substitution at position T142 of SEQ ID NO: 32 (T142W); and b) an ALK4-Fc fusion protein having an IgG2 Fc domain comprising a cysteine substitution at position Y125 of SEQ ID NO: 32 (Y125C), a serine substitution at position T142 of SEQ ID NO: 32 (T142S), an alanine substitution at position L144 of SEQ ID NO: 32 (L144A), and a valine substitution at position Y183 of SEQ ID NO: 32 (Y183V). In some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ALK4-Fc fusion protein having an IgG3 Fc domain comprising a cysteine substitution at position S139 of SEQ ID NO: 33 (S139C) and a tryptophan substitution at position T151 of SEQ ID NO: 33 (T151W); and b) the ActRIIB-Fc

fusion protein having an IgG3 Fc domain comprising a cysteine substitution at position Y134 of SEQ ID NO: 33 (Y134C), a serine substitution at position T151 of SEQ ID NO: 33 (T151S), an alanine substitution at position L153 of SEQ ID NO: 33 (L153A), and a valine substitution at position Y192 of SEQ ID NO: 33 (Y192V). In some embodiments, an

5 ALK4:ActRIIB heteromultimer comprises: a) an ActRIIB-Fc fusion protein having an IgG3 Fc domain comprising a cysteine substitution at position S139 of SEQ ID NO: 33 (S139C) and a tryptophan substitution at position T151 of SEQ ID NO: 33 (T151W); and b) an ALK4-Fc fusion protein having an IgG3 Fc domain comprising a cysteine substitution at position Y134 of SEQ ID NO: 33 (Y134C), a serine substitution at position T151 of SEQ ID NO: 33

10 (T151S), an alanine substitution at position L153 of SEQ ID NO: 33 (L153A), and a valine substitution at position Y192 of SEQ ID NO: 33 (Y192V). In some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ALK4-Fc fusion protein having an IgG4 Fc domain comprises a cysteine substitution at position S136 of SEQ ID NO: 35 (S136C) and a tryptophan substitution at position T148 of SEQ ID NO: 35 (T148W); and b) an ActRIIB-Fc

15 fusion protein having an IgG4 Fc domain comprises a cysteine substitution at position Y131 of SEQ ID NO: 35 (Y131C), a serine substitution at position T148 of SEQ ID NO: 35 (T148S), an alanine substitution at position L150 of SEQ ID NO: 35 (L150A), and a valine substitution at position Y189 of SEQ ID NO: 35 (Y189V). In some embodiments, an ALK4:ActRIIB heteromultimer comprises: a) an ActRIIB-Fc fusion protein having an IgG4

20 Fc domain comprising a cysteine substitution at position S136 of SEQ ID NO: 35 (S136C) and a tryptophan substitution at position T148 of SEQ ID NO: 35 (T148W); and b) an ALK4-Fc fusion protein having an IgG4 Fc domain comprising a cysteine substitution at position Y131 of SEQ ID NO: 35 (Y131C), a serine substitution at position T148 of SEQ ID NO: 35 (T148S), an alanine substitution at position L150 of SEQ ID NO: 35 (L150A), and a valine

25 substitution at position Y189 of SEQ ID NO: 35 (Y189V).

In certain aspects, an ALK4:ActRIIB heteromultimer of the disclosure comprises: a) an ALK4-Fc fusion protein having an Fc domain that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of SEQ ID NO: 66; and b) an ActRIIB-Fc fusion protein having an Fc domain that is at least

30 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of SEQ ID NO: 67. In some embodiments, the ALK4-Fc fusion protein Fc domain comprises one or more amino acid substitutions selected from: a) a glutamic acid at the position corresponding to 138 of SEQ ID NO: 66; b) an aspartic acid at the position corresponding to 217 of SEQ ID NO: 66; and c) a glutamic acid at the position

corresponding to 138 of SEQ ID NO: 66 and an aspartic acid at the position corresponding to 217 of SEQ ID NO: 66. Optionally, the ALK4-Fc fusion protein Fc domain further comprises a cysteine at the position corresponding to 132 of SEQ ID NO: 66 and a tryptophan at the position corresponding to 144 of SEQ ID NO: 66. In some embodiments, the ActRIIB-Fc fusion protein Fc domain comprises one or more amino acid substitutions selected from: a) an arginine at the position corresponding to 162 of SEQ ID NO: 67; b) an arginine at the position corresponding to 179 of SEQ ID NO: 67; and c) an arginine at the position corresponding to 162 of SEQ ID NO: 67 and an arginine at the position corresponding to 179 of SEQ ID NO: 67. Optionally, the ActRIIB-Fc fusion protein Fc domain further comprises a cysteine at the position corresponding to 127 of SEQ ID NO: 67, a serine at the position corresponding to 144 of SEQ ID NO: 67, an alanine at the position corresponding to 146 of SEQ ID NO: 67, and a valine at the position corresponding to 185 of SEQ ID NO: 67.

In certain aspects, an ALK4:ActRIIB heteromultimer of the disclosure comprises: a) an ActRIIB-Fc fusion protein having an Fc domain that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of SEQ ID NO: 66; and b) an ALK4-Fc fusion protein having an Fc domain that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of SEQ ID NO: 67. In some embodiments, the ActRIIB-Fc fusion protein Fc domain comprises one or more amino acid substitutions selected from: a) a glutamic acid at the position corresponding to 138 of SEQ ID NO: 66; b) an aspartic acid at the position corresponding to 217 of SEQ ID NO: 66; and c) a glutamic acid at the position corresponding to 138 of SEQ ID NO: 66 and an aspartic acid at the position corresponding to 217 of SEQ ID NO: 66. Optionally, the ActRIIB-Fc fusion protein Fc domain further comprises a cysteine at the position corresponding to 132 of SEQ ID NO: 66 and a tryptophan at the position corresponding to 144 of SEQ ID NO: 66. In some embodiments, the ALK4-Fc fusion protein Fc domain comprises one or more amino acid substitutions selected from: a) an arginine at the position corresponding to 162 of SEQ ID NO: 67; b) an arginine at the position corresponding to 179 of SEQ ID NO: 67; and c) an arginine at the position corresponding to 162 of SEQ ID NO: 67 and an arginine at the position corresponding to 179 of SEQ ID NO: 67. Optionally, the ALK4-Fc fusion protein Fc domain further comprises a cysteine at the position corresponding to 127 of SEQ ID NO: 67, a serine at the position corresponding to 144 of SEQ ID NO: 67, an alanine at the position

corresponding to 146 of SEQ ID NO: 67, and a valine at the position corresponding to 185 of SEQ ID NO: 67.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31; and b) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), and a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V). In some embodiments, wherein the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein : a) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31; and b) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), and a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V). In some embodiments, wherein the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%,

92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), and a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W); and b) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31. In some embodiments, wherein the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), and a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W); and b) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), and a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31. In some embodiments, wherein the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is a glutamic acid. In some embodiments,

the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein : a) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32; and b) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), and a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V). In some embodiments, wherein the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32; and b) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), and a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V). In some embodiments, wherein the acidic amino acid at the position corresponding

to H211 of SEQ ID NO: 32 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein : a) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), and a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W); and b) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32. In some embodiments, wherein the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), and a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W); and b) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), a valine at the position corresponding to Y183 of SEQ ID NO: 32

(Y183V), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32. In some embodiments, wherein the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35; and b) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), and a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V). In some embodiments, wherein the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35; and b) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position

corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), and a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V). In some embodiments, wherein the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

In certain aspects, the disclosure relates to recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), and a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W); and b) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35. In some embodiments, wherein the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

In certain aspects, the disclosure relates to recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein: a) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), and a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W); and b) the

ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), a valine at the position corresponding to Y189 of SEQ ID NO: 35

(Y189V), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35.

In some embodiments, wherein the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is an aspartic acid. In some embodiments, the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is a glutamic acid. In some embodiments, the ALK4-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35. In some embodiments, the ActRIIB-Fc fusion protein Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

Optionally, ALK4 polypeptides are connected directly (fused) to one or more heterologous domains, or an intervening sequence, such as a linker, may be positioned between the amino acid sequence of the ALK4 polypeptide and the one or more heterologous domains (e.g., an Fc domain of an immunoglobulin). Similarly, the ActRIIB polypeptide may be connected directly (fused) to one or more heterologous domains, or an intervening sequence, such as a linker, may be positioned between the amino acid sequence of the ActRIIB polypeptide and the one or more heterologous domains (e.g., an Fc domain of an immunoglobulin). Linkers may correspond to the roughly 15 amino acid unstructured region at the C-terminal end of the extracellular domain of ActRIIB or ALK4 (the “tail”), or it may be an artificial sequence of between 5 and 15, 20, 30, 50, 100 or more amino acids that are relatively free of secondary structure. A linker may be rich in glycine and proline residues and may, for example, contain repeating sequences of threonine/serine and glycines.

Examples of linkers include, but are not limited to, the sequences TGGG (SEQ ID NO: 17), SGGG (SEQ ID NO: 18), TGGGG (SEQ ID NO: 15), SGGGG (SEQ ID NO: 16), GGGGS (SEQ ID NO: 58), GGGG (SEQ ID NO: 14), and GGG (SEQ ID NO: 13).

In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 76, and wherein the ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%,

85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 72. In some embodiments, the the ALK4-Fc fusion protein comprises one or more amino acid selected from: a) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of

5 SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76; b) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76; c) a positively charged amino acid at the position corresponding to D286 of SEQ ID NO: 76; d) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76 and a positively charged amino

10 acid at the position corresponding to 286 of SEQ ID NO: 76; e) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at the position corresponding to 292 of SEQ ID NO: 76 (Y292V), and a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76; f) a cysteine at the

15 position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at position 292 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76; and g) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an

20 alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76, a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76. In some embodiments, the ActRIIB-Fc fusion protein comprises one or more amino acid selected from: a) a cysteine at the position

25 corresponding to 250 of SEQ ID NO: 72, and a tryptophan at position 262 of SEQ ID NO: 72; b) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72; c) a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; d) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72 and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; e) a

30 cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72; f) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; and g) a cysteine at the position

corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72. In some embodiments, the positively charged amino acid residue is a modified or naturally occurring (e.g., R, K, or H) amino acid. In some embodiments, the positively charged amino acid residue is R. In some embodiments, the negatively charged amino acid residue is a modified or naturally occurring (e.g., D or E) amino acid. In some embodiments, the negatively charged amino acid residue is D. In some embodiments, the negatively charged amino acid residue is E.

In certain aspects, the disclosure relates to a recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 76. In some embodiments, the ALK4-Fc fusion protein Fc domain comprises one or more amino acid selected from: a) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76; b) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76; c) a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76; d) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76 and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76; e) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at position 292 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76; f) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at the position corresponding to 292 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76; and g) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76, a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76. In some embodiments, the positively charged amino acid residue is a modified or

naturally occurring (e.g., R, K, or H) amino acid. In some embodiments, the positively charged amino acid residue is R.

In certain aspects, the disclosure relates to a recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 72. In some embodiments, the fusion protein comprises one or more amino acid selected from: a) a cysteine at the position corresponding to 250 of SEQ ID NO: 72 and a tryptophan at the position corresponding to 262 of SEQ ID NO: 72; b) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72; c) a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; d) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72 and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; e) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72; f) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; and g) a cysteine at the position corresponding to 250 of SEQ ID NO: 7, a tryptophan at position 262 of SEQ ID NO: 72, a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72. In some embodiments, the negatively charged amino acid residue is a modified or naturally occurring (e.g., D or E) amino acid. In some embodiments, the negatively charged amino acid residue is D. In some embodiments, the negatively charged amino acid residue is E.

In certain aspects, the disclosure relates to a recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 74. In some embodiments, the ALK4-Fc fusion protein Fc domain comprises one or more amino acid selected from: a) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, and a valine at position 316 of SEQ ID NO: 74; b) a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74; c) a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74; d) a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74 and a positively charged amino acid at the position corresponding to

310 of SEQ ID NO: 74; e) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, a valine at position 316 of SEQ ID NO: 74, and a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74; f) a
 5 cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, a valine at the position corresponding to 316 of SEQ ID NO: 74, and a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74 g) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position
 10 corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, a valine at the position corresponding to 316 of SEQ ID NO: 74, a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74, and a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74. In some embodiments, the positively charged amino acid residue is a modified or naturally occurring
 15 (e.g., R, K, or H) amino acid. In some embodiments, the positively charged amino acid residue is R.

In certain aspects, the disclosure relates to a recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid
 20 sequence of SEQ ID NO: 70. In some embodiments, the ActRIIB-Fc fusion protein Fc domain comprises one or more amino acid selected from: a) a cysteine at the position corresponding to 275 of SEQ ID NO: 70 and a tryptophan at the position corresponding to 287 of SEQ ID NO: 70; b) a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70; c) a negatively charged amino acid at the position corresponding to
 25 360 of SEQ ID NO: 70; d) a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70 and a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70; e) a cysteine at the position corresponding to 275 of SEQ ID NO: 70, a tryptophan at the position corresponding to 287 of SEQ ID NO: 70, and a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70; f) a cysteine at
 30 the position corresponding to 275 of SEQ ID NO: 70, a tryptophan at the position corresponding to 287 of SEQ ID NO: 70, and a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70; and g) a cysteine at the position corresponding to 275 of SEQ ID NO: 70, a tryptophan at the position corresponding to 287 of SEQ ID NO: 70, a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70, and

a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70. In some embodiments, the negatively charged amino acid residue is a modified or naturally occurring (e.g., D or E) amino acid. In some embodiments, the negatively charged amino acid residue is D. In some embodiments, the negatively charged amino acid residue is E.

5 In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 48, and wherein the
10 ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 80. In some embodiments, the ALK4-Fc fusion protein Fc domain comprises a cysteine at the position corresponding to 234 of SEQ ID NO: 48, a serine at the position corresponding to 251 of SEQ ID NO: 48, an alanine at the position
15 corresponding to 253 of SEQ ID NO: 48, and a valine at position 292 of SEQ ID NO: 48. In some embodiments, the ActRIIB-Fc fusion protein Fc domain comprises a cysteine at the position corresponding to 250 of SEQ ID NO: 80, a tryptophan at the position corresponding to 262 of SEQ ID NO: 80, and a arginine at the position corresponding to 331 of SEQ ID NO: 80.

20 In certain aspects, the disclosure relates to a recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 48. In some embodiments, the ALK4-Fc fusion protein Fc domain comprises a cysteine at the position corresponding to 234 of SEQ ID NO: 48, a serine at the
25 position corresponding to 251 of SEQ ID NO: 48, an alanine at the position corresponding to 253 of SEQ ID NO: 48, and a valine at position 292 of SEQ ID NO: 48.

In certain aspects, the disclosure relates to a recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid
30 sequence of SEQ ID NO: 80. In some embodiments the ActRIIB-Fc fusion protein Fc domain comprises a cysteine at the position corresponding to 250 of SEQ ID NO: 80, a tryptophan at the position corresponding to 262 of SEQ ID NO: 80, and a arginine at the position corresponding to 331 of SEQ ID NO: 80.

In certain aspects, the disclosure relates to a recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 47. In some embodiments, the ALK4-Fc fusion protein Fc domain
 5 comprises a cysteine at the position corresponding to 258 of SEQ ID NO: 47, a serine at the position corresponding to 275 of SEQ ID NO: 47, an alanine at the position corresponding to 277 of SEQ ID NO: 47, and a valine at position 316 of SEQ ID NO: 47.

In certain aspects, the disclosure relates to a recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%,
 10 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 78. In some embodiments, the ActRIIB-Fc fusion protein Fc domain comprises a cysteine at the position corresponding to 275 of SEQ ID NO: 78, a tryptophan at the position corresponding to 287 of SEQ ID NO: 78, and a arginine at the position corresponding to 356 of SEQ ID NO: 78.

15 In certain aspects, the disclosure relates to a recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 90%, 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 76, and wherein the ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 90%,
 20 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 72. In some embodiments, the ALK4-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 76, and the ActRIIB-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 72. In some embodiments, the ActRIIB-Fc fusion protein comprises the leader sequence of SEQ ID NO: 38. In some embodiments, the ActRIIB-Fc fusion protein comprises an
 25 amino acid sequence that is at least 90%, 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 70. In some embodiments, the ActRIIB-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 70. In some embodiments, the ALK4-Fc fusion protein comprises the leader sequence of SEQ ID NO: 38. In some embodiments, the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 90%, 95%, 97% or
 30 99% identical to the amino acid sequence of SEQ ID NO: 74. In some embodiments, the ALK4-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 74. In some embodiments, the ALK4-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 74, and the ActRIIB-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 70.

Optionally, an ALK4 and/or ActRIIB polypeptide comprises one or more modified amino acid residues selected from: a glycosylated amino acid, a PEGylated amino acid, a farnesylated amino acid, an acetylated amino acid, a biotinylated amino acid, an amino acid conjugated to a lipid moiety, and an amino acid conjugated to an organic derivatizing agent.

5 ALK4 and/or ActRIIB polypeptides may comprise at least one N-linked sugar, and may include two, three or more N-linked sugars. Such polypeptides may also comprise O-linked sugars. ALK4 and/or ActRIIB polypeptides may be produced in a variety of cell lines that glycosylate the protein in a manner that is suitable for patient use, including engineered insect or yeast cells, and mammalian cells such as COS cells, CHO cells, HEK cells and NSO cells.

10 In some embodiments an ALK4 and/or ActRIIB polypeptide is glycosylated and has a glycosylation pattern obtainable from a Chinese hamster ovary cell line. Preferably ALK4:ActRIIB heteromultimer complexes of the disclosure exhibit a serum half-life of at least 4, 6, 12, 24, 36, 48, or 72 hours in a mammal (*e.g.*, a mouse or a human). Optionally, ALK4:ActRIIB heteromultimers may exhibit a serum half-life of at least 6, 8, 10, 12, 14, 20,
15 25, or 30 days in a mammal (*e.g.*, a mouse or a human).

In certain aspects, ALK4:ActRIIB heteromultimers of the disclosure bind to one or more TGF-beta superfamily ligands. Optionally, ALK4:ActRIIB heteromultimers bind to one or more of these ligands with a K_D of less than or equal to 10^{-8} , 10^{-9} , 10^{-10} , 10^{-11} , or 10^{-12} M. For example, in some embodiments, ALK4:ActRIIB heteromultimers bind to activin B.

20 In some embodiments, ALK4:ActRIIB heteromultimers bind to activin A. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin AB. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin C. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin AC. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin BC. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin
25 BC. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin BE. In some embodiments, ALK4:ActRIIB heteromultimers bind to GDF11. In some embodiments, ALK4:ActRIIB heteromultimers bind to GDF8. In some embodiments, ALK4:ActRIIB heteromultimers bind to BMP6. In some embodiments, ALK4:ActRIIB heteromultimers bind to GDF3. In some embodiments, ALK4:ActRIIB heteromultimers bind to BMP10. In
30 some embodiments, ALK4:ActRIIB heteromultimers do not bind to, or do not substantially bind to, BMP9 (*e.g.*, bind with a K_D of greater than or equal to 10^{-8} or 10^{-7}). In some embodiments, ALK4:ActRIIB heteromultimers bind to activin B with stronger affinity compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers bind to GDF3 with weaker affinity compared to a

corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers bind to BMP10 with weaker affinity compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers bind to BMP9 with weaker affinity compared to a corresponding ActRIIB homomultimer.

5 In general, ALK4:ActRIIB heteromultimers of the disclosure antagonize (inhibit) one or more activities of at least one TGF-beta superfamily ligand, and such alterations in activity may be measured using various assays known in the art, including, for example, a cell-based assay such as those described herein. In certain aspects, ALK4:ActRIIB heteromultimers may be used to inhibit signaling (e.g., Smad 2/3 and/or Smad 1/5/8 signaling) mediated by
10 one or more TGF β superfamily ligands in, for example, a cell-based assay. For example, in some embodiments, ALK4:ActRIIB heteromultimers inhibit activin signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin A signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers
15 inhibit activin B signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin AB signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin C signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin AC signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin BC signaling
20 in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin E signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin AE signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit activin CE signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit GDF11 signaling in a cell-based assay. In some
25 embodiments, ALK4:ActRIIB heteromultimers inhibit GDF8 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit BMP6 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit GDF3 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers inhibit BMP10 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers does
30 not inhibit, or does not substantially inhibit, BMP9 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers are stronger inhibitors of activin B signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers are weaker inhibitors of GDF3 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers are weaker inhibitors of BMP10 signaling in a cell-based assay. In some

embodiments, ALK4:ActRIIB heteromultimers are weaker inhibitors of BMP9 signaling in a cell-based assay.

Any of the ALK4:ActRIIB heteromultimers described herein may be formulated as a pharmaceutical preparation (compositions). In some embodiments, pharmaceutical preparations comprise a pharmaceutically acceptable carrier. In some embodiments, a pharmaceutical preparation will be pyrogen-free (meaning pyrogen free to the extent required by regulations governing the quality of products for therapeutic use). A pharmaceutical preparation may also include one or more additional compounds such as a compound that is used to treat a disorder/condition described herein. In general, ALK4:ActRIIB heteromultimer pharmaceutical preparations are substantially free of ALK4 and/or ActRIIB homomultimers. For example, in some embodiments, ALK4:ActRIIB heteromultimer pharmaceutical preparations comprise less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ALK4 homomultimers. In some embodiments, ALK4:ActRIIB heteromultimer pharmaceutical preparations comprise less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ActRIIB homomultimers. In some embodiments, ALK4:ActRIIB heteromultimer pharmaceutical preparations comprise less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ALK4 homomultimers and less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ActRIIB homomultimers.

In certain aspects, the disclosure provides nucleic acids encoding an ActRIIB polypeptide as described herein. For example, an ActRIIB nucleic acid may comprise of a nucleic acid that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the sequence of 73-396 of SEQ ID NO: 7 or one that hybridizes under stringent conditions to the complement of nucleotides 73-396 of SEQ ID NO: 7. Such an nucleic acid may be one that comprises the sequence of SEQ ID NOs: 8. In some embodiments, an ActRIIB nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 71. In some embodiments, an ActRIIB nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 73. In some embodiments, an ActRIIB nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 79. In some embodiments, an ActRIIB nucleic acids comprises a nucleotide sequence that is

at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 81.

In certain aspects, the disclosure provides nucleic acids encoding an ActRIIB polypeptide as described herein. For example, an ALK4 nucleic acid may comprise, consists essentially of, or consists of a nucleic acid that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the sequence of 70-378 of SEQ ID NO: 11 or one that hybridizes under stringent conditions to the complement of nucleotides 70-378 of SEQ ID NO: 11. In some embodiments, an ALK4 nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 75. In some embodiments, an ALK4 nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 77. In some embodiments, an ALK4 nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 82. In some embodiments, an ALK4 nucleic acids comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 83.

In certain aspects, the present disclosure provides nucleic acids sequence comprising a coding sequence for and ALK4 polypeptide and a coding sequence for the ActRIIB polypeptide. For example, in some embodiments, nucleic acids of the disclosure a) comprises a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to any one of SEQ ID NOs: 71, 73, 79, and 77, and b) comprises, consists essentially of, or consists of a nucleotide sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to any one of SEQ ID Nos: 75, 77, 82, and 83.

Preferably, ALK4 and/or ActRIIB nucleic acids are isolated and/or recombinant nucleic acids. Nucleic acids disclosed herein may be operably linked to a promoter for expression. The present disclosure further provides vectors comprising such ALK4 and/or ActRIIB polynucleotides as well as cells (e.g., CHO cells), preferably cells isolated from a human or other vertebrate species, comprising such ALK4 and/or ActRIIB polynucleotides as well as vectors comprising such ALK4 and/or ActRIIB polynucleotides.

In certain aspects, an ALK4 polypeptides and/or ActRIIB polypeptides may be expressed in a mammalian cell line, optionally a cell line that mediates suitably natural glycosylation of the ActRIIB or ALK4 protein so as to diminish the likelihood of an unfavorable immune response in a patient (including the possibility of veterinary patients).

5 Human and CHO cell lines have been used successfully, and it is expected that other common mammalian expression vectors will be useful. Thus the disclosure provides cultured cells comprising any of the nucleic acids disclosed herein. Such cells may be mammalian cells, including CHO cells, NSO cells, HEK cells and COS cells. Other cells may be chosen depending on the species of the intended patient. Other cells are disclosed herein. Cultured
10 cells are understood to mean cells maintained in laboratory or other man-made conditions (e.g., frozen, or in media) and not part of a living organism.

In certain aspects, the disclosure provides methods for making any of the ALK4 and ActRIIB polypeptides described herein as well as ALK4:ActRIIB heteromultimer complexes comprising such polypeptides. Such a method may include expressing any of the nucleic
15 acids disclosed herein in a suitable cell (e.g., CHO cell or a COS cell). For example, in some embodiments a method of making a heteromultimer comprising an ALK4 polypeptide and an ActRIIB polypeptide comprises: culturing a cell under conditions suitable for expression of an ALK4 polypeptide and an ActRIIB polypeptide, wherein the cell comprises an ALK4 polynucleotide and an ActRIIB polynucleotide; optionally recovering the heteromultimer so
20 expressed. Alternatively, a method of making a heteromultimer comprising an ALK4 polypeptide and an ActRIIB polypeptide may comprise: a) culturing a first cell under conditions suitable for expression of an ALK4 polypeptide, wherein the first cell comprises an ALK4 polynucleotide; b) recovering the ALK4 polypeptide so expressed; c) culturing a second cell under conditions suitable for expression of an ActRIIB polypeptide, wherein the
25 second cell comprises an ActRIIB polynucleotide; d) recovering the ActRIIB polypeptide so expressed; e) combining the recovered ALK4 polypeptide and the recovered ActRIIB polypeptide under conditions suitable for ALK4:ActRIIB heteromultimer formation; optionally recovering the ALK4:ActRIIB heteromultimer. In certain embodiments, ALK4 and/or ActRIIB polypeptides are expressed using a TPA leader sequence (e.g., SEQ ID NO:
30 38). In certain embodiments, ALK4 and/or ActRIIB polypeptides are expressed in a CHO cell. ALK4 and ActRIIB polypeptides described herein, as well as protein complexes of the same, may be recovered as crude, partially purified, or highly purified fractions using any of the well-known techniques for obtaining protein from cell cultures. In general, such methods result in ALK4:ActRIIB heteromultimers that substantially free of ALK4 and/or ActRIIB

homomultimers. For example, in some embodiments, methods for producing ALK4:ActRIIB heteromultimers result in less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ALK4 homomultimers. In some embodiments, methods for producing ALK4:ActRIIB heteromultimers result in less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ActRIIB homomultimers. In some embodiments, methods for producing ALK4:ActRIIB heteromultimers result in less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ALK4 homomultimers and less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ActRIIB homomultimers.

The disclosure further provides methods and ALK4:ActRIIB heteromultimers for use in the treatment or prevention of various ALK4:ActRIIB-associated diseases and conditions associated with, for example, muscle, bone, fat, red blood cells, and other tissues. Such disease and disorders include, but are not limited to, disorders associated with muscle loss or insufficient muscle growth (*e.g.*, muscle atrophy; muscular dystrophy, including Duchenne muscular dystrophy, Becker muscular dystrophy, and facioscapulohumeral muscular dystrophy; amyotrophic lateral sclerosis; sporadic inclusion body myositis, hereditary inclusion body myositis, and cachexia) and disorders associated with undesirable weight gain (*e.g.*, obesity, type 2 diabetes or non-insulin dependent diabetes mellitus (NIDDM), cardiovascular disease, hypertension, osteoarthritis, stroke, respiratory problems, and gall bladder disease). In some embodiments, ALK4:ActRIIB heteromultimers may be used to decrease body fat content or reduce the rate of increase in body fat content in a subject in need thereof. In some embodiments, ALK4:ActRIIB heteromultimers may be used to reduce cholesterol and/or triglyceride levels in a patient. In some embodiments, ALK4:ActRIIB heteromultimers may be used to treat or prevent fibrosis or a fibrosis-associated disorder or condition (*e.g.*, renal failure, chronic renal disease, cystic fibrosis, and myelofibrosis).

The disclosure further provides methods and ALK4:ActRIIB heteromultimers for use in the treatment or prevention of various ALK4:ActRIIB-associated diseases and conditions associated with, for example, the kidney. Such diseases or conditions include, for example, chronic kidney disease or failure, acute kidney disease or failure, patients that have stage 1 kidney disease, patients that have stage 2 kidney disease, patients that have stage 3 kidney disease, patients that have stage 4 kidney disease, patients that have stage 5 kidney disease, non-diabetic kidney diseases, glomerulonephritis, interstitial nephritis, diabetic kidney diseases, diabetic nephropathy, glomerulosclerosis, rapid progressive glomerulonephritis, renal fibrosis, Alport syndrome, IDDM nephritis, mesangial proliferative glomerulonephritis,

membranoproliferative glomerulonephritis, crescentic glomerulonephritis, renal interstitial
 fibrosis, focal segmental glomerulosclerosis, membranous nephropathy, minimal change
 disease, pauci-immune rapid progressive glomerulonephritis, IgA nephropathy, polycystic
 kidney disease, Dent's disease, nephrocytinosis, Heymann nephritis, autosomal dominant
 5 (adult) polycystic kidney disease, autosomal recessive (childhood) polycystic kidney disease,
 acute kidney injury, nephrotic syndrome, renal ischemia, podocyte diseases or disorders,
 proteinuria, glomerular diseases, membranous glomerulonephritis, focal segmental
 glomerulonephritis, pre-eclampsia, eclampsia, kidney lesions, collagen vascular diseases,
 benign orthostatic (postural) proteinuria, IgM nephropathy, membranous nephropathy,
 10 sarcoidosis, diabetes mellitus, kidney damage due to drugs, Fabry's disease, aminoaciduria,
 Fanconi syndrome, hypertensive nephrosclerosis, interstitial nephritis, Sickle cell disease,
 hemoglobinuria, myoglobinuria, Wegener's Granulomatosis, Glycogen Storage Disease Type
 1, chronic kidney disease, chronic renal failure, low Glomerular Filtration Rate (GFR),
 nephroangiosclerosis, lupus nephritis, ANCA-positive pauci-immune crescentic
 15 glomerulonephritis, chronic allograft nephropathy, nephrotoxicity, renal toxicity, kidney
 necrosis, kidney damage, glomerular and tubular injury, kidney dysfunction, nephritic
 syndrome, acute renal failure, chronic renal failure, proximal tubal dysfunction, acute kidney
 transplant rejection, chronic kidney transplant rejection, non-IgA mesangioproliferative
 glomerulonephritis, postinfectious glomerulonephritis, vasculitides with renal involvement of
 20 any kind, any hereditary renal disease, any interstitial nephritis, renal transplant failure,
 kidney cancer, kidney disease associated with other conditions (e.g., hypertension, diabetes,
 and autoimmune disease), Dent's disease, nephrocytinosis, Heymann nephritis, a primary
 kidney disease, a collapsing glomerulopathy, a dense deposit disease, a cryoglobulinemia-
 associated glomerulonephritis, an Henoch-Schonlein disease, a postinfectious
 25 glomerulonephritis, a bacterial endocarditis, a microscopic polyangitis, a Churg-Strauss
 syndrome, an anti-GBM-antibody mediated glomerulonephritis, amyloidosis, a monoclonal
 immunoglobulin deposition disease, a fibrillary glomerulonephritis, an immunotactoid
 glomerulopathy, ischemic tubular injury, a medication-induced tubulo-interstitial nephritis, a
 toxic tubulo-interstitial nephritis, an infectious tubulo-interstitial nephritis, a bacterial
 30 pyelonephritis, a viral infectious tubulo-interstitial nephritis which results from a
 polyomavirus infection or an HIV infection, a metabolic-induced tubulo-interstitial disease, a
 mixed connective disease, a cast nephropathy, a crystal nephropathy which may results from
 urate or oxalate or drug-induced crystal deposition, an acute cellular tubulo-interstitial
 allograft rejection, a tumoral infiltrative disease which results from a lymphoma or a post-

transplant lymphoproliferative disease, an obstructive disease of the kidney, vascular disease, a thrombotic microangiopathy, a nephroangiosclerosis, an atheroembolic disease, a mixed connective tissue disease, a polyarteritis nodosa, a calcineurin-inhibitor induced-vascular disease, an acute cellular vascular allograft rejection, an acute humoral allograft rejection,

5 early renal function decline (ERFD), end stage renal disease (ESRD), renal vein thrombosis, acute tubular necrosis, renal occlusion, acute interstitial nephritis, established chronic kidney disease, renal artery stenosis, ischemic nephropathy, uremia, drug and toxin-induced chronic tubulointerstitial nephritis, reflux nephropathy, kidney stones, Goodpasture's syndrome, normocytic normochromic anemia, renal anemia, diabetic chronic kidney disease, IgG4-

10 related disease, von Hippel-Lindau syndrome, tuberous sclerosis, nephronophthisis, medullary cystic kidney disease, renal cell carcinoma, adenocarcinoma, nephroblastoma, lymphoma, leukemia, hyposialylation disorder, chronic cyclosporine nephropathy, renal reperfusion injury, renal dysplasia, azotemia, bilateral arterial occlusion, acute uric acid nephropathy, hypovolemia, acute bilateral obstructive uropathy, hypercalcemic nephropathy,

15 hemolytic uremic syndrome, acute urinary retention, malignant nephrosclerosis, postpartum glomerulosclerosis, scleroderma, non-Goodpasture's anti-GBM disease, microscopic polyarteritis nodosa, allergic granulomatosis, acute radiation nephritis, post-streptococcal glomerulonephritis, Waldenstrom's macroglobulinemia, analgesic nephropathy, arteriovenous fistula, arteriovenous graft, dialysis, ectopic kidney, medullary sponge kidney, renal

20 osteodystrophy, solitary kidney, hydronephrosis, microalbuminuria, uremia, haematuria, hyperlipidemia, hypoalbuminaemia, lipiduria, acidosis, and hyperkalemia. In some embodiments, the disclosure further provides methods and ALK4:ActRIIB antagonists for use in delaying or preventing progression from: stage 1 to stage 2 kidney disease, stage 2 to stage 3 kidney disease, stage 3 to stage 4 kidney disease, or stage 4 to stage 5 kidney disease.

25 In some embodiments, the disclosure further provides methods and ALK4:ActRIIB heteromultimers for use in preventing or reducing kidney inflammation. In some embodiments, the disclosure further provides methods and ALK4:ActRIIB heteromultimers for use in preventing or reducing kidney damage. In some embodiments, the disclosure further provides methods and ALK4:ActRIIB heteromultimers for use in preventing or

30 reducing kidney fibrosis.

In certain aspects, the disclosure relates to methods of treating pulmonary arterial hypertension comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer such as those described herein (e.g., an ALK4:ActRIIB

heterodimer). In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases ventricle hypertrophy in the patient. In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases ventricle hypertrophy in the patient by at least 10% (e.g., 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, or at least 80%). In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases smooth muscle hypertrophy in the patient. In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases smooth muscle hypertrophy in the patient by at least 10% (e.g., 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, or at least 80%). In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases pulmonary arteriole muscularity in the patient. In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases pulmonary arteriole muscularity in the patient by at least 10% (e.g., 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, or at least 80%). In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases pulmonary vascular resistance in the patient. In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases pulmonary vascular resistance in the patient by at least 10% (e.g., 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, or at least 80%). In some embodiments, administration of the ALK4:ActRIIB heteromultimer decreases pulmonary vascular resistance in the patient by at least 25-30%. In some embodiments, the patient has pulmonary arterial hypertension and has Functional Class II or Class III pulmonary hypertension in accordance with the World Health Organization's functional classification system for pulmonary hypertension. In some embodiments, the patient has pulmonary arterial hypertension that is classified as one or more subtypes selected from the group consisting of: idiopathic or heritable pulmonary arterial hypertension, drug- and/or toxin-induced pulmonary hypertension, pulmonary hypertension associated with connective tissue disease, and pulmonary hypertension associated with congenital systemic-to-pulmonary shunts at least 1 year following shunt repair. In some embodiments, the patient has been treated with one or more vasodilators. In some embodiments, the patient has been treated with one or more agents selected from the group consisting of: phosphodiesterase type 5 inhibitors, soluble guanylate cyclase stimulators, prostacyclin receptor agonist, and endothelin receptor antagonists. In some embodiments, the one or more agents is selected from the group consisting of: bosentan, sildenafil, beraprost, macitentan, selexipag, epoprostenol, treprostinil, iloprost, ambrisentan, and tadalafil. In some embodiments, the method further comprises administration of one or more vasodilators. In some embodiments,

the method further comprises administration of one or more agents selected from the group consisting of: phosphodiesterase type 5 inhibitors, soluble guanylate cyclase stimulators, prostacyclin receptor agonist, and endothelin receptor antagonists. In some embodiments, the one or more agents is selected from the group consisting of: bosentan, sildenafil, beraprost, macitentan, selexipag, epoprostenol, treprostinil, iloprost, ambrisentan, and tadalafil. In some
5 embodiments, the patient has a 6-minute walk distance from 150 to 400 meters. In some
embodiments, the method increases the patient's 6-minute walk distance by at least 10 meters
(e.g., at least 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 125, 150, 175, 200, 250, 300, or more
than 400 meters). In some embodiments, the patient has a hemoglobin level from >8 and <15
10 g/dl. In some embodiments, the method delays clinical worsening of pulmonary arterial
hypertension. In some embodiments, the method delays clinical worsening of pulmonary
hypertension in accordance with the World Health Organization's functional classification
system for pulmonary hypertension. In some embodiments, the method reduces the risk of
hospitalization for one or more complications associated with pulmonary arterial
15 hypertension.

In some embodiments, the present disclosure relates to methods of treating pulmonary
hypertension comprising administering to a patient in need thereof an effective amount of an
ALK4:ActRIIB heteromultimer. In certain aspects, the disclosure relates to methods of
preventing pulmonary hypertension comprising administering to a patient in need thereof an
20 effective amount of an ALK4:ActRIIB heteromultimer. In certain aspects, the disclosure
relates to methods of reducing the progression rate of pulmonary hypertension comprising
administering to a patient in need thereof an effective amount of an ALK4:ActRIIB
heteromultimer. In some embodiments, the disclosure provides for a method of treating an
interstitial lung disease, comprising administering to a patient in need thereof an effective
25 amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the disclosure provides
for a method of treating, preventing, or reducing the progression rate and/or severity of one or
more complications of an interstitial lung disease, comprising administering to a patient in
need thereof an effective amount of an ALK4:ActRIIB heteromultimer. In some
embodiments, the interstitial lung disease is idiopathic pulmonary fibrosis. In certain aspects,
30 the disclosure relates to methods of reducing the severity of pulmonary hypertension
comprising administering to a patient in need thereof an effective amount of an
ALK4:ActRIIB heteromultimer. In certain aspects, the disclosure relates to methods of
treating one or more complications (e.g., smooth muscle and/or endothelial cell proliferation

in the pulmonary artery, angiogenesis in the pulmonary artery, dyspnea, chest pain, pulmonary vascular remodeling, right ventricular hypertrophy, and pulmonary fibrosis) of pulmonary hypertension comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer. In certain aspects, the disclosure relates to

5 methods of preventing one or more complication of pulmonary hypertension (e.g., smooth muscle and/or endothelial cell proliferation in the pulmonary artery, angiogenesis in the pulmonary artery, dyspnea, chest pain, pulmonary vascular remodeling, right ventricular hypertrophy, and pulmonary fibrosis) comprising administering to a patient in need thereof an effective amount an ALK4:ActRIIB heteromultimer. In certain aspects, the disclosure

10 relates to methods of reducing the progression rate of one or more complication of pulmonary hypertension (e.g., smooth muscle and/or endothelial cell proliferation in the pulmonary artery, angiogenesis in the pulmonary artery, dyspnea, chest pain, pulmonary vascular remodeling, right ventricular hypertrophy, and pulmonary fibrosis) comprising administering to a patient in need thereof an effective amount an ALK4:ActRIIB heteromultimer. In certain

15 aspects, the disclosure relates to methods of reducing the severity of one or more complication of pulmonary hypertension (e.g., smooth muscle and/or endothelial cell proliferation in the pulmonary artery, angiogenesis in the pulmonary artery, dyspnea, chest pain, pulmonary vascular remodeling, right ventricular hypertrophy, and pulmonary fibrosis) comprising administering to a patient in need thereof an effective amount of an

20 ALK4:ActRIIB heteromultimer. In certain preferred embodiments, methods described herein relate to a patient having pulmonary arterial hypertension. In some embodiments, methods described herein relate to a patient having a resting pulmonary arterial pressure (PAP) of at least 25 mm Hg (e.g., at least 25, 30, 35, 40, 45, or 50 mm Hg). In some embodiments, the methods described herein reduce PAP in a patient having pulmonary hypertension. For

25 example, the method may reduce PAP by at least 3 mmHg (e.g., at least 3, 5, 7, 10, 12, 15, 20, or 25 mm Hg) in a patient having pulmonary hypertension. In some embodiments, the methods described herein reduce pulmonary vascular resistance in a patient having pulmonary hypertension. In some embodiments, the methods described herein increase pulmonary capillary wedge pressure in a patient having pulmonary hypertension. In some

30 embodiments, the methods described herein increase left ventricular end-diastolic pressure in a patient having pulmonary hypertension. In some embodiments, the methods described herein increase (improves) exercise capacity (ability, tolerance) in a patient having pulmonary hypertension. For example, the method may increase 6-minute walk distance in a patient having pulmonary hypertension, optionally increasing 6-minute walk distance by at

least 10 meters (e.g., at least 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 or more meters). In addition, the method may reduce the patient's Borg dyspnea index (BDI), which optionally may be assessed after a 6-minute walk test. In some embodiments, the method reduces the patient's Borg dyspnea index (BDI) by at least 0.5 index points (e.g., at least 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, or 10 index points). In some embodiments, the methods described herein relate to a patient having Class I, Class II, Class III, or Class IV pulmonary hypertension as recognized by the World Health Organization. In some embodiments, the methods described herein relate to delaying clinical progression (worsening) of pulmonary hypertension (e.g., progression as measured by the World Health Organization standard). In some embodiments, the method prevents or delays pulmonary hypertension Class progression (e.g., prevents or delays progression from Class I to Class II, Class II to Class III, or Class III to Class IV pulmonary hypertension as recognized by the World Health Organization). In some embodiments, the method promotes or increases pulmonary hypertension Class regression (e.g., promotes or increases regression from Class IV to Class III, Class III to Class II, or Class II to Class I pulmonary hypertension as recognized by the World Health Organization). In some embodiments, the patient is further administered one or more supportive therapies or active agents for treating pulmonary hypertension in addition to the one or more GDF/BMP antagonist. For example, the patient also may be administered one or more supportive therapies or active agents selected from the group consisting of: prostacyclin and derivatives thereof (e.g., epoprostenol, treprostinil, and iloprost); prostacyclin receptor agonists (e.g., selexipag); endothelin receptor antagonists (e.g., thelin, ambrisentan, macitentan, and bosentan); calcium channel blockers (e.g., amlodipine, diltiazem, and nifedipine); anticoagulants (e.g., warfarin); diuretics; oxygen therapy; atrial septostomy; pulmonary thromboendarterectomy; phosphodiesterase type 5 inhibitors (e.g., sildenafil and tadalafil); activators of soluble guanylate cyclase (e.g., cinaciguat and riociguat); ASK-1 inhibitors (e.g., CIIA; SCH79797; GS-4997; MSC2032964A; 3H-naphtho[1,2,3-de]quiniline-2,7-diones, NQDI-1; 2-thioxo-thiazolidines, 5-bromo-3-(4-oxo-2-thioxo-thiazolidine-5-ylidene)-1,3-dihydro-indol-2-one); NF- κ B antagonists (e.g., dh404, CDDO-epoxide; 2,2-difluoropropionamide; C28 imidazole (CDDO-Im); 2-cyano-3,12-dioxolean-1,9-dien-28-oic acid (CDDO); 3-Acetyloleanolic Acid; 3-Trifluoroacetyloleanolic Acid; 28-Methyl-3-acetyloleanane; 28-Methyl-3-trifluoroacetyloleanane; 28-Methoxyoleanolic Acid; SZC014; SCZ015; SZC017; PEGylated derivatives of oleanolic acid; 3-O-(beta-D-glucopyranosyl) oleanolic acid; 3-O-[beta-D-glucopyranosyl-(1-->3)-beta-D-glucopyranosyl] oleanolic acid; 3-O-[beta-D-glucopyranosyl-(1-->2)-beta-D-

glucopyranosyl] oleanolic acid; 3-O-[beta-D-glucopyranosyl-(1-->3)-beta-D-glucopyranosyl]
 oleanolic acid 28-O-beta-D-glucopyranosyl ester; 3-O-[beta-D-glucopyranosyl-(1-->2)-beta-
 D-glucopyranosyl] oleanolic acid 28-O-beta-D-glucopyranosyl ester; 3-O-[a-L-
 rhamnopyranosyl-(1-->3)-beta-D-glucuronopyranosyl] oleanolic acid; 3-O-[alpha-L-
 5 rhamnopyranosyl-(1-->3)-beta-D-glucuronopyranosyl] oleanolic acid 28-O-beta-D-
 glucopyranosyl ester; 28-O-β-D-glucopyranosyl-oleanolic acid; 3-O-β-D-glucopyranosyl
 (1→3)-β-D-glucopyranosiduronic acid (CS1); oleanolic acid 3-O-β-D-glucopyranosyl
 (1→3)-β-D-glucopyranosiduronic acid (CS2); methyl 3,11-dioxolean-12-en-28-olate
 (DIOXOL); ZCVI₄-2; Benzyl 3-dehydr-oxy-1,2,5-oxadiazolo[3',4':2,3]oleanolate) lung
 10 and/or heart transplantation.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an alignment of extracellular domains of human ActRIIA (SEQ ID NO: 49) and human ActRIIB (SEQ ID NO: 2) with the residues that are deduced herein,
 15 based on composite analysis of multiple ActRIIB and ActRIIA crystal structures, to directly
 contact ligand indicated with boxes.

Figure 2 shows a multiple sequence alignment of various vertebrate ActRIIB
 precursor proteins without their intracellular domains (SEQ ID NOs: 50-55, respectively)
 human ActRIIA precursor protein without its intracellular domain (SEQ ID NO: 56), and a
 20 consensus ActRII precursor protein (SEQ ID NO: 57).

Figure 3 shows multiple sequence alignment of Fc domains from human IgG isotypes
 using Clustal 2.1. Hinge regions are indicated by dotted underline. Double underline
 indicates examples of positions engineered in IgG1 Fc to promote asymmetric chain pairing
 and the corresponding positions with respect to other isotypes IgG2, IgG3 and IgG4.

Figure 4 shows comparative ligand binding data for an ALK4-Fc:ActRIIB-Fc
 25 heterodimeric protein complex compared to ActRIIB-Fc homodimer and ALK4-Fc
 homodimer. For each protein complex, ligands are ranked by k_{off} , a kinetic constant that
 correlates well with ligand signaling inhibition, and listed in descending order of binding
 affinity (ligands bound most tightly are listed at the top). At left, yellow, red, green, and blue
 30 lines indicate magnitude of the off-rate constant. Solid black lines indicate ligands whose
 binding to heterodimer is enhanced or unchanged compared with homodimer, whereas

dashed red lines indicate substantially reduced binding compared with homodimer. As shown, the ALK4-Fc:ActRIIB-Fc heterodimer displays enhanced binding to activin B compared with either homodimer, retains strong binding to activin A, GDF8, and GDF11 as observed with ActRIIB-Fc homodimer, and exhibits substantially reduced binding to BMP9, BMP10, and GDF3. Like ActRIIB-Fc homodimer, the heterodimer retains intermediate-level binding to BMP6.

Figure 5 shows a multiple sequence alignment of ALK4 extracellular domains derived from various vertebrate species (SEQ ID NOs: 59-65).

Figures 6A-6D show schematic examples of heteromeric protein complexes comprising an ALK4 polypeptide and an ActRIIB polypeptide.

In the illustrated embodiments, the ALK4 polypeptide (from left to right) is part of a fusion polypeptide that comprises a first member of an interaction pair (“C₁”), and the ActRIIB polypeptide is part of a fusion polypeptide that comprises a second member of an interaction pair (“C₂”). Suitable interaction pairs included, for example, heavy chain and/or light chain immunoglobulin interaction pairs, truncations, and variants thereof such as those described herein [e.g., Spiess et al (2015) *Molecular Immunology* 67(2A): 95-106]. In each fusion polypeptide, a linker may be positioned between the ALK4 or ActRIIB polypeptide and the corresponding member of the interaction pair. The first and second members of the interaction pair may be unguided, meaning that the members of the pair may associate with each other or self-associate without substantial preference, and they may have the same or different amino acid sequences. See Figure 6A. Alternatively, the interaction pair may be a guided (asymmetric) pair, meaning that the members of the pair associate preferentially with each other rather than self-associate. See Figure 6B. Complexes of higher order can be envisioned. See Figure 6C and 6D.

Figure 7 shows comparative ALK4-Fc:ActRIIB-Fc heterodimer/ActRIIB-Fc:ActRIIB-Fc homodimer IC₅₀ data as determined by an A-204 Reporter Gene Assay as described herein. ALK4-Fc:ActRIIB-Fc heterodimer inhibits activin A, activin B, GDF8, and GDF11 signaling pathways similarly to the ActRIIB-Fc:ActRIIB-Fc heterodimer. However, ALK4-Fc:ActRIIB-Fc heterodimer inhibition of BMP9 and BMP10 signaling pathways is significantly reduced compared to the ActRIIB-Fc:ActRIIB-Fc heterodimer. These data demonstrate that ALK4:ActRIIB heterodimers are more selective antagonists of

activin A, activin B, GDF8, and GDF11 compared to corresponding ActRIIB:ActRIIB homodimers.

Figures 8A-8C shows gene expression profiles of fibrotic genes (Colla1, Fibronectin, PAI-1, CTGF, and α -SMA), inflammatory genes (TNF- α , and MCP1), cytokine genes (TGF- β 1, GF- β 2, TGF- β 3, and activin A), kidney injury gene (NGAL), Hypoxia-inducible factor 1- α (HIF1 α), and activin A receptor (Acvr2A) from mouse kidneys subjected to unilateral ureteral obstruction (UUO). Samples from the contralateral, non-surgery kidney were used as a control (Ctrl). Gene expression profiles were obtained at 17 days post-surgery. Mice were administered either PBS or an ALK4-Fc:ActRIIB-Fc homodimer at days 3, 7, 10, and 14 post-surgery. (\$) denotes a statistical difference between UUO kidneys at 17 days in mice administered only PBS compared UUO kidneys at 17 days in mice administered the ALK7-Fc:ActRIIB-Fc homodimer. (@) denotes that no transcript was detected.

Figures 9A and 9B shows proteinuria levels in Col4a3 and Col4a5 Alport mice treated with vehicle (Col4a3-Veh and Col4a5-Veh) or an ALK4-Fc:ActRIIB-Fc fusion protein (Col4a3-IIB/ALK4 and Col4a5-IIB/ALK4). Figure 9A shows that ALK4-Fc:ActRIIB-Fc treatment significantly reduced proteinuria levels compared to vehicle in the Col4a3 Alport mice. Figure 9B shows that ALK4-Fc:ActRIIB-Fc treatment significantly reduced proteinuria levels compared to vehicle in the Col4a5 Alport mice.

Figures 10A-10C show histological analysis of kidney tissue from Col4a3^{-/-} Alport mice treated with vehicle (Col4a3-Veh) or an ALK4-Fc:ActRIIB-Fc heterodimer (Col4a3-IIB/ALK4). Figure 10A represents the percentage of tissue fibrosis as revealed by collagen-I staining. Collagen-I staining indicates that ALK4-Fc:ActRIIB-Fc treatment significantly reduced kidney fibrosis in this Alport mouse model. Figure 10B represents the percentage of tissue fibrosis as revealed by trichrome staining. Trichrome staining indicates that ALK4-Fc:ActRIIB-Fc treatment significantly reduced kidney fibrosis in this Alport mouse model. Figure 10C represents the percentage of sclerotic glomeruli as revealed by histological analysis. The data indicate that ALK4-Fc:ActRIIB-Fc treatment significantly reduced sclerotic glomeruli in this Alport mouse model.

DETAILED DESCRIPTION OF THE INVENTION

1. Overview

In part, the present disclosure relates to heteromultimers comprising a TGF β superfamily type I receptor polypeptide and a TGF β superfamily type II receptor polypeptide, uses thereof, and methods of making such heteromultimers. See, e.g., Figure 6. In certain preferred embodiments, heteromultimers comprise an extracellular domain of a TGF β superfamily type I receptor polypeptide and an extracellular domain of a TGF β superfamily type II receptor polypeptide. In particular, the disclosure provides heteromultimers that comprise an ALK4 polypeptide and an ActRIIB polypeptide. Preferably such ALK4 polypeptides comprise a ligand-binding domain of an ALK4 receptor and such ActRIIB polypeptides comprise a ligand-binding domain of an ActRIIB receptor. In certain preferred embodiments, ALK4:ActRIIB heteromultimers of the disclosure have an altered TGF β superfamily ligand binding profile/specificity compared to a corresponding sample of a homomultimer (*e.g.*, an ALK4:ActRIIB heterodimer compared to an ActRIIB:ActRIIB homodimer or an ALK4:ALK4 homodimer).

The TGF- β superfamily is comprised of over 30 secreted factors including TGF-betas, activins, nodals, bone morphogenetic proteins (BMPs), growth and differentiation factors (GDFs), and anti-Mullerian hormone (AMH) [Weiss *et al.* (2013) *Developmental Biology*, 2(1): 47-63]. Members of the superfamily, which are found in both vertebrates and invertebrates, are ubiquitously expressed in diverse tissues and function during the earliest stages of development throughout the lifetime of an animal. Indeed, TGF- β superfamily proteins are key mediators of stem cell self-renewal, gastrulation, differentiation, organ morphogenesis, and adult tissue homeostasis. Consistent with this ubiquitous activity, aberrant TGF-beta superfamily signaling is associated with a wide range of human pathologies including, for example, autoimmune disease, cardiovascular disease, fibrotic disease, and cancer.

Ligands of the TGF-beta superfamily share the same dimeric structure in which the central 3-1/2 turn helix of one monomer packs against the concave surface formed by the beta-strands of the other monomer. The majority of TGF-beta family members are further stabilized by an intermolecular disulfide bond. This disulfide bond traverses through a ring formed by two other disulfide bonds generating what has been termed a 'cysteine knot' motif [Lin *et al.* (2006) *Reproduction* 132: 179-190; and Hinck *et al.* (2012) *FEBS Letters* 586: 1860-1870].

TGF-beta superfamily signaling is mediated by heteromeric complexes of type I and type II serine/threonine kinase receptors, which phosphorylate and activate downstream SMAD proteins (*e.g.*, SMAD proteins 1, 2, 3, 5, and 8) upon ligand stimulation [Massagué (2000) *Nat. Rev. Mol. Cell Biol.* 1:169-178]. These type I and type II receptors are

5 transmembrane proteins, composed of a ligand-binding extracellular domain with cysteine-rich region, a transmembrane domain, and a cytoplasmic domain with predicted serine/threonine kinase specificity. In general, type I receptors mediate intracellular signaling while the type II receptors are required for binding TGF-beta superfamily ligands. Type I and II receptors form a stable complex after ligand binding, resulting in phosphorylation of

10 type I receptors by type II receptors.

The TGF-beta family can be divided into two phylogenetic branches based on the type I receptors they bind and the Smad proteins they activate. One is the more recently evolved branch, which includes, *e.g.*, the TGF-betas, activins, GDF8, GDF9, GDF11, BMP3 and nodal, which signal through type I receptors that activate Smads 2 and 3 [Hinck (2012)

15 *FEBS Letters* 586:1860-1870]. The other branch comprises the more distantly related proteins of the superfamily and includes, *e.g.*, BMP2, BMP4, BMP5, BMP6, BMP7, BMP8a, BMP8b, BMP9, BMP10, GDF1, GDF5, GDF6, and GDF7, which signal through Smads 1, 5, and 8.

Activins are members of the TGF-beta superfamily and were initially discovered as

20 regulators of secretion of follicle-stimulating hormone, but subsequently various reproductive and non-reproductive roles have been characterized. There are three principal activin forms (A, B, and AB) that are homo/heterodimers of two closely related β subunits ($\beta_A\beta_A$, $\beta_B\beta_B$, and $\beta_A\beta_B$, respectively). The human genome also encodes an activin C and an activin E, which are primarily expressed in the liver, and heterodimeric forms containing β_C or β_E are also

25 known. In the TGF-beta superfamily, activins are unique and multifunctional factors that can stimulate hormone production in ovarian and placental cells, support neuronal cell survival, influence cell-cycle progress positively or negatively depending on cell type, and induce mesodermal differentiation at least in amphibian embryos [DePaolo *et al.* (1991) *Proc Soc Exp Biol Med.* 198:500-512; Dyson *et al.* (1997) *Curr Biol.* 7:81-84; and Woodruff (1998)

30 *Biochem Pharmacol.* 55:953-963]. In several tissues, activin signaling is antagonized by its related heterodimer, inhibin. For example, in the regulation of follicle-stimulating hormone (FSH) secretion from the pituitary, activin promotes FSH synthesis and secretion, while inhibin reduces FSH synthesis and secretion. Other proteins that may regulate activin

bioactivity and/or bind to activin include follistatin (FS), follistatin-related protein (FSRP, also known as FLRG or FSTL3), and α_2 -macroglobulin.

As described herein, agents that bind to “activin A” are agents that specifically bind to the β_A subunit, whether in the context of an isolated β_A subunit or as a dimeric complex (*e.g.*, a $\beta_A\beta_A$ homodimer or a $\beta_A\beta_B$ heterodimer). In the case of a heterodimer complex (*e.g.*, a $\beta_A\beta_B$ heterodimer), agents that bind to “activin A” are specific for epitopes present within the β_A subunit, but do not bind to epitopes present within the non- β_A subunit of the complex (*e.g.*, the β_B subunit of the complex). Similarly, agents disclosed herein that antagonize (inhibit) “activin A” are agents that inhibit one or more activities as mediated by a β_A subunit, whether in the context of an isolated β_A subunit or as a dimeric complex (*e.g.*, a $\beta_A\beta_A$ homodimer or a $\beta_A\beta_B$ heterodimer). In the case of $\beta_A\beta_B$ heterodimers, agents that inhibit “activin A” are agents that specifically inhibit one or more activities of the β_A subunit, but do not inhibit the activity of the non- β_A subunit of the complex (*e.g.*, the β_B subunit of the complex). This principle applies also to agents that *bind to* and/or *inhibit* “activin B”, “activin C”, and “activin E”. Agents disclosed herein that antagonize “activin AB” are agents that inhibit one or more activities as mediated by the β_A subunit and one or more activities as mediated by the β_B subunit. The same principle also applies to agent that bind to and/or inhibit “activin AC”, “activin BC”, “activin AE”, and “activin BE”.

The BMPs and GDFs together form a family of cysteine-knot cytokines sharing the characteristic fold of the TGF-beta superfamily [Rider *et al.* (2010) *Biochem J.*, 429(1):1-12]. This family includes, for example, BMP2, BMP4, BMP6, BMP7, BMP2a, BMP3, BMP3b (also known as GDF10), BMP4, BMP5, BMP6, BMP7, BMP8, BMP8a, BMP8b, BMP9 (also known as GDF2), BMP10, BMP11 (also known as GDF11), BMP12 (also known as GDF7), BMP13 (also known as GDF6), BMP14 (also known as GDF5), BMP15, GDF1, GDF3 (also known as VGR2), GDF8 (also known as myostatin), GDF9, GDF15, and decapentaplegic. Besides the ability to induce bone formation, which gave the BMPs their name, the BMP/GDFs display morphogenetic activities in the development of a wide range of tissues. BMP/GDF homo- and hetero-dimers interact with combinations of type I and type II receptor dimers to produce multiple possible signaling complexes, leading to the activation of one of two competing sets of SMAD transcription factors. BMP/GDFs have highly specific and localized functions. These are regulated in a number of ways, including the developmental restriction of BMP/GDF expression and through the secretion of several specific BMP

antagonist proteins that bind with high affinity to the cytokines. Curiously, a number of these antagonists resemble TGF-beta superfamily ligands.

Growth and differentiation factor-8 (GDF8) is also known as myostatin. GDF8 is a negative regulator of skeletal muscle mass and is highly expressed in developing and adult skeletal muscle. The GDF8 null mutation in transgenic mice is characterized by a marked hypertrophy and hyperplasia of skeletal muscle [McPherron *et al.* Nature (1997) 387:83-90]. Similar increases in skeletal muscle mass are evident in naturally occurring mutations of GDF8 in cattle and, strikingly, in humans [Ashmore *et al.* (1974) Growth, 38:501-507; Swatland and Kieffer, J. Anim. Sci. (1994) 38:752-757; McPherron and Lee, Proc. Natl. Acad. Sci. USA (1997) 94:12457-12461; Kambadur *et al.* Genome Res. (1997) 7:910-915; and Schuelke *et al.* (2004) N Engl J Med, 350:2682-8]. Studies have also shown that muscle wasting associated with HIV-infection in humans is accompanied by increases in GDF8 protein expression [Gonzalez-Cadavid *et al.*, PNAS (1998) 95:14938-43]. In addition, GDF8 can modulate the production of muscle-specific enzymes (*e.g.*, creatine kinase) and modulate myoblast cell proliferation [International Patent Application Publication No. WO 00/43781]. The GDF8 propeptide can noncovalently bind to the mature GDF8 domain dimer, inactivating its biological activity [Miyazono *et al.* (1988) J. Biol. Chem., 263: 6407-6415; Wakefield *et al.* (1988) J. Biol. Chem., 263; 7646-7654; and Brown *et al.* (1990) Growth Factors, 3: 35-43]. Other proteins which bind to GDF8 or structurally related proteins and inhibit their biological activity include follistatin, and potentially, follistatin-related proteins [Gamer *et al.* (1999) Dev. Biol., 208: 222-232].

GDF11, also known as BMP11, is a secreted protein that is expressed in the tail bud, limb bud, maxillary and mandibular arches, and dorsal root ganglia during mouse development [McPherron *et al.* (1999) Nat. Genet., 22: 260-264; and Nakashima *et al.* (1999) Mech. Dev., 80: 185-189]. GDF11 plays a unique role in patterning both mesodermal and neural tissues [Gamer *et al.* (1999) Dev Biol., 208:222-32]. GDF11 was shown to be a negative regulator of chondrogenesis and myogenesis in developing chick limb [Gamer *et al.* (2001) Dev Biol., 229:407-20]. The expression of GDF11 in muscle also suggests its role in regulating muscle growth in a similar way to GDF8. In addition, the expression of GDF11 in brain suggests that GDF11 may also possess activities that relate to the function of the nervous system. Interestingly, GDF11 was found to inhibit neurogenesis in the olfactory epithelium [Wu *et al.* (2003) Neuron., 37:197-207]. Hence, inhibitors GDF11 may have in

vitro and in vivo applications in the treatment of diseases such as muscle diseases and neurodegenerative diseases (*e.g.*, amyotrophic lateral sclerosis).

As described herein, comparative binding data demonstrated that an ALK4:ActRIIB heterodimer has an altered binding profile (ligand selectivity) compared to either
5 corresponding ActRIIB or ALK4 homodimers. In particular, the ALK4:ActRIIB heterodimer displays enhanced binding to activin B compared with either homodimer, and retains strong binding to activin A, GDF8, and GDF11 as observed with the ActRIIB homodimer. However, the ALK4:ActRIIB heterodimer exhibits substantially reduced binding to BMP9, BMP10, and GDF3 compared to the ActRIIB homodimer. In particular, BMP9 displays low
10 or no observable affinity for the ALK4:ActRIIB heterodimer, whereas this ligand binds strongly to ActRIIB homodimer.

These results therefore demonstrate that ALK4:ActRIIB heterodimers are more selective antagonists of activin A, activin B, GDF8, and GDF11 compared to ActRIIB homodimers. Accordingly, an ALK4:ActRIIB heterodimer will be more useful than an
15 ActRIIB homodimer in certain applications where such selective antagonism is advantageous. Examples include therapeutic applications where it is desirable to retain antagonism of one or more of activin (*e.g.*, activin A, activin B, activin AC, activin AB), GDF8, and GDF11 but minimize antagonism of one or more of BMP9, BMP10, and BMP6.

Moreover, ALK4:ActRIIB heterodimers, as described herein, exert beneficial
20 anabolic effects on skeletal muscle and bone as well as catabolic effects on adipose tissue, very similar to those of an ActRIIB homodimer. However, unlike ActRIIB homodimer, an ActRIIB:ALK4 heterodimer exhibits only low-affinity or transient binding to BMP9 and BMP10 and so will have little to no concurrent inhibition on processes mediated by those ligands, such as angiogenesis. This novel selectivity will be useful, for example, in treating
25 patients in need of stimulatory effects on, *e.g.*, muscle and bone, and inhibitory effects on fat, but not in need of altered angiogenesis.

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

The terms “heteromer” or “heteromultimer” is a complex comprising at least a first polypeptide chain and a second polypeptide chain, wherein the second polypeptide chain differs in amino acid sequence from the first polypeptide chain by at least one amino acid residue. The heteromer can comprise a “heterodimer” formed by the first and second
5 polypeptide chains or can form higher order structures where one or more polypeptide chains in addition to the first and second polypeptide chains are present. Exemplary structures for the heteromultimer include heterodimers, heterotrimers, heterotetramers and further oligomeric structures. Heterodimers are designated herein as X:Y or equivalently as X-Y, where X represents a first polypeptide chain and Y represents a second polypeptide chain.
10 Higher-order heteromers and oligomeric structures are designated herein in a corresponding manner. In certain embodiments a heteromultimer is recombinant (e.g., one or more polypeptide components may be a recombinant protein), isolated and/or purified.

“Homologous,” in all its grammatical forms and spelling variations, refers to the relationship between two proteins that possess a “common evolutionary origin,” including
15 proteins from superfamilies in the same species of organism, as well as homologous proteins from different species of organism. Such proteins (and their encoding nucleic acids) have sequence homology, as reflected by their sequence similarity, whether in terms of percent identity or by the presence of specific residues or motifs and conserved positions. However, in common usage and in the instant application, the term “homologous,” when modified with
20 an adverb such as “highly,” may refer to sequence similarity and may or may not relate to a common evolutionary origin.

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

25 “Percent (%) sequence identity” with respect to a reference polypeptide (or nucleotide) sequence is defined as the percentage of amino acid residues (or nucleic acids) in a candidate sequence that are identical to the amino acid residues (or nucleic acids) in the reference polypeptide (nucleotide) sequence, after aligning the sequences and introducing gaps, if necessary, to achieve the maximum percent sequence identity, and not considering any
30 conservative substitutions as part of the sequence identity. Alignment for purposes of determining percent amino acid sequence identity can be achieved in various ways that are within the skill in the art, for instance, using publicly available computer software such as BLAST, BLAST-2, ALIGN or Megalign (DNASTAR) software. Those skilled in the art can

determine appropriate parameters for aligning sequences, including any algorithms needed to achieve maximal alignment over the full length of the sequences being compared. For purposes herein, however, % amino acid (nucleic acid) sequence identity values are generated using the sequence comparison computer program ALIGN-2. The ALIGN-2 sequence

5 comparison computer program was authored by Genentech, Inc., and the source code has been filed with user documentation in the U.S. Copyright Office, Washington D.C., 20559, where it is registered under U.S. Copyright Registration No. TXU510087. The ALIGN-2 program is publicly available from Genentech, Inc., South San Francisco, Calif., or may be compiled from the source code. The ALIGN-2 program should be compiled for use on a
10 UNIX operating system, including digital UNIX V4.0D. All sequence comparison parameters are set by the ALIGN-2 program and do not vary.

“Agonize”, in all its grammatical forms, refers to the process of activating a protein and/or gene (*e.g.*, by activating or amplifying that protein’s gene expression or by inducing an inactive protein to enter an active state) or increasing a protein’s and/or gene’s activity.

15 “Antagonize”, in all its grammatical forms, refers to the process of inhibiting a protein and/or gene (*e.g.*, by inhibiting or decreasing that protein’s gene expression or by inducing an active protein to enter an inactive state) or decreasing a protein’s and/or gene’s activity.

The terms "about" and "approximately" as used in connection with a numerical value throughout the specification and the claims denotes an interval of accuracy, familiar and
20 acceptable to a person skilled in the art. In general, such interval of accuracy is $\pm 10\%$. Alternatively, and particularly in biological systems, the terms "about" and "approximately" may mean values that are within an order of magnitude, preferably ≤ 5 -fold and more preferably ≤ 2 -fold of a given value.

Numeric ranges disclosed herein are inclusive of the numbers defining the ranges.

25 The terms "a" and "an" include plural referents unless the context in which the term is used clearly dictates otherwise. The terms "a" (or "an"), as well as the terms "one or more," and "at least one" can be used interchangeably herein. Furthermore, "and/or" where used herein is to be taken as specific disclosure of each of the two or more specified features or components with or without the other. Thus, the term “and/or” as used in a phrase such as "A
30 and/or B" herein is intended to include "A and B," "A or B," "A" (alone), and "B" (alone). Likewise, the term "and/or" as used in a phrase such as "A, B, and/or C" is intended to encompass each of the following aspects: A, B, and C; A, B, or C; A or C; A or B; B or C; A and C; A and B; B and C; A (alone); B (alone); and C (alone).

2. ALK4:ActRIIB Heteromultimers

In certain aspects, the present disclosure relates to heteromultimers comprising one or more ALK4 receptor polypeptides (e.g., SEQ ID NOs: 9, 10, 19, 20, 42, 44, 47, 48, 74, and 76) and one or more ActRIIB receptor polypeptides (e.g., SEQ ID NOs: 1, 2, 3, 4, 5, 6, 39, 41, 45, 46, 70, 72, 78, and 80) which are generally referred to herein as “ALK4:ActRIIB heteromultimer complexes” or “ALK4:ActRIIB heteromultimers”. Preferably, ALK4:ActRIIB heteromultimers of the disclosure are soluble, for example, a heteromultimer may comprises a soluble portion (domain) of an ALK4 receptor and a soluble portion (domain) of an ActRIIB receptor. In general, the extracellular domains of ALK4 and ActRIIB correspond to a soluble portion of these receptors. Therefore, in some embodiments, heteromultimers of the disclosure comprise an extracellular domain of an ALK4 receptor and an extracellular domain of an ActRIIB receptor. Example extracellular domains ALK4 and ActRIIB receptors are disclosed herein and such sequences, as well as fragments, functional variants, and modified forms thereof, may be used in accordance with the inventions of the disclosure (e.g., ALK4:ActRIIB heteromultimer compositions and uses thereof). ALK4:ActRIIB heteromultimers of the disclosure include, e.g., heterodimers, heterotrimers, heterotetramers and higher order oligomeric structures. See, e.g., Figure 6. In certain preferred embodiments, heteromultimers of the disclosure are ALK4:ActRIIB heterodimers.

Preferably, ALK4:ActRIIB heteromultimers of the disclosure bind to one or more TGF-beta superfamily ligands. In some embodiments, ALK4:ActRIIB heteromultimers may bind to one or more of activin (e.g., activin A, activin B, activin C, activin E, activin AC, activin AB, activin BC, activin AE, and activin BE), GDF8, GDF11, BMP6, GDF3, and BMP10. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin A. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin B. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin C. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin E. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin AB. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin AC. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin AE. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin BC. In some embodiments, ALK4:ActRIIB heteromultimers bind to activin BE. In some embodiments, ALK4:ActRIIB heteromultimers bind to GDF11. In some embodiments, ALK4:ActRIIB heteromultimers bind to GDF8. In some embodiments, ALK4:ActRIIB heteromultimers bind to BMP6. In

some embodiments, ALK4:ActRIIB heteromultimers bind to GDF3. In some embodiments, ALK4:ActRIIB heteromultimers bind to BMP10. In some embodiments, ALK4:ActRIIB heteromultimers do not bind to, or do not substantially bind to BMP9 (e.g., have indeterminate K_a or K_d due to the transient nature of the interaction between BMP9 and an ALK4:ActRIIB heteromultimer). In some embodiments, ALK4:ActRIIB heteromultimers binds with stronger affinity to activin B compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers binds with weaker affinity to GDF3 compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers binds with weaker affinity to BMP9 compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers binds with weaker affinity to BMP10 compared to a corresponding ActRIIB homomultimer. Optionally, ALK4:ActRIIB heteromultimers may further bind to one or more of BMP2, BMP2/7, BMP3, BMP4, BMP4/7, BMP5, BMP7, BMP8a, BMP8b, GDF5, GDF6/BMP13, GDF7, GDF9b/BMP15, GDF15/MIC1, TGF- β 1, TGF- β 2, TGF- β 3, nodal, glial cell-derived neurotrophic factor (GDNF), neurturin, artemin, persephin, MIS, and Lefty.

In some embodiments, ALK4:ActRIIB heteromultimers may be used to inhibit (antagonize) signaling (e.g., Smad 2/3 and/or Smad 1/5/8 signaling) mediated by one or more TGF β superfamily ligands. In particular, ALK4:ActRIIB heteromultimers of the disclosure may be used to inhibit intracellular signaling by one or more TGF β superfamily ligands in, for example, a cell-based assay such as those described herein. For example, ALK4:ActRIIB heteromultimers may inhibit signaling mediated by one or more of activin (e.g., activin A, activin B, activin C, activin E, activin AC, activin AB, activin BC, activin AE, and activin BE), GDF8, GDF11, BMP6, GDF3, and BMP10 in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin A signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin B signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin C signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin D signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin E signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin AB signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin AC signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin BC signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers

may inhibit activin AE signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit activin BE signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit GDF11 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit GDF8 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit BMP6 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit GDF3 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers may inhibit BMP9 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers do not inhibit, or do not substantially inhibit BMP9 signaling in a cell-based assay. In some embodiments, ALK4:ActRIIB heteromultimers are stronger inhibitors of activin B signaling in a cell-based assay compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers are weaker inhibitors of BMP10 signaling in a cell-based assay compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers are stronger inhibitors of GDF3 signaling in a cell-based assay compared to a corresponding ActRIIB homomultimer. In some embodiments, ALK4:ActRIIB heteromultimers are stronger inhibitors of BMP9 signaling in a cell-based assay compared to a corresponding ActRIIB homomultimer. Optionally, ALK4:ActRIIB heteromultimers may further inhibit intracellular signaling by one or more of BMP2, BMP2/7, BMP3, BMP4, BMP4/7, BMP5, BMP7, BMP8a, BMP8b, GDF5, GDF6/BMP13, GDF7, GDF9b/BMP15, GDF15/MIC1, TGF- β 1, TGF- β 2, TGF- β 3, nodal, glial cell-derived neurotrophic factor (GDNF), neurturin, artemin, persephin, MIS, and Lefty in a cell-based assay.

As used herein, the term “ActRIIB” refers to a family of activin receptor type IIB (ActRIIB) proteins from any species and variants derived from such ActRIIB proteins by mutagenesis or other modification. Reference to ActRIIB herein is understood to be a reference to any one of the currently identified forms. Members of the ActRIIB family are generally transmembrane proteins, composed of a ligand-binding extracellular domain comprising a cysteine-rich region, a transmembrane domain, and a cytoplasmic domain with predicted serine/threonine kinase activity.

The term “ActRIIB polypeptide” includes polypeptides comprising any naturally occurring polypeptide of an ActRIIB family member as well as any variants thereof (including mutants, fragments, fusions, and peptidomimetic forms) that retain a useful activity. Examples of such variant ActRIIB polypeptides are provided throughout the present

disclosure as well as in International Patent Application Publication Nos. WO 2006/012627, WO 2008/097541, and WO 2010/151426, which are incorporated herein by reference in their entirety. Numbering of amino acids for all ActRIIB-related polypeptides described herein is based on the numbering of the human ActRIIB precursor protein sequence provided below

5 (SEQ ID NO: 1), unless specifically designated otherwise.

The human ActRIIB precursor protein sequence is as follows:

1 MTAPWVALAL LWGSLCAGSG **RGEAETRECI** **YYNANWELER** TNQSGLERCE
 51 **GEQDKRLHCY** **ASWRNSSGTI** **ELVKKGCWLD** **DFNCYDRQEC** **VATEENPQVY**
 101 **FCCCEGNFCN** **ERFTHLPEAG** **GPEVTYEPPP** **TAPTLLTVLA** YSLLPIGGLS
 10 151 LIVLLAFWMY RHRKPPYGHV DIHEDPGPPP PSPLVGLKPL QLEIKARGR
 201 FGCVWKAQLM NDFVAVKIFP LQDKQSWQSE REIFSTPGMK HENLLQFIAA
 251 EKRGSNLEVE LWLITAFHDK GSLTDYLGKN IITWNECHV AETMSRGLSY
 301 LHEDVPWCRG EGHKPSIAHR DFKSKNVLLK SDLTAVLADF GLAVRFEPGK
 351 PPGDTHGQVG TRRYMAPEVL EGAINFQRDA FLRIDMYAMG LVLWELVSRC
 15 401 KAADGPVDEY MLPFEEEIGQ HPSLEELQEV VVHKKMRPTI KDHWLKHPGL
 451 AQLCVTIEEC WDHDAEARLS AGCVEERVSL IRRSVNGTTS DCLVSLVTSV
 501 TNVDLPPKES SI (SEQ ID NO: 1)

The signal peptide is indicated with a single underline; the extracellular domain is indicated in **bold** font; and the potential, endogenous N-linked glycosylation sites are indicated with a double underline.

The processed extracellular ActRIIB polypeptide sequence is as follows:

GRGEAETRECIYYNANWELERTNQSGLERCEGEQDKRLHCYASWRNSSGTIELVKKGCWLDD
 FNCYDRQECVATEENPQVYFCCCEGNFCNERFTHLPEAGGPEVTYEPPPTAPT (SEQ ID
 NO: 2)

25 In some embodiments, the protein may be produced with an “SGR...” sequence at the N-terminus. The C-terminal “tail” of the extracellular domain is indicated by a single underline. The sequence with the “tail” deleted (a $\Delta 15$ sequence) is as follows:

GRGEAETRECIYYNANWELERTNQSGLERCEGEQDKRLHCYASWRNSSGTIELVKKGCWLDD
 FNCYDRQECVATEENPQVYFCCCEGNFCNERFTHLPEA (SEQ ID NO: 3)

30 A form of ActRIIB with an alanine at position 64 of SEQ ID NO: 1 (A64) is also reported in the literature See, *e.g.*, Hilden *et al.* (1994) Blood, 83(8): 2163-2170. Applicants have ascertained that an ActRIIB-Fc fusion protein comprising an extracellular domain of

ActRIIB with the A64 substitution has a relatively low affinity for activin and GDF11. By contrast, the same ActRIIB-Fc fusion protein with an arginine at position 64 (R64) has an affinity for activin and GDF11 in the low nanomolar to high picomolar range. Therefore, sequences with an R64 are used as the “wild-type” reference sequence for human ActRIIB in this disclosure.

The form of ActRIIB with an alanine at position 64 is as follows:

```

1  MTAPWVALAL LWGSLCAGSG RGEAETRECI YYNANWELER TNQSGLERCE
51 GEQDKRLHCY ASWANSSGTI ELVKKGCWLD DFNCYDRQEC VATEENPQVY
101 FCCCEGNFCN ERFTHLPEAG GPEVTYEPPP TAPTLLTVLA YSLLPIGGLS
10 151 LIVLLAFWMY RHRKPPYGHV DIHEDPGPPP PSPLVGLKPL QLEIKARGR
201 FGCVWKAQLM NDFVAVKIFP LQDKQSWQSE REIFSTPGMK HENLLQFIAA
251 EKRGSNLEVE LWLITAFHDK GSLTDYLKGN IITWNELVCHV AETMSRGLSY
301 LHEDVPWCRG EGHKPSIAHR DFKSKNVLLK SDLTAVLADF GLAVRFEPGK
351 PPGDTHGQVG TRRYMAPEVL EGAINFQRDA FLRIDMYAMG LVLWELVSRG
15 401 KAADGPVDEY MLPFEEEIGQ HPSLEELQEV VVHKKMRPTI KDHWLKHPGL
451 AQLCVTIEEC WDHDAEARLS AGCVEERVSL IRRSVNGTTS DCLVSLVTSV
501 TNVDLPPKES SI (SEQ ID NO: 4)

```

The signal peptide is indicated by single underline and the extracellular domain is indicated by **bold** font.

20 The processed extracellular ActRIIB polypeptide sequence of the alternative A64 form is as follows:

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GRGEAETRECIYYNANWELERTNQSGLERCEGEQDKRLHCYASWANSSGTIELVKKGCWLDD
FNCYDRQECVATEENPQVYFCCCEGNFCNERFTHLPEAGGPEVTYEPPPTAPT (SEQ ID
NO: 5)

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25 In some embodiments, the protein may be produced with an “SGR...” sequence at the N-terminus. The C-terminal “tail” of the extracellular domain is indicated by single underline. The sequence with the “tail” deleted (a $\Delta 15$ sequence) is as follows:

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GRGEAETRECIYYNANWELERTNQSGLERCEGEQDKRLHCYASWANSSGTIELVKKGCWLDD
FNCYDRQECVATEENPQVYFCCCEGNFCNERFTHLPEA (SEQ ID NO: 6)

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30 A nucleic acid sequence encoding the human ActRIIB precursor protein is shown below (SEQ ID NO: 7), representing nucleotides 25-1560 of Genbank Reference Sequence NM_001106.3, which encode amino acids 1-513 of the ActRIIB precursor. The sequence as

shown provides an arginine at position 64 and may be modified to provide an alanine instead.

The signal sequence is underlined.

```

1  ATGACGGCGC CCTGGGTGGC CCTCGCCCTC CTCTGGGGAT CGCTGTGCGC
51 CGGCTCTGGG CGTGGGGAGG CTGAGACACG GGAGTGCATC TACTACAACG
5  101 CCAACTGGGA GCTGGAGCGC ACCAACCAGA GCGGCCTGGA GCGCTGCGAA
    151 GGCGAGCAGG ACAAGCGGCT GCACTGCTAC GCCTCCTGGC GCAACAGCTC
    201 TGGCACCATC GAGCTCGTGA AGAAGGGCTG CTGGCTAGAT GACTTCAACT
    251 GCTACGATAG GCAGGAGTGT GTGGCCACTG AGGAGAACCC CCAGGTGTAC
    301 TTCTGCTGCT GTGAAGGCAA CTTCTGCAAC GAACGCTTCA CTCATTTGCC
10  351 AGAGGCTGGG GGCCCGGAAG TCACGTACGA GCCACCCCCG ACAGCCCCCA
    401 CCCTGCTCAC GGTGCTGGCC TACTCACTGC TGCCCATCGG GGGCCTTTCC
    451 CTCATCGTCC TGCTGGCCTT TTGGATGTAC CGGCATCGCA AGCCCCCCTA
    501 CGGTCATGTG GACATCCATG AGGACCCTGG GCCTCCACCA CCATCCCCTC
    551 TGGTGGGCCT GAAGCCACTG CAGCTGCTGG AGATCAAGGC TCGGGGGCGC
15  601 TTTGGCTGTG TCTGGAAGGC CCAGCTCATG AATGACTTTG TAGCTGTCAA
    651 GATCTTCCCA CTCCAGGACA AGCAGTCGTG GCAGAGTGAA CGGGAGATCT
    701 TCAGCACACC TGGCATGAAG CACGAGAACC TGCTACAGTT CATTGCTGCC
    751 GAGAAGCGAG GCTCCAACCT CGAAGTAGAG CTGTGGCTCA TCACGGCCTT
    801 CCATGACAAG GGCTCCCTCA CGGATTACCT CAAGGGGAAC ATCATCACAT
20  851 GGAACGAACT GTGTCATGTA GCAGAGACGA TGTCACGAGG CCTCTCATA
    901 CTGCATGAGG ATGTGCCCTG GTGCCGTGGC GAGGGCCACA AGCCGTCTAT
    951 TGCCCACAGG GACTTTAAAA GTAAGAATGT ATTGCTGAAG AGCGACCTCA
1001 CAGCCGTGCT GGCTGACTTT GGCTTGGCTG TTCGATTTGA GCCAGGGAAA
1051 CCTCCAGGGG ACACCCACGG ACAGGTAGGC ACGAGACGGT ACATGGCTCC
25  1101 TGAGGTGCTC GAGGGAGCCA TCAACTTCCA GAGAGATGCC TTCCTGCGCA
    1151 TTGACATGTA TGCCATGGGG TTGGTGCTGT GGGAGCTTGT GTCTCGCTGC
    1201 AAGGCTGCAG ACGGACCCGT GGATGAGTAC ATGCTGCCCT TTGAGGAAGA
    1251 GATTGGCCAG CACCCTTCGT TGGAGGAGCT GCAGGAGGTG GTGGTGCACA
    1301 AGAAGATGAG GCCCACCATT AAAGATCACT GGTGAAACA CCCGGGCCTG
30  1351 GCCCAGCTTT GTGTGACCAT CGAGGAGTGC TGGGACCATG ATGCAGAGGC
    1401 TCGCTTGTCC GCGGGCTGTG TGGAGGAGCG GGTGTCCCTG ATTCGGAGGT
    1451 CGGTCAACGG CACTACCTCG GACTGTCTCG TTTCCCTGGT GACCTCTGTC
    1501 ACCAATGTGG ACCTGCCCCC TAAAGAGTCA AGCATC (SEQ ID NO: 7)

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A nucleic acid sequence encoding processed extracellular human ActRIIB polypeptide is as follows (SEQ ID NO: 8). The sequence as shown provides an arginine at position 64, and may be modified to provide an alanine instead.

```

1  GGGCGTGGGG AGGCTGAGAC ACGGGAGTGC ATCTACTACA ACGCCAACTG
5  51  GGAGCTGGAG CGCACCAACC AGAGCGGCCT GGAGCGCTGC GAAGGCGAGC
101 AGGACAAGCG GCTGCACTGC TACGCCTCCT GGCGCAACAG CTCTGGCACC
151 ATCGAGCTCG TGAAGAAGGG CTGCTGGCTA GATGACTTCA ACTGCTACGA
201 TAGGCAGGAG TGTGTGGCCA CTGAGGAGAA CCCCCAGGTG TACTTCTGCT
251 GCTGTGAAGG CAACTTCTGC AACGAACGCT TCACTCATTT GCCAGAGGCT
10  301 GGGGGCCCCG AAGTCACGTA CGAGCCACCC CCGACAGCCC CCACC
(SEQ ID NO: 8)

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An alignment of the amino acid sequences of human ActRIIB extracellular domain and human ActRIIA extracellular domain are illustrated in Figure 1. This alignment indicates amino acid residues within both receptors that are believed to directly contact ActRII ligands. For example, the composite ActRII structures indicated that the ActRIIB-ligand binding pocket is defined, in part, by residues Y31, N33, N35, L38 through T41, E47, E50, Q53 through K55, L57, H58, Y60, S62, K74, W78 through N83, Y85, R87, A92, and E94 through F101. At these positions, it is expected that conservative mutations will be tolerated.

In addition, ActRIIB is well-conserved among vertebrates, with large stretches of the extracellular domain completely conserved. For example, Figure 2 depicts a multi-sequence alignment of a human ActRIIB extracellular domain compared to various ActRIIB orthologs. Many of the ligands that bind to ActRIIB are also highly conserved. Accordingly, from these alignments, it is possible to predict key amino acid positions within the ligand-binding domain that are important for normal ActRIIB-ligand binding activities as well as to predict amino acid positions that are likely to be tolerant of substitution without significantly altering normal ActRIIB-ligand binding activities. Therefore, an active, human ActRIIB variant polypeptide useful in accordance with the presently disclosed methods may include one or more amino acids at corresponding positions from the sequence of another vertebrate ActRIIB, or may include a residue that is similar to that in the human or other vertebrate sequences. Without meaning to be limiting, the following examples illustrate this approach to defining an active ActRIIB variant. L46 in the human extracellular domain (SEQ ID NO: 53) is a valine in *Xenopus* ActRIIB (SEQ ID NO: 55), and so this position may be altered, and optionally may be altered to another hydrophobic residue, such as V, I or F, or a non-

polar residue such as A. E52 in the human extracellular domain is a K in *Xenopus*, indicating that this site may be tolerant of a wide variety of changes, including polar residues, such as E, D, K, R, H, S, T, P, G, Y and probably A. T93 in the human extracellular domain is a K in *Xenopus*, indicating that a wide structural variation is tolerated at this position, with polar residues favored, such as S, K, R, E, D, H, G, P, G and Y. F108 in the human extracellular domain is a Y in *Xenopus*, and therefore Y or other hydrophobic group, such as I, V or L should be tolerated. E111 in the human extracellular domain is K in *Xenopus*, indicating that charged residues will be tolerated at this position, including D, R, K and H, as well as Q and N. R112 in the human extracellular domain is K in *Xenopus*, indicating that basic residues are tolerated at this position, including R and H. A at position 119 in the human extracellular domain is relatively poorly conserved, and appears as P in rodents and V in *Xenopus*, thus essentially any amino acid should be tolerated at this position.

Moreover, ActRII proteins have been characterized in the art in terms of structural and functional characteristics, particularly with respect to ligand binding [Attisano *et al.* (1992) Cell 68(1):97-108; Greenwald *et al.* (1999) Nature Structural Biology 6(1): 18-22; Allendorph *et al.* (2006) PNAS 103(20: 7643-7648; Thompson *et al.* (2003) The EMBO Journal 22(7): 1555-1566; as well as U.S. Patent Nos: 7,709,605, 7,612,041, and 7,842,663]. In addition to the teachings herein, these references provide amply guidance for how to generate ActRIIB variants that retain one or more normal activities (e.g., ligand-binding activity).

For example, a defining structural motif known as a three-finger toxin fold is important for ligand binding by type I and type II receptors and is formed by conserved cysteine residues located at varying positions within the extracellular domain of each monomeric receptor [Greenwald *et al.* (1999) Nat Struct Biol 6:18-22; and Hinck (2012) FEBS Lett 586:1860-1870]. Accordingly, the core ligand-binding domains of human ActRIIB, as demarcated by the outermost of these conserved cysteines, corresponds to positions 29-109 of SEQ ID NO: 1 (ActRIIB precursor). Thus, the structurally less-ordered amino acids flanking these cysteine-demarcated core sequences can be truncated by about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, or 28 residues at the N-terminus and/or by about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, or 25 residues at the C-terminus without necessarily altering ligand binding. Exemplary ActRIIB extracellular domains for N-terminal and/or C-terminal truncation include SEQ ID NOs: 2, 3, 5, and 6.

Attisano *et al.* showed that a deletion of the proline knot at the C-terminus of the extracellular domain of ActRIIB reduced the affinity of the receptor for activin. An ActRIIB-Fc fusion protein containing amino acids 20-119 of present SEQ ID NO: 1, “ActRIIB(20-119)-Fc”, has reduced binding to GDF11 and activin relative to an ActRIIB(20-134)-Fc, which includes the proline knot region and the complete juxtamembrane domain (see, *e.g.*, U.S. Patent No. 7,842,663). However, an ActRIIB(20-129)-Fc protein retains similar, but somewhat reduced activity, relative to the wild-type, even though the proline knot region is disrupted.

Thus, ActRIIB extracellular domains that stop at amino acid 134, 133, 132, 131, 130 and 129 (with respect to SEQ ID NO: 1) are all expected to be active, but constructs stopping at 134 or 133 may be most active. Similarly, mutations at any of residues 129-134 (with respect to SEQ ID NO: 1) are not expected to alter ligand-binding affinity by large margins. In support of this, it is known in the art that mutations of P129 and P130 (with respect to SEQ ID NO: 1) do not substantially decrease ligand binding. Therefore, an ActRIIB polypeptide of the present disclosure may end as early as amino acid 109 (the final cysteine), however, forms ending at or between 109 and 119 (*e.g.*, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, or 119) are expected to have reduced ligand binding. Amino acid 119 (with respect to present SEQ ID NO:1) is poorly conserved and so is readily altered or truncated. ActRIIB polypeptides ending at 128 (with respect to SEQ ID NO: 1) or later should retain ligand-binding activity. ActRIIB polypeptides ending at or between 119 and 127 (*e.g.*, 119, 120, 121, 122, 123, 124, 125, 126, or 127), with respect to SEQ ID NO: 1, will have an intermediate binding ability. Any of these forms may be desirable to use, depending on the clinical or experimental setting.

At the N-terminus of ActRIIB, it is expected that a protein beginning at amino acid 29 or before (with respect to SEQ ID NO: 1) will retain ligand-binding activity. Amino acid 29 represents the initial cysteine. An alanine-to-asparagine mutation at position 24 (with respect to SEQ ID NO: 1) introduces an N-linked glycosylation sequence without substantially affecting ligand binding [U.S. Patent No. 7,842,663]. This confirms that mutations in the region between the signal cleavage peptide and the cysteine cross-linked region, corresponding to amino acids 20-29, are well tolerated. In particular, ActRIIB polypeptides beginning at position 20, 21, 22, 23, and 24 (with respect to SEQ ID NO: 1) should retain general ligand-binding activity, and ActRIIB polypeptides beginning at positions 25, 26, 27, 28, and 29 (with respect to SEQ ID NO: 1) are also expected to retain ligand-binding activity.

It has been demonstrated, *e.g.*, U.S. Patent No. 7,842,663, that, surprisingly, an ActRIIB construct beginning at 22, 23, 24, or 25 will have the most activity.

Taken together, a general formula for an active portion (*e.g.*, ligand-binding portion) of ActRIIB comprises amino acids 29-109 of SEQ ID NO: 1. Therefore ActRIIB

5 polypeptides may, for example, comprise, consist essentially of, or consist of an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to a portion of ActRIIB beginning at a residue corresponding to any one of amino acids 20-29 (*e.g.*, beginning at any one of amino acids 20, 21, 22, 23, 24, 25, 26, 27, 28, or 29) of SEQ ID NO: 1 and ending at a position
10 corresponding to any one amino acids 109-134 (*e.g.*, ending at any one of amino acids 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, or 134) of SEQ ID NO: 1. Other examples include polypeptides that begin at a position from 20-29 (*e.g.*, any one of positions 20, 21, 22, 23, 24, 25, 26, 27, 28, or 29) or 21-29 (*e.g.*, any one of positions 21, 22, 23, 24, 25, 26, 27, 28, or 29) of SEQ ID NO: 1
15 and end at a position from 119-134 (*e.g.*, any one of positions 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, or 134), 119-133 (*e.g.*, any one of positions 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, or 133), 129-134 (*e.g.*, any one of positions 129, 130, 131, 132, 133, or 134), or 129-133 (*e.g.*, any one of positions 129, 130, 131, 132, or 133) of SEQ ID NO: 1. Other examples include constructs that begin at a
20 position from 20-24 (*e.g.*, any one of positions 20, 21, 22, 23, or 24), 21-24 (*e.g.*, any one of positions 21, 22, 23, or 24), or 22-25 (*e.g.*, any one of positions 22, 22, 23, or 25) of SEQ ID NO: 1 and end at a position from 109-134 (*e.g.*, any one of positions 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, or 134), 119-134 (*e.g.*, any one of positions 119, 120, 121, 122, 123, 124, 125, 126, 127,
25 128, 129, 130, 131, 132, 133, or 134) or 129-134 (*e.g.*, any one of positions 129, 130, 131, 132, 133, or 134) of SEQ ID NO: 1. Variants within these ranges are also contemplated, particularly those having at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identity to the corresponding portion of SEQ ID NO: 1.

30 The variations described herein may be combined in various ways. In some embodiments, ActRIIB variants comprise no more than 1, 2, 5, 6, 7, 8, 9, 10 or 15 conservative amino acid changes in the ligand-binding pocket, and zero, one, or more non-conservative alterations at positions 40, 53, 55, 74, 79 and/or 82 in the ligand-binding pocket.

Sites outside the binding pocket, at which variability may be particularly well tolerated, include the amino and carboxy termini of the extracellular domain (as noted above), and positions 42-46 and 65-73 (with respect to SEQ ID NO: 1). An asparagine-to-alanine alteration at position 65 (N65A) actually improves ligand binding in the A64 background, and is thus expected to have no detrimental effect on ligand binding in the R64 background [U.S. Patent No. 7,842,663]. This change probably eliminates glycosylation at N65 in the A64 background, thus demonstrating that a significant change in this region is likely to be tolerated. While an R64A change is poorly tolerated, R64K is well-tolerated, and thus another basic residue, such as H may be tolerated at position 64 [U.S. Patent No. 7,842,663].

Additionally, the results of the mutagenesis program described in the art indicate that there are amino acid positions in ActRIIB that are often beneficial to conserve. With respect to SEQ ID NO: 1, these include position 80 (acidic or hydrophobic amino acid), position 78 (hydrophobic, and particularly tryptophan), position 37 (acidic, and particularly aspartic or glutamic acid), position 56 (basic amino acid), position 60 (hydrophobic amino acid, particularly phenylalanine or tyrosine). Thus, the disclosure provides a framework of amino acids that may be conserved in ActRIIB polypeptides. Other positions that may be desirable to conserve are as follows: position 52 (acidic amino acid), position 55 (basic amino acid), position 81 (acidic), 98 (polar or charged, particularly E, D, R or K), all with respect to SEQ ID NO: 1.

In certain embodiments, the disclosure relates to heteromultimers that comprise at least one ActRIIB polypeptide, which includes fragments, functional variants, and modified forms thereof. Preferably, ActRIIB polypeptides for use in accordance with inventions of the disclosure are soluble (*e.g.*, an extracellular domain of ActRIIB). In other preferred embodiments, ActRIIB polypeptides for use in accordance with the disclosure bind to one or more TGF-beta superfamily ligands. Therefore, in some embodiments, ActRIIB polypeptides for use in accordance with the disclosure inhibit (antagonize) activity (*e.g.*, inhibition of Smad signaling) of one or more TGF-beta superfamily ligands. In some embodiments, heteromultimers of the disclosure comprise at least one ActRIIB polypeptide that comprise, consist essentially of, or consist of an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to a portion of ActRIIB beginning at a residue corresponding to amino acids 20-29 (*e.g.*, beginning at any one of amino acids 20, 21, 22, 23, 24, 25, 26, 27, 28, or 29) of SEQ ID NO: 1 and ending at a position corresponding to amino acids 109-134

(*e.g.*, ending at any one of amino acids 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, or 134) of SEQ ID NO:

1. In certain preferred embodiments, heteromultimers of the disclosure comprise at least one ActRIIB polypeptide that comprises, consists, or consists essentially of an amino acid

sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical amino acids 29-109 of SEQ ID NO: 1

In other preferred embodiments, heteromultimer complexes of the disclosure comprise at least one ActRIIB polypeptide that comprises, consists of, or consists essentially of an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%,

93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical amino acids 25-131 of SEQ ID

NO: 1. In some embodiments, heteromultimers of the disclosure comprise at least one

ActRIIB polypeptide that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of any one of SEQ ID NOs: 1, 2, 3, 4, 5, 6, 39, 41, 45, or 46. In certain preferred embodiments,

heteromultimers of the disclosure comprise do not comprise an ActRIIB polypeptide wherein the position corresponding to L79 of SEQ ID NO: 1 is an acidic amino acid (*i.e.*, is not a naturally occurring D or E amino acid residue or artificial acidic amino acid).

In certain aspects, the present disclosure relates to protein complexes that comprise an ALK4 polypeptide. As used herein, the term “ALK4” refers to a family of activin receptor-like kinase-4 proteins from any species and variants derived from such ALK4 proteins by mutagenesis or other modification. Reference to ALK4 herein is understood to be a reference to any one of the currently identified forms. Members of the ALK4 family are generally transmembrane proteins, composed of a ligand-binding extracellular domain with a cysteine-rich region, a transmembrane domain, and a cytoplasmic domain with predicted serine/threonine kinase activity.

The term “ALK4 polypeptide” includes polypeptides comprising any naturally occurring polypeptide of an ALK4 family member as well as any variants thereof (including mutants, fragments, fusions, and peptidomimetic forms) that retain a useful activity.

Numbering of amino acids for all ALK4-related polypeptides described herein is based on the numbering of the human ALK4 precursor protein sequence below (SEQ ID NO: 9), unless specifically designated otherwise.

A human ALK4 precursor protein sequence (NCBI Ref Seq NP_004293) is as follows:

1 MAESAGASSF FPLVVLLLAG SGG**SGPRGVQ ALLCACTSCL QANYTCETDG ACMVSIENLD**
 61 **GMEHHVRTCI PKVELVPAGK PFYCLSEDL RNTHCCYTDY CNRIDLRVPS GHLKEPEHPS**
 121**MWGPVELVGI** IAGPVFLLFL IIIIVFLVIN YHQRVYHNRQ RLDMEDPSCE MCLSKDKTLQ
 181DLVYDLSTSG SGSGLPLFVQ RTVARTIVLQ EIIGKGRFGE VWRGRWRGGD VAVKIFSSRE
 5 241ERSWFREAEI YQTVMLRHEN ILGFIAADNK DNGTWTQLWL VSDYHEHGS LFDYLNRYTVT
 301IEGMIKLALS AASGLAHLHM EIVGTQGKPG IAHARDLKSKN ILVKKNGMCA IADLGLAVRH
 361DAVTDITIDIA PNQRVGTKRY MAPEVLDETI NMKHFDSFKC ADIYALGLVY WEIARRCNSG
 421GVHEEYQLPY YDLVPSDPSI EEMRKVVCDQ KLRPNIPNWW QSYEALRVMG KMMRECWYAN
 481GAARLTALRI KKTLSQLSVQ EDVKI (SEQ ID NO: 9)

10 The signal peptide is indicated by a single underline and the extracellular domain is indicated in **bold font**.

A processed extracellular human ALK4 polypeptide sequence is as follows:

SGPRGVQALLCACTSCLQANYTCETDGACMVSIENLDGMEHHVRTCIPKVELVPAGKPFYCL
 SSEDLRNTHCCYTDYCNRIDLRVPSGHLKEPEHPSMWGPVE (SEQ ID NO: 10)

15 A nucleic acid sequence encoding the ALK4 precursor protein is shown below (SEQ ID NO: 11), corresponding to nucleotides 78-1592 of Genbank Reference Sequence NM_004302.4. The signal sequence is underlined and the extracellular domain is indicated in **bold font**.

ATGGCGGAGTCGGCCGGAGCCTCCTCCTTCTTCCCCCTTGTTGTCCTCCTGCTCGCCGGCAG
 20 CGGCGGGTCCGGGCCCCGGGGGGTCCAGGCTCTGCTGTGTGCGTGACACCAGCTGCCTCCAGG
 CCAACTACACGTGTGAGACAGATGGGGCCTGCATGGTTTCCATTTTCAATCTGGATGGGATG
 GAGCACCATGTGCGCACCTGCATCCCCAAAGTGGAGCTGGTCCCTGCCGGGAAGCCCTTCTA
 CTGCCTGAGCTCGGAGGACCTGCGCAACACCCACTGCTGCTACACTGACTACTGCAACAGGA
 TCGACTTGAGGGTGCCCAGTGGTCACCTCAAGGAGCCTGAGCACCCGTCCATGTGGGGCCCCG
 25 **GTGGAG**CTGGTAGGCATCATCGCCGGCCCCGGTGTTCCTCCTGTTCCCTCATCATCATCATTGT
 TTCCTTGTCATTAACTATCATCAGCGTGTCTATCACAACCGCCAGAGACTGGACATGGAAG
 ATCCCTCATGTGAGATGTGTCTCTCCAAAGACAAGACGCTCCAGGATCTTGTCTACGATCTC
 TCCACCTCAGGGTCTGGCTCAGGGTTACCCCTCTTTGTCCAGCGCACAGTGGCCCGAACCAT
 CGTTTTACAAGAGATTATTGGCAAGGGTCGGTTTGGGGAAGTATGGCGGGGCGCTGGAGGG
 30 GTGGTGATGTGGCTGTGAAAATATTCTCTTCTCGTGAAGAACGGTCTTGGTTCAGGGAAGCA
 GAGATATACCAGACGGTCATGCTGCGCCATGAAAACATCCTTGGATTTATTGCTGCTGACAA
 TAAAGATAATGGCACCTGGACACAGCTGTGGCTTGTTTCTGACTATCATGAGCACGGGTCCC
 TGTTTGATTATCTGAACCGGTACACAGTGACAATTGAGGGGATGATTAAGCTGGCCTTGTCT
 GCTGCTAGTGGGCTGGCACACCTGCACATGGAGATCGTGGGCACCCAAGGGAAGCCTGGAAT

TGCTCATCGAGACTTAAAGTCAAAGAACATTCTGGTGAAGAAAAATGGCATGTGTGCCATAG
 CAGACCTGGGCCTGGCTGTCCGTCATGATGCAGTCACTGACACCATTGACATTGCCCCGAAT
 CAGAGGGTGGGGACCAAACGATACATGGCCCCCTGAAGTACTTGATGAAACCATTAATATGAA
 ACACTTTGACTCCTTTAAATGTGCTGATATTTATGCCCTCGGGCTTGTATATTGGGAGATTG
 5 CTCGAAGATGCAATTCTGGAGGAGTCCATGAAGAATATCAGCTGCCATATTACGACTTAGTG
 CCCTCTGACCCTTCCATTGAGGAAATGCGAAAGGTTGTATGTGATCAGAAGCTGCGTCCCAA
 CATCCCCAACTGGTGGCAGAGTTATGAGGCACTGCGGGTGATGGGGAAGATGATGCGAGAGT
 GTTGGTATGCCAACGGCGCAGCCCGCCTGACGGCCCTGCGCATCAAGAAGACCCTCTCCCAG
 CTCAGCGTGCAGGAAGACGTGAAGATC (SEQ ID NO: 11)

10 A nucleic acid sequence encoding an extracellular ALK4 polypeptide is as follows:

TCCGGGCCCCGGGGGGTCCAGGCTCTGCTGTGTGCGTGCACCAGCTGCCTCCAGGCCAACTA
 CACGTGTGAGACAGATGGGGCCTGCATGGTTTCCATTTTCAATCTGGATGGGATGGAGCACC
 ATGTGCGCACCTGCATCCCCAAAGTGGAGCTGGTCCCTGCCGGGAAGCCCTTCTACTGCCTG
 AGCTCGGAGGACCTGCGCAACACCCACTGCTGCTACACTGACTACTGCAACAGGATCGACTT
 15 GAGGGTGCCCAGTGGTCACCTCAAGGAGCCTGAGCACCCGTCCATGTGGGGCCCCGGTGGAG
 (SEQ ID NO: 12)

An alternative isoform of human ALK4 precursor protein sequence, isoform C (NCBI Ref Seq NP_064733.3), is as follows:

1 MAESAGASSF FPLVVLLLAG SGG**SGPRGVQ ALLCACTSCL QANYTCETDG ACMVSI FNLD**
 20 61 **GMEHHVRTCI PKVELVPAGK PFYCL**SEDL RNT**HCCYTDY** CNRIDLRVPS **GHLKEPEHPS**
 121**MWGPVE**LVGI IAGPVFLLFL IIIIVFLVIN YHQRVYHNRQ RLDMEDPSCE MCLSKDKTLQ
 181DLVYDLSTSG SG**SGLPLFVQ** RTVARTIVLQ EIIGKGRFGE VWRGRWRGGD VAVKIESSRE
 241ERSWFREAEI YQTVMLRHEN ILGFIAADNK ADCSFLTLPW EVVMVSAAPK LRSLRLQYKG
 301GRGRARFLFP LNNGTWTQLW LVSDYHEHGS LFDYLNRYTV TIEGMIKLAL SAASGLAHLH
 25 361MEIVGTQGKP GIAHRDLKSK NILVKKNGMC AIADLGLAVR HDAVTDITIDI APNQRVGTKR
 421YMAPEVLDET INMKHFDSFK CADIYALGLV YWEIARRCNS GGVHEEYQLP YYDLVPSDPS
 481IEEMRKVVCD QKL RPNIPNW WQSYEALRVM GKMMRECWYA NGAARLTALR IKKTLSQLSV
 541QEDVKI (SEQ ID NO: 19)

30 The signal peptide is indicated by a single underline and the extracellular domain is indicated in **bold font**.

A processed extracellular ALK4 polypeptide sequence (isoform C) is as follows:

SGPRGVQALLCACTSCLQANYTCETDGACMVSI FNLDGMEHHVRTCIPKVELVPAGKPFYCL
 SSEDLRNTHCCYTDYCNRIDLRVPSGHLKEPEHPSMWGPVE (SEQ ID NO: 20)

A nucleic acid sequence encoding the ALK4 precursor protein (isoform C) is shown below (SEQ ID NO: 21), corresponding to nucleotides 78-1715 of Genbank Reference Sequence NM_020328.3. The signal sequence is underlined and the extracellular domain is indicated in **bold font**.

5 ATGGCGGAGTCGGCCGGAGCCTCCTCCTTCTTCCCCCTTGTTGTCCTCCTGCTCGCCGGCAG
CGGCGGGTCCGGGCCCCGGGGGGTCCAGGCTCTGCTGTGTGCGTGCACCAGCTGCCTCCAGG
CCAACTACACGTGTGAGACAGATGGGGCCTGCATGGTTTCCATTTTCAATCTGGATGGGATG
GAGCACCATGTGCGCACCTGCATCCCCAAAGTGGAGCTGGTCCCTGCCGGGAAGCCCTTCTA
CTGCCTGAGCTCGGAGGACCTGCGCAACACCCACTGCTGCTACACTGACTACTGCAACAGGA
10 **TCGACTTGAGGGTGCCCAGTGGTCACCTCAAGGAGCCTGAGCACCCGTCCATGTGGGGCCCCG**
GTGGAGCTGGTAGGCATCATCGCCGGCCCCGGTGTTCCTCCTGTTTCCTCATCATCATCATTGT
TTTCCTTGTCATTAACATCATCAGCGTGTCTATCACAACCGCCAGAGACTGGACATGGAAG
ATCCCTCATGTGAGATGTGTCTCTCCAAAGACAAGACGCTCCAGGATCTTGTCTACGATCTC
TCCACCTCAGGGTCTGGCTCAGGGTTACCCCTCTTTGTCCAGCGCACAGTGGCCCGAACCAT
15 CGTTTTACAAGAGATTATTGGCAAGGGTCGGTTTGGGGAAGTATGGCGGGGCGCTGGAGGG
GTGGTGATGTGGCTGTGAAAATATTCTCTTCTCGTGAAGAACGGTCTTGGTTCAGGGAAGCA
GAGATATAACCAGACGGTCATGCTGCGCCATGAAAACATCCTTGGATTTATTGCTGCTGACAA
TAAAGCAGACTGCTCATTCCTCACATTGCCATGGGAAGTTGTAATGGTCTCTGCTGCCCCCA
AGCTGAGGAGCCTTAGACTCCAATACAAGGGAGGAAGGGGAAGAGCAAGATTTTTTATTCCCA
20 CTGAATAATGGCACCTGGACACAGCTGTGGCTTGTTTCTGACTATCATGAGCACGGGTCCCT
GTTTGATTATCTGAACCGGTACACAGTGACAATTGAGGGGATGATTAAGCTGGCCTTGTCTG
CTGCTAGTGGGCTGGCACACCTGCACATGGAGATCGTGGGCACCCAAGGGAAGCCTGGAATT
GCTCATCGAGACTTAAAGTCAAAGAACATTCTGGTGAAGAAAAATGGCATGTGTGCCATAGC
AGACCTGGGCCTGGCTGTCCGTCATGATGCAGTCACTGACACCATTGACATTGCCCCGAATC
25 AGAGGGTGGGGACCAAACGATACATGGCCCCCTGAAGTACTTGATGAAACCATTAATATGAAA
CACTTTGACTCCTTTAAATGTGCTGATATTTATGCCCTCGGGCTTGTATATTGGGAGATTGC
TCGAAGATGCAATTCTGGAGGAGTCCATGAAGAATATCAGCTGCCATATTACGACTTAGTGC
CCTCTGACCCTTCCATTGAGGAAATGCGAAAGGTTGTATGTGATCAGAAGCTGCGTCCCAAC
ATCCCCAACTGGTGGCAGAGTTATGAGGCACTGCGGGTGATGGGGAAGATGATGCGAGAGTG
30 TTGGTATGCCAACGGCGCAGCCCGCCTGACGGCCCTGCGCATCAAGAAGACCCTCTCCCAGC
TCAGCGTGCAGGAAGACGTGAAGATC (SEQ ID NO: 21)

A nucleic acid sequence encoding an extracellular ALK4 polypeptide (isoform C) is as follows:

TCCGGGCCCCGGGGGGTCCAGGCTCTGCTGTGTGCGTGCACCAGCTGCCTCCAGGCCAACTA
CACGTGTGAGACAGATGGGGCCTGCATGGTTTCCATTTTCAATCTGGATGGGATGGAGCACC
ATGTGCGCACCTGCATCCCCAAAGTGGAGCTGGTCCCTGCCGGGAAGCCCTTCTACTGCCTG
AGCTCGGAGGACCTGCGCAACACCCACTGCTGCTACACTGACTACTGCAACAGGATCGACTT
5 GAGGGTGCCCAGTGGTCACCTCAAGGAGCCTGAGCACCCGTCCATGTGGGGCCCCGGTGGAG
(SEQ ID NO: 22)

In certain embodiments, the disclosure relates to heteromultimers that comprise at least one ALK4 polypeptide, which includes fragments, functional variants, and modified forms thereof. Preferably, ALK4 polypeptides for use in accordance with inventions of the disclosure (*e.g.*, heteromultimers comprising an ALK4 polypeptide and uses thereof) are
10 soluble (*e.g.*, an extracellular domain of ALK4). In other preferred embodiments, ALK4 polypeptides for use in accordance with the inventions of the disclosure bind to and/or inhibit (antagonize) activity (*e.g.*, Smad signaling) of one or more TGF-beta superfamily ligands. In some embodiments, heteromultimers of the disclosure comprise at least one ALK4
15 polypeptide that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 97%, 98%, or 99% identical to the amino acid sequence of SEQ ID NO: 9, 10, 19, 20, 42, 44, 47, 48, 74, and 76. In some embodiments, heteromultimer complexes of the disclosure consist or consist essentially of at least one ALK4 polypeptide that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 97%, 98%,
20 or 99% identical to the amino acid sequence of SEQ ID NO: 9, 10, 19, 20, 42, 44, 47, 48, 74, and 76.

ALK4 is well-conserved among vertebrates, with large stretches of the extracellular domain completely conserved. For example, Figure 5 depicts a multi-sequence alignment of a human ALK4 extracellular domain compared to various ALK4 orthologs. Many of the
25 ligands that bind to ALK4 are also highly conserved. Accordingly, from these alignments, it is possible to predict key amino acid positions within the ligand-binding domain that are important for normal ALK4-ligand binding activities as well as to predict amino acid positions that are likely to be tolerant to substitution without significantly altering normal ALK4-ligand binding activities. Therefore, an active, human ALK4 variant polypeptide
30 useful in accordance with the presently disclosed methods may include one or more amino acids at corresponding positions from the sequence of another vertebrate ALK4, or may include a residue that is similar to that in the human or other vertebrate sequences. Without meaning to be limiting, the following examples illustrate this approach to defining an active

ALK4 variant. V6 in the human ALK4 extracellular domain (SEQ ID NO: 59) is isoleucine in *Mus musculus* ALK4 (SEQ ID NO: 63), and so the position may be altered, and optionally may be altered to another hydrophobic residue such as L, I, or F, or a non-polar residue such as A, as is observed in *Gallus gallus* ALK4 (SEQ ID NO: 62). E40 in the human

5 extracellular domain is K in *Gallus gallus* ALK4, indicating that this site may be tolerant of a wide variety of changes, including polar residues, such as E, D, K, R, H, S, T, P, G, Y, and probably a non-polar residue such as A. S15 in the human extracellular domain is D in *Gallus gallus* ALK4, indicating that a wide structural variation is tolerated at this position, with polar residues favored, such as S, T, R, E, K, H, G, P, G and Y. E40 in the human
10 extracellular domain is K in *Gallus gallus* ALK4, indicating that charged residues will be tolerated at this position, including D, R, K, H, as well as Q and N. R80 in the human extracellular domain is K in *Condylura cristata* ALK4 (SEQ ID NO: 60), indicating that basic residues are tolerated at this position, including R, K, and H. Y77 in the human extracellular domain is F in *Sus scrofa* ALK4 (SEQ ID NO: 64), indicating that aromatic
15 residues are tolerated at this position, including F, W, and Y. P93 in the human extracellular domain is relatively poorly conserved, appearing as S in *Erinaceus europaeus* ALK4 (SEQ ID NO: 61) and N in *Gallus gallus* ALK4, thus essentially any amino acid should be tolerated at this position.

Moreover, ALK4 proteins have been characterized in the art in terms of structural and
20 functional characteristics, particularly with respect to ligand binding [e.g., Harrison et al. (2003) J Biol Chem 278(23):21129-21135; Romano et al. (2012) J Mol Model 18(8):3617-3625; and Calvanese et al. (2009) 15(3):175-183]. In addition to the teachings herein, these references provide amply guidance for how to generate ALK4 variants that retain one or more normal activities (e.g., ligand-binding activity).

25 For example, a defining structural motif known as a three-finger toxin fold is important for ligand binding by type I and type II receptors and is formed by conserved cysteine residues located at varying positions within the extracellular domain of each monomeric receptor [Greenwald et al. (1999) Nat Struct Biol 6:18-22; and Hinck (2012) FEBS Lett 586:1860-1870]. Accordingly, the core ligand-binding domains of human ALK4,
30 as demarcated by the outermost of these conserved cysteines, corresponds to positions 34-101 of SEQ ID NO: 9 (ALK4 precursor). Thus, the structurally less-ordered amino acids flanking these cysteine-demarcated core sequences can be truncated by 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, residues at the N-terminus or 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20,

21, 22, 23, 24, 25, or 26 residues at the C-terminus without necessarily altering ligand binding. Exemplary ALK4 extracellular domains for N-terminal and/or C-terminal truncation include SEQ ID NOs: 10 and 20.

Accordingly, a general formula for an active portion (e.g., a ligand-binding portion) of ALK4 comprises amino acids 34-101. Therefore ALK4 polypeptides may, for example, comprise, consists essentially of, or consists of an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to a portion of ALK4 beginning at a residue corresponding to any one of amino acids 24-34 (e.g., beginning at any one of amino acids 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, or 34) of SEQ ID NO: 1 and ending at a position corresponding to any one amino acids 101-126 (e.g., ending at any one of amino acids 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, or 126) of SEQ ID NO: 9. Other examples include constructs that begin at a position from 24-34 (e.g., any one of positions 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, or 34), 25-34 (e.g., any one of positions 25, 26, 27, 28, 29, 30, 31, 32, 33, or 34), or 26-34 (e.g., any one of positions 26, 27, 28, 29, 30, 31, 32, 33, or 34) of SEQ ID NO: 9 and end at a position from 101-126 (e.g., any one of positions 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, or 126), 102-126 (e.g., any one of positions 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, or 126), 101-125 (e.g., any one of positions 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, or 125), 101-124 (e.g., any one of positions 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, or 124), 101-121 (e.g., any one of positions 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, or 121), 111-126 (e.g., any one of positions 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, or 126), 111-125 (e.g., any one of positions 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, or 125), 111-124 (e.g., any one of positions 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, or 124), 121-126 (e.g., any one of positions 121, 122, 123, 124, 125, or 126), 121-125 (e.g., any one of positions 121, 122, 123, 124, or 125), 121-124 (e.g., any one of positions 121, 122, 123, or 124), or 124-126 (e.g., any one of positions 124, 125, or 126) of SEQ ID NO: 9. Variants within these ranges are also contemplated, particularly those having at least 70%, 75%, 80%,

85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identity to the corresponding portion of SEQ ID NO: 9.

The variations described herein may be combined in various ways. In some embodiments, ALK4 variants comprise no more than 1, 2, 5, 6, 7, 8, 9, 10 or 15 conservative amino acid changes in the ligand-binding pocket. Sites outside the binding pocket, at which variability may be particularly well tolerated, include the amino and carboxy termini of the extracellular domain (as noted above),

In some embodiments, the present disclosure contemplates making functional variants by modifying the structure of an ALK4 polypeptide and/or an ActRIIB polypeptide. Variants can be produced by amino acid substitution, deletion, addition, or combinations thereof. For instance, it is reasonable to expect that an isolated replacement of a leucine with an isoleucine or valine, an aspartate with a glutamate, a threonine with a serine, or a similar replacement of an amino acid with a structurally related amino acid (*e.g.*, conservative mutations) will not have a major effect on the biological activity of the resulting molecule. Conservative replacements are those that take place within a family of amino acids that are related in their side chains. Whether a change in the amino acid sequence of a polypeptide of the disclosure results in a functional homolog can be readily determined by assessing the ability of the variant polypeptide to produce a response in cells in a fashion similar to the wild-type polypeptide, or to bind to one or more TGF-beta superfamily ligands including, for example, BMP2, BMP2/7, BMP3, BMP4, BMP4/7, BMP5, BMP6, BMP7, BMP8a, BMP8b, BMP9, BMP10, GDF3, GDF5, GDF6/BMP13, GDF7, GDF8, GDF9b/BMP15, GDF11/BMP11, GDF15/MIC1, TGF- β 1, TGF- β 2, TGF- β 3, activin A, activin B, activin C, activin E, activin AB, activin AC, activin BC, activin AE, activin BE, nodal, glial cell-derived neurotrophic factor (GDNF), neurturin, artemin, persephin, MIS, and Lefty.

In some embodiments, the present disclosure contemplates making functional variants by modifying the structure of an ALK4 and/or ActRIIB polypeptide for such purposes as enhancing therapeutic efficacy or stability (*e.g.*, increase shelf-life and/or resistance to proteolytic degradation).

In some embodiments, the present disclosure contemplates specific mutations of an ALK4 polypeptide and/or an ActRIIB polypeptide so as to alter the glycosylation of the polypeptide. Such mutations may be selected so as to introduce or eliminate one or more glycosylation sites, such as O-linked or N-linked glycosylation sites. Asparagine-linked

glycosylation recognition sites generally comprise a tripeptide sequence, asparagine-X-threonine or asparagine-X-serine (where “X” is any amino acid) which is specifically recognized by appropriate cellular glycosylation enzymes. The alteration may also be made by the addition of, or substitution by, one or more serine or threonine residues to the sequence of the polypeptide (for O-linked glycosylation sites). A variety of amino acid substitutions or deletions at one or both of the first or third amino acid positions of a glycosylation recognition site (and/or amino acid deletion at the second position) results in non-glycosylation at the modified tripeptide sequence. Another means of increasing the number of carbohydrate moieties on a polypeptide is by chemical or enzymatic coupling of glycosides to the polypeptide. Depending on the coupling mode used, the sugar(s) may be attached to (a) arginine and histidine; (b) free carboxyl groups; (c) free sulfhydryl groups such as those of cysteine; (d) free hydroxyl groups such as those of serine, threonine, or hydroxyproline; (e) aromatic residues such as those of phenylalanine, tyrosine, or tryptophan; or (f) the amide group of glutamine. Removal of one or more carbohydrate moieties present on a polypeptide may be accomplished chemically and/or enzymatically. Chemical deglycosylation may involve, for example, exposure of a polypeptide to the compound trifluoromethanesulfonic acid, or an equivalent compound. This treatment results in the cleavage of most or all sugars except the linking sugar (N-acetylglucosamine or N-acetylgalactosamine), while leaving the amino acid sequence intact. Enzymatic cleavage of carbohydrate moieties on polypeptides can be achieved by the use of a variety of endo- and exo-glycosidases as described by Thotakura *et al.* [Meth. Enzymol. (1987) 138:350]. The sequence of a polypeptide may be adjusted, as appropriate, depending on the type of expression system used, as mammalian, yeast, insect, and plant cells may all introduce differing glycosylation patterns that can be affected by the amino acid sequence of the peptide. In general, heteromeric complexes of the present disclosure for use in humans may be expressed in a mammalian cell line that provides proper glycosylation, such as HEK293 or CHO cell lines, although other mammalian expression cell lines are expected to be useful as well.

The present disclosure further contemplates a method of generating mutants, particularly sets of combinatorial mutants of an ALK4 and/or an ActRIIB polypeptide as well as truncation mutants. Pools of combinatorial mutants are especially useful for identifying functionally active (e.g., TGF-beta superfamily ligand binding) ALK4 and/or ActRIIB sequences. The purpose of screening such combinatorial libraries may be to generate, for

example, polypeptides variants which have altered properties, such as altered pharmacokinetic or altered ligand binding. A variety of screening assays are provided below, and such assays may be used to evaluate variants. For example, ALK4:ActRIIB complex variants may be screened for ability to bind to one or more TGF-beta superfamily ligands to prevent binding of a TGF-beta superfamily ligand to a TGF-beta superfamily receptor, and/or to interfere with signaling caused by an TGF-beta superfamily ligand.

The activity of a ALK4:ActRIIB heteromultimer may be tested, for example, in a cell-based or *in vivo* assay. For example, the effect of an ALK4:ActRIIB heteromultimer on the expression of genes or activity of proteins involved in muscle production in a muscle cell may be assessed. This may, as needed, be performed in the presence of one or more TGF-beta superfamily ligands, and cells may be transfected so as to produce an ALK4:ActRIIB heteromultimer, and optionally, a TGF-beta superfamily ligand. Likewise, an ALK4:ActRIIB heteromultimer may be administered to a mouse or other animal, and one or more measurements, such as muscle formation and strength may be assessed using art-recognized methods. Similarly, the activity of an ALK4:ActRIIB heteromultimer, or variants thereof, may be tested, for example, in osteoblasts, adipocytes, and/or neuronal cells for any effect on growth of these cells, for example, by the assays as described herein and those of common knowledge in the art. A SMAD-responsive reporter gene may be used in such cell lines to monitor effects on downstream signaling.

Combinatorial-derived variants can be generated which have increased selectivity or generally increased potency relative to a reference ALK4:ActRIIB heteromultimer. Such variants, when expressed from recombinant DNA constructs, can be used in gene therapy protocols. Likewise, mutagenesis can give rise to variants which have intracellular half-lives dramatically different than the corresponding unmodified ALK4:ActRIIB heteromultimer. For example, the altered protein can be rendered either more stable or less stable to proteolytic degradation or other cellular processes which result in destruction, or otherwise inactivation, of an unmodified polypeptide. Such variants, and the genes which encode them, can be utilized to alter polypeptide complex levels by modulating the half-life of the polypeptide. For instance, a short half-life can give rise to more transient biological effects and, when part of an inducible expression system, can allow tighter control of recombinant polypeptide complex levels within the cell. In an Fc fusion protein, mutations may be made in the linker (if any) and/or the Fc portion to alter one or more activities of the

ALK4:ActRIIB heteromultimer including, for example, immunogenicity, half-life, and solubility.

A combinatorial library may be produced by way of a degenerate library of genes encoding a library of polypeptides which each include at least a portion of potential ALK4 and/or ActRIIB sequences. For instance, a mixture of synthetic oligonucleotides can be enzymatically ligated into gene sequences such that the degenerate set of potential ALK4 and/or ActRIIB encoding nucleotide sequences are expressible as individual polypeptides, or alternatively, as a set of larger fusion proteins (*e.g.*, for phage display).

There are many ways by which the library of potential homologs can be generated from a degenerate oligonucleotide sequence. Chemical synthesis of a degenerate gene sequence can be carried out in an automatic DNA synthesizer, and the synthetic genes can then be ligated into an appropriate vector for expression. The synthesis of degenerate oligonucleotides is well known in the art [Narang, SA (1983) *Tetrahedron* 39:3; Itakura *et al.* (1981) *Recombinant DNA, Proc. 3rd Cleveland Sympos. Macromolecules*, ed. AG Walton, Amsterdam: Elsevier pp273-289; Itakura *et al.* (1984) *Annu. Rev. Biochem.* 53:323; Itakura *et al.* (1984) *Science* 198:1056; and Ike *et al.* (1983) *Nucleic Acid Res.* 11:477]. Such techniques have been employed in the directed evolution of other proteins [Scott *et al.*, (1990) *Science* 249:386-390; Roberts *et al.* (1992) *PNAS USA* 89:2429-2433; Devlin *et al.* (1990) *Science* 249: 404-406; Cwirla *et al.*, (1990) *PNAS USA* 87: 6378-6382; as well as U.S. Patent Nos: 5,223,409, 5,198,346, and 5,096,815].

Alternatively, other forms of mutagenesis can be utilized to generate a combinatorial library. For example, ALK4:ActRIIB heteromultimers can be generated and isolated from a library by screening using, for example, alanine scanning mutagenesis [Ruf *et al.* (1994) *Biochemistry* 33:1565-1572; Wang *et al.* (1994) *J. Biol. Chem.* 269:3095-3099; Balint *et al.* (1993) *Gene* 137:109-118; Grodberg *et al.* (1993) *Eur. J. Biochem.* 218:597-601; Nagashima *et al.* (1993) *J. Biol. Chem.* 268:2888-2892; Lowman *et al.* (1991) *Biochemistry* 30:10832-10838; and Cunningham *et al.* (1989) *Science* 244:1081-1085], by linker scanning mutagenesis [Gustin *et al.* (1993) *Virology* 193:653-660; and Brown *et al.* (1992) *Mol. Cell Biol.* 12:2644-2652; McKnight *et al.* (1982) *Science* 232:316], by saturation mutagenesis [Meyers *et al.*, (1986) *Science* 232:613]; by PCR mutagenesis [Leung *et al.* (1989) *Method Cell Mol Biol* 1:11-19]; or by random mutagenesis, including chemical mutagenesis [Miller *et al.* (1992) *A Short Course in Bacterial Genetics*, CSHL Press, Cold Spring Harbor, NY; and Greener *et al.* (1994) *Strategies in Mol Biol* 7:32-34]. Linker scanning mutagenesis,

particularly in a combinatorial setting, is an attractive method for identifying truncated (bioactive) forms of ALK4 and/or ActRIIB polypeptides.

A wide range of techniques are known in the art for screening gene products of combinatorial libraries made by point mutations and truncations, and, for that matter, for
 5 screening cDNA libraries for gene products having a certain property. Such techniques will be generally adaptable for rapid screening of the gene libraries generated by the combinatorial mutagenesis of ALK4:ActRIIB heteromultimers. The most widely used techniques for screening large gene libraries typically comprise cloning the gene library into replicable expression vectors, transforming appropriate cells with the resulting library of
 10 vectors, and expressing the combinatorial genes under conditions in which detection of a desired activity facilitates relatively easy isolation of the vector encoding the gene whose product was detected. Preferred assays include TGF-beta superfamily ligand (*e.g.*, BMP2, BMP2/7, BMP3, BMP4, BMP4/7, BMP5, BMP6, BMP7, BMP8a, BMP8b, BMP9, BMP10, GDF3, GDF5, GDF6/BMP13, GDF7, GDF8, GDF9b/BMP15, GDF11/BMP11,
 15 GDF15/MIC1, TGF- β 1, TGF- β 2, TGF- β 3, activin A, activin B, activin C, activin E, activin AB, activin AC, activin BC, activin AE, activin BE, nodal, glial cell-derived neurotrophic factor (GDNF), neurturin, artemin, persephin, MIS, and Lefty) binding assays and/or TGF-beta ligand-mediated cell signaling assays.

In certain embodiments, ALK4:ActRIIB heteromultimers may further comprise post-
 20 translational modifications in addition to any that are naturally present in the ALK4 and/or ActRIIB polypeptide. Such modifications include, but are not limited to, acetylation, carboxylation, glycosylation, phosphorylation, lipidation, and acylation. As a result, ALK4:ActRIIB heteromultimers may comprise non-amino acid elements, such as polyethylene glycols, lipids, polysaccharide or monosaccharide, and phosphates. Effects of
 25 such non-amino acid elements on the functionality of a heteromultimer complex may be tested as described herein for other heteromultimer variants. When a polypeptide of the disclosure is produced in cells by cleaving a nascent form of the polypeptide, post-translational processing may also be important for correct folding and/or function of the protein. Different cells (*e.g.*, CHO, HeLa, MDCK, 293, WI38, NIH-3T3 or HEK293) have
 30 specific cellular machinery and characteristic mechanisms for such post-translational activities and may be chosen to ensure the correct modification and processing of the ALK4 and/or ActRIIB polypeptide as well as heteromultimers comprising the same.

In certain preferred embodiments, heteromultimers described herein comprise at least one ALK4 polypeptide associated, covalently or non-covalently, with at least one ActRIIB polypeptide. Preferably, polypeptides disclosed herein form heterodimeric complexes, although higher order heteromultimeric complexes are also included such as, but not limited to, heterotrimers, heterotetramers, and further oligomeric structures (see, e.g., Figure 6). In some embodiments, ALK4 and/or ActRIIB polypeptides comprise at least one multimerization domain. As disclosed herein, the term “multimerization domain” refers to an amino acid or sequence of amino acids that promote covalent or non-covalent interaction between at least a first polypeptide and at least a second polypeptide. Polypeptides disclosed herein may be joined covalently or non-covalently to a multimerization domain. Preferably, a multimerization domain promotes interaction between a first polypeptide (e.g., an ALK4 polypeptide) and a second polypeptide (e.g., an ActRIIB polypeptide) to promote heteromultimer formation (e.g., heterodimer formation), and optionally hinders or otherwise disfavors homomultimer formation (e.g., homodimer formation), thereby increasing the yield of desired heteromultimer (see, e.g., Figure 6).

Many methods known in the art can be used to generate ALK4:ActRIIB heteromultimers. For example, non-naturally occurring disulfide bonds may be constructed by replacing on a first polypeptide (e.g., an ALK4 polypeptide) a naturally occurring amino acid with a free thiol-containing residue, such as cysteine, such that the free thiol interacts with another free thiol-containing residue on a second polypeptide (e.g., an ActRIIB polypeptide) such that a disulfide bond is formed between the first and second polypeptides. Additional examples of interactions to promote heteromultimer formation include, but are not limited to, ionic interactions such as described in Kjaergaard *et al.*, WO2007147901; electrostatic steering effects such as described in Kannan *et al.*, U.S.8,592,562; coiled-coil interactions such as described in Christensen *et al.*, U.S.20120302737; leucine zippers such as described in Pack & Plueckthun,(1992) Biochemistry 31: 1579-1584; and helix-turn-helix motifs such as described in Pack *et al.*, (1993) Bio/Technology 11: 1271-1277. Linkage of the various segments may be obtained via, e.g., covalent binding such as by chemical cross-linking, peptide linkers, disulfide bridges, *etc.*, or affinity interactions such as by avidin-biotin or leucine zipper technology.

In certain aspects, a multimerization domain may comprise one component of an interaction pair. In some embodiments, the polypeptides disclosed herein may form protein complexes comprising a first polypeptide covalently or non-covalently associated with a

second polypeptide, wherein the first polypeptide comprises the amino acid sequence of an ALK4 polypeptide and the amino acid sequence of a first member of an interaction pair; and the second polypeptide comprises the amino acid sequence of an ActRIIB polypeptide and the amino acid sequence of a second member of an interaction pair. The interaction pair may be any two polypeptide sequences that interact to form a complex, particularly a heterodimeric complex although operative embodiments may also employ an interaction pair that can form a homodimeric complex. One member of the interaction pair may be fused to an ALK4 or ActRIIB polypeptide as described herein, including for example, a polypeptide sequence comprising, consisting essentially of, or consisting of an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the sequence of any one of SEQ ID NOs: 2, 3, 5, 6, 10, and 20. An interaction pair may be selected to confer an improved property/activity such as increased serum half-life, or to act as an adaptor on to which another moiety is attached to provide an improved property/activity. For example, a polyethylene glycol moiety may be attached to one or both components of an interaction pair to provide an improved property/activity such as improved serum half-life.

The first and second members of the interaction pair may be an asymmetric pair, meaning that the members of the pair preferentially associate with each other rather than self-associate. Accordingly, first and second members of an asymmetric interaction pair may associate to form a heterodimeric complex (see, e.g., Figure 6). Alternatively, the interaction pair may be unguided, meaning that the members of the pair may associate with each other or self-associate without substantial preference and thus may have the same or different amino acid sequences. Accordingly, first and second members of an unguided interaction pair may associate to form a homodimer complex or a heterodimeric complex. Optionally, the first member of the interaction pair (e.g., an asymmetric pair or an unguided interaction pair) associates covalently with the second member of the interaction pair. Optionally, the first member of the interaction pair (e.g., an asymmetric pair or an unguided interaction pair) associates non-covalently with the second member of the interaction pair.

As specific examples, the present disclosure provides fusion proteins comprising ALK4 or ActRIIB fused to a polypeptide comprising a constant domain of an immunoglobulin, such as a CH1, CH2, or CH3 domain of an immunoglobulin or an Fc domain. Fc domains derived from human IgG1, IgG2, IgG3, and IgG4 are provided herein. Other mutations are known that decrease either CDC or ADCC activity, and collectively, any

of these variants are included in the disclosure and may be used as advantageous components of a heteromultimeric complex of the disclosure. Optionally, the IgG1 Fc domain of SEQ ID NO: 31 has one or more mutations at residues such as Asp-265, Lys-322, and Asn-434 (numbered in accordance with the corresponding full-length IgG1). In certain cases, the mutant Fc domain having one or more of these mutations (e.g., Asp-265 mutation) has reduced ability of binding to the Fcγ receptor relative to a wildtype Fc domain. In other cases, the mutant Fc domain having one or more of these mutations (e.g., Asn-434 mutation) has increased ability of binding to the MHC class I-related Fc-receptor (FcRN) relative to a wildtype Fc domain.

An example of a native amino acid sequence that may be used for the Fc portion of human IgG1 (G1Fc) is shown below (SEQ ID NO: 31). Dotted underline indicates the hinge region, and solid underline indicates positions with naturally occurring variants. In part, the disclosure provides polypeptides comprising, consisting essentially of, or consisting of amino acid sequences with 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identity to SEQ ID NO: 31. Naturally occurring variants in G1Fc would include E134D and M136L according to the numbering system used in SEQ ID NO: 31 (see Uniprot P01857).

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1  THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51  VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
20  101  VSNKALPAPI EKTISKAKGQ PREPQVYTLF PSREEMTKNQ VSLTCLVKGF
151  YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
201  FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 31)

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An example of a native amino acid sequence that may be used for the Fc portion of human IgG2 (G2Fc) is shown below (SEQ ID NO: 32). Dotted underline indicates the hinge region and double underline indicates positions where there are data base conflicts in the sequence (according to UniProt P01859). In part, the disclosure provides polypeptides comprising, consisting essential of, or consisting of amino acid sequences with 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identity to SEQ ID NO: 32.

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30  1  VECPPCPAPP VAGPSVFLFP PKPKDTLMIS RTPEVTCVVV DVSHEDPEVQ
51  FNWYVDGVEV HNAKTKPREE QFNSTFRVVS VLTVVHQDWL NGKEYKCKVS
101  NKGLPAPIEK TISKTKGQPR EPQVYTLPPS REEMTKNQVS LTCLVKGFYP
151  SDIAVEWESN GQPENNYKTT PPMLDSDGSF FLYSKLTVDK SRWQQGNVES

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201 CSVMHEALHN HYTQKSLSLSPGK (SEQ ID NO: 32)

Two examples of amino acid sequences that may be used for the Fc portion of human IgG3 (G3Fc) are shown below. The hinge region in G3Fc can be up to four times as long as in other Fc chains and contains three identical 15-residue segments preceded by a similar 17-residue segment. The first G3Fc sequence shown below (SEQ ID NO: 33) contains a short hinge region consisting of a single 15-residue segment, whereas the second G3Fc sequence (SEQ ID NO: 34) contains a full-length hinge region. In each case, dotted underline indicates the hinge region, and solid underline indicates positions with naturally occurring variants according to UniProt P01859. In part, the disclosure provides polypeptides comprising, consisting essential of, or consisting of amino acid sequences with 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identity to SEQ ID NOs: 33 and 34.

1 EPKSCDTPPP CPRCPAPELL GGPSVFLFPP KPKDTLMISR TPEVTCVVVD
51 VSHEDPEVQF KQYVDGVEVH NAKTKPREEQ YNSTFRVVS LTVLHQDWLN
15 101 GKEYKCKVSN KALPAPIEKT ISKTKGQPRE PQVYTLPPSR EEMTKNQVSL
151 TCLVKGFYPS DIAVEWESSG QPENNYNTTP PMLDSDGSFF LYSKLTVDKS
201 RWQQGNIFSC SVMHEALHNR FTQKSLSLSP GK (SEQ ID NO: 33)

1 ELKTPLGDTT HTCPRCPEPK SCDTPPPCPR CPEPKSCDTP PPCPRCPEPK
20 51 SCDTPPPCPR CPAPELLGGP SVFLFPPKPK DTLMISRTPE VTCVVVDVSH
101 EDPEVQFKWY VDGVEVHNAK TKPREEQYNS TFRVVSVLTV LHQDWLNGKE
151 YKCKVSNKAL PAPIEKTISK TKGQPREPQV YTLPPSREEM TKNQVSLTCL
201 VKGFYPSDIA VEWESSGQPE NNYNTTPPML DSDGSFFLYS KLTVDKSRWQ
251 QGNIFSCSVM HEALHNRFTQ KSLSLSPGK (SEQ ID NO: 34)

25 Naturally occurring variants in G3Fc (for example, see Uniprot P01860) include E68Q, P76L, E79Q, Y81F, D97N, N100D, T124A, S169N, S169del, F221Y when converted to the numbering system used in SEQ ID NO: 33, and the present disclosure provides fusion proteins comprising G3Fc domains containing one or more of these variations. In addition, the human immunoglobulin IgG3 gene (*IGHG3*) shows a structural polymorphism
30 characterized by different hinge lengths [see Uniprot P01859]. Specifically, variant WIS is lacking most of the V region and all of the CH1 region. It has an extra interchain disulfide bond at position 7 in addition to the 11 normally present in the hinge region. Variant ZUC lacks most of the V region, all of the CH1 region, and part of the hinge. Variant OMM may represent an allelic form or another gamma chain subclass. The present disclosure provides

additional fusion proteins comprising G3Fc domains containing one or more of these variants.

An example of a native amino acid sequence that may be used for the Fc portion of human IgG4 (G4Fc) is shown below (SEQ ID NO: 35). Dotted underline indicates the hinge region. In part, the disclosure provides polypeptides comprising, consisting essential of, or consisting of amino acid sequences with 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identity to SEQ ID NO: 35.

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1   ESKYGPPCPS_CPAPEFLGGP SVFLFPPKPK DTLMISRTPE VTCVVVDVSQ
51  EDPEVQFNWY VDGVEVHNAK TKPREEQFNS TYRVVSVLTV LHQDWLNGKE
101 YKCKVSNKGL PSSIEKTISK AKGQPREPQV YTLPPSQEEM TKNQVSLTCL
151 VKGFYPSDIA VEWESNGQPE NNYKTTTPVL DSDGSFFLYS RLTVDKSRWQ
201 EGNVFSCSVM HEALHNHYTQ KSLSLSLGK      (SEQ ID NO: 35)

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A variety of engineered mutations in the Fc domain are presented herein with respect to the G1Fc sequence (SEQ ID NO: 31), and analogous mutations in G2Fc, G3Fc, and G4Fc can be derived from their alignment with G1Fc in Figure 3. Due to unequal hinge lengths, analogous Fc positions based on isotype alignment (Figure 3) possess different amino acid numbers in SEQ ID NOs: 31, 32, 33, 34, and 35. It can also be appreciated that a given amino acid position in an immunoglobulin sequence consisting of hinge, C_H2, and C_H3 regions (*e.g.*, SEQ ID NOs: 31, 32, 33, 34, and 35) will be identified by a different number than the same position when numbering encompasses the entire IgG1 heavy-chain constant domain (consisting of the C_H1, hinge, C_H2, and C_H3 regions) as in the Uniprot database. For example, correspondence between selected C_H3 positions in a human G1Fc sequence (SEQ ID NO: 31), the human IgG1 heavy chain constant domain (Uniprot P01857), and the human IgG1 heavy chain is as follows.

Correspondence of C _H 3 Positions in Different Numbering Systems		
G1Fc (Numbering begins at first threonine in hinge region)	IgG1 heavy chain constant domain (Numbering begins at C _H 1)	IgG1 heavy chain (EU numbering scheme of Kabat et al., 1991*)
Y127	Y232	Y349
S132	S237	S354
E134	E239	E356
K138	K243	K360

T144	T249	T366
L146	L251	L368
N162	N267	N384
K170	K275	K392
D177	D282	D399
D179	D284	D401
Y185	Y290	Y407
K187	K292	K409
H213	H318	H435
K217	K322	K439
* Kabat et al. (eds) 1991; pp. 688-696 in <i>Sequences of Proteins of Immunological Interest</i> , 5 th ed., Vol. 1, NIH, Bethesda, MD.		

A problem that arises in large-scale production of asymmetric immunoglobulin-based proteins from a single cell line is known as the “chain association issue”. As confronted prominently in the production of bispecific antibodies, the chain association issue concerns the challenge of efficiently producing a desired multichain protein from among the multiple combinations that inherently result when different heavy chains and/or light chains are produced in a single cell line [Klein et al (2012) mAbs 4:653-663]. This problem is most acute when two different heavy chains and two different light chains are produced in the same cell, in which case there are a total of 16 possible chain combinations (although some of these are identical) when only one is typically desired. Nevertheless, the same principle accounts for diminished yield of a desired multichain fusion protein that incorporates only two different (asymmetric) heavy chains.

Various methods are known in the art that increase desired pairing of Fc-containing fusion polypeptide chains in a single cell line to produce a preferred asymmetric fusion protein at acceptable yields [Klein et al (2012) mAbs 4:653-663; and Spiess et al (2015) Molecular Immunology 67(2A): 95-106]. Methods to obtain desired pairing of Fc-containing chains include, but are not limited to, charge-based pairing (electrostatic steering), “knobs-into-holes” steric pairing, SEEDbody pairing, and leucine zipper-based pairing [Ridgway et al (1996) Protein Eng 9:617-621; Merchant et al (1998) Nat Biotech 16:677-681; Davis et al (2010) Protein Eng Des Sel 23:195-202; Gunasekaran et al (2010); 285:19637-19646;

Wranik et al (2012) J Biol Chem 287:43331-43339; US5932448; WO 1993/011162; WO 2009/089004, and WO 2011/034605]. As described herein, these methods may be used to generate ALK4-Fc:ActRIIB-Fc heteromultimer complexes. See Figure 6.

For example, one means by which interaction between specific polypeptides may be promoted is by engineering protuberance-into-cavity (knob-into-holes) complementary regions such as described in Arathoon *et al.*, U.S.7,183,076 and Carter *et al.*, U.S.5,731,168. “Protuberances” are constructed by replacing small amino acid side chains from the interface of the first polypeptide (*e.g.*, a first interaction pair) with larger side chains (*e.g.*, tyrosine or tryptophan). Complementary “cavities” of identical or similar size to the protuberances are optionally created on the interface of the second polypeptide (*e.g.*, a second interaction pair) by replacing large amino acid side chains with smaller ones (*e.g.*, alanine or threonine). Where a suitably positioned and dimensioned protuberance or cavity exists at the interface of either the first or second polypeptide, it is only necessary to engineer a corresponding cavity or protuberance, respectively, at the adjacent interface.

At neutral pH (7.0), aspartic acid and glutamic acid are negatively charged and lysine, arginine, and histidine are positively charged. These charged residues can be used to promote heterodimer formation and at the same time hinder homodimer formation. Attractive interactions take place between opposite charges and repulsive interactions occur between like charges. In part, protein complexes disclosed herein make use of the attractive interactions for promoting heteromultimer formation (*e.g.*, heterodimer formation), and optionally repulsive interactions for hindering homodimer formation (*e.g.*, homodimer formation) by carrying out site directed mutagenesis of charged interface residues.

For example, the IgG1 CH3 domain interface comprises four unique charge residue pairs involved in domain-domain interactions: Asp356-Lys439', Glu357-Lys370', Lys392-Asp399', and Asp399-Lys409' [residue numbering in the second chain is indicated by (')]. It should be noted that the numbering scheme used here to designate residues in the IgG1 CH3 domain conforms to the EU numbering scheme of Kabat. Due to the 2-fold symmetry present in the CH3-CH3 domain interactions, each unique interaction will be represented twice in the structure (*e.g.*, Asp-399-Lys409' and Lys409-Asp399'). In the wild-type sequence, K409-D399' favors both heterodimer and homodimer formation. A single mutation switching the charge polarity (*e.g.*, K409E; positive to negative charge) in the first chain leads to unfavorable interactions for the formation of the first chain homodimer. The

unfavorable interactions arise due to the repulsive interactions occurring between the same charges (negative-negative; K409E-D399' and D399-K409E'). A similar mutation switching the charge polarity (D399K'; negative to positive) in the second chain leads to unfavorable interactions (K409'-D399K' and D399K-K409') for the second chain homodimer formation.

- 5 But, at the same time, these two mutations (K409E and D399K') lead to favorable interactions (K409E-D399K' and D399-K409') for the heterodimer formation.

The electrostatic steering effect on heterodimer formation and homodimer discouragement can be further enhanced by mutation of additional charge residues which may or may not be paired with an oppositely charged residue in the second chain including,
10 for example, Arg355 and Lys360. The table below lists possible charge change mutations that can be used, alone or in combination, to enhance ALK4:ActRIIB heteromultimer formation.

Examples of Pair-Wise Charged Residue Mutations to Enhance Heterodimer Formation			
Position in first chain	Mutation in first chain	Interacting position in second chain	Corresponding mutation in second chain
Lys409	Asp or Glu	Asp399'	Lys, Arg, or His
Lys392	Asp or Glu	Asp399'	Lys, Arg, or His
Lys439	Asp or Glu	Asp356'	Lys, Arg, or His
Lys370	Asp or Glu	Glu357'	Lys, Arg, or His
Asp399	Lys, Arg, or His	Lys409'	Asp or Glu
Asp399	Lys, Arg, or His	Lys392'	Asp or Glu
Asp356	Lys, Arg, or His	Lys439'	Asp or Glu
Glu357	Lys, Arg, or His	Lys370'	Asp or Glu

In some embodiments, one or more residues that make up the CH3-CH3 interface in a
15 fusion protein of the instant application are replaced with a charged amino acid such that the interaction becomes electrostatically unfavorable. For example, a positive-charged amino acid in the interface (*e.g.*, a lysine, arginine, or histidine) is replaced with a negatively charged amino acid (*e.g.*, aspartic acid or glutamic acid). Alternatively, or in combination with the forgoing substitution, a negative-charged amino acid in the interface is replaced with
20 a positive-charged amino acid. In certain embodiments, the amino acid is replaced with a non-naturally occurring amino acid having the desired charge characteristic. It should be

noted that mutating negatively charged residues (Asp or Glu) to His will lead to increase in side chain volume, which may cause steric issues. Furthermore, His proton donor- and acceptor-form depends on the localized environment. These issues should be taken into consideration with the design strategy. Because the interface residues are highly conserved in human and mouse IgG subclasses, electrostatic steering effects disclosed herein can be applied to human and mouse IgG1, IgG2, IgG3, and IgG4. This strategy can also be extended to modifying uncharged residues to charged residues at the CH3 domain interface.

In part, the disclosure provides desired pairing of asymmetric Fc-containing polypeptide chains using Fc sequences engineered to be complementary on the basis of charge pairing (electrostatic steering). One of a pair of Fc sequences with electrostatic complementarity can be arbitrarily fused to the ALK4 or ActRIIB polypeptide of the construct, with or without an optional linker, to generate an ALK4:ActRIIB heteromultimer. This single chain can be coexpressed in a cell of choice along with the Fc sequence complementary to the first Fc to favor generation of the desired multichain construct (e.g., ALK4:ActRIIB heteromultimer). In this example based on electrostatic steering, SEQ ID NO: 23 [human G1Fc(E134K/D177K)] and SEQ ID NO: 24 [human G1Fc(K170D/K187D)] are examples of complementary Fc sequences in which the engineered amino acid substitutions are double underlined, and the TGF-beta superfamily type I or type II receptor polypeptide of the construct can be fused to either SEQ ID NO: 23 or SEQ ID NO: 24, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that amino acid substitutions at corresponding positions in hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will generate complementary Fc pairs which may be used instead of the complementary hG1Fc pair below (SEQ ID NOs: 23 and 24).

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1  THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVYTLP PSRKEMTKNQ VSLTCLVKGF
151 YPSDIAVEWE SNGQPENNYK TTPPVLKSDG SFFLYSKLTV DKSRWQQGNV
201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 23)

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1  THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVYTLP PSREEMTKNQ VSLTCLVKGF
151 YPSDIAVEWE SNGQPENNYD TTPPVLDSDG SFFLYSDLTV DKSRWQQGNV
201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 24)

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In part, the disclosure provides desired pairing of asymmetric Fc-containing polypeptide chains using Fc sequences engineered for steric complementarity. In part, the disclosure provides knobs-into-holes pairing as an example of steric complementarity. One of a pair of Fc sequences with steric complementarity can be arbitrarily fused to the ALK4 or ActRIIB polypeptide of the construct, with or without an optional linker, to generate an ALK4:ActRIIB heteromultimer. This single chain can be co-expressed in a cell of choice along with the Fc sequence complementary to the first Fc to favor generation of the desired multi-chain construct. In this example based on knobs-into-holes pairing, SEQ ID NO: 25 [human G1Fc(T144Y)] and SEQ ID NO: 26 [human G1Fc(Y185T)] are examples of complementary Fc sequences in which the engineered amino acid substitutions are double underlined, and the ALK4 or ActRIIB polypeptide of the construct can be fused to either SEQ ID NO: 25 or SEQ ID NO: 26, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that amino acid substitutions at corresponding positions in hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will generate complementary Fc pairs which may be used instead of the complementary hG1Fc pair below (SEQ ID NOs: 25 and 26).

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1   THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51  VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVYTLF PSREEMTKNQ VSLYCLVKGF
20 151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 25)

1   THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51  VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVYTLF PSREEMTKNQ VSLTCLVKGF
25 151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLTSKLTV DKSRWQQGNV
201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 26)

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An example of Fc complementarity based on knobs-into-holes pairing combined with an engineered disulfide bond is disclosed in SEQ ID NO: 27 [hG1Fc(S132C/T144W)] and SEQ ID NO: 28 [hG1Fc(Y127C/T144S/L146A/Y185V)]. The engineered amino acid substitutions in these sequences are double underlined, and the TGF-beta superfamily type I or type II polypeptide of the construct can be fused to either SEQ ID NO: 27 or SEQ ID NO: 28, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that amino acid substitutions at corresponding positions in hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will

generate complementary Fc pairs which may be used instead of the complementary hG1Fc pair below (SEQ ID NOs: 27 and 28).

5
1 THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVYTL PCREEMTKNQ VSLWCLVKGF
151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 27)

10
1 THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVCTLP PSREEMTKNQ VSLSCAVKGF
151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLVSKLTV DKSRWQQGNV
201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 28)

In part, the disclosure provides desired pairing of asymmetric Fc-containing polypeptide chains using Fc sequences engineered to generate interdigitating β -strand segments of human IgG and IgA C_H3 domains. Such methods include the use of strand-exchange engineered domain (SEED) C_H3 heterodimers allowing the formation of SEEDbody fusion proteins [Davis et al. (2010) Protein Eng Design Sel 23:195-202]. One of a pair of Fc sequences with SEEDbody complementarity can be arbitrarily fused to the ALK4 or ActIIB of the construct, with or without an optional linker, to generate an ALK4 or ActRIIB fusion polypeptide. This single chain can be co-expressed in a cell of choice along with the Fc sequence complementary to the first Fc to favor generation of the desired multi-chain construct. In this example based on SEEDbody (Sb) pairing, SEQ ID NO: 29 [hG1Fc(Sb_{AG})] and SEQ ID NO: 30 [hG1Fc(Sb_{GA})] are examples of complementary IgG Fc sequences in which the engineered amino acid substitutions from IgA Fc are double underlined, and the ALK4 or ActRIIB polypeptide of the construct can be fused to either SEQ ID NO: 29 or SEQ ID NO: 30, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that amino acid substitutions at corresponding positions in hG1Fc, hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will generate an Fc monomer which may be used in the complementary IgG-IgA pair below (SEQ ID NOs: 29 and 30).

1 THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PFRPEVHLLP PSREEMTKNQ VSLTCLARGF
151 YPKDIAVEWE SNGQPENNYK TTPSRQEPSQ GTTTFAVTSK LTVDKSRWQQ

201 GNVFSCSVMH EALHNHYTQK TISLSPGK (SEQ ID NO: 29)

1 THTCPFPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
 51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
 101 VSNKALPAPI EKTISKAKGQ PREPQVYTLP PPSEELALNE LVTLTCLVKG
 5 151 FYPSDIAVEW ESNGQELPRE KYLTWAPVLD SDGSFFLYSI LRVAAEDWKK
 201 GDTFSCSVMH EALHNHYTQK SLDRSPGK (SEQ ID NO: 30)

In part, the disclosure provides desired pairing of asymmetric Fc-containing polypeptide chains with a cleavable leucine zipper domain attached at the C-terminus of the Fc C_H3 domains. Attachment of a leucine zipper is sufficient to cause preferential assembly of heterodimeric antibody heavy chains [Wranik et al (2012) J Biol Chem 287:43331-43339]. As disclosed herein, one of a pair of Fc sequences attached to a leucine zipper-forming strand can be arbitrarily fused to the ALK4 or ActRIIB polypeptide of the construct, with or without an optional linker, to generate an ALK4 or ActRIIB fusion polypeptide. This single chain can be co-expressed in a cell of choice along with the Fc sequence attached to a complementary leucine zipper-forming strand to favor generation of the desired multi-chain construct. Proteolytic digestion of the construct with the bacterial endoproteinase Lys-C post purification can release the leucine zipper domain, resulting in an Fc construct whose structure is identical to that of native Fc. In this example based on leucine zipper pairing, SEQ ID NO: 36 [hG1Fc-Ap1 (acidic)] and SEQ ID NO: 37 [hG1Fc-Bp1 (basic)] are examples of complementary IgG Fc sequences in which the engineered complimentary leucine zipper sequences are underlined, and the ALK4 or ActRIIB polypeptide of the construct can be fused to either SEQ ID NO: 36 or SEQ ID NO: 37, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that leucine zipper-forming sequences attached, with or without an optional linker, to hG1Fc, hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will generate an Fc monomer which may be used in the complementary leucine zipper-forming pair below (SEQ ID NOs: 36 and 37).

1 THTCPFPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
 51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
 30 101 VSNKALPAPI EKTISKAKGQ PREPQVYTLP PSREEMTKNQ VSLTCLVKGF
 151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
 201 FSCSVMHEAL HNHYTQKSLS LSPGKGGSQA LEKELQALEK ENAOLEWELQ
 251 ALEKELAQGA T (SEQ ID NO: 36)

1 THTCPFPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE

51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
 101 VSNKALPAPI EKTISKAKGQ PREPQVYTL P SREEMTKNQ VSLTCLVKGF
 151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
 201 FSCSVMHEAL HNHYTQKSLS LSPGKGGSQA LKKKLQALKK KNAQLKWKLO
 5 251 ALKKKLAQGA T (SEQ ID NO: 37)

In certain aspects, the disclosure relates to ALK4 polypeptides (e.g., ALK4-Fc fusion proteins) comprising one or more amino acid modifications that alter the isoelectric point (pI) of the ALK4 polypeptide and/or ActRIIB polypeptides (e.g., ActRIIB-Fc fusion proteins) comprising one or more amino acid modifications that alter the isoelectric point of the ActRIIB polypeptide. In some embodiments, one or more candidate domains that have a pI value higher than about 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, or 9.0 are selected for construction of the full multidomain protein. In other embodiments, one or more candidate domains that have a pI value less than about 9.0, 8.5, 8.0, 7.5, 7.0, 6.5, 6.0, 5.5, or 5.0 are selected for construction of the full multidomain protein. It will be understood by one skilled in the art that a single protein will have multiple charge forms. Without wishing to be bound by any particular theory, the charge of a protein can be modified by a number of different mechanisms including but not limited to, amino acid substitution, cationization, deamination, carboxyl-terminal amino acid heterogeneity, phosphorylation and glycosylation.

The pI of a protein may be determined by a variety of methods including but not limited to, isoelectric focusing and various computer algorithms (see for example Bjellqvist et al., 1993, Electrophoresis 14:1023). In one embodiment, pI is determined using a Pharmacia Biotech Multiphor 2 electrophoresis system with a multi temp refrigerated bath recirculation unit and an EPS 3501 XL power supply. Pre-cast ampholine gels (e.g., Amersham Biosciences, pI range 2.5-10) are loaded with protein samples. Broad range pI marker standards (e.g., Amersham, pI range 3-10, 8 .mu.L) are used to determine relative pI for the proteins. Electrophoresis is performed, for example, at 1500 V, 50 mA for 105 minutes. The gel is fixed using, for example, a Sigma fixing solution (5x) diluted with purified water to 1x. Staining is performed, for example, overnight at room temperature using Simply Blue stain (Invitrogen). Destaining is carried out, for example, with a solution that consisted of 25% ethanol, 8% acetic acid and 67% purified water. Isoelectric points are determined using, for example, a Bio-Rad Densitometer relative to calibration curves of the standards. The one or more metrics may further include metrics characterizing stability of the domain under one or more different conditions selected from the group consisting of

different pH values, different temperatures, different shear stresses, and different freeze/thaw cycles.

In part, the disclosure provides desired pairing of asymmetric Fc-containing polypeptide chains by methods described above in combination with additional mutations in the Fc domain which facilitate purification of the desired heteromeric species. An example is complementarity of Fc domains based on knobs-into-holes pairing combined with an engineered disulfide bond, as disclosed in SEQ ID NOs: 27-28, plus additional substitution of two negatively charged amino acids (aspartic acid or glutamic acid) in one Fc-containing polypeptide chain and two positively charged amino acids (e.g., arginine) in the complementary Fc-containing polypeptide chain (SEQ ID NOs: 66-67). These four amino acid substitutions facilitate selective purification of the desired heteromeric fusion protein from a heterogeneous polypeptide mixture based on differences in isoelectric point or net molecular charge. The engineered amino acid substitutions in these sequences are double underlined below, and the ALK4 or ActRIIB polypeptide of the construct can be fused to either SEQ ID NO: 66 or SEQ ID NO: 67, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that amino acid substitutions at corresponding positions in hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will generate complementary Fc pairs which may be used instead of the complementary hG1Fc pair below (SEQ ID NOs: 66-67).

20 1 THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
 51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
 101 VSNKALPAPI EKTISKAKGQ PREPQVYTL PCREEMTENQ VSLWCLVKGF
 151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
 201 FSCSVMHEAL HNHYTQDSLS LSPGK (SEQ ID NO: 66)

25 1 THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
 51 VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
 101 VSNKALPAPI EKTISKAKGQ PREPQVCTLP PSREEMTKNQ VSLSCAVKGF
 151 YPSDIAVEWE SRGQPENNYK TTPPVLDSRG SFFLVSKLTV DKSRWQQGNV
 201 FSCSVMHEAL HNHYTQKSLS LSPGK (SEQ ID NO: 67)

30 Another example involves complementarity of Fc domains based on knobs-into-holes pairing combined with an engineered disulfide bond, as disclosed in SEQ ID NOs: 27-28, plus a histidine-to-arginine substitution at position 213 in one Fc-containing polypeptide chain (SEQ ID NO: 68). This substitution (denoted H435R in the numbering system of Kabat et al.) facilitates separation of desired heteromer from undesirable homodimer based

on differences in affinity for protein A. The engineered amino acid substitution is indicated by double underline, and the ALK4 or ActRIIB polypeptide of the construct can be fused to either SEQ ID NO: 68 or SEQ ID NO: 28, but not both. Given the high degree of amino acid sequence identity between native hG1Fc, native hG2Fc, native hG3Fc, and native hG4Fc, it can be appreciated that amino acid substitutions at corresponding positions in hG2Fc, hG3Fc, or hG4Fc (see Figure 3) will generate complementary Fc pairs which may be used instead of the complementary hG1Fc pair of SEQ ID NO: 68 (below) and SEQ ID NO: 28.

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1   THTCPPCPAP ELLGGPSVFL FPPKPKDTLM ISRTPEVTCV VVDVSHEDPE
51  VKFNWYVDGV EVHNAKTKPR EEQYNSTYRV VSVLTVLHQD WLNGKEYKCK
101 VSNKALPAPI EKTISKAKGQ PREPQVYTLF PCREEMTKNQ VSLWCLVKGF
151 YPSDIAVEWE SNGQPENNYK TTPPVLDSDG SFFLYSKLTV DKSRWQQGNV
201 FSCSVMHEAL HNRYTQKSLS LSPGK      (SEQ ID NO: 68)

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A variety of engineered mutations in the Fc domain are presented above with respect to the G1Fc sequence (SEQ ID NO: 31). Analogous mutations in G2Fc, G3Fc, and G4Fc can be derived from their alignment with G1Fc in Figure 3. Due to unequal hinge lengths, analogous Fc positions based on isotype alignment (Figure 3) possess different amino acid numbers in SEQ ID NOs: 31, 32, 33, 34, and 35 as summarized in the following table.

Correspondence between C _H 3 Positions for Human Fc Isotypes*			
IgG1	IgG4	IgG2	IgG3
SEQ ID NO: 31	SEQ ID NO: 35	SEQ ID NO: 32	SEQ ID NO: 33
Numbering begins at THT...	Numbering begins at ESK...	Numbering begins at VEC...	Numbering begins at EPK...
Y127	Y131	Y125	Y134
S132	S136	S130	S139
E134	E138	E132	E141
K138	K142	K136	K145
T144	T148	T142	T151
L146	L150	L144	L153
N162	N166	N160	S169
K170	K174	K168	N177
D177	D181	D175	D184
D179	D183	D177	D186

Y185	Y189	Y183	Y192
K187	R191	K185	K194
H213	H217	H211	R220
K217	K221	K215	K224
* Numbering based on multiple sequence alignment shown in Figure 3			

It is understood that different elements of the fusion proteins (*e.g.*, immunoglobulin Fc fusion proteins) may be arranged in any manner that is consistent with desired functionality. For example, an ALK4 and/or ActRIIB polypeptide domain may be placed C-terminal to a heterologous domain, or alternatively, a heterologous domain may be placed C-terminal to an ALK4 and/or ActRIIB polypeptide domain. The ALK4 and/or ActRIIB polypeptide domain and the heterologous domain need not be adjacent in a fusion protein, and additional domains or amino acid sequences may be included C- or N-terminal to either domain or between the domains.

For example, an ALK4 and/or ActRIIB receptor fusion protein may comprise an amino acid sequence as set forth in the formula A-B-C. The B portion corresponds to an ALK4 or ActRIIB polypeptide domain. The A and C portions may be independently zero, one, or more than one amino acid, and both the A and C portions when present are heterologous to B. The A and/or C portions may be attached to the B portion via a linker sequence. A linker may be rich in glycine (*e.g.*, 2-10, 2-5, 2-4, 2-3 glycine residues) or glycine and proline residues and may, for example, contain a single sequence of threonine/serine and glycines or repeating sequences of threonine/serine and/or glycines, *e.g.*, GGG (SEQ ID NO: 13), GGGG (SEQ ID NO: 14), TGGGG (SEQ ID NO: 15), SGGGG (SEQ ID NO: 16), TGGG (SEQ ID NO: 17), SGGG (SEQ ID NO: 18), or GGGGS (SEQ ID NO: 58) singlets, or repeats. In certain embodiments, an ALK4 and/or ActRIIB fusion protein comprises an amino acid sequence as set forth in the formula A-B-C, wherein A is a leader (signal) sequence, B consists of an ALK4 and/or ActRIIB polypeptide domain, and C is a polypeptide portion that enhances one or more of *in vivo* stability, *in vivo* half-life, uptake/administration, tissue localization or distribution, formation of protein complexes, and/or purification. In certain embodiments, an ALK4 and/or ActRIIB fusion protein comprises an amino acid sequence as set forth in the formula A-B-C, wherein A is a TPA leader sequence, B consists of a ALK4 or ActRIIB receptor polypeptide domain, and C is an

immunoglobulin Fc domain. Preferred fusion proteins comprise the amino acid sequence set forth in any one of SEQ ID NOs: 39, 41, 42, 44, 45, 46, 47, 48, 70, 72, 74, 76, 78, and 80.

In some embodiments, ALK4:ActRIIB heteromultimers further comprise one or more heterologous portions (domains) so as to confer a desired property. For example, some fusion domains are particularly useful for isolation of the fusion proteins by affinity chromatography. Well-known examples of such fusion domains include, but are not limited to, polyhistidine, Glu-Glu, glutathione S-transferase (GST), thioredoxin, protein A, protein G, an immunoglobulin heavy-chain constant region (Fc), maltose binding protein (MBP), or human serum albumin. For the purpose of affinity purification, relevant matrices for affinity chromatography, such as glutathione-, amylase-, and nickel- or cobalt- conjugated resins are used. Many of such matrices are available in “kit” form, such as the Pharmacia GST purification system and the QIAexpressTM system (Qiagen) useful with (HIS₆) fusion partners. As another example, a fusion domain may be selected so as to facilitate detection of the ligand trap polypeptides. Examples of such detection domains include the various fluorescent proteins (*e.g.*, GFP) as well as “epitope tags,” which are usually short peptide sequences for which a specific antibody is available. Well-known epitope tags for which specific monoclonal antibodies are readily available include FLAG, influenza virus haemagglutinin (HA), and c-myc tags. In some cases, the fusion domains have a protease cleavage site, such as for factor Xa or thrombin, which allows the relevant protease to partially digest the fusion proteins and thereby liberate the recombinant proteins therefrom. The liberated proteins can then be isolated from the fusion domain by subsequent chromatographic separation.

In certain embodiments, ALK4 and/or ActRIIB polypeptides may contain one or more modifications that are capable of stabilizing the polypeptides. For example, such modifications enhance the *in vitro* half-life of the polypeptides, enhance circulatory half-life of the polypeptides, and/or reduce proteolytic degradation of the polypeptides. Such stabilizing modifications include, but are not limited to, fusion proteins (including, for example, fusion proteins comprising an ALK4 and/or ActRIIB polypeptide domain and a stabilizer domain), modifications of a glycosylation site (including, for example, addition of a glycosylation site to a polypeptide of the disclosure), and modifications of carbohydrate moiety (including, for example, removal of carbohydrate moieties from a polypeptide of the disclosure). As used herein, the term “stabilizer domain” not only refers to a fusion domain (*e.g.*, an immunoglobulin Fc domain) as in the case of fusion proteins, but also includes

nonproteinaceous modifications such as a carbohydrate moiety, or nonproteinaceous moiety, such as polyethylene glycol.

In preferred embodiments, ALK4:ActRIIB heteromultimers to be used in accordance with the methods described herein are isolated complexes. As used herein, an isolated
 5 protein (or protein complex) or polypeptide (or polypeptide complex) is one which has been separated from a component of its natural environment. In some embodiments, a heteromultimer of the disclosure is purified to greater than 95%, 96%, 97%, 98%, or 99% purity as determined by, for example, electrophoretic (*e.g.*, SDS-PAGE, isoelectric focusing (IEF), capillary electrophoresis) or chromatographic (*e.g.*, ion exchange or reverse phase
 10 HPLC). Methods for assessment of antibody purity are well known in the art [Flatman *et al.*, (2007) J. Chromatogr. B 848:79-87]. In some embodiments, ALK4:ActRIIB heteromultimer preparations are substantially free of ALK4 and/or ActRIIB homomultimers. For example, in some embodiments, ALK4:ActRIIB heteromultimer preparations comprise less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than 1% ALK4 homomultimers. In some
 15 embodiments, ALK4:ActRIIB heteromultimer preparations comprise less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than 1% ActRIIB homomultimers. In some embodiments, ALK4:ActRIIB heteromultimer preparations comprise less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than 1% ALK4 homomultimers and less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than 1% ActRIIB homomultimers.

20 In certain embodiments, ALK4 and/or ActRIIB polypeptides, as well as heteromultimers comprising the same, of the disclosure can be produced by a variety of art-known techniques. For example, polypeptides can be synthesized using standard protein chemistry techniques such as those described in Bodansky, M. Principles of Peptide Synthesis, Springer Verlag, Berlin (1993) and Grant G. A. (ed.), Synthetic Peptides: A User's
 25 Guide, W. H. Freeman and Company, New York (1992). In addition, automated peptide synthesizers are commercially available (Advanced ChemTech Model 396; Milligen/Biosearch 9600). Alternatively, the polypeptides, including fragments or variants thereof, may be recombinantly produced using various expression systems [*E. coli*, Chinese Hamster Ovary (CHO) cells, COS cells, baculovirus] as is well known in the art. In a further
 30 embodiment, the modified or unmodified polypeptides may be produced by digestion of recombinantly produced full-length ALK4 and/or ActRIIB polypeptides by using, for example, a protease, *e.g.*, trypsin, thermolysin, chymotrypsin, pepsin, or paired basic amino acid converting enzyme (PACE). Computer analysis (using commercially available software,

e.g., MacVector, Omega, PCGene, Molecular Simulation, Inc.) can be used to identify proteolytic cleavage sites.

3. Nucleic Acids Encoding ALK4 and/or ActRIIB polypeptides

5 In certain embodiments, the present disclosure provides isolated and/or recombinant nucleic acids encoding ALK4 and/or ActRIIB polypeptides (including fragments, functional variants, and fusion proteins thereof) disclosed herein. For example, SEQ ID NO: 11 encodes a naturally occurring human ALK4 precursor polypeptide, while SEQ ID NO: 12 encodes a processed extracellular domain of ALK4. The subject nucleic acids may be single-
10 stranded or double stranded. Such nucleic acids may be DNA or RNA molecules. These nucleic acids may be used, for example, in methods for making ALK4:ActRIIB heteromultimers as described herein.

As used herein, isolated nucleic acid(s) refers to a nucleic acid molecule that has been separated from a component of its natural environment. An isolated nucleic acid includes a
15 nucleic acid molecule contained in cells that ordinarily contain the nucleic acid molecule, but the nucleic acid molecule is present extrachromosomally or at a chromosomal location that is different from its natural chromosomal location.

In certain embodiments, nucleic acids encoding ALK4 and/or ActRIIB polypeptides of the present disclosure are understood to include any one of SEQ ID NOs: 7, 8, 11, 12, 21,
20 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83, as well as variants thereof. Variant nucleotide sequences include sequences that differ by one or more nucleotide substitutions, additions, or deletions including allelic variants, and therefore, will include coding sequences that differ from the nucleotide sequence designated in any one of SEQ ID NOs: 7, 8, 11, 12, 21, 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83.

25 In certain embodiments, ALK4 and/or ActRIIB polypeptides of the present disclosure are encoded by isolated or recombinant nucleic acid sequences that comprise, consist essentially of, or consists of a sequence that is least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% identical to SEQ ID NOs: 7, 8, 11, 12, 21, 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83. One of ordinary skill in the
30 art will appreciate that nucleic acid sequences that comprise, consist essentially of, or consists of a sequence complementary to a sequence that is least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% identical to

SEQ ID NOs: 7, 8, 11, 12, 21, 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83 also within the scope of the present disclosure. In further embodiments, the nucleic acid sequences of the disclosure can be isolated, recombinant, and/or fused with a heterologous nucleotide sequence or in a DNA library.

5 In other embodiments, nucleic acids of the present disclosure also include nucleotide sequences that hybridize under stringent conditions to the nucleotide sequence designated in SEQ ID NOs: 7, 8, 11, 12, 21, 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83, the complement sequence of SEQ ID NOs: 7, 8, 11, 12, 21, 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83, or fragments thereof. One of ordinary skill in the art will understand readily that appropriate
10 stringency conditions which promote DNA hybridization can be varied. For example, one could perform the hybridization at 6.0 x sodium chloride/sodium citrate (SSC) at about 45 °C, followed by a wash of 2.0 x SSC at 50 °C. For example, the salt concentration in the wash step can be selected from a low stringency of about 2.0 x SSC at 50 °C to a high stringency of about 0.2 x SSC at 50 °C. In addition, the temperature in the wash step can be increased from
15 low stringency conditions at room temperature, about 22 °C, to high stringency conditions at about 65 °C. Both temperature and salt may be varied, or temperature or salt concentration may be held constant while the other variable is changed. In one embodiment, the disclosure provides nucleic acids which hybridize under low stringency conditions of 6 x SSC at room temperature followed by a wash at 2 x SSC at room temperature.

20 Isolated nucleic acids which differ from the nucleic acids as set forth in SEQ ID NOs: 7, 8, 11, 12, 21, 22, 40, 43, 71, 73, 75, 77, 79, 81, 82, or 83 to degeneracy in the genetic code are also within the scope of the disclosure. For example, a number of amino acids are designated by more than one triplet. Codons that specify the same amino acid, or synonyms (for example, CAU and CAC are synonyms for histidine) may result in “silent” mutations
25 which do not affect the amino acid sequence of the protein. However, it is expected that DNA sequence polymorphisms that do lead to changes in the amino acid sequences of the subject proteins will exist among mammalian cells. One skilled in the art will appreciate that these variations in one or more nucleotides (up to about 3-5% of the nucleotides) of the nucleic acids encoding a particular protein may exist among individuals of a given species
30 due to natural allelic variation. Any and all such nucleotide variations and resulting amino acid polymorphisms are within the scope of this disclosure.

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

In certain aspects, the subject nucleic acid is provided in an expression vector comprising a nucleotide sequence encoding an ALK4 and/or ActRIIB polypeptide and operably linked to at least one regulatory sequence. Regulatory sequences are art-recognized and are selected to direct expression of ALK4 and/or ActRIIB polypeptide. Accordingly, the term regulatory sequence includes promoters, enhancers, and other expression control elements. Exemplary regulatory sequences are described in Goeddel; *Gene Expression Technology: Methods in Enzymology*, Academic Press, San Diego, CA (1990). For instance, any of a wide variety of expression control sequences that control the expression of a DNA sequence when operatively linked to it may be used in these vectors to express DNA sequences encoding a ALK4 and/or ActRIIB polypeptides. Such useful expression control sequences, include, for example, the early and late promoters of SV40, *tet* promoter, adenovirus or cytomegalovirus immediate early promoter, RSV promoters, the lac system, the *trp* system, the TAC or TRC system, T7 promoter whose expression is directed by T7 RNA polymerase, the major operator and promoter regions of phage lambda, the control regions for fd coat protein, the promoter for 3-phosphoglycerate kinase or other glycolytic enzymes, the promoters of acid phosphatase, *e.g.*, Pho5, the promoters of the yeast α -mating factors, the polyhedron promoter of the baculovirus system and other sequences known to control the expression of genes of prokaryotic or eukaryotic cells or their viruses, and various

combinations thereof. It should be understood that the design of the expression vector may depend on such factors as the choice of the host cell to be transformed and/or the type of protein desired to be expressed. Moreover, the vector's copy number, the ability to control that copy number and the expression of any other protein encoded by the vector, such as
5 antibiotic markers, should also be considered.

A recombinant nucleic acid of the present disclosure can be produced by ligating the cloned gene, or a portion thereof, into a vector suitable for expression in either prokaryotic cells, eukaryotic cells (yeast, avian, insect or mammalian), or both. Expression vehicles for production of a recombinant ALK4 and/or ActRIIB polypeptides include plasmids and other
10 vectors. For instance, suitable vectors include plasmids of the following types: pBR322-derived plasmids, pEMBL-derived plasmids, pEX-derived plasmids, pBTac-derived plasmids and pUC-derived plasmids for expression in prokaryotic cells, such as *E. coli*.

Some mammalian expression vectors contain both prokaryotic sequences to facilitate the propagation of the vector in bacteria, and one or more eukaryotic transcription units that
15 are expressed in eukaryotic cells. The pcDNAI/amp, pcDNAI/neo, pRc/CMV, pSV2gpt, pSV2neo, pSV2-dhfr, pTk2, pRSVneo, pMSG, pSVT7, pko-neo and pHyg derived vectors are examples of mammalian expression vectors suitable for transfection of eukaryotic cells. Some of these vectors are modified with sequences from bacterial plasmids, such as pBR322, to facilitate replication and drug resistance selection in both prokaryotic and eukaryotic cells.
20 Alternatively, derivatives of viruses such as the bovine papilloma virus (BPV-1), or Epstein-Barr virus (pHEBo, pREP-derived and p205) can be used for transient expression of proteins in eukaryotic cells. Examples of other viral (including retroviral) expression systems can be found below in the description of gene therapy delivery systems. The various methods employed in the preparation of the plasmids and in transformation of host organisms are well
25 known in the art. For other suitable expression systems for both prokaryotic and eukaryotic cells, as well as general recombinant procedures [Molecular Cloning A Laboratory Manual, 3rd Ed., ed. by Sambrook, Fritsch and Maniatis Cold Spring Harbor Laboratory Press, 2001]. In some instances, it may be desirable to express the recombinant polypeptides by the use of a baculovirus expression system. Examples of such baculovirus expression systems include
30 pVL-derived vectors (such as pVL1392, pVL1393 and pVL941), pAcUW-derived vectors (such as pAcUW1), and pBlueBac-derived vectors (such as the β -gal containing pBlueBac III).

In a preferred embodiment, a vector will be designed for production of the subject ALK4 and/or ActRIIB polypeptides in CHO cells, such as a Pcmv-Script vector (Stratagene, La Jolla, Calif.), pcDNA4 vectors (Invitrogen, Carlsbad, Calif.) and pCI-neo vectors (Promega, Madison, Wisc.). As will be apparent, the subject gene constructs can be used to
5 cause expression of the subject ALK4 and/or ActRIIB polypeptide in cells propagated in culture, *e.g.*, to produce proteins, including fusion proteins or variant proteins, for purification.

This disclosure also pertains to a host cell transfected with a recombinant gene including a coding sequence for one or more of the subject ALK4 and/or ActRIIB polypeptides. The host cell may be any prokaryotic or eukaryotic cell. For example, an
10 ALK4 and/or ActRIIB polypeptide may be expressed in bacterial cells such as *E. coli*, insect cells (*e.g.*, using a baculovirus expression system), yeast, or mammalian cells [*e.g.* a Chinese hamster ovary (CHO) cell line]. Other suitable host cells are known to those skilled in the art.

Accordingly, the present disclosure further pertains to methods of producing the subject ALK4 and/or ActRIIB polypeptides. For example, a host cell transfected with an
15 expression vector encoding an ALK4 and/or ActRIIB polypeptide can be cultured under appropriate conditions to allow expression of the ALK4 and/or ActRIIB polypeptide to occur. The polypeptide may be secreted and isolated from a mixture of cells and medium containing the polypeptide. Alternatively, ALK4 and/or ActRIIB polypeptide may be isolated from a cytoplasmic or membrane fraction obtained from harvested and lysed cells. A cell culture
20 includes host cells, media and other byproducts. Suitable media for cell culture are well known in the art. The subject polypeptides can be isolated from cell culture medium, host cells, or both, using techniques known in the art for purifying proteins, including ion-exchange chromatography, gel filtration chromatography, ultrafiltration, electrophoresis, immunoaffinity purification with antibodies specific for particular epitopes of ALK4 and/or
25 ActRIIB polypeptides and affinity purification with an agent that binds to a domain fused to ALK4 and/or ActRIIB polypeptide (*e.g.*, a protein A column may be used to purify ALK4-Fc and/or ActRIIB-Fc fusion proteins). In some embodiments, the ALK4 and/or ActRIIB polypeptide is a fusion protein containing a domain which facilitates its purification.

In some embodiments, purification is achieved by a series of column chromatography
30 steps, including, for example, three or more of the following, in any order: protein A chromatography, Q sepharose chromatography, phenylsepharose chromatography, size exclusion chromatography, and cation exchange chromatography. The purification could be completed with viral filtration and buffer exchange. An ALK4 and/or ActRIIB polypeptides,

as well as fusion proteins thereof, may be purified to a purity of >90%, >95%, >96%, >98%, or >99% as determined by size exclusion chromatography and >90%, >95%, >96%, >98%, or >99% as determined by SDS PAGE. The target level of purity should be one that is sufficient to achieve desirable results in mammalian systems, particularly non-human

5 primates, rodents (mice), and humans.

In another embodiment, a fusion gene coding for a purification leader sequence, such as a poly-(His)/enterokinase cleavage site sequence at the N-terminus of the desired portion of the recombinant ALK4 and/or ActRIIB polypeptide, can allow purification of the expressed fusion protein by affinity chromatography using a Ni^{2+} metal resin. The purification leader sequence can then be subsequently removed by treatment with enterokinase to provide the purified ALK4 and/or ActRIIB polypeptide, as well as heteromultimers thereof [Hochuli *et al.* (1987) *J. Chromatography* 411:177; and Janknecht *et al.* (1991) *PNAS USA* 88:8972].

Techniques for making fusion genes are well known. Essentially, the joining of various DNA fragments coding for different polypeptide sequences is performed in accordance with conventional techniques, employing blunt-ended or stagger-ended termini for ligation, restriction enzyme digestion to provide for appropriate termini, filling-in of cohesive ends as appropriate, alkaline phosphatase treatment to avoid undesirable joining, and enzymatic ligation. In another embodiment, the fusion gene can be synthesized by conventional techniques including automated DNA synthesizers. Alternatively, PCR amplification of gene fragments can be carried out using anchor primers which give rise to complementary overhangs between two consecutive gene fragments which can subsequently be annealed to generate a chimeric gene sequence. See, *e.g.*, Current Protocols in Molecular Biology, eds. Ausubel *et al.*, John Wiley & Sons: 1992.

4. Exemplary Therapeutic Uses

In certain embodiments, an ALK4:ActRIIB heteromultimer (e.g., ALK4:ActRIIB heterodimers) can be used to treat or prevent a disease or condition that is associated with abnormal activity of an ALK4:ActRIIB-binding ligand. These diseases, disorders, or conditions are generally referred to herein as “ALK4:ActRIIB-associated conditions” or “ALK4:ActRIIB-associated disorders.” In certain embodiments, the present disclosure provides methods of treating or preventing an ALK4:ActRIIB-associated condition in an

individual by administering to an individual in need thereof a therapeutically effective amount of an ALK4:ActRIIB heteromultimer. The terms "subject," an "individual," or a "patient" are interchangeable throughout the specification. Any of the ALK4:ActRIIB heteromultimers of the disclosure can potentially be employed individually or in combination for therapeutic uses disclosed herein. These methods are particularly aimed at therapeutic and prophylactic treatments of mammals including, for example, rodents, primates, and humans.

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

In general, treatment or prevention of a disease or condition as described in the present disclosure is achieved by administering an ALK4:ActRIIB heteromultimer of the present disclosure in an "effective amount". An effective amount of an agent refers to an amount effective, at dosages and for periods of time necessary, to achieve the desired therapeutic or prophylactic result. A "therapeutically effective amount" of an agent of the present disclosure may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the agent to elicit a desired response in the individual. A "prophylactically effective amount" refers to an amount effective, at dosages and for periods of time necessary, to achieve the desired prophylactic result.

Naturally occurring ALK4 and ActRIIB receptor-ligand complexes play essential roles in tissue growth as well as early developmental processes such as the correct formation of various structures or in one or more post-developmental capacities including sexual development, pituitary hormone production, and creation of bone and cartilage. Thus, ALK4:ActRIIB-associated conditions include, but are not limited to, abnormal tissue growth and developmental defects. In addition, ALK4:ActRIIB-associated conditions include, but are not limited to, disorders of cell growth and differentiation such as inflammation, allergy, autoimmune diseases, and tumors.

For example, ALK4:ActRIIB-associated conditions include neuromuscular disorders (*e.g.*, muscular dystrophy and muscle atrophy), congestive obstructive pulmonary disease (and muscle wasting associated with COPD), muscle wasting syndrome, sarcopenia, cachexia, adipose tissue disorders (*e.g.*, obesity), type 2 diabetes (NIDDM, adult-onset diabetes), and bone degenerative disease (*e.g.*, osteoporosis). Other exemplary ALK4:ActRIIB-associated conditions include musculodegenerative and neuromuscular disorders, tissue repair (*e.g.*, wound healing), neurodegenerative diseases (*e.g.*, amyotrophic lateral sclerosis), and immunologic disorders (*e.g.*, disorders related to abnormal proliferation or function of lymphocytes).

In some embodiments, the ALK4:ActRIIB-associated condition is an interstitial lung disease (*e.g.*, idiopathic pulmonary fibrosis). In some embodiments, the interstitial lung disease is pulmonary fibrosis. In some embodiments, the interstitial lung disease is caused by any one of the following: silicosis, asbestosis, berylliosis, hypersensitivity pneumonitis, drug use (*e.g.*, antibiotics, chemotherapeutic drugs, antiarrhythmic agents, statins), systemic sclerosis, polymyositis, dermatomyositis, systemic lupus erythematosus, rheumatoid arthritis, an infection (*e.g.*, atypical pneumonia, pneumocystis pneumonia, tuberculosis, chlamydia trachomatis, and/or respiratory syncytial virus), lymphangitic carcinomatosis, cigarette smoking, or developmental disorders. In some embodiments, the interstitial lung disease is idiopathic (*e.g.*, sarcoidosis, idiopathic pulmonary fibrosis, Hamman-Rich syndrome, and/or antisynthetase syndrome). In particular embodiments, the interstitial lung disease is idiopathic pulmonary fibrosis. In some embodiments, the treatment for idiopathic pulmonary fibrosis is administered in combination with an additional therapeutic agent. In some embodiments, the additional therapeutic agent is selected from the group consisting of: pirfenidone, N-acetylcysteine, prednisone, azathioprine, nintedanib, derivatives thereof and combinations thereof.

In certain embodiments, an ALK4:ActRIIB heteromultimer of the disclosure may be used as part of a treatment for a muscular dystrophy. The term “muscular dystrophy” refers to a group of degenerative muscle diseases characterized by gradual weakening and deterioration of skeletal muscles and sometimes the heart and respiratory muscles. Muscular dystrophies are genetic disorders characterized by progressive muscle wasting and weakness that begin with microscopic changes in the muscle. As muscles degenerate over time, the person’s muscle strength declines. Exemplary muscular dystrophies that can be treated with a regimen including the subject TGF-beta superfamily heteromultimer complexes include:

Duchenne muscular dystrophy (DMD), Becker muscular dystrophy (BMD), Emery-Dreifuss muscular dystrophy (EDMD), limb-girdle muscular dystrophy (LGMD), facioscapulohumeral muscular dystrophy (FSH or FSHD) (also known as Landouzy-Dejerine), myotonic dystrophy (MMD; also known as Steinert's Disease), oculopharyngeal muscular dystrophy (OPMD), distal muscular dystrophy (DD), congenital muscular dystrophy (CMD).

Duchenne muscular dystrophy (DMD) was first described by the French neurologist Guillaume Benjamin Amand Duchenne in the 1860s. Becker muscular dystrophy (BMD) is named after the German doctor Peter Emil Becker, who first described this variant of DMD in the 1950s. DMD is one of the most frequent inherited diseases in males, affecting one in 3,500 boys. DMD occurs when the dystrophin gene, located on the short arm of the X chromosome, is defective. Since males only carry one copy of the X chromosome, they only have one copy of the dystrophin gene. Without the dystrophin protein, muscle is easily damaged during cycles of contraction and relaxation. While early in the disease muscle compensates by regeneration, later on muscle progenitor cells cannot keep up with the ongoing damage and healthy muscle is replaced by non-functional fibro-fatty tissue.

BMD results from different mutations in the dystrophin gene. BMD patients have some dystrophin, but it is either of insufficient quantity or poor quality. The presence of some dystrophin protects the muscles of patients with BMD from degenerating as severely or as quickly as those of patients with DMD.

Studies in animals indicate that inhibition of the GDF8 signaling pathway may effectively treat various aspects of disease in DMD and BMD patients (Bogdanovich et al., 2002, Nature 420:418-421; Pistilli et al., 2011, Am J Pathol 178:1287-1297). Thus, ALK4:ActRIIB antagonists of the disclosure may act as GDF8 inhibitors (antagonists), and constitute an alternative means of blocking signaling by GDF8 and/or related TGF β superfamily ligands *in vivo* in DMD and BMD patients.

Similarly, ALK4:ActRIIB heteromultimers of the disclosure may provide an effective means to increase muscle mass in other disease conditions that are in need of muscle growth. For example, amyotrophic lateral sclerosis (ALS), also called Lou Gehrig's disease or motor neuron disease, is a chronic, progressive, and incurable CNS disorder that attacks motor neurons, which are components of the central nervous system required for initiation of skeletal muscle contraction. In ALS, motor neurons deteriorate and eventually die, and

though a person's brain normally remains fully functioning and alert, initiation of muscle contraction is blocked at the spinal level. Individuals who develop ALS are typically between 40 and 70 years old, and the first motor neurons to degenerate are those innervating the arms or legs. Patients with ALS may have trouble walking, may drop things, fall, slur
 5 their speech, and laugh or cry uncontrollably. As the disease progresses, muscles in the limbs begin to atrophy from disuse. Muscle weakness becomes debilitating, and patients eventually require a wheel chair or become confined to bed. Most ALS patients die from respiratory failure or from complications of ventilator assistance like pneumonia 3-5 years from disease onset.

10 In some embodiments, ALK4:ActRIIB heteromultimers of the disclosure may be used to treat inflammatory muscle diseases/disorders such as dermatomyositis, inclusion body myositis or polymyositis. In some embodiments, the inflammatory muscle disease/disorder is dermatomyositis. In some embodiments, the inflammatory muscle disease/disorder is polymyositis. In some embodiments, the inflammatory muscle disease/disorder is inclusion
 15 body myositis. In some embodiments, the inclusion body myositis is hereditary inclusion body myositis. In some embodiments, the inclusion body myositis is sporadic inclusion body myositis.

Sporadic inclusion body myositis is associated with both autoimmune and degenerative processes. This disorder typically first appears in patients who are over 50
 20 years of age, and predominantly appears in males. Clinically, sporadic inclusion body myositis is characterized by progressive quadriceps femoris and deep flexors weakness and atrophy. Many patients become wheelchair dependent and severely disabled 10-15 years after symptom onset. Patients also frequently display dysphagia due to esophageal and pharyngeal muscle involvement. Diagnosis for sporadic inclusion body myositis is usually
 25 based on some combination of factors such as elevated creatine kinase levels in the blood, abnormal electromyography results; or muscle biopsies displaying inflammatory cell invasion of muscle, vacuolar degeneration and/or inclusions of plaques of abnormal proteins.

Promotion of increased muscle mass by ALK4:ActRIIB heteromultimers might also benefit those suffering from muscle wasting diseases. Gonzalez-Cadavid *et al.* (supra)
 30 reported that GDF8 expression correlates inversely with fat-free mass in humans and that increased expression of the GDF8 gene is associated with weight loss in men with AIDS wasting syndrome. By inhibiting the function of GDF8 in AIDS patients, at least certain

symptoms of AIDS may be alleviated, if not completely eliminated, thus significantly improving quality of life in AIDS patients.

Since loss of GDF8 function is also associated with fat loss without diminution of nutrient intake (Zimmers et al., supra; McPherron and Lee, supra), the subject

5 ALK4:ActRIIB heteromultimers may further be used as a therapeutic agent for slowing or preventing the development of obesity and type 2 diabetes.

Cancer anorexia-cachexia syndrome is among the most debilitating and life-threatening aspects of cancer. This syndrome is a common feature of many types of cancer – present in approximately 80% of cancer patients at death – and is responsible not only for a poor quality of life and poor response to chemotherapy but also a shorter survival time than is found in patients with comparable tumors but without weight loss. Cachexia is typically suspected in patients with cancer if an involuntary weight loss of greater than five percent of premorbid weight occurs within a six-month period. Associated with anorexia, wasting of fat and muscle tissue, and psychological distress, cachexia arises from a complex interaction between the cancer and the host. Cancer cachexia affects cytokine production, release of lipid-mobilizing and proteolysis-inducing factors, and alterations in intermediary metabolism. Although anorexia is common, a decreased food intake alone is unable to account for the changes in body composition seen in cancer patients, and increasing nutrient intake is unable to reverse the wasting syndrome. Currently, there is no treatment to control or reverse the cachexic process. Since systemic overexpression of GDF8 in adult mice was found to induce profound muscle and fat loss analogous to that seen in human cachexia syndromes (Zimmers et al., supra), the subject ALK4:ActRIIB heteromultimers may be beneficially used to prevent, treat, or alleviate the symptoms of the cachexia syndrome, where muscle growth is desired. An example of a heteromeric complex useful for preventing, treating, or alleviating muscle loss as described above is an ALK4:ActRIIB heterodimer.

In certain embodiments, an ALK4:ActRIIB heteromultimer of the present disclosure may be used in methods of inducing bone and/or cartilage formation, preventing bone loss, increasing bone mineralization, preventing the demineralization of bone, and/or increasing bone density. ALK4:ActRIIB heteromultimers may be useful in patients who are diagnosed with subclinical low bone density, as a protective measure against the development of osteoporosis.

In some embodiments, an ALK4:ActRIIB heteromultimer of the present disclosure may find medical utility in the healing of bone fractures and cartilage defects in humans and other animals. The subject methods and compositions may also have prophylactic use in closed as well as open fracture reduction and also in the improved fixation of artificial joints.

5 De novo bone formation induced by an osteogenic agent is useful for repair of craniofacial defects that are congenital, trauma-induced, or caused by oncologic resection, and is also useful in cosmetic plastic surgery. Further, methods and compositions of the invention may be used in the treatment of periodontal disease and in other tooth repair processes. In certain cases, an ALK4:ActRIIB heteromultimer may provide an environment to attract bone-
10 forming cells, stimulate growth of bone-forming cells, or induce differentiation of progenitors of bone-forming cells. An ALK4:ActRIIB heteromultimer of the disclosure may also be useful in the treatment of osteoporosis. Further, ALK4:ActRIIB heteromultimers may be used in repair of cartilage defects and prevention/reversal of osteoarthritis. Examples of heteromeric complexes useful for inducing bone formation, preventing bone loss, increasing
15 bone mineralization, preventing the demineralization of bone, and/or increasing bone density as described herein are ALK4:ActRIIB heterodimers.

Rosen et al. (ed) Primer on the Metabolic Bone Diseases and Disorders of Mineral Metabolism, 7th ed. American Society for Bone and Mineral Research, Washington D.C. (incorporated herein by reference) provides an extensive discussion of bone disorders that
20 may be subject to treatment with an ALK4:ActRIIB heteromultimer. A partial listing is provided herein. Methods and compositions of the invention can be applied to conditions characterized by or causing bone loss, such as osteoporosis (including secondary osteoporosis), hyperparathyroidism, chronic kidney disease mineral bone disorder, sex hormone deprivation or ablation (e.g. androgen and/or estrogen), glucocorticoid treatment,
25 rheumatoid arthritis, severe burns, hyperparathyroidism, hypercalcemia, hypocalcemia, hypophosphatemia, osteomalacia (including tumor-induced osteomalacia), hyperphosphatemia, vitamin D deficiency, hyperparathyroidism (including familial hyperparathyroidism) and pseudohypoparathyroidism, tumor metastases to bone, bone loss as a consequence of a tumor or chemotherapy, tumors of the bone and bone marrow (e.g.,
30 multiple myeloma), ischemic bone disorders, periodontal disease and oral bone loss, Cushing's disease, Paget's disease, thyrotoxicosis, chronic diarrheal state or malabsorption, renal tubular acidosis, or anorexia nervosa. Methods and compositions of the invention may also be applied to conditions characterized by a failure of bone formation or healing,

including non-union fractures, fractures that are otherwise slow to heal, fetal and neonatal bone dysplasias (e.g., hypocalcemia, hypercalcemia, calcium receptor defects and vitamin D deficiency), osteonecrosis (including osteonecrosis of the jaw) and osteogenesis imperfecta.

Additionally, the anabolic effects will cause such antagonists to diminish bone pain

5 associated with bone damage or erosion. As a consequence of the anti-resorptive effects, such antagonists may be useful to treat disorders of abnormal bone formation, such as osteoblastic tumor metastases (e.g., associated with primary prostate or breast cancer), osteogenic osteosarcoma, osteopetrosis, progressive diaphyseal dysplasia, endosteal hyperostosis, osteopoikilosis, and melorheostosis. Other disorders that may be treated
10 include fibrous dysplasia and chondrodysplasias.

In another specific embodiment, the disclosure provides a therapeutic method and composition for repairing fractures and other conditions related to cartilage and/or bone defects or periodontal diseases. The invention further provides therapeutic methods and compositions for wound healing and tissue repair. The types of wounds include, but are not
15 limited to, burns, incisions and ulcers. See, e.g., PCT Publication No. WO 84/01106. Such compositions comprise a therapeutically effective amount of at least one of the ALK4:ActRIIB heteromultimers of the disclosure in admixture with a pharmaceutically acceptable vehicle, carrier, or matrix.

In some embodiments, an ALK4:ActRIIB heteromultimer of the disclosure can be
20 applied to conditions causing bone loss such as osteoporosis, hyperparathyroidism, Cushing's disease, thyrotoxicosis, chronic diarrheal state or malabsorption, renal tubular acidosis, or anorexia nervosa. It is commonly appreciated that being female, having a low body weight, and leading a sedentary lifestyle are risk factors for osteoporosis (loss of bone mineral density, leading to fracture risk). However, osteoporosis can also result from the long-term use of
25 certain medications. Osteoporosis resulting from drugs or another medical condition is known as secondary osteoporosis. In Cushing's disease, the excess amount of cortisol produced by the body results in osteoporosis and fractures. The most common medications associated with secondary osteoporosis are the corticosteroids, a class of drugs that act like cortisol, a hormone produced naturally by the adrenal glands. Although adequate levels of
30 thyroid hormones are needed for the development of the skeleton, excess thyroid hormone can decrease bone mass over time. Antacids that contain aluminum can lead to bone loss when taken in high doses by people with kidney problems, particularly those undergoing dialysis. Other medications that can cause secondary osteoporosis include phenytoin

(Dilantin) and barbiturates that are used to prevent seizures; methotrexate (Rheumatrex, Immunex, Folex PFS), a drug for some forms of arthritis, cancer, and immune disorders; cyclosporine (Sandimmune, Neoral), a drug used to treat some autoimmune diseases and to suppress the immune system in organ transplant patients; luteinizing hormone-releasing hormone agonists (Lupron, Zoladex), used to treat prostate cancer and endometriosis; heparin (Calciparine, Liquaemin), an anticlotting medication; and cholestyramine (Questran) and colestipol (Colestid), used to treat high cholesterol. Bone loss resulting from cancer therapy is widely recognized and termed cancer therapy-induced bone loss (CTIBL). Bone metastases can create cavities in the bone that may be corrected by treatment with an ALK4:ActRIIB heteromultimers. Bone loss can also be caused by gum disease, a chronic infection in which bacteria located in gum recesses produce toxins and harmful enzymes.

In a further embodiment, the present disclosure provides methods and therapeutic agents for treating diseases or disorders associated with abnormal or unwanted bone growth. For example, patients with the congenital disorder fibrodysplasia ossificans progressiva (FOP) are afflicted by progressive ectopic bone growth in soft tissues spontaneously or in response to tissue trauma, with a major impact on quality of life. Additionally, abnormal bone growth can occur after hip replacement surgery and thus ruin the surgical outcome. This is a more common example of pathological bone growth and a situation in which the subject methods and compositions may be therapeutically useful. The same methods and compositions may also be useful for treating other forms of abnormal bone growth (e.g., pathological growth of bone following trauma, burns or spinal cord injury), and for treating or preventing the undesirable conditions associated with the abnormal bone growth seen in connection with metastatic prostate cancer or osteosarcoma.

In certain embodiments, an ALK4:ActRIIB heteromultimer of the disclosure may be used to promote bone formation in patients with cancer. Patients having certain tumors (e.g. prostate, breast, multiple myeloma or any tumor causing hyperparathyroidism) are at high risk for bone loss due to tumor-induced bone loss, bone metastases, and therapeutic agents. Such patients may be treated with a TGF-beta superfamily heteromultimer complex, or a combination of complexes, even in the absence of evidence of bone loss or bone metastases. Patients may also be monitored for evidence of bone loss or bone metastases, and may be treated with an ALK4:ActRIIB heteromultimer in the event that indicators suggest an increased risk. Generally, DEXA scans are employed to assess changes in bone density, while indicators of bone remodeling may be used to assess the likelihood of bone metastases.

Serum markers may be monitored. Bone specific alkaline phosphatase (BSAP) is an enzyme that is present in osteoblasts. Blood levels of BSAP are increased in patients with bone metastasis and other conditions that result in increased bone remodeling. Osteocalcin and procollagen peptides are also associated with bone formation and bone metastases. Increases
5 in BSAP have been detected in patients with bone metastasis caused by prostate cancer, and to a lesser degree, in bone metastases from breast cancer. BMP7 levels are high in prostate cancer that has metastasized to bone, but not in bone metastases due to bladder, skin, liver, or lung cancer. Type I carboxy-terminal telopeptide (ICTP) is a crosslink found in collagen that is formed during to the resorption of bone. Since bone is constantly being broken down and
10 reformed, ICTP will be found throughout the body. However, at the site of bone metastasis, the level will be significantly higher than in an area of normal bone. ICTP has been found in high levels in bone metastasis due to prostate, lung, and breast cancer. Another collagen crosslink, Type I N-terminal telopeptide (NTx), is produced along with ICTP during bone turnover. The amount of NTx is increased in bone metastasis caused by many different types
15 of cancer including lung, prostate, and breast cancer. Also, the levels of NTx increase with the progression of the bone metastasis. Therefore, this marker can be used to both detect metastasis as well as measure the extent of the disease. Other markers of resorption include pyridinoline and deoxypyridinoline. Any increase in resorption markers or markers of bone metastases indicate the need for therapy with an ALK4:ActRIIB heteromultimer in a patient.

20 In another embodiment, an ALK4:ActRIIB heteromultimer may be used in patients with chronic kidney disease mineral bone disorder (CKD-MBD), a broad syndrome of interrelated skeletal, cardiovascular, and mineral-metabolic disorders arising from kidney disease. CKD-MBD encompasses various skeletal pathologies often referred to as renal osteodystrophy (ROD), which is a preferred embodiment for treatment with, an
25 ALK4:ActRIIB heteromultimer. Depending on the relative contribution of different pathogenic factors, ROD is manifested as diverse pathologic patterns of bone remodeling (Hruska et al., 2008, Chronic kidney disease mineral bone disorder (CKD-MBD); in Rosen et al. (ed) Primer on the Metabolic Bone Diseases and Disorders of Mineral Metabolism, 7th ed. American Society for Bone and Mineral Research, Washington D.C., pp 343-349). At one
30 end of the spectrum is ROD with uremic osteodystrophy and low bone turnover, characterized by a low number of active remodeling sites, profoundly suppressed bone formation, and low bone resorption. At the other extreme is ROD with hyperparathyroidism, high bone turnover, and osteitis fibrosa. Given that an ALK4:ActRIIB heteromultimer may

exert both anabolic and antiresorptive effects, these agents may be useful in patients across the ROD pathology spectrum.

An ALK4:ActRIIB heteromultimer of the disclosure may be conjointly administered with other bone-active pharmaceutical agents. Conjoint administration may be accomplished
5 by administration of a single co-formulation, by simultaneous administration, or by administration at separate times. ALK4:ActRIIB heteromultimers may be particularly advantageous if administered with other bone-active agents. A patient may benefit from conjointly receiving an ALK4:ActRIIB heteromultimer and taking calcium supplements, vitamin D, appropriate exercise and/or, in some cases, other medication. Examples of other
10 medications include, bisphosphonates (alendronate, ibandronate and risedronate), calcitonin, estrogens, parathyroid hormone and raloxifene. The bisphosphonates (alendronate, ibandronate and risedronate), calcitonin, estrogens and raloxifene affect the bone remodeling cycle and are classified as anti-resorptive medications. Bone remodeling consists of two distinct stages: bone resorption and bone formation. Anti-resorptive medications slow or stop
15 the bone-resorbing portion of the bone-remodeling cycle but do not slow the bone-forming portion of the cycle. As a result, new formation continues at a greater rate than bone resorption, and bone density may increase over time. Teriparatide, a form of parathyroid hormone, increases the rate of bone formation in the bone remodeling cycle. Alendronate is approved for both the prevention (5 mg per day or 35 mg once a week) and treatment (10 mg
20 per day or 70 mg once a week) of postmenopausal osteoporosis. Alendronate reduces bone loss, increases bone density and reduces the risk of spine, wrist and hip fractures. Alendronate also is approved for treatment of glucocorticoid-induced osteoporosis in men and women as a result of long-term use of these medications (i.e., prednisone and cortisone) and for the treatment of osteoporosis in men. Alendronate plus vitamin D is approved for the
25 treatment of osteoporosis in postmenopausal women (70 mg once a week plus vitamin D), and for treatment to improve bone mass in men with osteoporosis. Ibandronate is approved for the prevention and treatment of postmenopausal osteoporosis. Taken as a once-a-month pill (150 mg), ibandronate should be taken on the same day each month. Ibandronate reduces bone loss, increases bone density and reduces the risk of spine fractures. Risedronate is
30 approved for the prevention and treatment of postmenopausal osteoporosis. Taken daily (5 mg dose) or weekly (35 mg dose or 35 mg dose with calcium), risedronate slows bone loss, increases bone density and reduces the risk of spine and non-spine fractures. Risedronate also is approved for use by men and women to prevent and/or treat glucocorticoid-induced

osteoporosis that results from long-term use of these medications (i.e., prednisone or cortisone). Calcitonin is a naturally occurring hormone involved in calcium regulation and bone metabolism. In women who are more than 5 years beyond menopause, calcitonin slows bone loss, increases spinal bone density, and may relieve the pain associated with bone fractures. Calcitonin reduces the risk of spinal fractures. Calcitonin is available as an injection (50-100 IU daily) or nasal spray (200 IU daily).

A patient may also benefit from conjointly receiving an ALK4:ActRIIB heteromultimer and additional bone-active medications. Estrogen therapy (ET)/hormone therapy (HT) is approved for the prevention of osteoporosis. ET has been shown to reduce bone loss, increase bone density in both the spine and hip, and reduce the risk of hip and spinal fractures in postmenopausal women. ET is administered most commonly in the form of a pill or skin patch that delivers a low dose of approximately 0.3 mg daily or a standard dose of approximately 0.625 mg daily and is effective even when started after age 70. When estrogen is taken alone, it can increase a woman's risk of developing cancer of the uterine lining (endometrial cancer). To eliminate this risk, healthcare providers prescribe the hormone progestin in combination with estrogen (hormone replacement therapy or HT) for those women who have an intact uterus. ET/HT relieves menopause symptoms and has been shown to have a beneficial effect on bone health. Side effects may include vaginal bleeding, breast tenderness, mood disturbances and gallbladder disease. Raloxifene, 60 mg a day, is approved for the prevention and treatment of postmenopausal osteoporosis. It is from a class of drugs called Selective Estrogen Receptor Modulators (SERMs) that have been developed to provide the beneficial effects of estrogens without their potential disadvantages. Raloxifene increases bone mass and reduces the risk of spine fractures. Data are not yet available to demonstrate that raloxifene can reduce the risk of hip and other non-spine fractures. Teriparatide, a form of parathyroid hormone, is approved for the treatment of osteoporosis in postmenopausal women and men who are at high risk for a fracture. This medication stimulates new bone formation and significantly increases bone mineral density. In postmenopausal women, fracture reduction was noted in the spine, hip, foot, ribs and wrist. In men, fracture reduction was noted in the spine, but there were insufficient data to evaluate fracture reduction at other sites. Teriparatide is self-administered as a daily injection for up to 24 months.

In other embodiments, an ALK4:ActRIIB heteromultimer can be used for regulating body fat content in an animal and for treating or preventing conditions related thereto, and

particularly, health-compromising conditions related thereto. According to the present invention, to regulate (control) body weight can refer to reducing or increasing body weight, reducing or increasing the rate of weight gain, or increasing or reducing the rate of weight loss, and also includes actively maintaining, or not significantly changing body weight (*e.g.*,
5 against external or internal influences which may otherwise increase or decrease body weight). One embodiment of the present disclosure relates to regulating body weight by administering to an animal (*e.g.*, a human) in need thereof a ALK4:ActRIIB heteromultimers.

In some embodiments, an ALK4:ActRIIB heteromultimer of the present disclosure can be used for reducing body weight and/or reducing weight gain in an animal, and more
10 particularly, for treating or ameliorating obesity in patients at risk for or suffering from obesity. In another specific embodiment, the present invention is directed to methods and compounds for treating an animal that is unable to gain or retain weight (*e.g.*, an animal with a wasting syndrome). Such methods are effective to increase body weight and/or mass, or to reduce weight and/or mass loss, or to improve conditions associated with or caused by
15 undesirably low (*e.g.*, unhealthy) body weight and/or mass. In addition, disorders of high cholesterol (*e.g.*, hypercholesterolemia or dislipidemia) may be treated with an ALK4:ActRIIB heteromultimer of the disclosure.

In other embodiments, an ALK4:ActRIIB heteromultimer can be used for regulating body fat content in an animal and for treating or preventing conditions related thereto, and
20 particularly, health-compromising conditions related thereto. According to the present invention, to regulate (control) body weight can refer to reducing or increasing body weight, reducing or increasing the rate of weight gain, or increasing or reducing the rate of weight loss, and also includes actively maintaining, or not significantly changing body weight (*e.g.*, against external or internal influences which may otherwise increase or decrease body
25 weight). One embodiment of the present disclosure relates to regulating body weight by administering to an animal (*e.g.*, a human) in need thereof an ALK4:ActRIIB heteromultimer. For example, in some embodiments, an ALK4:ActRIIB heteromultimer may be used to treat or prevent a disorder or condition selected from obesity (*e.g.*, abdominal obesity); overweight; insulin resistance; metabolic syndrome and other metabolic diseases or conditions; a lipid
30 disorder such as, low HDL levels, high LDL levels, hyperlipidemia, hypertriglyceridemia or dyslipidemia; lipoprotein aberrations; decreased triglycerides; inflammation (*e.g.*, liver inflammation and/or inflammation of adipose tissue), fatty liver disease; non-alcoholic fatty liver disease; hyperglycemia; impaired glucose tolerance (IGT); hyperinsulinemia; high

cholesterol (*e.g.*, high LDL levels and hypercholesterolemia); cardiovascular disease such as, heart disease including coronary heart disease, congestive heart failure, stroke, peripheral vascular disease, atherosclerosis; arteriosclerosis, and hypertension; Syndrome X; vascular restenosis; neuropathy; retinopathy; neurodegenerative disease; endothelial dysfunction, respiratory dysfunction; pancreatitis; polycystic ovarian syndrome; elevated uric acid levels; haemochromatosis (iron overload); acanthosis nigricans (dark patches on the skin); or cancer (*e.g.*, ovarian, breast, endometrial, and colon cancer); or a another disorders/conditions associated with one or more of the above diseases or conditions. In some embodiments, the disease or condition treated using an ALK4:ActRIIB heteromultimer is associated with

10 overweight (*e.g.*, BMI of $\geq 25 \text{ kg/m}^2$), or with too much body fat.

In one embodiment, the disclosure provides a method of reducing body weight comprising administering to a subject desiring to reduce body weight, or in need thereof, an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the subject is overweight (*e.g.*, pre-obese). In some embodiments, the subject has a body mass index

15 (BMI) of 25 kg/m^2 or greater. In further embodiments, the subject has a BMI of 25 kg/m^2 to 29.9 kg/m^2 , 30 kg/m^2 to 39.9 kg/m^2 , 25 kg/m^2 to 39.9 kg/m^2 , or 25 kg/m^2 to 50 kg/m^2 . In some embodiments, the subject is obese. In some embodiments, the subject has a BMI of 30 kg/m^2 or greater (*e.g.*, 30 to 39.9 kg/m^2 or 30 kg/m^2 to 50 kg/m^2). In some embodiments, the subject is morbidly obese. In some embodiments, the subject has a BMI of 40 kg/m^2 or

20 greater. In further embodiments, the subject has a BMI of 40 kg/m^2 to 45 kg/m^2 , or 40 kg/m^2 to 50 kg/m^2 . In some embodiments, the subject has central obesity (*e.g.*, excess adiposity in the abdominal region, including belly fat and/or visceral fat). In some embodiments, the subject has a waist/hip circumference ratio (WHR) of 0.85 or greater. In some embodiments, the subject has peripheral obesity (*e.g.*, excess adiposity on the hips). In some embodiments,

25 the subject has type 2 diabetes mellitus. The ALK4:ActRIIB heteromultimer may administered alone or as a combination therapy other type of supportive therapy. For example, in some embodiments, the supportive therapy is diet and/or exercise.

In one embodiment, the disclosure provides a method of reducing weight gain comprising administering to a subject desiring to reduce weight gain, or in need thereof, an

30 effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the subject is overweight (*e.g.*, pre-obese). In some embodiments, the subject has a BMI of 25 kg/m^2 or greater. In further embodiments, the subject has a BMI of 25 kg/m^2 to 29.9 kg/m^2 , 30 kg/m^2 to 39.9 kg/m^2 , 25 kg/m^2 to 39.9 kg/m^2 , or 25 kg/m^2 to 50 kg/m^2 . In some embodiments, the

subject is obese. In some embodiments, the subject has a BMI of 30 kg/m^2 or greater (*e.g.*, 30 to 39.9 kg/m^2 or 30 kg/m^2 to 50 kg/m^2). In some embodiments, the subject is morbidly obese. In some embodiments, the subject has a BMI of 40 kg/m^2 or greater. In further embodiments, the subject has a BMI of 40 kg/m^2 to 45 kg/m^2 , or 40 kg/m^2 to 50 kg/m^2 . In some embodiments, the subject has type 2 diabetes mellitus.

Also provided is a method of treating or preventing a disease or condition associated with excess body weight, comprising administering to a subject in need of treatment or prevention, an effective amount of an ALK4:ActRIIB heteromultimer. In one embodiment, the treated or prevented disease or condition is obesity. In one embodiment, the treated or prevented disease or condition is insulin resistance. In one embodiment, the treated or prevented disease or condition is a member selected from the group consisting of: dyslipidemia, hyperlipidemia (total cholesterol level $>240 \text{ mg/dL}$), hypercholesterolemia (*e.g.*, total cholesterol level of $>200 \text{ mg/dL}$, $>220 \text{ mg/dL}$, $>240 \text{ mg/dL}$, $>250 \text{ mg/dL}$, or $>275 \text{ mg/dL}$), low HDL serum level (*e.g.*, $<40 \text{ mg/dL}$, $<45 \text{ mg/dL}$, or $<50 \text{ mg/dL}$), high LDL serum level (*e.g.*, $\geq 100 \text{ mg/dL}$, $\geq 130 \text{ mg/dL}$, $\geq 160 \text{ mg/dL}$, or $\geq 190 \text{ mg/dL}$), and hypertriglyceridemia (*e.g.*, a fasting TG level of $\geq 150 \text{ mg/dL}$, $\geq 175 \text{ mg/dL}$, $\geq 200 \text{ mg/dL}$, $\geq 300 \text{ mg/dL}$, $\geq 400 \text{ mg/dL}$, or $\geq 499 \text{ mg/dL}$). In certain instances, the ALK4:ActRIIB antagonists treatment is an adjunct to diet and/or exercise.

In another embodiment the disclosure provides a method of reducing body weight in a subject who is overweight. The method includes administering to an overweight subject an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the subject has a body mass index (BMI) of 25 kg/m^2 or greater. In further embodiments, the subject has a BMI of 25 kg/m^2 to 29.9 kg/m^2 , 30 kg/m^2 to 39.9 kg/m^2 , 25 kg/m^2 to 39.9 kg/m^2 , or 25 kg/m^2 to 50 kg/m^2 or 27 to 40 kg/m^2 . In some embodiments, the subject is obese. In some embodiments, the subject has a BMI of 30 kg/m^2 or greater (*e.g.*, 30 to 39.9 kg/m^2 or 30 kg/m^2 to 50 kg/m^2). The ALK4:ActRIIB heteromultimer is administered alone or as a combination therapy. In some embodiments, the ALK4:ActRIIB heteromultimer treatment is an adjunct to diet and/or exercise.

In one embodiment the disclosure provides a method of reducing body weight in an obese subject. The method includes administering to the subject an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the subject has a BMI of 30 kg/m^2 or greater (*e.g.*, 30 to 39.9 kg/m^2 or 30 kg/m^2 to 50 kg/m^2). In some embodiments, the subject has a BMI of 40 kg/m^2 or greater. In some embodiments, the subject has central obesity (*e.g.*, excess adiposity in the abdominal region, including belly fat and/or visceral fat). In some

embodiments, the subject has a waist/hip circumference ratio (WHR) of 0.85 or greater. In some embodiments, the subject has peripheral obesity (*e.g.*, excess adiposity on the hips). In some embodiments, the ALK4:ActRIIB heteromultimer treatment is an adjunct to diet and/or exercise.

5 In another embodiment, the disclosure provides a method of treating and/or ameliorating obesity or a disease or condition associated with obesity, comprising administering to an obese subject, an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the subject has a BMI of 30 kg/m² or greater. In further embodiments, the subject has a BMI of 30 to 39.9 kg/m² or 30 kg/m² to 50 kg/m². In some embodiments, 10 the subject is morbidly obese. In some embodiments, the subject has a body BMI of 40 kg/m² or greater. In further embodiments, the subject has a BMI of 40 kg/m² to 45 kg/m², or 40 kg/m² to 50 kg/m². In some embodiments, the subject has type 2 diabetes mellitus. In some embodiments, the subject has a BMI of 30 kg/m² or greater (*e.g.*, 30 to 39.9 kg/m²). In some embodiments, the subject has a BMI of at least 40 kg/m². In some embodiments, the subject 15 has central obesity (*e.g.*, excess adiposity in the abdominal region, including belly fat and/or visceral fat). In some embodiments, the subject has a waist/hip circumference ratio (WHR) of 0.85 or greater. In some embodiments, the subject has peripheral obesity (*e.g.*, excess adiposity on the hips). In some embodiments, the ALK4:ActRIIB heteromultimer treatment is an adjunct to diet and/or exercise.

20 Also provided is a method of treating or preventing a disease or condition associated with obesity, comprising administering to a subject in need of treatment or prevention, an effective amount of an ALK4:ActRIIB heteromultimer. In one embodiment, the treated or prevented disease or condition is a member selected from the group consisting of: dyslipidemia, hyperlipidemia (total cholesterol level >240 mg/dL), hypercholesterolemia 25 (*e.g.*, total cholesterol level of >200 mg/dL, >220 mg/dL, >240 mg/dL, >250 mg/dL, or >275 mg/dL), low HDL serum level (*e.g.*, <40mg/dL, <45 mg/dL, or <50 mg/dL), high LDL serum level (*e.g.*, ≥ 100 mg/dL, ≥ 130 mg/dL, ≥ 160 mg/dL, or ≥ 190 mg/dL), and hypertriglyceridemia (*e.g.*, a fasting TG level of ≥ 150 mg/dL, ≥ 175 mg/dL, ≥ 200 mg/dL, ≥ 300 mg/dL, ≥ 400 mg/dL, or ≥ 499 mg/dL). In one embodiment, the treated or prevented 30 disease or condition is cardiovascular disease. In an additional embodiment, the treated or prevented disease or condition is hypertension (high blood pressure), myocardial infarction, peripheral artery disease, vasoregulation dysfunction, arteriosclerosis congestive heart failure, atherosclerosis, coronary heart disease, or microvascular disease. In one embodiment, the treated or prevented disease or condition is liver disease. In one embodiment, the treated or

prevented liver disease or condition is NAFLD. In one embodiment, the liver disease is fatty liver. In one embodiment, the liver disease is NASH. In another embodiment, the treated or prevented disease or condition is a member selected from the group: steatohepatitis, steatosis, fibrosis, and/or cirrhosis. In certain instances, the ALK4:ActRIIB heteromultimer treatment
5 is an adjunct to diet and/or exercise.

In another embodiment, the disclosure provides a method of treating, ameliorating, and/or preventing type 2 diabetes mellitus or a disease or condition associated with diabetes comprising administering to a subject having type 2 diabetes mellitus, or at risk of developing type 2 diabetes, an effective amount of an heteromultimer. In some embodiments, the subject
10 has a body mass index BMI of 30 kg/m² or greater (*e.g.*, 30 to 39.9 kg/m²). In some embodiments, the subject has a BMI of at least 40 kg/m². In some embodiments, the subject has central obesity (*e.g.*, excess adiposity in the abdominal region, including belly fat and/or visceral fat). In some embodiments, the subject has a WHR of 0.85 or greater. In some embodiments, the subject has peripheral obesity (*e.g.*, excess adiposity on the hips). In some
15 embodiments, the ALK4:ActRIIB heteromultimer treatment is an adjunct to diet and/or exercise.

Also provided is a method of treating, ameliorating or preventing a disease or condition associated with diabetes, comprising administering to a subject having diabetes, an effective amount of an ALK4:ActRIIB heteromultimer. In one embodiment, the treated or
20 prevented disease or condition is a member selected from the group consisting of: dyslipidemia, hyperlipidemia (total cholesterol level >240 mg/dL), hypercholesterolemia (*e.g.*, total cholesterol level of >200 mg/dL, >220 mg/dL, >240 mg/dL, >250 mg/dL, or >275 mg/dL), low HDL serum level (*e.g.*, <40mg/dL, <45 mg/dL, or <50 mg/dL), high LDL serum level (*e.g.*, ≥ 100 mg/dL, ≥ 130 mg/dL, ≥ 160 mg/dL, or ≥ 190 mg/dL), and
25 hypertriglyceridemia (*e.g.*, a fasting TG level of ≥ 150 mg/dL, ≥ 175 mg/dL, ≥ 200 mg/dL, ≥ 300 mg/dL, ≥ 400 mg/dL, or ≥ 499 mg/dL). In one embodiment, the treated or prevented disease or condition is cardiovascular disease. In an additional embodiment, the treated or prevented disease or condition is hypertension (high blood pressure), myocardial infarction, peripheral artery disease, vasoregulation dysfunction, or arteriosclerosis. In one embodiment,
30 the treated or prevented disease or condition is liver disease. In another embodiment, the treated or prevented disease or condition is a member selected from the group: fatty liver disease, steatohepatitis, steatosis, and/or cirrhosis. In one embodiment, the treated or prevented disease or condition is a member selected from the group consisting of: cataracts, obstructive sleep apnea, phlebitis, gout, osteoarthritis, gallbladder disease, and high

cholesterol. In certain instances, the ALK4:ActRIIB heteromultimer treatment is an adjunct to diet and/or exercise.

The disclosure also provides a method for improving the blood-lipid profile in a subject, comprising administering to a subject in need of such treatment an effective amount
5 of an ALK4:ActRIIB heteromultimer. In some embodiments, the disclosure provides a method for reducing levels of LDL cholesterol or increasing levels of HDL-cholesterol. In one embodiment, the subject has dyslipidemia. In another embodiment, the subject has elevated serum lipids (*e.g.*, cholesterol (hypercholesterolemia) and/or triglycerides (*e.g.*, hypertriglyceridemia). In one embodiment the subject has an LDL-C ≥ 100 mg/dL, ≥ 130
10 mg/dL, or ≥ 160 mg/dL). In one embodiment the subject has a TG ≥ 150 mg/dL, ≥ 160 mg/dL, ≥ 170 mg/dL). In one embodiment, the subject has elevated plasma insulin levels (hyperinsulinemia; *e.g.*, fasting insulin level of >20 ug/ml can exceed 100). In some embodiments, the subject has type II diabetes.

According to one embodiment, the disclosure provides a method of treating or
15 preventing a metabolic disease or disorder or a condition associated with a metabolic disease or disorder, comprising administering an ALK4:ActRIIB heteromultimer to a subject in need thereof. In one embodiment, the treated metabolic disease, disorder, or condition is hyperglycemia (*e.g.*, > 130 mg/dL in the fasting state or following glucose administration during an oral glucose tolerance test). In one embodiment, the treated metabolic disease,
20 disorder, or condition is a lipid metabolism disease, disorder, or condition. In one embodiment, the treated metabolic disease, disorder, or condition is dislipidemia. In a further embodiment, the lipid metabolism disease, disorder, or condition is a member selected from: low HDL levels, high LDL levels, high triglyceride levels, hyperlipidemia, and a lipoprotein aberration. In one embodiment, the subject has a total cholesterol level of >200 mg/dL, >220
25 mg/dL, >240 mg/dL, >250 mg/dL, or >275 mg/dL. In one embodiment, the subject has a HDL serum level of <40 mg/dL, <45 mg/dL, or <50 mg/dL). In one embodiment, the subject has a LDL serum level ≥ 100 mg/dL, ≥ 130 mg/dL, ≥ 160 mg/dL, or ≥ 190 mg/dL. In one embodiment, the subject has fasting TG level of ≥ 150 mg/dL, ≥ 175 mg/dL, ≥ 200 mg/dL, ≥ 300 mg/dL, ≥ 400 mg/dL, or ≥ 499 mg/dL. In one embodiment, the treated metabolic
30 disease, disorder, or condition is a glucose metabolism disease, disorder, or condition. In a further embodiment, the glucose metabolism disease, disorder, or condition is a member selected from: glucose intolerance, insulin resistance, impaired glucose tolerance (IGT), impaired fasting glucose (IFG). In one embodiment, the treated metabolic disease, disorder, or condition is a member selected from the group consisting of: high uric acid levels,

NAFLD, fatty liver, NASH, and polycystic ovarian syndrome. In one embodiment, the treated subject has hyperinsulinemia. In one embodiment, the treated subject is obese (*e.g.*, the subject has abdominal obesity). In another embodiment, the treated subject has type II diabetes.

5 Metabolic syndrome is a condition involving a set of disorders that enhances the risk of heart disease. The major components of metabolic syndrome are excess weight, the cardiovascular parameters (high blood pressure, dyslipidemia, high levels of triglycerides and/or low levels of HDL in the blood), atherosclerosis, diabetes, and/or insulin resistance. A subject having several of these components, *i.e.* metabolic syndrome, is highly prone to heart
10 disease, though each component is a risk factor. The disclosure also provides a method for treating or preventing 1, 2, 3, or more of the above components of metabolic syndrome, comprising administering to a subject in need of treatment an effective amount of an ALK4:ActRIIB heteromultimer.

Additionally provided is a method of treating, preventing or ameliorating a
15 cardiovascular disease or condition, comprising administering an ALK4:ActRIIB heteromultimer to a subject in need thereof. In one embodiment, the treated, prevented, or ameliorated cardiovascular disease or condition is atherosclerosis. In one embodiment, the treated, prevented, or ameliorated cardiovascular disease or condition is hypertension (*e.g.*, blood pressure >130/80 mmHg or >140/90 mmHg, in a resting state. In one embodiment, the
20 cardiovascular disease is atherosclerosis (coronary heart disease).

In one embodiment, the disclosure provides a method for treating and/or ameliorating an inflammatory liver disease or condition that comprises administering an ALK4:ActRIIB heteromultimer, to a subject in need thereof. In one embodiment, the disease or condition is NAFLD. In a further embodiment, the disease or condition is fatty liver. In a further
25 embodiment, the disease or condition is steatosis (*e.g.*, nonalcoholic steatohepatitis (NASH)). In a further embodiment, the disease or condition is alcoholic fatty liver disease.

This disclosure also provides a method of improving glycemic control, comprising administering to a subject in need of treatment an effective amount of an ALK4:ActRIIB heteromultimer. In one embodiment, the subject is administered has a fasting blood sugar
30 level of >130, >135, >140, >145, or >150 mg/dL. In one embodiment, the subject is administered has a postprandial blood sugar level of >180, >185, >190, >195, or >200 mg/dL 2 hours after eating. In certain instances, the ALK4:ActRIIB heteromultimer treatment is an adjunct to diet and/or exercise. The administration can also reduce body weight or treat obesity. In certain instances, the subject has type 2 diabetes mellitus. In certain instances,

the subject has a BMI of 27 to 40 kg/m². In certain instances, the subject has a BMI of 30 to 39.9 kg/m². In certain instances, the subject has a BMI of at least 40. In certain instances, the subject is overweight. In certain instances, the subject is obese. An improvement in glycemic control can be assessed using techniques known in the art such as a mixed-meal
5 test.

The disclosure also provides compositions and methods for treating, preventing or ameliorating hyperglycemia or a condition associated with hyperglycemia in a subject comprising administering to a subject in need of such treatment an effective amount of an ALK4:ActRIIB heteromultimer. In one embodiment, the subject is administered has a fasting
10 blood sugar level of >130, >135, >140, >145, or >150 mg/dL. In one embodiment, the subject is administered has a postprandial blood sugar level of >180, >185, >190, >195, or >200 mg/dL 2 hours after eating. In one embodiment, the result of the treatment, prevention or amelioration is a member selected from the group consisting of: a decrease in serum levels of glucose, a decrease in serum levels of triglycerides, a decrease in serum levels of insulin,
15 and/or a decrease in serum levels of non-esterified fatty acids, as compared to serum levels in the subject prior to treatment. In one embodiment, the result of the treatment, prevention or amelioration is an increase in body temperature of about 0.4°C to 1°C as compared to body temperature of the subject prior to treatment. In some embodiments, the ALK4:ActRIIB treatment also reduces body weight of the subject.

In another embodiment, the disclosure provides a method of decreasing plasma insulin levels in a subject, comprising administering an effective amount of an ALK4:ActRIIB heteromultimer to a subject in need of such treatment. In one embodiment, the subject has a fasting blood sugar level of >130, >135, >140, >145, or >150 mg/dL. In one
20 embodiment, the subject has a postprandial blood sugar level of >180, >185, >190, >195, or >200 mg/dL 2 hours after eating. In one embodiment, the subject is overweight. In one embodiment, the subject is obese. In another embodiment, the subject has type 2 diabetes.

The disclosure also provides compositions and methods for treating, preventing or ameliorating hyperglycemia or a condition associated with hyperglycemia in a subject comprising administering to a subject in need of such treatment an effective amount of an ALK4:ActRIIB heteromultimer. In one embodiment, the subject has a fasting blood sugar
30 level of >130, >135, >140, >145, or >150 mg/dL. In one embodiment, the subject has a postprandial blood sugar level of >180, >185, >190, >195, or >200 mg/dL 2 hours after eating. In one embodiment, the result of the treatment, prevention or amelioration is a member selected from the group consisting of: a decrease in serum levels of glucose, a

decrease in serum levels of triglycerides, a decrease in serum levels of insulin, and/or a decrease in serum levels of non-esterified fatty acids, as compared to serum levels in the subject prior to treatment. In one embodiment, the result of the treatment, prevention or amelioration is an increase in body temperature of about 0.4°C to 1°C as compared to body temperature of the subject prior to treatment. In some embodiments, the ALK4:ActRIIB heteromultimer treatment also reduces body weight of the subject.

In another embodiment, the disclosure provides a method of decreasing plasma insulin levels in a subject, comprising administering an effective amount of an ALK4:ActRIIB heteromultimer to a subject in need of such treatment. In one embodiment, the subject has a fasting blood sugar level of >130, >135, >140, >145, or >150 mg/dL. In one embodiment, the subject has a postprandial blood sugar level of >180, >185, >190, >195, or >200 mg/dL 2 hours after eating. In one embodiment, the subject is overweight. In one embodiment, the subject is obese. In another embodiment, the subject has type 2 diabetes.

In another embodiment, the disclosure provides a method of treating, preventing, or ameliorating liver disease in a subject, comprising administering an effective amount of an ALK4:ActRIIB heteromultimer to a subject having a liver disease. In one embodiment, the subject has inflammation of the liver. In one embodiment, the subject has NAFLD. In one embodiment the subject has fatty liver. In another embodiment, the subject has NASH. In one embodiment the subject has fatty liver. In another embodiment, the subject has alcoholic fatty liver disease. In one embodiment, the treated, prevented or ameliorated liver disease is fibrosis, scarring, cirrhosis, or liver failure. In another embodiment, the treated, prevented or ameliorated liver disease is liver cancer. In one embodiment, the subject is overweight. In another embodiment, the subject is obese. In another embodiment, the subject has type 2 diabetes.

Fibrosis generally refers to an excessive deposition of both collagen fibers and extracellular matrix combined with a relative decrease of cell number in an organ or tissue. While this process is an important feature of natural wound healing following injury, fibrosis can lead to pathological damage in various tissue and organs including, for example, the lungs, kidneys, liver, bone, muscle, and skin. The role TGF-beta in fibrosis has been extensively studied. However, other TGF-beta superfamily ligands have also been implicated in fibrosis including, for example, activins (e.g., activin A and activin B) and GDF8 [Hedger et al (2013) Cytokine and Growth Factor Reviews 24:285-295; Hardy et al. (2015) 93: 567-574; and Cantini et al. (2008) J Sex Med 5:1607-1622]. Therefore, in some embodiments, an

ALK4:ActRIIB heteromultimer of the present disclosure can be used to treat fibrosis, particularly fibrosis-associated disorders and conditions. For example, an ALK4:ActRIIB heteromultimer may be used to treat or prevent one or more of: pulmonary fibrosis, hypersensitivity pneumonitis, idiopathic fibrosis, tuberculosis, pneumonia, cystic fibrosis, asthma, chronic obstructive pulmonary disease (COPD), emphysema, renal (kidney) fibrosis, renal (kidney) failure, chronic renal (kidney) disease, bone fibrosis, myelofibrosis, rheumatoid arthritis, systemic lupus erythematosus, scleroderma, sarcoidosis, granulomatosis with polyangiitis, Peyronie's disease, liver fibrosis, Wilson's disease, glycogen storage diseases (particularly types III, IV, IX, and X), iron-overload, Gaucher disease, Zellweger syndrome, nonalcoholic and alcoholic steatohepatitis, biliary cirrhosis, sclerosing cholangitis, Budd-Chiari syndrome, surgery-associated fibrosis, Crohn's disease, Duputren's contracture, mediastinal fibrosis, nephrogenic fibrosis, retroperitoneal fibrosis, atrial fibrosis, endomyocardial fibrosis, pancreatic fibrosis and idiopathic pulmonary fibrosis.

The kidneys maintain many features of the blood, including volume, pH balance, electrolyte concentrations, and blood pressure, as well as bearing responsibility for toxin and waste filtration. These functions depend upon the intricate structure of the kidney nephrons, constant flow of blood through the various capillaries of the kidney, and the regulation of the kidney by signals from the rest of the body, including endocrine hormones. Problems with kidney function manifest by direct mechanisms (*e.g.* genetic defects, infection, or toxin exposure) and by indirect mechanisms progressively proceeding from long term stressors like hypertrophy and hyperfiltration (themselves often a result of more direct insults to kidney function). Due to the central role of the kidney in blood maintenance and waste secretion, kidney-associated disease manifestations are many and varied; they can be reviewed in Harrison's Principles of Internal Medicine, 18th edition, McGraw Hill, N.Y., Part 13, Chp 277-289.

As described herein, an ALK4:ActRIIB heteromultimer had various beneficial effects in a kidney disease model. In particular, treatment with an ALK4:ActRIIB heteromultimer reduced kidney tissue damage, inflammation, and fibrosis in subjects having unilateral ureteral obstruction. These data indicate that ALK4:ActRIIB heteromultimer may be used to treat or prevent kidney disease, particularly treating or preventing various complications (manifestations) of kidney disease including, for example, kidney tissue damage, inflammation, and/or fibrosis.

Therefore, methods of this invention can be applied to various kidney-associated diseases or conditions. As used herein, "kidney-associated disease or condition" can refer to any disease, disorder, or condition that affects the kidneys or the renal system. Examples of kidney-associated diseases or conditions include, but are not limited to, chronic kidney

5 diseases (or failure), acute kidney diseases (or failure), primary kidney diseases, non-diabetic kidney diseases, glomerulonephritis, interstitial nephritis, diabetic kidney diseases, diabetic nephropathy, glomerulosclerosis, rapid progressive glomerulonephritis, renal fibrosis, Alport syndrome, IDDM nephritis, mesangial proliferative glomerulonephritis, membranoproliferative glomerulonephritis, crescentic glomerulonephritis, renal interstitial

10 fibrosis, focal segmental glomerulosclerosis, membranous nephropathy, minimal change disease, pauci-immune rapid progressive glomerulonephritis, IgA nephropathy, polycystic kidney disease, Dent's disease, nephrocytinosis, Heymann nephritis, autosomal dominant (adult) polycystic kidney disease, autosomal recessive (childhood) polycystic kidney disease, acute kidney injury, nephrotic syndrome, renal ischemia, podocyte diseases or disorders,

15 proteinuria, glomerular diseases, membranous glomerulonephritis, focal segmental glomerulonephritis, pre-eclampsia, eclampsia, kidney lesions, collagen vascular diseases, benign orthostatic (postural) proteinuria, IgM nephropathy, membranous nephropathy, sarcoidosis, diabetes mellitus, kidney damage due to drugs, Fabry's disease, aminoaciduria, Fanconi syndrome, hypertensive nephrosclerosis, interstitial nephritis, Sickle cell disease,

20 hemoglobinuria, myoglobinuria, Wegener's Granulomatosis, Glycogen Storage Disease Type 1, chronic kidney disease, chronic renal failure, low Glomerular Filtration Rate (GFR), nephroangiosclerosis, lupus nephritis, ANCA-positive pauci-immune crescentic glomerulonephritis, chronic allograft nephropathy, nephrotoxicity, renal toxicity, kidney necrosis, kidney damage, glomerular and tubular injury, kidney dysfunction, nephritic

25 syndrome, acute renal failure, chronic renal failure, proximal tubal dysfunction, acute kidney transplant rejection, chronic kidney transplant rejection, non-IgA mesangioproliferative glomerulonephritis, postinfectious glomerulonephritis, vasculitides with renal involvement of any kind, any hereditary renal disease, any interstitial nephritis, renal transplant failure, kidney cancer, kidney disease associated with other conditions (e.g., hypertension, diabetes,

30 and autoimmune disease), Dent's disease, nephrocytinosis, Heymann nephritis, a primary kidney disease, a collapsing glomerulopathy, a dense deposit disease, a cryoglobulinemia-associated glomerulonephritis, an Henoch-Schonlein disease, a postinfectious glomerulonephritis, a bacterial endocarditis, a microscopic polyangitis, a Churg-Strauss syndrome, an anti-GBM-antibody mediated glomerulonephritis, amyloidosis, a monoclonal

immunoglobulin deposition disease, a fibrillary glomerulonephritis, an immunotactoid glomerulopathy, ischemic tubular injury, a medication-induced tubulo-interstitial nephritis, a toxic tubulo-interstitial nephritis, an infectious tubulo-interstitial nephritis, a bacterial pyelonephritis, a viral infectious tubulo-interstitial nephritis which results from a

5 polyomavirus infection or an HIV infection, a metabolic-induced tubulo-interstitial disease, a mixed connective disease, a cast nephropathy, a crystal nephropathy which may results from urate or oxalate or drug-induced crystal deposition, an acute cellular tubulo-interstitial allograft rejection, a tumoral infiltrative disease which results from a lymphoma or a post-transplant lymphoproliferative disease, an obstructive disease of the kidney, vascular disease,

10 a thrombotic microangiopathy, a nephroangiosclerosis, an atheroembolic disease, a mixed connective tissue disease, a polyarteritis nodosa, a calcineurin-inhibitor induced-vascular disease, an acute cellular vascular allograft rejection, an acute humoral allograft rejection, early renal function decline (ERFD), end stage renal disease (ESRD), renal vein thrombosis, acute tubular necrosis, acute interstitial nephritis, established chronic kidney disease, renal

15 artery stenosis, ischemic nephropathy, uremia, drug and toxin-induced chronic tubulointerstitial nephritis, reflux nephropathy, kidney stones, Goodpasture's syndrome, normocytic normochromic anemia, renal anemia, diabetic chronic kidney disease, IgG4-related disease, von Hippel-Lindau syndrome, tuberous sclerosis, nephronophthisis, medullary cystic kidney disease, renal cell carcinoma, adenocarcinoma, nephroblastoma,

20 lymphoma, leukemia, hyposialylation disorder, chronic cyclosporine nephropathy, renal reperfusion injury, renal dysplasia, azotemia, bilateral arterial occlusion, acute uric acid nephropathy, hypovolemia, acute bilateral obstructive uropathy, hypercalcemic nephropathy, hemolytic uremic syndrome, acute urinary retention, malignant nephrosclerosis, postpartum glomerulosclerosis, scleroderma, non-Goodpasture's anti-GBM disease, microscopic

25 polyarteritis nodosa, allergic granulomatosis, acute radiation nephritis, post-streptococcal glomerulonephritis, Waldenstrom's macroglobulinemia, analgesic nephropathy, arteriovenous fistula, arteriovenous graft, dialysis, ectopic kidney, medullary sponge kidney, renal osteodystrophy, solitary kidney, hydronephrosis, microalbuminuria, uremia, haematuria, hyperlipidemia, hypoalbuminaemia, lipiduria, acidosis, hyperkalemia, and edema.

30 In some embodiments, an ALK4:ActRIIB heteromultimer of the present disclosure may be used to treat or prevent chronic kidney disease, optionally in combination with one or more supportive therapies for treating chronic kidney disease. In some embodiments, an ALK4:ActRIIB heteromultimer of the present disclosure may be used to treat or prevent one

or more complications (symptoms or manifestations) of chronic kidney disease, optionally in combination with one or more supportive therapies for treating chronic kidney disease. In some embodiments, an ALK4:ActRIIB heteromultimer of the present disclosure may be used to treat or prevent end-stage kidney failure, optionally in combination with one or more

5 supportive therapies for treating end-stage kidney disease. Chronic kidney disease (CKD), also known as chronic renal disease, is a progressive loss in renal function over a period of months or years. The symptoms of worsening kidney function may include feeling generally unwell and experiencing a reduced appetite. Often, chronic kidney disease is diagnosed as a result of screening of people known to be at risk of kidney problems, such as those with high

10 blood pressure or diabetes and those with a blood relative with CKD. This disease may also be identified when it leads to one of its recognized complications, such as cardiovascular disease, anemia, or pericarditis. Recent professional guidelines classify the severity of CKD in five stages, with stage 1 being the mildest and usually causing few symptoms and stage 5 being a severe illness with poor life expectancy if untreated. Stage 5 CKD is often called

15 end-stage kidney disease, end-stage renal disease, or end-stage kidney failure, and is largely synonymous with the now outdated terms chronic renal failure or chronic kidney failure; and usually means the patient requires renal replacement therapy, which may involve a form of dialysis, but ideally constitutes a kidney transplant. CKD is initially without specific symptoms and is generally only detected as an increase in serum creatinine or protein in the

20 urine. As the kidney function decreases and various symptoms may manifest as described below. Blood pressure may be increased due to fluid overload and production of vasoactive hormones created by the kidney via the renin-angiotensin system, increasing one's risk of developing hypertension and/or suffering from congestive heart failure. Urea may accumulate, leading to azotemia and ultimately uremia (symptoms ranging from lethargy to

25 pericarditis and encephalopathy). Due to its high systemic circulation, urea is excreted in eccrine sweat at high concentrations and crystallizes on skin as the sweat evaporates ("uremic frost"). Potassium may accumulate in the blood (hyperkalemia with a range of symptoms including malaise and potentially fatal cardiac arrhythmias). Hyperkalemia usually does not develop until the glomerular filtration rate falls to less than 20-25 ml/min/1.73 m², at which

30 point the kidneys have decreased ability to excrete potassium. Hyperkalemia in CKD can be exacerbated by acidemia (which leads to extracellular shift of potassium) and from lack of insulin. Erythropoietin synthesis may be decreased causing anemia. Fluid volume overload symptoms may occur, ranging from mild edema to life-threatening pulmonary edema. Hyperphosphatemia, due to reduced phosphate excretion, may occur generally following the

decrease in glomerular filtration. Hyperphosphatemia is associated with increased cardiovascular risk, being a direct stimulus to vascular calcification. Hypocalcemia may manifest, which is generally caused by stimulation of fibroblast growth factor-23. Osteocytes are responsible for the increased production of FGF23, which is a potent inhibitor of the enzyme 1-alpha-hydroxylase (responsible for the conversion of 25-hydroxycholecalciferol into 1,25 dihydroxyvitamin D3). Later, this progresses to secondary hyperparathyroidism, renal osteodystrophy, and vascular calcification that further impairs cardiac function. Metabolic acidosis (due to accumulation of sulfates, phosphates, uric acid etc.) may occur and cause altered enzyme activity by excess acid acting on enzymes; and also increased excitability of cardiac and neuronal membranes by the promotion of hyperkalemia due to excess acid (acidemia). Acidosis is also due to decreased capacity to generate enough ammonia from the cells of the proximal tubule. Iron deficiency anemia, which increases in prevalence as kidney function decreases, is especially prevalent in those requiring haemodialysis. It is multifactorial in cause, but includes increased inflammation, reduction in erythropoietin, and hyperuricemia leading to bone marrow suppression. People with CKD suffer from accelerated atherosclerosis and are more likely to develop cardiovascular disease than the general population. Patients afflicted with CKD and cardiovascular disease tend to have significantly worse prognoses than those suffering only from the latter.

As used herein, “in combination with”, “combinations of”, or “conjoint administration” refers to any form of administration such that additional therapies (e.g., second, third, fourth, etc.) are still effective in the body (e.g., multiple compounds are simultaneously effective in the patient, which may include synergistic effects of those compounds). Effectiveness may not correlate to measurable concentration of the agent in blood, serum, or plasma. For example, the different therapeutic compounds can be administered either in the same formulation or in separate formulations, either concomitantly or sequentially, and on different schedules. Thus, an individual who receives such treatment can benefit from a combined effect of different therapies. One or more ALK4:ActRIIB heteromultimer of the disclosure can be administered concurrently with, prior to, or subsequent to, one or more other additional agents or supportive therapies. In general, each therapeutic agent will be administered at a dose and/or on a time schedule determined for that particular agent. The particular combination to employ in a regimen will take into account compatibility of the antagonist of the present disclosure with the therapy and/or the desired.

In some embodiments, if a patient has Duchenne Muscular Dystrophy or Becker Muscular Dystrophy, any of the ALK4:ActRIIB heteromultimers disclosed herein may be administered in combination with one or more of: eteplirsen, a corticosteroid (*e.g.*, deflazacourt), steroids (*e.g.*, prednisone), a blood pressure and/or heart medication (*e.g.*, angiotensin converting enzyme inhibitors, beta blockers, and diuretics), an anti-asthmatic (*e.g.*, albuterol), a vitamin/neutrient/antioxidant (*e.g.*, amino acids, carnitine, coenzyme Q10, creatine, fish oil, green tea extracts, vitamin E), surgery, physical therapy, stem cell therapy, gene therapy, assisted ventilation, diet and/or exercise.

In some embodiments, if a patient has facioscapulohumeral muscular dystrophy, any of the ALK4:ActRIIB heteromultimers disclosed herein may be administered in combination with one or more of: albuterol, speech therapy, surgery, walking aid, back brace, a T-cell inhibitor (*e.g.*, truncated histidyl-tRNA synthetase), stem cell therapy, gene therapy, and/or foot support devices.

In some embodiments, if a patient has amyotrophic lateral sclerosis, any of the ALK4:ActRIIB heteromultimers disclosed herein may be administered in combination with one or more of: riluzole, edaravone, masitinib, an antioxidant, physical therapy, speech therapy, nutritional support, breathing support (*e.g.*, a non-invasive ventilator), stem cell therapy, and/or gene therapy.

In some embodiments, if a patient has sporadic inclusion body myositis, any of the ALK4:ActRIIB heteromultimers disclosed herein may be administered in combination with one or more of: corticosteroids, prednisone, oxandrolone, methotrexate, mycophenolate mofetil, intravenous immunoglobulin, beta interferon-1a, etanercept, alemtuzumab, follistatin, lithium, bimagrumab, arimoclomol, rapamycin, antioxidants, carnitine, coenzyme Q10, physical therapy, occupational therapy, stem cell therapy, and/or gene therapy.

In some embodiments, if a patient has Alport Syndrome, any of the ALK4:ActRIIB heteromultimers disclosed herein may be administered in combination with one or more of: an angiotensin converting enzyme (ACE) inhibitor (*e.g.*, benazepril, cilazapril, enalapril, fosinopril, Lisinopril, perinopril, ramapril and quinapril), an angiotensin receptor blocker (*e.g.*, candesartan, epresartan, irbesartan, losartan, telmisartan and valsartan), a statin (*e.g.*, fluvastatin), a non-dihydropyridine calcium channel blocker (*e.g.*, diltiazem), cyclosporine, and/or aldosterone inhibitors.

In some embodiments, if a patient has sarcopenia, any of the ALK4:ActRIIB heteromultimers disclosed herein may be administered in combination with one or more of: urocortin II, hormone replacement therapy (*e.g.*, testosterone or human growth hormone), creatine, vitamin D, exercise, diet, and/or strength training.

5 Pulmonary hypertension (PH) has been previously classified as primary (idiopathic) or secondary. Recently, the World Health Organization (WHO) has classified pulmonary hypertension into five groups: Group 1: pulmonary arterial hypertension (PAH); Group 2: pulmonary hypertension with left heart disease; Group 3: pulmonary hypertension with lung disease and/or hypoxemia; Group 4: pulmonary hypertension due to chronic thrombotic
10 and/or embolic disease; and Group 5: miscellaneous conditions (*e.g.*, sarcoidosis, histiocytosis X, lymphangiomatosis and compression of pulmonary vessels). See, for example, Rubin (2004) Chest 126:7-10.

In certain aspects, the disclosure relates to methods of treating, preventing, or reducing the progression rate and/or severity of pulmonary hypertension (*e.g.*, treating,
15 preventing, or reducing the progression rate and/or severity of one or more complications of pulmonary hypertension) comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the method relates to pulmonary hypertension patients that have pulmonary arterial hypertension. In some
20 embodiments, the method relates pulmonary hypertension patients that have pulmonary hypertension with left heart disease. In some embodiments, the method relates to pulmonary hypertension patients that have lung disease and/or hypoxemia. In some embodiments, the method relates to pulmonary hypertension patients that have chronic thrombotic and/or
25 embolic disease. In some embodiments, the method relates to pulmonary hypertension patients that have sarcoidosis, histiocytosis X, or lymphangiomatosis and compression of pulmonary vessels.

Pulmonary arterial hypertension is a serious, progressive and life-threatening disease of the pulmonary vasculature, characterized by profound vasoconstriction and an abnormal proliferation of smooth muscle cells in the walls of the pulmonary arteries. Severe constriction of the blood vessels in the lungs leads to very high pulmonary arterial pressures.
30 These high pressures make it difficult for the heart to pump blood through the lungs to be oxygenated. Patients with PAH suffer from extreme shortness of breath as the heart struggles to pump against these high pressures. Patients with PAH typically develop significant increases in pulmonary vascular resistance (PVR) and sustained elevations in pulmonary

artery pressure (PAP), which ultimately lead to right ventricular failure and death. Patients diagnosed with PAH have a poor prognosis and equally compromised quality of life, with a mean life expectancy of 2 to 5 years from the time of diagnosis if untreated.

A variety of factors contribute to the pathogenesis of pulmonary hypertension including proliferation of pulmonary cells which can contribute to vascular remodeling (i.e., hyperplasia). For example, pulmonary vascular remodeling occurs primarily by proliferation of arterial endothelial cells and smooth muscle cells of patients with pulmonary hypertension. Overexpression of various cytokines is believed to promote pulmonary hypertension. Further, it has been found that pulmonary hypertension may rise from the hyperproliferation of pulmonary arterial smooth cells and pulmonary endothelial cells. Still further, advanced PAH may be characterized by muscularization of distal pulmonary arterioles, concentric intimal thickening, and obstruction of the vascular lumen by proliferating endothelial cells. Pietra et al., J. Am. Coll. Cardiol., 43:255-325 (2004).

In certain aspects, the disclosure relates to methods of treating, preventing, or reducing the progression rate and/or severity of pulmonary hypertension (e.g., treating, preventing, or reducing the progression rate and/or severity of one or more complications of pulmonary hypertension) comprising administering to a patient in need thereof an effective amount an ALK4:ActRIIB heteromultimer, wherein the patient has resting pulmonary arterial pressure (PAP) of at least 25 mm Hg (e.g., 25, 30, 35, 40, 45, or 50 mm Hg). In some embodiments, the method relates to patients having a resting PAP of at least 25 mm Hg. In some embodiments, the method relates to patients having a resting PAP of at least 30 mm Hg. In some embodiments, the method relates to patients having a resting PAP of at least 35 mm Hg. In some embodiments, the method relates to patients having a resting PAP of at least 40 mm Hg. In some embodiments, the method relates to patients having a resting PAP of at least 45 mm Hg. In some embodiments, the method relates to patients having a resting PAP of at least 50 mm Hg.

In some embodiments, the disclosure relates to methods of adjusting one or more hemodynamic parameters in the PH patient toward a more normal level (e.g., normal as compared to healthy people of similar age and sex), comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the method relates to reducing PAP. In some embodiments, the method relates to reducing the patient's PAP by at least 3 mmHg. In certain embodiments, the method relates to reducing the patient's PAP by at least 5 mmHg. In certain embodiments, the

method relates to reducing the patient's PAP by at least 7 mmHg. In certain embodiments, the method relates to reducing the patient's PAP by at least 10 mmHg. In certain embodiments, the method relates to reducing the patient's PAP by at least 12 mmHg. In certain embodiments, the method relates to reducing the patient's PAP by at least 15 mmHg.

5 In certain embodiments, the method relates to reducing the patient's PAP by at least 20 mmHg. In certain embodiments, the method relates to reducing the patient's PAP by at least 25 mmHg. In some embodiments, the method relates to reducing pulmonary vascular resistance (PVR). In some embodiments, the method relate to increasing pulmonary capillary wedge pressure (PCWP). In some embodiments, the method relate to increasing left
10 ventricular end-diastolic pressure (LVEDP).

In certain aspects, the disclosure relates to methods of treating, preventing, or reducing the progression rate and/or severity of one or more complications of pulmonary hypertension comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer. In some embodiments, the method relates to treating,
15 preventing, or reducing the progression rate and/or severity of cell proliferation in the pulmonary artery of a pulmonary hypertension patient. In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of smooth muscle and/or endothelial cells proliferation in the pulmonary artery of a pulmonary hypertension patient. In some embodiments, the method relates to treating, preventing, or
20 reducing the progression rate and/or severity of angiogenesis in the pulmonary artery of a pulmonary hypertension patient. In some embodiments, the method relates to increasing physical activity of a patient having pulmonary hypertension. In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of dyspnea in a pulmonary hypertension patient. In some embodiments, the method relates to
25 treating, preventing, or reducing the progression rate and/or severity of chest pain in a pulmonary hypertension patient. In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of fatigue in a pulmonary hypertension patient. In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of pulmonary fibrosis in a pulmonary
30 hypertension patient. In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of fibrosis in a pulmonary hypertension patient. In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of pulmonary vascular remodeling in a pulmonary hypertension patient.

In some embodiments, the method relates to treating, preventing, or reducing the progression rate and/or severity of right ventricular hypertrophy in a pulmonary hypertension patient.

In certain aspects, the disclosure relates to methods of increasing exercise capacity in a patient having pulmonary hypertension comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer. Any suitable measure of exercise capacity can be used. For example, exercise capacity in a 6-minute walk test (6MWT), which measures how far the subject can walk in 6 minutes, i.e., the 6-minute walk distance (6MWD), is frequently used to assess pulmonary hypertension severity and disease progression. The Borg dyspnea index (BDI) is a numerical scale for assessing perceived dyspnea (breathing discomfort). It measures the degree of breathlessness, for example, after completion of the 6MWT, where a BDI of 0 indicates no breathlessness and 10 indicates maximum breathlessness. In some embodiments, the method relates to increasing 6MWD by at least 10 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 20 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 30 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 40 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 50 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 60 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 70 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 80 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 90 meters in the patient having pulmonary hypertension. In some embodiments, the method relates to increasing 6MWD by at least 100 meters in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 0.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 1 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 1.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 2 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 2.5 index

points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 3 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 3.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 4 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 4.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 5.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 6 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 6.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 7 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 7.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 8 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 8.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 9 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 9.5 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by at least 3 index points in the patient having pulmonary hypertension. In some embodiments, the method relate to lowering BDI by 10 index points in the patient having pulmonary hypertension.

Pulmonary hypertension at baseline can be mild, moderate or severe, as measured for example by World Health Organization (WHO) functional class, which is a measure of disease severity in patients with pulmonary hypertension. The WHO functional classification is an adaptation of the New York Heart Association (NYHA) system and is routinely used to qualitatively assess activity tolerance, for example in monitoring disease progression and response to treatment (Rubin (2004) Chest 126:7-10). Four functional classes are recognized in the WHO system: Class I: pulmonary hypertension without resulting limitation of physical activity; ordinary physical activity does not cause undue dyspnea or fatigue, chest pain or

near syncope; Class II: pulmonary hypertension resulting in slight limitation of physical activity; patient comfortable at rest; ordinary physical activity causes undue dyspnea or fatigue, chest pain or near syncope; Class III: pulmonary hypertension resulting in marked limitation of physical activity; patient comfortable at rest; less than ordinary activity causes undue dyspnea or fatigue, chest pain or near syncope; Class IV: pulmonary hypertension resulting in inability to carry out any physical activity without symptoms; patient manifests signs of right-heart failure; dyspnea and/or fatigue may be present even at rest; discomfort is increased by any physical activity.

In certain aspects, the disclosure relates to methods of treating, preventing, or reducing the progression rate and/or severity of pulmonary hypertension (e.g., treating, preventing, or reducing the progression rate and/or severity of one or more complications of pulmonary hypertension) comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer, wherein the patient has Class I, Class II, Class III, or Class IV pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to a patient that has Class I pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to a patient that has Class II pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to preventing or delaying patient progression from Class I pulmonary hypertension to Class II pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to promoting or increasing patient regression from Class II pulmonary hypertension to Class I pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to a patient that has Class III pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to preventing or delaying patient progression from Class II pulmonary hypertension to Class III pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to promoting or increasing patient regression from Class III pulmonary hypertension to Class II pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to promoting or increasing patient regression from Class III pulmonary hypertension to Class I pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to a patient that has Class IV pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to preventing or delaying patient progression from Class III pulmonary hypertension to Class IV pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to promoting or increasing patient

regression from Class IV pulmonary hypertension to Class III pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to promoting or increasing patient regression from Class IV pulmonary hypertension to Class II pulmonary hypertension as recognized by the WHO. In some embodiments, the method relates to promoting or increasing patient regression from Class IV pulmonary hypertension to Class I pulmonary hypertension as recognized by the WHO.

There is no known cure for pulmonary hypertension; current methods of treatment focus on prolonging patient lifespan and enhancing patient quality of life. Current methods of treatment of pulmonary hypertension include administration of: vasodilators such as prostacyclin, epoprostenol, and sildenafil; endothelin receptor antagonists such as bosentan; calcium channel blockers such as amlodipine, diltiazem, and nifedipine; anticoagulants such as warfarin; and diuretics. Treatment of pulmonary hypertension has also been carried out using oxygen therapy, atrial septostomy, pulmonary thromboendarterectomy, and lung and/or heart transplantation. Each of these methods, however, suffers from one or multiple drawbacks which may include lack of effectiveness, serious side effects, low patient compliance, and high cost. In certain aspects, the method relate to treating, preventing, or reducing the progression rate and/or severity of pulmonary hypertension (e.g., treating, preventing, or reducing the progression rate and/or severity of one or more complications of pulmonary hypertension) comprising administering to a patient in need thereof an effective amount of an ALK4:ActRIIB heteromultimer in combination (e.g., administered at the same time or different times, but generally in such a manner as to achieve overlapping pharmacological/physiological effects) with one or more additional active agents and/or supportive therapies for treating pulmonary hypertension (e.g., vasodilators such as prostacyclin, epoprostenol, and sildenafil; endothelin receptor antagonists such as bosentan; calcium channel blockers such as amlodipine, diltiazem, and nifedipine; anticoagulants such as warfarin; diuretics; oxygen therapy; atrial septostomy; pulmonary thromboendarterectomy; and lung and/or heart transplantation); BMP9 polypeptides; BMP10 polypeptides; bardoxolone methyl or a derivative thereof; oleanolic acid or derivative thereof.

5. Pharmaceutical Compositions

In certain aspects, ALK4:ActRIIB heteromultimers of the present disclosure can be administered alone or as a component of a pharmaceutical formulation (also referred to as a

therapeutic composition or pharmaceutical composition). A pharmaceutical formation refers to a preparation which is in such form as to permit the biological activity of an active ingredient (*e.g.*, an agent of the present disclosure) contained therein to be effective and which contains no additional components which are unacceptably toxic to a subject to which the formulation would be administered. The subject compounds may be formulated for administration in any convenient way for use in human or veterinary medicine. For example, one or more agents of the present disclosure may be formulated with a pharmaceutically acceptable carrier. A pharmaceutically acceptable carrier refers to an ingredient in a pharmaceutical formulation, other than an active ingredient, which is generally nontoxic to a subject. A pharmaceutically acceptable carrier includes, but is not limited to, a buffer, excipient, stabilizer, and/or preservative. In general, pharmaceutical formulations for use in the present disclosure are in a pyrogen-free, physiologically-acceptable form when administered to a subject. Therapeutically useful agents other than those described herein, which may optionally be included in the formulation as described above, may be administered in combination with the subject agents in the methods of the present disclosure.

In certain embodiments, compositions will be administered parenterally [*e.g.*, by intravenous (I.V.) injection, intraarterial injection, intraosseous injection, intramuscular injection, intrathecal injection, subcutaneous injection, or intradermal injection]. Pharmaceutical compositions suitable for parenteral administration may comprise one or more agents of the disclosure in combination with one or more pharmaceutically acceptable sterile isotonic aqueous or nonaqueous solutions, dispersions, suspensions or emulsions, or sterile powders which may be reconstituted into sterile injectable solutions or dispersions just prior to use. Injectable solutions or dispersions may contain antioxidants, buffers, bacteriostats, suspending agents, thickening agents, or solutes which render the formulation isotonic with the blood of the intended recipient. Examples of suitable aqueous and nonaqueous carriers which may be employed in the pharmaceutical formulations of the present disclosure include water, ethanol, polyols (*e.g.*, glycerol, propylene glycol, polyethylene glycol, *etc.*), vegetable oils (*e.g.*, olive oil), injectable organic esters (*e.g.*, ethyl oleate), and suitable mixtures thereof. Proper fluidity can be maintained, for example, by the use of coating materials (*e.g.*, lecithin), by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants.

In some embodiments, a therapeutic method of the present disclosure includes administering the pharmaceutical composition systemically, or locally, from an implant or

device. Further, the pharmaceutical composition may be encapsulated or injected in a form for delivery to a target tissue site (*e.g.*, bone marrow or muscle). In certain embodiments, compositions of the present disclosure may include a matrix capable of delivering one or more of the agents of the present disclosure to a target tissue site (*e.g.*, bone marrow or muscle), providing a structure for the developing tissue and optimally capable of being resorbed into the body. For example, the matrix may provide slow release of one or more agents of the present disclosure. Such matrices may be formed of materials presently in use for other implanted medical applications.

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

In certain embodiments, pharmaceutical compositions of present disclosure can be administered topically. “Topical application” or “topically” means contact of the pharmaceutical composition with body surfaces including, for example, the skin, wound sites, and mucous membranes. The topical pharmaceutical compositions can have various application forms and typically comprises a drug-containing layer, which is adapted to be placed near to or in direct contact with the tissue upon topically administering the composition. Pharmaceutical compositions suitable for topical administration may comprise one or more one or more ALK4:ActRIIB heteromultimers of the disclosure in combination formulated as a liquid, a gel, a cream, a lotion, an ointment, a foam, a paste, a putty, a semi-solid, or a solid. Compositions in the liquid, gel, cream, lotion, ointment, foam, paste, or putty form can be applied by spreading, spraying, smearing, dabbing or rolling the

composition on the target tissue. The compositions also may be impregnated into sterile dressings, transdermal patches, plasters, and bandages. Compositions of the putty, semi-solid or solid forms may be deformable. They may be elastic or non-elastic (*e.g.*, flexible or rigid). In certain aspects, the composition forms part of a composite and can include fibers, particulates, or multiple layers with the same or different compositions.

Topical compositions in the liquid form may include pharmaceutically acceptable solutions, emulsions, microemulsions, and suspensions. In addition to the active ingredient(s), the liquid dosage form may contain an inert diluent commonly used in the art including, for example, water or other solvent, a solubilizing agent and/or emulsifier [*e.g.*, ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, or 1,3-butylene glycol, an oil (*e.g.*, cottonseed, groundnut, corn, germ, olive, castor, and sesame oil), glycerol, tetrahydrofuryl alcohol, a polyethylene glycol, a fatty acid ester of sorbitan, and mixtures thereof].

Topical gel, cream, lotion, ointment, semi-solid or solid compositions may include one or more thickening agents, such as a polysaccharide, synthetic polymer or protein-based polymer. In one embodiment of the invention, the gelling agent herein is one that is suitably nontoxic and gives the desired viscosity. The thickening agents may include polymers, copolymers, and monomers of: vinylpyrrolidones, methacrylamides, acrylamides N-vinylimidazoles, carboxy vinyls, vinyl esters, vinyl ethers, silicones, polyethyleneoxides, polyethyleneglycols, vinylalcohols, sodium acrylates, acrylates, maleic acids, NN-dimethylacrylamides, diacetone acrylamides, acrylamides, acryloyl morpholine, pluronic, collagens, polyacrylamides, polyacrylates, polyvinyl alcohols, polyvinylenes, polyvinyl silicates, polyacrylates substituted with a sugar (*e.g.*, sucrose, glucose, glucosamines, galactose, trehalose, mannose, or lactose), acylamidopropane sulfonic acids, tetramethoxyorthosilicates, methyltrimethoxyorthosilicates, tetraalkoxyorthosilicates, trialkoxyorthosilicates, glycols, propylene glycol, glycerine, polysaccharides, alginates, dextrans, cyclodextrin, celluloses, modified celluloses, oxidized celluloses, chitosans, chitins, guar, carrageenans, hyaluronic acids, inulin, starches, modified starches, agarose, methylcelluloses, plant gums, hylaronans, hydrogels, gelatins, glycosaminoglycans, carboxymethyl celluloses, hydroxyethyl celluloses, hydroxy propyl methyl celluloses, pectins, low-methoxy pectins, cross-linked dextrans, starch-acrylonitrile graft copolymers, starch sodium polyacrylate, hydroxyethyl methacrylates, hydroxyl ethyl acrylates, polyvinylene, polyethylvinylethers, polymethyl methacrylates, polystyrenes, polyurethanes, polyalkanoates,

polylactic acids, polylactates, poly(3-hydroxybutyrate), sulfonated hydrogels, AMPS (2-acrylamido-2-methyl-1-propanesulfonic acid), SEM (sulfoethylmethacrylate), SPM (sulfopropyl methacrylate), SPA (sulfopropyl acrylate), N,N-dimethyl-N-methacryloxyethyl-N-(3-sulfopropyl)ammonium betaine, methacrylic acid amidopropyl-dimethyl ammonium sulfobetaine, SPI (itaconic acid-bis(1-propyl sulfonizacid-3) ester di-potassium salt), itaconic acids, AMBC (3-acrylamido-3-methylbutanoic acid), beta-carboxyethyl acrylate (acrylic acid dimers), and maleic anhydride-methylvinyl ether polymers, derivatives thereof, salts thereof, acids thereof, and combinations thereof. In certain embodiments, pharmaceutical compositions of present disclosure can be administered orally, for example, in the form of capsules, cachets, pills, tablets, lozenges (using a flavored basis such as sucrose and acacia or tragacanth), powders, granules, a solution or a suspension in an aqueous or non-aqueous liquid, an oil-in-water or water-in-oil liquid emulsion, or an elixir or syrup, or pastille (using an inert base, such as gelatin and glycerin, or sucrose and acacia), and/or a mouth wash, each containing a predetermined amount of a compound of the present disclosure and optionally one or more other active ingredients. A compound of the present disclosure and optionally one or more other active ingredients may also be administered as a bolus, electuary, or paste.

In solid dosage forms for oral administration (*e.g.*, capsules, tablets, pills, dragees, powders, and granules), one or more compounds of the present disclosure may be mixed with one or more pharmaceutically acceptable carriers including, for example, sodium citrate, dicalcium phosphate, a filler or extender (*e.g.*, a starch, lactose, sucrose, glucose, mannitol, and silicic acid), a binder (*e.g.* carboxymethylcellulose, an alginate, gelatin, polyvinyl pyrrolidone, sucrose, and acacia), a humectant (*e.g.*, glycerol), a disintegrating agent (*e.g.*, agar-agar, calcium carbonate, potato or tapioca starch, alginic acid, a silicate, and sodium carbonate), a solution retarding agent (*e.g.* paraffin), an absorption accelerator (*e.g.* a quaternary ammonium compound), a wetting agent (*e.g.*, cetyl alcohol and glycerol monostearate), an absorbent (*e.g.*, kaolin and bentonite clay), a lubricant (*e.g.*, a talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate), a coloring agent, and mixtures thereof. In the case of capsules, tablets, and pills, the pharmaceutical formulation (composition) may also comprise a buffering agent. Solid compositions of a similar type may also be employed as fillers in soft and hard-filled gelatin capsules using one or more excipients including, *e.g.*, lactose or a milk sugar as well as a high molecular-weight polyethylene glycol.

Liquid dosage forms for oral administration of the pharmaceutical composition may include pharmaceutically acceptable emulsions, microemulsions, solutions, suspensions, syrups, and elixirs. In addition to the active ingredient(s), the liquid dosage form may contain an inert diluent commonly used in the art including, for example, water or other solvent, a solubilizing agent and/or emulsifier [*e.g.*, ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, or 1,3-butylene glycol, an oil (*e.g.*, cottonseed, groundnut, corn, germ, olive, castor, and sesame oil), glycerol, tetrahydrofuryl alcohol, a polyethylene glycol, a fatty acid ester of sorbitan, and mixtures thereof]. Besides inert diluents, the oral formulation can also include an adjuvant including, for example, a wetting agent, an emulsifying and suspending agent, a sweetening agent, a flavoring agent, a coloring agent, a perfuming agent, a preservative agent, and combinations thereof.

Suspensions, in addition to the active compounds, may contain suspending agents including, for example, an ethoxylated isostearyl alcohol, polyoxyethylene sorbitol, a sorbitan ester, microcrystalline cellulose, aluminum metahydroxide, bentonite, agar-agar, tragacanth, and combinations thereof.

Prevention of the action and/or growth of microorganisms may be ensured by the inclusion of various antibacterial and antifungal agents including, for example, paraben, chlorobutanol, and phenol sorbic acid.

In certain embodiments, it may be desirable to include an isotonic agent including, for example, a sugar or sodium chloride into the compositions. In addition, prolonged absorption of an injectable pharmaceutical form may be brought about by the inclusion of an agent that delay absorption including, for example, aluminum monostearate and gelatin.

It is understood that the dosage regimen will be determined by the attending physician considering various factors which modify the action of the one or more of the agents of the present disclosure. In the case of a ALK4:ActRIIB heteromultimer that promotes red blood cell formation, various factors may include, but are not limited to, the patient's red blood cell count, hemoglobin level, the desired target red blood cell count, the patient's age, the patient's sex, the patient's diet, the severity of any disease that may be contributing to a depressed red blood cell level, the time of administration, and other clinical factors. The addition of other known active agents to the final composition may also affect the dosage. Progress can be

monitored by periodic assessment of one or more of red blood cell levels, hemoglobin levels, reticulocyte levels, and other indicators of the hematopoietic process.

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

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

Alternatively, tissue culture cells can be directly transfected with plasmids encoding the retroviral structural genes (*gag*, *pol*, and *env*), by conventional calcium phosphate transfection. These cells are then transfected with the vector plasmid containing the genes of interest. The resulting cells release the retroviral vector into the culture medium.

Another targeted delivery system for one or more of the agents of the present disclosure is a colloidal dispersion system. Colloidal dispersion systems include, for example, macromolecule complexes, nanocapsules, microspheres, beads, and lipid-based systems including oil-in-water emulsions, micelles, mixed micelles, and liposomes. In certain embodiments, the preferred colloidal system of this disclosure is a liposome. Liposomes are artificial membrane vesicles which are useful as delivery vehicles *in vitro* and *in vivo*. RNA,

DNA, and intact virions can be encapsulated within the aqueous interior and be delivered to cells in a biologically active form [Fraley, et al. (1981) Trends Biochem. Sci., 6:77].

Methods for efficient gene transfer using a liposome vehicle are known in the art [Mannino, *et al.* (1988) Biotechniques, 6:682, 1988].

5 The composition of the liposome is usually a combination of phospholipids, which may include a steroid (*e.g.* cholesterol). The physical characteristics of liposomes depend on pH, ionic strength, and the presence of divalent cations. Other phospholipids or other lipids may also be used including, for example a phosphatidyl compound (*e.g.*,
10 phosphatidylglycerol, phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine, a sphingolipid, a cerebroside, and a ganglioside), egg phosphatidylcholine, dipalmitoylphosphatidylcholine, and distearoylphosphatidylcholine. The targeting of liposomes is also possible based on, for example, organ-specificity, cell-specificity, and organelle-specificity and is known in the art.

15 INCORPORATION BY REFERENCE

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

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

25 EXEMPLIFICATION

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

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Example 1. Generation of an ALK4:ActRIIB heterodimer

Soluble ALK4-Fc:ActRIIB-Fc heteromeric complexes comprising the extracellular domains of human ActRIIB and human ALK4, which are each separately fused to an Fc domain with a linker positioned between the extracellular domain and the Fc domain, were constructed. The individual constructs are referred to as ActRIIB-Fc fusion polypeptide and
 5 ALK4-Fc fusion polypeptide, respectively, and the sequences for each are provided below.

A methodology for promoting formation of ALK4-Fc:ActRIIB-Fc heteromeric complexes, as opposed to ActRIIB-Fc or ALK4-Fc homodimeric complexes, is to introduce alterations in the amino acid sequence of the Fc domains to guide the formation of asymmetric heteromeric complexes. Many different approaches to making asymmetric
 10 interaction pairs using Fc domains are described in this disclosure.

In one approach, illustrated in the ActRIIB-Fc and ALK4-Fc polypeptide sequences of SEQ ID NOs: 39-41 and 42-44, respectively, one Fc domain is altered to introduce cationic amino acids at the interaction face, while the other Fc domain is altered to introduce anionic amino acids at the interaction face. ActRIIB-Fc fusion polypeptide and ALK4-Fc
 15 fusion polypeptide each employ the tissue plasminogen activator (TPA) leader:
 MDAMKRGLCCVLLLCGAVFVSP (SEQ ID NO: 38).

The ActRIIB-Fc polypeptide sequence (SEQ ID NO: 39) is shown below:

1 MDAMKRGLCC VLLLCGAVFV SPGASGRGEA ETRECIYYNA NWELERTNQ
 51 GLERCEGEQD KRLHCYASWR NSSGTIELVK KGCWLDDFNC YDRQECVATE
 20 101 ENPQVYFCCC EGNFCNERFT HLPEAGGPEV TYEPPPTAPT GGGTHTCPPC
 151 PAPELLGGPS VFLFPPKPKD TLMISRTPEV TCVVVDVSHE DPEVKFNWYV
 201 DGVEVHNAKT KPREEQYNST YRVVSVLTVL HQDWLNGKEY KCKVSNKALP
 251 APIEKTISKA KGQPREPQVY TLPPSRKEMT KNQVSLTCLV KGFYPSDIAV
 301 EWESNGQPEN NYKTTPPVLK SDGSFFLYSK LTVDKSRWQQ GNVFSCSVMH
 25 351 EALHNHYTQK SLSLSPGK (SEQ ID NO: 39)

The leader (signal) sequence and linker are underlined. To promote formation of ALK4-Fc:ActRIIB-Fc heterodimer rather than either of the possible homodimeric complexes, two amino acid substitutions (replacing acidic amino acids with lysine) can be introduced
 30 into the Fc domain of the ActRIIB fusion protein as indicated by double underline above. The amino acid sequence of SEQ ID NO: 39 may optionally be provided with lysine (K) removed from the C-terminus.

This ActRIIB-Fc fusion protein is encoded by the following nucleic acid sequence (SEQ ID NO: 40):

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1   ATGGATGCAA TGAAGAGAGG GCTCTGCTGT GTGCTGCTGC TGTGTGGAGC
51  AGTCTTCGTT TCGCCCGGCG CCTCTGGGCG TGGGGAGGCT GAGACACGGG
5   101  AGTGCATCTA CTACAACGCC AACTGGGAGC TGGAGCGCAC CAACCAGAGC
151  GGCTTGGAGC GCTGCGAAGG CGAGCAGGAC AAGCGGCTGC ACTGCTACGC
201  CTCCTGGCGC AACAGCTCTG GCACCATCGA GCTCGTGAAG AAGGGCTGCT
251  GGCTAGATGA CTTCAACTGC TACGATAGGC AGGAGTGTGT GGCCACTGAG
301  GAGAACCCCC AGGTGTACTT CTGCTGCTGT GAAGGCAACT TCTGCAACGA
10  351  GCGCTTCACT CATTTGCCAG AGGCTGGGGG CCCGGAAGTC ACGTACGAGC
401  CACCCCCGAC AGCCCCCACC GGTGGTGGAA CTCACACATG CCCACCGTGC
451  CCAGCACCTG AACTCCTGGG GGGACCGTCA GTCTTCCTCT TCCCCC AAA
501  ACCCAAGGAC ACCCTCATGA TCTCCCGGAC CCCTGAGGTC ACATGCGTGG
551  TGGTGGACGT GAGCCACGAA GACCCTGAGG TCAAGTTCAA CTGGTACGTG
15  601  GACGGCGTGG AGGTGCATAA TGCCAAGACA AAGCCGCGGG AGGAGCAGTA
651  CAACAGCACG TACCGTGTGG TCAGCGTCCT CACCGTCCTG CACCAGGACT
701  GGCTGAATGG CAAGGAGTAC AAGTGCAAGG TCTCCAACAA AGCCCTCCCA
751  GCCCCCATCG AGAAAACCAT CTCCAAAGCC AAAGGGCAGC CCCGAGAACC
801  ACAGGTGTAC ACCCTGCCCC CATCCCGGAA GGAGATGACC AAGAACCAGG
20  851  TCAGCCTGAC CTGCCTGGTC AAAGGCTTCT ATCCCAGCGA CATCGCCGTG
901  GAGTGGGAGA GCAATGGGCA GCCGGAGAAC AACTACAAGA CCACGCCTCC
951  CGTGCTGAAG TCCGACGGCT CCTTCTTCCT CTATAGCAAG CTCACCGTGG
1001  ACAAGAGCAG GTGGCAGCAG GGGAACGTCT TCTCATGCTC CGTGATGCAT
1051  GAGGCTCTGC ACAACCACTA CACGCAGAAG AGCCTCTCCC TGTCTCCGGG
25  1101  TAAA      (SEQ ID NO: 40)

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The mature ActRIIB-Fc fusion polypeptide (SEQ ID NO: 41) is as follows, and may optionally be provided with lysine (K) removed from the C-terminus.

```

1   GRGEAETREC IYYNANWELE RTNQSGLERC EGEQDKRLHC YASWRNSSGT
51  IELVKKGCWL DDFNCYDRQE CVATEENPQV YFCCCEGNFC NERFTHLPEA
30  101  GGPEVTYEPP PTAPTGGGTH TCPPCPAPEL LGGPSVFLFP PKPKDTLMIS
151  RTPEVTCVVV DVSHEDPEVK FNWYVDGVEV HNAKTKPREE QYNSTYRVVS
201  VLTVLHQDWL NGKEYKCKVS NKALPAPIEK TISKAKGQPR EPQVYTLPPS
251  RKEMTKNQVS LTCLVKGFYP SDIAVEWESN GQPENNYKTT PPVLKSDGSF

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301 FLYSKLTVDK SRWQQGNVFS CSVMHEALHN HYTQKSLSL PGK
(SEQ ID NO: 41)

The complementary form of ALK4-Fc fusion polypeptide (SEQ ID NO: 42) is as follows:

5 1 MDAMKRGLCC VLLLCGAVFV SPGASGPRGV QALLCACTSC LQANYTCETD
51 GACMVSIFNL DGMEHHVRTC IPKVELVPAG KPFYCLSED LRNTHCCYTD
101 YCNRIDLRVP SGHLKEPEHP SMWGPVETGG GTHTCPPCPA PELLGGPSVF
151 LFPPKPKDTL MISRTPEVTC VVVDVSHEDP EVKFNWYVDG VEVHNAKTKP
201 REEQYNSTYR VVSVLTVLHQ DWLNGKEYKC KVSNAKALPAP IEKTISKAKG
10 251 QPREPQVYTL PPSREEMTKN QVSLTCLVKG FYPSDIAVEW ESNGQPENNY
301 DTTPPVLDSD GSFFLYSDLT VDKSRWQQGN VFSCSVMHEA LHNHYTQKSL
351 SLSPG (SEQ ID NO: 42)

15 The leader sequence and linker are underlined. To guide heterodimer formation with the ActRIIB-Fc fusion polypeptide of SEQ ID NOs: 39 and 41 above, two amino acid substitutions (replacing lysines with aspartic acids) can be introduced into the Fc domain of the ALK4-Fc fusion polypeptide as indicated by double underline above. The amino acid sequence of SEQ ID NO: 42 may optionally be provided with lysine (K) added at the C-terminus.

20 This ALK4-Fc fusion protein is encoded by the following nucleic acid (SEQ ID NO: 43):

1 ATGGATGCAA TGAAGAGAGG GCTCTGCTGT GTGCTGCTGC TGTGTGGAGC
51 AGTCTTCGTT TCGCCCGGCG CCTCCGGGCC CCGGGGGGTC CAGGCTCTGC
101 TGTGTGCGTG CACCAGCTGC CTCCAGGCCA ACTACACGTG TGAGACAGAT
25 151 GGGGCCTGCA TGGTTTCCAT TTTCAATCTG GATGGGATGG AGCACCATGT
201 GCGCACCTGC ATCCCCAAAG TGGAGCTGGT CCCTGCCGGG AAGCCCTTCT
251 ACTGCCTGAG CTCGGAGGAC CTGCGCAACA CCCACTGCTG CTACACTGAC
301 TACTGCAACA GGATCGACTT GAGGGTGCCC AGTGGTCACC TCAAGGAGCC
351 TGAGCACCCG TCCATGTGGG GCCCGGTGGA GACCGGTGGT GGAAC TCACA
30 401 CATGCCCACC GTGCCCAGCA CCTGAACTCC TGGGGGGACC GTCAGTCTTC
451 CTCTTCCCCC CAAAACCCAA GGACACCCTC ATGATCTCCC GGACCCCTGA
501 GGTCACATGC GTGGTGGTGG ACGTGAGCCA CGAAGACCCT GAGGTCAAGT
551 TCAACTGGTA CGTGGACGGC GTGGAGGTGC ATAATGCCAA GACAAAGCCG

601 CGGGAGGAGC AGTACAACAG CACGTACCGT GTGGTCAGCG TCCTCACCGT
 651 CCTGCACCAG GACTGGCTGA ATGGCAAGGA GTACAAGTGC AAGGTCTCCA
 701 ACAAAGCCCT CCCAGCCCCC ATCGAGAAAA CCATCTCCAA AGCCAAAGGG
 751 CAGCCCCGAG AACCACAGGT GTACACCCTG CCCCATCCC GGGAGGAGAT
 5 801 GACCAAGAAC CAGGTCAGCC TGACCTGCCT GGTCAAAGGC TTCTATCCCA
 851 GCGACATCGC CGTGGAGTGG GAGAGCAATG GGCAGCCGGA GAACAACACTAC
 901 GACACCACGC CTCCCGTGCT GGACTCCGAC GGCTCCTTCT TCCTCTATAG
 951 CGACCTCACC GTGGACAAGA GCAGGTGGCA GCAGGGGAAC GTCTTCTCAT
 1001 GCTCCGTGAT GCATGAGGCT CTGCACAACC ACTACACGCA GAAGAGCCTC
 10 1051 TCCCTGTCTC CGGGT (SEQ ID NO: 43)

The mature ALK4-Fc fusion protein sequence (SEQ ID NO: 44) is as follows and may optionally be provided with lysine (K) added at the C-terminus.

1 SGPRGVQALL CACTSCLQAN YTCETDGACM VSIFNLDGME HHVRTCIPKV
 51 ELVPAGKPFY CLSSEDLRNT HCCYTDYCNR IDLRVPSGHL KEPEHPSMWG
 15 101 PVETGGGTHT CPPCPAPELL GGPSVFLFPP KPKDTLMISR TPEVTCVVVD
 151 VSHEDPEVKF NWYVDGVEVH NAKTKPREEQ YNSTYRVVSV LTVLHQDWLN
 201 GKEYKCKVSN KALPAPIEKT ISKAKGQPRE PQVYTLPPSR EEMTKNQVSL
 251 TCLVKGFYPS DIAVEWESNG QPENNYDTTP PVLDS DGSFF LYSDLTVDKS
 301 RWQQGNVFSC SVMHEALHNH YTQKSLSLSP G (SEQ ID NO: 44)

20 The ActRIIB-Fc and ALK4-Fc proteins of SEQ ID NO: 41 and SEQ ID NO: 44, respectively, may be co-expressed and purified from a CHO cell line, to give rise to a heteromeric complex comprising ALK4-Fc:ActRIIB-Fc.

In another approach to promote the formation of heteromultimer complexes using asymmetric Fc fusion proteins the Fc domains are altered to introduce complementary
 25 hydrophobic interactions and an additional intermolecular disulfide bond as illustrated in the ActRIIB-Fc and ALK4-Fc polypeptide sequences of SEQ ID NOs: 45-46 and 47-48, respectively. The ActRIIB-Fc fusion polypeptide and ALK4-Fc fusion polypeptide each employ the tissue plasminogen activator (TPA) leader: MDAMKRGLCCVLLLCGAVFVSP (SEQ ID NO: 38) .

30 The ActRIIB-Fc polypeptide sequence (SEQ ID NO: 45) is shown below:

1 MDAMKRGLCC VLLLCGAVFV SPGASGRGEA ETRECIYYNA NWELERTNQS
 51 GLERCEGEQD KRLHCYASWR NSSGTIELVK KGCWLDDFNC YDRQECVATE

101 ENPQVYFCCC EGNFCNERFT HLPEAGGPEV TYEPPPTAPT GGGTHTCPPC
 151 PAPELLGGPS VFLFPPKPKD TLMISRTPEV TCVVVDVSHE DPEVKFNWYV
 201 DGVEVHNAKT KPREEQYNST YRVVSVLTVL HQDWLNGKEY KCKVSNKALP
 251 APIEKTISKA KGQPREPQVY TLPPCREEMT KNQVSLWCLV KGFYPSDIAV
 5 301 EWESNGQPEN NYKTTPPVLD SDGSFFLYSK LTVDKSRWQQ GNVFSCSVMH
 351 EALHNHYTQK SLSLSPGK (SEQ ID NO: 45)

The leader (signal) sequence and linker are underlined. To promote formation of the ALK4-Fc:ActRIIB-Fc heterodimer rather than either of the possible homodimeric complexes, two amino acid substitutions (replacing a serine with a cysteine and a threonine with a tryptophan) can be introduced into the Fc domain of the fusion protein as indicated by double underline above. The amino acid sequence of SEQ ID NO: 45 may optionally be provided with lysine (K) removed from the C-terminus.

The mature ActRIIB-Fc fusion polypeptide is as follows:

1 GRGEAETREC IYYNANWELE RTNQSGLERC EGEQDKRLHC YASWRNSSGT
 15 51 IELVKKGCWL DDFNCYDRQE CVATEENPQV YFCCCEGNFC NERFTHLPEA
 101 GGPEVTYEPPTAPTGGGTH TCPPCPAPEL LGGPSVFLFP PKPKDTLMIS
 151 RTPEVTCVVV DVSHEDPEVK FNWYVDGVEV HNAKTKPREE QYNSTYRVVS
 201 VLTVLHQDWL NGKEYKCKVS NKALPAPIEK TISKAKGQPR EPQVYTLPPC
 251 REEMTKNQVS LWCLVKGFYP SDIAVEWESN GQPENNYKTT PPVLDSDGSF
 20 301 FLYSKLTVDK SRWQQGNVFS CSVMHEALHN HYTQKSLSLS PGK
 (SEQ ID NO: 46)

The complementary form of ALK4-Fc fusion polypeptide (SEQ ID NO: 47) is as follows and may optionally be provided with lysine (K) removed from the C-terminus.

1 MDAMKRGLCC VLLLCGAVFV SPGASGPRGV QALLCACTSC LQANYTCETD
 25 51 GACMVSIFNL DGMEHHVRTC IPKVELVPAG KPFYCLSED LRNTHCCYTD
 101 YCNRIDLRVP SGHLKEPEHP SMWGPVETGG GTHTCPPCPA PELLGGPSVF
 151 LFPPKPKDTL MISRTPEVTC VVVDVSHEDP EVKFNWYVDG VEVHNAKTKP
 201 REEQYNSTYR VVSVLTVLHQ DWLNGKEYKC KVSNNKALPAP IEKTISKAKG
 251 QPREPQVCTL PPSREEMTKN QVSLSCAVKG FYPSDIAVEW ESNGQPENNY
 30 301 KTTTPVLDSD GSFFLYSSKLT VDKSRWQQGN VFSCSVMHEA LHNHYTQKSL
 351 SLSPGK (SEQ ID NO: 47)

The leader sequence and the linker are underlined. To guide heterodimer formation with the ActRIIB-Fc fusion polypeptide of SEQ ID NOs: 45 and 46 above, four amino acid substitutions can be introduced into the Fc domain of the ALK4 fusion polypeptide as indicated by double underline above. The amino acid sequence of SEQ ID NO: 47 may optionally be provided with lysine (K) removed from the C-terminus.

The mature ALK4-Fc fusion protein sequence is as follows and may optionally be provided with lysine (K) removed from the C-terminus.

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1   SGPRGVQALL  CACTSCLQAN  YTCETDGACM  VSIFNLDGME  HHVRTCIPKV
51  ELVPAGKPFY  CLSSEDLRNT  HCCYTDYCNR  IDLRVPSGHL  KEPEHPSMWG
10  101  PVETGGGTHT  CPPCPAPELL  GGPSVFLFPP  KPKDTLMISR  TPEVTCVVVD
151  VSHEDPEVKF  NWYVDGVEVH  NAKTKPREEQ  YNSTYRVVSV  LTVLHQDWLN
201  GKEYKCKVSN  KALPAPIEKT  ISKAKGQPRE  PQVCTLPPSR  EEMTKNQVSL
251  SCAVKGFYPS  DIAVEWESNG  QPENNYKTTP  PVLDSGGSFF  LVSKLTVDKS
301  RWQQGNVFSC  SVMHEALHNH  YTQKSLSLSP  GK          (SEQ ID NO: 48)

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ActRIIB-Fc and ALK4-Fc proteins of SEQ ID NO: 46 and SEQ ID NO: 48, respectively, may be co-expressed and purified from a CHO cell line, to give rise to a heteromeric complex comprising ALK4-Fc:ActRIIB-Fc.

Purification of various ALK4-Fc:ActRIIB-Fc complexes could be achieved by a series of column chromatography steps, including, for example, three or more of the following, in any order: protein A chromatography, Q sepharose chromatography, phenylsepharose chromatography, size exclusion chromatography, cation exchange chromatography, and epitope-based affinity chromatography (e.g., with an antibody or functionally equivalent ligand directed against an epitope on ALK4 or ActRIIB). The purification could be completed with viral filtration and buffer exchange.

In another approach to promote the formation of heteromultimer complexes using asymmetric Fc fusion proteins, the Fc domains are altered to introduce complementary hydrophobic interactions, an additional intermolecular disulfide bond, and electrostatic differences between the two Fc domains for facilitating purification based on net molecular charge, as illustrated in the ActRIIB-Fc and ALK4-Fc polypeptide sequences of SEQ ID NOs: 70-73 and 74-77, respectively. The ActRIIB-Fc fusion polypeptide and ALK4-Fc fusion polypeptide each employ the tissue plasminogen activator (TPA) leader: MDAMKRGLCCVLLLCGAVFVSP (SEQ ID NO: 38).

The ActRIIB-Fc polypeptide sequence (SEQ ID NO: 70) is shown below:

1 MDAMKRGLCC VLLLCGAVFV SPGASGRGEA ETRECIYYNA NWELERTNQS
 51 GLERCEGEQD KRLHCYASWR NSSGTIELVK KGCWLDDFNC YDRQECVATE
 101 ENPQVYFCCC EGNFCNERFT HLPEAGGPEV TYEPPPTAPT GGGTHTCPPC
 5 151 PAPELLGGPS VFLFPPKPKD TLMISRTPEV TCVVVDVSHE DPEVKFNWYV
 201 DGVEVHNAKT KPREEQYNST YRVVSVLTVL HQDWLNGKEY KCKVSNKALP
 251 APIEKTISKA KGQPREPQVY TLPPCREEMT ENQVSLWCLV KGFYPSDIAV
 301 EWESNGQPEN NYKTTPPVLD SDGSFFLYSK LTVDKSRWQQ GNVFSCSVMH
 351 EALHNHYTQD SLSLSPG (SEQ ID NO: 70)

10 The leader sequence and linker are underlined. To promote formation of the ALK4-
 Fc:ActRIIB-Fc heterodimer rather than either of the possible homodimeric complexes, two
 amino acid substitutions (replacing a serine with a cysteine and a threonine with a tryptophan)
 can be introduced into the Fc domain of the fusion protein as indicated by double underline
 above. To facilitate purification of the ALK4-Fc:ActRIIB-Fc heterodimer, two amino acid
 15 substitutions (replacing lysines with acidic amino acids) can also be introduced into the Fc
 domain of the fusion protein as indicated by double underline above. The amino acid
 sequence of SEQ ID NO: 70 may optionally be provided with a lysine added at the C-
 terminus.

20 This ActRIIB-Fc fusion protein is encoded by the following nucleic acid (SEQ ID NO:
 71):

1 ATGGATGCAA TGAAGAGAGG GCTCTGCTGT GTGCTGCTGC TGTGTGGAGC
 51 AGTCTTCGTT TCGCCCGGCG CCTCTGGGCG TGGGGAGGCT GAGACACGGG
 101 AGTGCATCTA CTACAACGCC AACTGGGAGC TGGAGCGCAC CAACCAGAGC
 151 GGCCTGGAGC GCTGCGAAGG CGAGCAGGAC AAGCGGCTGC ACTGCTACGC
 25 201 CTCCTGGCGC AACAGCTCTG GCACCATCGA GCTCGTGAAG AAGGGCTGCT
 251 GGCTAGATGA CTTCAACTGC TACGATAGGC AGGAGTGTGT GGCCACTGAG
 301 GAGAACCCCC AGGTGTACTT CTGCTGCTGT GAAGGCAACT TCTGCAACGA
 351 GCGCTTCACT CATTTGCCAG AGGCTGGGGG CCCGGAAGTC ACGTACGAGC
 401 CACCCCCGAC AGCCCCCACC GGTGGTGGAA CTCACACATG CCCACCGTGC
 30 451 CCAGCACCTG AACTCCTGGG GGGACCGTCA GTCTTCCTCT TCCCCC AAA
 501 ACCCAAGGAC ACCCTCATGA TCTCCCGGAC CCCTGAGGTC ACATGCGTGG
 551 TGGTGGACGT GAGCCACGAA GACCCTGAGG TCAAGTTCAA CTGGTACGTG
 601 GACGGCGTGG AGGTGCATAA TGCCAAGACA AAGCCGCGGG AGGAGCAGTA

651 CAACAGCACG TACCGTGTGG TCAGCGTCCT CACCGTCCTG CACCAGGACT
 701 GGCTGAATGG CAAGGAGTAC AAGTGCAAGG TCTCCAACAA AGCCCTCCCA
 751 GCCCCCATCG AGAAAACCAT CTCCAAAGCC AAAGGGCAGC CCCGAGAACC
 801 ACAGGTGTAC ACCCTGCCCC CATGCCGGGA GGAGATGACC GAGAACCAGG
 5 851 TCAGCCTGTG GTGCCTGGTC AAAGGCTTCT ATCCCAGCGA CATCGCCGTG
 901 GAGTGGGAGA GCAATGGGCA GCCGGAGAAC AACTACAAGA CCACGCCTCC
 951 CGTGCTGGAC TCCGACGGCT CCTTCTTCCT CTATAGCAAG CTCACCGTGG
 1001 ACAAGAGCAG GTGGCAGCAG GGAACGTCT TCTCATGCTC CGTGATGCAT
 1051 GAGGCTCTGC ACAACCACTA CACGCAGGAC AGCCTCTCCC TGTCTCCGGG
 10 1101 T (SEQ ID NO: 71)

The mature ActRIIB-Fc fusion polypeptide is as follows (SEQ ID NO: 72) and may optionally be provided with a lysine added to the C-terminus.

1 GRGEAETREC IYYNANWELE RTNQSGLERC EGEQDKRLHC YASWRNSSGT
 51 IELVKKGCWL DDFNCYDRQE CVATEENPQV YFCCCEGNFC NERFTHLPEA
 15 101 GGPEVTYEPP PTAPTGGGTH TCPPCPAPEL LGGPSVFLFP PKPKDTLMIS
 151 RTPEVTCVVV DVSHEDPEVK FNWYVDGVEV HNAKTKPREE QYNSTYRVVS
 201 VLTVLHQDWL NGKEYKCKVS NKALPAPIEK TISKAKGQPR EPQVYTLPPC
 251 REEMTENQVS LWCLVKGFYP SDIAVEWESN GQPENNYKTT PPVLDSGDGSF
 301 FLYSKLTVDK SRWQQGNVFS CSVMHEALHN HYTQDSL SLS PG
 20 (SEQ ID NO: 72)

This ActRIIB-Fc fusion polypeptide is encoded by the following nucleic acid (SEQ ID NO: 73):

1 GGGCGTGGGG AGGCTGAGAC ACGGGAGTGC ATCTACTACA ACGCCAACTG
 51 GGAGCTGGAG CGCACCAACC AGAGCGGCCT GGAGCGCTGC GAAGGCGAGC
 25 101 AGGACAAGCG GCTGCACTGC TACGCCTCCT GGCGCAACAG CTCTGGCACC
 151 ATCGAGCTCG TGAAGAAGGG CTGCTGGCTA GATGACTTCA ACTGCTACGA
 201 TAGGCAGGAG TGTGTGGCCA CTGAGGAGAA CCCCCAGGTG TACTTCTGCT
 251 GCTGTGAAGG CAACTTCTGC AACGAGCGCT TCACTCATTT GCCAGAGGCT
 301 GGGGGCCCGG AAGTCACGTA CGAGCCACCC CCGACAGCCC CCACCGGTGG
 30 351 TGGAAC TCAC ACATGCCCAC CGTGCCCAGC ACCTGAACTC CTGGGGGGGAC
 401 CGTCAGTCTT CCTCTTCCCC CCAAAACCCA AGGACACCCT CATGATCTCC
 451 CGGACCCCTG AGGTCACATG CGTGGTGGTG GACGTGAGCC ACGAAGACCC
 501 TGAGGTCAAG TTCAACTGGT ACGTGGACGG CGTGGAGGTG CATAATGCCA

551 AGACAAAGCC GCGGGAGGAG CAGTACAACA GCACGTACCG TGTGGTCAGC
 601 GTCCTCACCG TCCTGCACCA GGACTGGCTG AATGGCAAGG AGTACAAGTG
 651 CAAGGTCTCC AACAAAGCCC TCCCAGCCCC CATCGAGAAA ACCATCTCCA
 701 AAGCCAAAGG GCAGCCCCGA GAACCACAGG TGTACACCCT GCCCCCATGC
 5 751 CGGGAGGAGA TGACCGAGAA CCAGGTCAGC CTGTGGTGCC TGGTCAAAGG
 801 CTTCTATCCC AGCGACATCG CCGTGGAGTG GGAGAGCAAT GGGCAGCCGG
 851 AGAACAATA CAAGACCACG CCTCCCGTGC TGGACTCCGA CGGCTCCTTC
 901 TTCCTCTATA GCAAGCTCAC CGTGGACAAG AGCAGGTGGC AGCAGGGGAA
 951 CGTCTTCTCA TGCTCCGTGA TGCATGAGGC TCTGCACAAC CACTACACGC
 10 1001 AGGACAGCCT CTCCCTGTCT CCGGGT (SEQ ID NO: 73)

The complementary form of ALK4-Fc fusion polypeptide (SEQ ID NO: 74) is as follows and may optionally be provided with lysine removed from the C-terminus.

1 MDAMKRGLCC VLLLCGAVFV SPGASGPRGV QALLCACTSC LQANYTCETD
 51 GACMVSIFNL DGMEHHVRTC IPKVELVPAG KPFYCLSED LRNTHCCYTD
 15 101 YCNRIDLRVP SGHLKEPEHP SMWGPVETGG GTHTCPPCPA PELLGGPSVF
 151 LFPPKPKDTL MISRTPEVTC VVVDVSHEDP EVKFNWYVDG VEVHNAKTKP
 201 REEQYNSTYR VVSVLTVLHQ DWLNGKEYKC KVSNAKALPAP IEKTISKAKG
 251 QPREPQVCTL PPSREEMTKN QVSLSCAVKG FYPSDIAVEW ESRGQPENNY
 301 K^TTPPVLDSR GSFFLVSKLT VDKSRWQQGN VFSCSVMHEA LHNHYTQKSL
 20 351 SLSPGK (SEQ ID NO: 74)

The leader sequence and the linker are underlined. To guide heterodimer formation with the ActRIIB-Fc fusion polypeptide of SEQ ID NOs: 70 and 72 above, four amino acid substitutions (replacing a tyrosine with a cysteine, a threonine with a serine, a leucine with an alanine, and a tyrosine with a valine) can be introduced into the Fc domain of the ALK4
 25 fusion polypeptide as indicated by double underline above. To facilitate purification of the ALK4-Fc:ActRIIB-Fc heterodimer, two amino acid substitutions (replacing an asparagine with an arginine and an aspartate with an arginine) can also be introduced into the Fc domain of the ALK4-Fc fusion polypeptide as indicated by double underline above. The amino acid
 30 sequence of SEQ ID NO: 74 may optionally be provided with lysine removed from the C-terminus.

This ALK4-Fc fusion polypeptide is encoded by the following nucleic acid (SEQ ID NO: 75):

1 ATGGATGCAA TGAAGAGAGG GCTCTGCTGT GTGCTGCTGC TGTGTGGAGC
 51 AGTCTTCGTT TCGCCCGGCG CCTCCGGGCC CCGGGGGGTC CAGGCTCTGC
 101 TGTGTGCGTG CACCAGCTGC CTCCAGGCCA ACTACACGTG TGAGACAGAT
 151 GGGGCCTGCA TGGTTTCCAT TTTCAATCTG GATGGGATGG AGCACCATGT
 5 201 GCGCACCTGC ATCCCCAAAG TGGAGCTGGT CCCTGCCGGG AAGCCCTTCT
 251 ACTGCCTGAG CTCGGAGGAC CTGCGCAACA CCCACTGCTG CTACACTGAC
 301 TACTGCAACA GGATCGACTT GAGGGTGCCC AGTGGTCACC TCAAGGAGCC
 351 TGAGCACCCG TCCATGTGGG GCCCGGTGGA GACCGGTGGT GGAACTCACA
 401 CATGCCCACC GTGCCCAGCA CCTGAACTCC TGGGGGGACC GTCAGTCTTC
 10 451 CTCTTCCCCC CAAAACCCAA GGACACCCTC ATGATCTCCC GGACCCCTGA
 501 GGTCACATGC GTGGTGGTGG ACGTGAGCCA CGAAGACCCT GAGGTCAAGT
 551 TCAACTGGTA CGTGGACGGC GTGGAGGTGC ATAATGCCAA GACAAAGCCG
 601 CGGGAGGAGC AGTACAACAG CACGTACCGT GTGGTCAGCG TCCTCACCGT
 651 CCTGCACCAG GACTGGCTGA ATGGCAAGGA GTACAAGTGC AAGGTCTCCA
 15 701 ACAAAGCCCT CCCAGCCCCC ATCGAGAAAA CCATCTCCAA AGCCAAAGGG
 751 CAGCCCCGAG AACCACAGGT GTGCACCCTG CCCCATCCC GGGAGGAGAT
 801 GACCAAGAAC CAGGTCAGCC TGTCTGCGC CGTCAAAGGC TTCTATCCCA
 851 GCGACATCGC CGTGGAGTGG GAGAGCCGCG GGCAGCCGGA GAACAACTAC
 901 AAGACCACGC CTCCCGTGCT GGACTCCCGC GGCTCCTTCT TCCTCGTGAG
 20 951 CAAGCTCACC GTGGACAAGA GCAGGTGGCA GCAGGGGAAC GTCTTCTCAT
 1001 GCTCCGTGAT GCATGAGGCT CTGCACAACC ACTACACGCA GAAGAGCCTC
 1051 TCCCTGTCTC CGGGTAAA (SEQ ID NO: 75)

The mature ALK4-Fc fusion polypeptide sequence is as follows (SEQ ID NO: 76) and may optionally be provided with lysine removed from the C-terminus.

25 1 SGPRGVQALL CACTSCLQAN YTCETDGACM VSIFNLDGME HHVRTCIPKV
 51 ELVPAGKPFY CLSSEDLRNT HCCYTDYCNR IDLRVPSGHL KEPEHPSMWG
 101 PVETGGGTHT CPPCPAPELL GGPSVFLFPP KPKDTLMISR TPEVTCVVVD
 151 VSHEDPEVKF NWYVDGVEVH NAKTKPREEQ YNSTYRVVSV LTVLHQDWLN
 201 GKEYKCKVSN KALPAPIEKT ISKAKGQPRE PQVCTLPPSR EEMTKNQVSL
 30 251 SCAVKGFYPS DIAVEWESRG QPENNYKTTP PVLDSRGSFF LVSKLTVDKS
 301 RWQQGNVFSC SVMHEALHNH YTQKSLSLSP GK (SEQ ID NO: 76)

This ALK4-Fc fusion polypeptide is encoded by the following nucleic acid (SEQ ID NO: 77):

1 TCCGGGCCCC GGGGGGTCCA GGCTCTGCTG TGTGCGTGCA CCAGCTGCCT
 51 CCAGGCCAAC TACACGTGTG AGACAGATGG GGCCTGCATG GTTTCCATTT
 101 TCAATCTGGA TGGGATGGAG CACCATGTGC GCACCTGCAT CCCCAAAGTG
 151 GAGCTGGTCC CTGCCGGGAA GCCCTTCTAC TGCCTGAGCT CGGAGGACCT
 5 201 GCGCAACACC CACTGCTGCT ACACTGACTA CTGCAACAGG ATCGACTTGA
 251 GGGTGCCCAG TGGTCACCTC AAGGAGCCTG AGCACCCGTC CATGTGGGGC
 301 CCGGTGGAGA CCGGTGGTGG AACTCACACA TGCCCACCGT GCCCAGCACC
 351 TGAACTCCTG GGGGGACCGT CAGTCTTCCT CTTCCCCCCA AAACCCAAGG
 401 ACACCCTCAT GATCTCCCGG ACCCCTGAGG TCACATGCGT GGTGGTGGAC
 10 451 GTGAGCCACG AAGACCCTGA GGTCAAGTTC AACTGGTACG TGGACGGCGT
 501 GGAGGTGCAT AATGCCAAGA CAAAGCCGCG GGAGGAGCAG TACAACAGCA
 551 CGTACCGTGT GGTCAGCGTC CTCACCGTCC TGCACCAGGA CTGGCTGAAT
 601 GGCAAGGAGT ACAAGTGCAA GGTCTCCAAC AAAGCCCTCC CAGCCCCCAT
 651 CGAGAAAACC ATCTCCAAAG CCAAAGGGCA GCCCCGAGAA CCACAGGTGT
 15 701 GCACCCTGCC CCCATCCCGG GAGGAGATGA CCAAGAACCA GGTCAGCCTG
 751 TCCTGCGCCG TCAAAGGCTT CTATCCCAGC GACATCGCCG TGGAGTGGGA
 801 GAGCCGCGGG CAGCCGGAGA ACAACTACAA GACCACGCCT CCCGTGCTGG
 851 ACTCCCGCGG CTCCTTCTTC CTCGTGAGCA AGCTCACCGT GGACAAGAGC
 901 AGGTGGCAGC AGGGGAACGT CTTCTCATGC TCCGTGATGC ATGAGGCTCT
 20 951 GCACAACCAC TACACGCAGA AGAGCCTCTC CCTGTCTCCG GGTA
 (SEQ ID NO: 77)

ActRIIB-Fc and ALK4-Fc proteins of SEQ ID NO: 72 and SEQ ID NO: 76, respectively, may be co-expressed and purified from a CHO cell line, to give rise to a heteromeric complex comprising ALK4-Fc:ActRIIB-Fc.

25 Purification of various ALK4-Fc:ActRIIB-Fc complexes could be achieved by a series of column chromatography steps, including, for example, three or more of the following, in any order: protein A chromatography, Q sepharose chromatography, phenylsepharose chromatography, size exclusion chromatography, cation exchange chromatography, epitope-based affinity chromatography (e.g., with an antibody or
 30 functionally equivalent ligand directed against an epitope on ALK4 or ActRIIB), and multimodal chromatography (e.g., with resin containing both electrostatic and hydrophobic ligands). The purification could be completed with viral filtration and buffer exchange.

In another approach to promote the formation of heteromultimer complexes using asymmetric Fc fusion proteins, the Fc domains are altered to introduce complementary hydrophobic interactions, an additional intermolecular disulfide bond, and a histidine-to-arginine substitution specifically in the ActRIIB-Fc polypeptide chain for facilitating purification based on protein A affinity, as illustrated in the ActRIIB-Fc polypeptide sequences of SEQ ID NOs: 78-81 and the ALK4-Fc polypeptide sequences of SEQ ID NOs: 47, 48, 82, and 83. The ActRIIB-Fc fusion polypeptide and ALK4-Fc fusion polypeptide each employ the TPA leader: MDAMKRGLCCVLLLCGAVFVSP (SEQ ID NO: 38).

The ActRIIB-Fc polypeptide sequence (SEQ ID NO: 78) is shown below:

```

10      1  MDAMKRGLCC VLLLCGAVFV SPGASGRGEA ETRECIYNA NWELERTNQS
      51  GLERCEGEQD KRLHCYASWR NSSGTIELVK KGCWLDDFNC YDRQECVATE
     101  ENPQVYFCCC EGNFCNERFT HLPEAGGPEV TYEPPPTAPT GGGTHTCPPC
     151  PAPELLGGPS VFLFPPKPKD TLMISRTPEV TCVVVDVSHE DPEVKFNWYV
     201  DGVEVHNAKT KPREEQYNST YRVVSVLTVL HQDWLNGKEY KCKVSNKALP
15      251  APIEKTISKA KGQPREPQVY TLPPCREEMT KNQVSLWCLV KGFYPSDIAV
     301  EWESNGQPEN NYKTTPPVLD SDGSFFLYSK LTVDKSRWQQ GNVFSCSVMH
     351  EALHNRYTQK SLSLSPGK (SEQ ID NO: 78)

```

The leader sequence and linker are underlined. To promote formation of the ALK4-Fc:ActRIIB-Fc heterodimer rather than either of the possible homodimeric complexes, two amino acid substitutions (replacing a serine with a cysteine and a threonine with a tryptophan) can be introduced into the Fc domain of the ActRIIB-Fc fusion polypeptide as indicated by double underline above. Another amino acid substitution (replacing histidine with arginine) can also be introduced into the Fc domain of the fusion protein as indicated by double underline above to facilitate purification of the ALK4-Fc:ActRIIB-Fc heterodimer. The amino acid sequence of SEQ ID NO: 78 may optionally be provided with lysine removed from the C-terminus.

This ActRIIB-Fc fusion protein is encoded by the following nucleic acid (SEQ ID NO: 79):

```

30      1  ATGGATGCAA TGAAGAGAGG GCTCTGCTGT GTGCTGCTGC TGTGTGGAGC
     51  AGTCTTCGTT TCGCCCGGCG CCTCTGGGCG TGGGGAGGCT GAGACACGGG
     101  AGTGCATCTA CTACAACGCC AACTGGGAGC TGGAGCGCAC CAACCAGAGC
     151  GGCCTGGAGC GCTGCGAAGG CGAGCAGGAC AAGCGGCTGC ACTGCTACGC

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201 CTCCTGGCGC AACAGCTCTG GCACCATCGA GCTCGTGAAG AAGGGCTGCT
 251 GGCTAGATGA CTTCAACTGC TACGATAGGC AGGAGTGTGT GGCCACTGAG
 301 GAGAACCCCC AGGTGTACTT CTGCTGCTGT GAAGGCAACT TCTGCAACGA
 351 GCGCTTCACT CATTTGCCAG AGGCTGGGGG CCCGGAAGTC ACGTACGAGC
 5 401 CACCCCCGAC AGCCCCCACC GGTGGTGGAA CTCACACATG CCCACCGTGC
 451 CCAGCACCTG AACTCCTGGG GGGACCGTCA GTCTTCCTCT TCCCCC AAA
 501 ACCCAAGGAC ACCCTCATGA TCTCCCGGAC CCCTGAGGTC ACATGCGTGG
 551 TGGTGGACGT GAGCCACGAA GACCCTGAGG TCAAGTTCAA CTGGTACGTG
 601 GACGGCGTGG AGGTGCATAA TGCCAAGACA AAGCCGCGGG AGGAGCAGTA
 10 651 CAACAGCACG TACCGTGTGG TCAGCGTCCT CACCGTCCTG CACCAGGACT
 701 GGCTGAATGG CAAGGAGTAC AAGTGCAAGG TCTCCAACAA AGCCCTCCCA
 751 GCCCCCATCG AGAAAACCAT CTCCAAAGCC AAAGGGCAGC CCCGAGAACC
 801 ACAGGTGTAC ACCCTGCCCC CATGCCGGGA GGAGATGACC AAGAACCAGG
 851 TCAGCCTGTG GTGCCTGGTC AAAGGCTTCT ATCCCAGCGA CATCGCCGTG
 15 901 GAGTGGGAGA GCAATGGGCA GCCGGAGAAC AACTACAAGA CCACGCCTCC
 951 CGTGCTGGAC TCCGACGGCT CCTTCTTCCT CTATAGCAAG CTCACCGTGG
 1001 ACAAGAGCAG GTGGCAGCAG GGGAACGTCT TCTCATGCTC CGTGATGCAT
 1051 GAGGCTCTGC ACAACCGCTA CACGCAGAAG AGCCTCTCCC TGTCTCCGGG
 1101 TAAA (SEQ ID NO: 79)

20 The mature ActRIIB-Fc fusion polypeptide is as follows (SEQ ID NO: 80) and may optionally be provided with lysine removed from the C-terminus.

1 GRGEAETREC IYYNANWELE RTNQSGLERC EGEQDKRLHC YASWRNSSGT
 51 IELVKKGCWL DDFNCYDRQE CVATEENPQV YFCCCEGNFC NERFTHLPEA
 101 GGPEVTYEPPTAPTGGGTH TCPPCPAPEL LGGPSVFLFP PKPKDTLMIS
 25 151 RTPEVTCVVV DVSHEDPEVK FNWYVDGVEV HNAKTKPREE QYNSTYRVVS
 201 VLTVLHQDWL NGKEYKCKVS NKALPAPIEK TISKAKGQPR EPQVYTLPPC
 251 REEMTKNQVS LWCLVKGFYP SDIAVEWESN GQPENNYKTT PPVLDSDGSF
 301 FLYSKLTVDK SRWQQGNVFS CSVMHEALHN RYTQKSLSLS PGK
 (SEQ ID NO: 80)

30 This ActRIIB-Fc fusion polypeptide is encoded by the following nucleic acid (SEQ ID NO: 81):

1 GGGCGTGGGG AGGCTGAGAC ACGGGAGTGC ATCTACTACA ACGCCAACTG
 51 GGAGCTGGAG CGCACCAACC AGAGCGGCCT GGAGCGCTGC GAAGGCGAGC

101 AGGACAAGCG GCTGCACTGC TACGCCTCCT GGCGCAACAG CTCTGGCACC
 151 ATCGAGCTCG TGAAGAAGGG CTGCTGGCTA GATGACTTCA ACTGCTACGA
 201 TAGGCAGGAG TGTGTGGCCA CTGAGGAGAA CCCCCAGGTG TACTTCTGCT
 251 GCTGTGAAGG CAACTTCTGC AACGAGCGCT TCACTCATTT GCCAGAGGCT
 5 301 GGGGGCCCCG AAGTCACGTA CGAGCCACCC CCGACAGCCC CCACCGGTGG
 351 TGGAACTCAC ACATGCCCAC CGTGCCCAGC ACCTGAACTC CTGGGGGGAC
 401 CGTCAGTCTT CCTCTTCCCC CCAAACCCA AGGACACCCT CATGATCTCC
 451 CGGACCCCTG AGGTCACATG CGTGGTGGTG GACGTGAGCC ACGAAGACCC
 501 TGAGGTCAAG TTCAACTGGT ACGTGGACGG CGTGGAGGTG CATAATGCCA
 10 551 AGACAAAGCC GCGGGAGGAG CAGTACAACA GCACGTACCG TGTGGTCAGC
 601 GTCCTCACCG TCCTGCACCA GGACTGGCTG AATGGCAAGG AGTACAAGTG
 651 CAAGGTCTCC AACAAAGCCC TCCCAGCCCC CATCGAGAAA ACCATCTCCA
 701 AAGCCAAAGG GCAGCCCCGA GAACCACAGG TGTACACCCT GCCCCCATGC
 751 CGGGAGGAGA TGACCAAGAA CCAGGTCAGC CTGTGGTGCC TGGTCAAAGG
 15 801 CTTCTATCCC AGCGACATCG CCGTGGAGTG GGAGAGCAAT GGGCAGCCGG
 851 AGAACAACTA CAAGACCACG CCTCCCGTGC TGGACTCCGA CGGCTCCTTC
 901 TTCCTCTATA GCAAGCTCAC CGTGGACAAG AGCAGGTGGC AGCAGGGGAA
 951 CGTCTTCTCA TGCTCCGTGA TGCATGAGGC TCTGCACAAC CGCTACACGC
 1001 AGAAGAGCCT CTCCCTGTCT CCGGGTAAA (SEQ ID NO: 81)

20 The complementary form of ALK4-Fc fusion polypeptide is SEQ ID NO: 47 (shown above), which contains four amino acid substitutions to guide heterodimer formation with the ActRIIB-Fc fusion polypeptide of SEQ ID NOs: 78 and 80 and may optionally be provided with lysine removed from the C-terminus.

25 This ALK4-Fc fusion polypeptide is encoded by the following nucleic acid (SEQ ID NO: 82):

1 ATGGATGCAA TGAAGAGAGG GCTCTGCTGT GTGCTGCTGC TGTGTGGAGC
 51 AGTCTTCGTT TCGCCCGGCG CCTCCGGGCC CCGGGGGGTC CAGGCTCTGC
 101 TGTGTGCGTG CACCAGCTGC CTCCAGGCCA ACTACACGTG TGAGACAGAT
 151 GGGGCCTGCA TGGTTTCCAT TTTCAATCTG GATGGGATGG AGCACCATGT
 30 201 GCGCACCTGC ATCCCCAAAG TGGAGCTGGT CCCTGCCGGG AAGCCCTTCT
 251 ACTGCCTGAG CTCGGAGGAC CTGCGCAACA CCCACTGCTG CTACACTGAC
 301 TACTGCAACA GGATCGACTT GAGGGTGCCC AGTGGTCACC TCAAGGAGCC
 351 TGAGCACCCG TCCATGTGGG GCCCGGTGGA GACCGGTGGT GGAAC TCACA

401 CATGCCCACC GTGCCCAGCA CCTGAACTCC TGGGGGGACC GTCAGTCTTC
 451 CTCTTCCCCC CAAAACCCAA GGACACCCTC ATGATCTCCC GGACCCCTGA
 501 GGTCACATGC GTGGTGGTGG ACGTGAGCCA CGAAGACCCT GAGGTCAAGT
 551 TCAACTGGTA CGTGGACGGC GTGGAGGTGC ATAATGCCAA GACAAAGCCG
 5 601 CGGGAGGAGC AGTACAACAG CACGTACCGT GTGGTCAGCG TCCTCACCGT
 651 CCTGCACCAG GACTGGCTGA ATGGCAAGGA GTACAAGTGC AAGGTCTCCA
 701 ACAAAGCCCT CCCAGCCCCC ATCGAGAAAA CCATCTCCAA AGCCAAAGGG
 751 CAGCCCCGAG AACCACAGGT GTGCACCCTG CCCCATCCC GGGAGGAGAT
 801 GACCAAGAAC CAGGTCAGCC TGTCTGCGC CGTCAAAGGC TTCTATCCCA
 10 851 GCGACATCGC CGTGGAGTGG GAGAGCAATG GGCAGCCGGA GAACAACACTAC
 901 AAGACCACGC CTCCCGTGCT GGACTCCGAC GGCTCCTTCT TCCTCGTGAG
 951 CAAGCTCACC GTGGACAAGA GCAGGTGGCA GCAGGGGAAC GTCTTCTCAT
 1001 GCTCCGTGAT GCATGAGGCT CTGCACAACC ACTACACGCA GAAGAGCCTC
 1051 TCCCTGTCTC CGGGTAAA (SEQ ID NO: 82)

15 The mature ALK4-Fc fusion polypeptide sequence is SEQ ID NO: 48 (shown above) and may optionally be provided with lysine removed from the C-terminus.

This ALK4-Fc fusion polypeptide is encoded by the following nucleic acid (SEQ ID NO: 83):

1 TCCGGGCCCC GGGGGGTCCA GGCTCTGCTG TGTGCGTGCA CCAGCTGCCT
 20 51 CCAGGCCAAC TACACGTGTG AGACAGATGG GGCCTGCATG GTTTCCATTT
 101 TCAATCTGGA TGGGATGGAG CACCATGTGC GCACCTGCAT CCCCAGAGTG
 151 GAGCTGGTCC CTGCCGGGAA GCCCTTCTAC TGCCTGAGCT CGGAGGACCT
 201 GCGCAACACC CACTGCTGCT ACACTGACTA CTGCAACAGG ATCGACTTGA
 251 GGGTGCCCAG TGGTCACCTC AAGGAGCCTG AGCACCCGTC CATGTGGGGC
 25 301 CCGGTGGAGA CCGGTGGTGG AACTCACACA TGCCCACCGT GCCCAGCACC
 351 TGAACTCCTG GGGGGACCGT CAGTCTTCCT CTTCCCCCCA AAACCCAAGG
 401 ACACCCTCAT GATCTCCCGG ACCCCTGAGG TCACATGCGT GGTGGTGGAC
 451 GTGAGCCACG AAGACCCTGA GGTCAAGTTC AACTGGTACG TGGACGGCGT
 501 GGAGGTGCAT AATGCCAAGA CAAAGCCGCG GGAGGAGCAG TACAACAGCA
 30 551 CGTACCGTGT GGTCAGCGTC CTCACCGTCC TGCACCAGGA CTGGCTGAAT
 601 GGCAAGGAGT ACAAGTGCAA GGTCTCCAAC AAAGCCCTCC CAGCCCCCAT
 651 CGAGAAAACC ATCTCCAAAG CCAAAGGGCA GCCCCGAGAA CCACAGGTGT
 701 GCACCCTGCC CCCATCCCGG GAGGAGATGA CCAAGAACCA GGTCAGCCTG

751 TCCTGCGCCG TCAAAGGCTT CTATCCCAGC GACATCGCCG TGGAGTGGGA
801 GAGCAATGGG CAGCCGGAGA ACAACTACAA GACCACGCCT CCCGTGCTGG
851 ACTCCGACGG CTCCTTCTTC CTCGTGAGCA AGCTCACCGT GGACAAGAGC
901 AGGTGGCAGC AGGGGAACGT CTTCTCATGC TCCGTGATGC ATGAGGCTCT
5 951 GCACAACCAC TACACGCAGA AGAGCCTCTC CCTGTCTCCG GTAAA
(SEQ ID NO: 83)

ActRIIB-Fc and ALK4-Fc proteins of SEQ ID NO: 80 and SEQ ID NO: 48, respectively, may be co-expressed and purified from a CHO cell line, to give rise to a heteromeric complex comprising ALK4-Fc:ActRIIB-Fc.

10 Purification of various ALK4-Fc:ActRIIB-Fc complexes could be achieved by a series of column chromatography steps, including, for example, three or more of the following, in any order: protein A chromatography, Q sepharose chromatography, phenylsepharose chromatography, size exclusion chromatography and epitope-based affinity chromatography (e.g., with an antibody or functionally equivalent ligand directed against an
15 epitope on ALK4 or ActRIIB), and multimodal chromatography (e.g., with resin containing both electrostatic and hydrophobic ligands). The purification could be completed with viral filtration and buffer exchange.

**Example 2. Ligand binding profile of ALK4-Fc:ActRIIB-Fc heterodimer compared to
20 ActRIIB-Fc homodimer and ALK4-Fc homodimer**

A BiacoreTM-based binding assay was used to compare ligand binding selectivity of the ALK4-Fc:ActRIIB-Fc heterodimeric complex described above with that of ActRIIB-Fc and ALK4-Fc homodimer complexes. The ALK4-Fc:ActRIIB-Fc heterodimer, ActRIIB-Fc homodimer, and ALK4-Fc homodimer were independently captured onto the system using an
25 anti-Fc antibody. Ligands were injected and allowed to flow over the captured receptor protein. Results are summarized in the table below, in which ligand off-rates (k_d) most indicative of effective ligand traps are denoted by gray shading.

Ligand binding profile of ALK4-Fc:ActRIIB-Fc heterodimer compared to ActRIIB-Fc homodimer and ALK4-Fc homodimer									
Ligand	ActRIIB-Fc homodimer			ALK4-Fc homodimer			ALK4-Fc:ActRIIB-Fc heterodimer		
	k_a (1/Ms)	k_d (1/s)	K_D (pM)	k_a (1/Ms)	k_d (1/s)	K_D (pM)	k_a (1/Ms)	k_d (1/s)	K_D (pM)

Activin A	1.2×10^7	2.3×10^{-4}	19	5.8×10^5	1.2×10^{-2}	20000	1.3×10^7	1.5×10^{-4}	12
Activin B	5.1×10^6	1.0×10^{-4}	20	No binding			7.1×10^6	4.0×10^{-5}	6
BMP6	3.2×10^7	6.8×10^{-3}	190	---			2.0×10^6	5.5×10^{-3}	2700
BMP9	1.4×10^7	1.1×10^{-3}	77	---			Transient*		3400
BMP10	2.3×10^7	2.6×10^{-4}	11	---			5.6×10^7	4.1×10^{-3}	74
GDF3	1.4×10^6	2.2×10^{-3}	1500	---			3.4×10^6	1.7×10^{-2}	4900
GDF8	8.3×10^5	2.3×10^{-4}	280	1.3×10^5	1.9×10^{-3}	15000†	3.9×10^5	2.1×10^{-4}	550
GDF11	5.0×10^7	1.1×10^{-4}	2	5.0×10^6	4.8×10^{-3}	270†	3.8×10^7	1.1×10^{-4}	3
* Indeterminate due to transient nature of interaction † Very low signal --- Not tested									

These comparative binding data demonstrate that ALK4-Fc:ActRIIB-Fc heterodimer has an altered binding profile/selectivity relative to either ActRIIB-Fc or ALK4-Fc homodimers. ALK4-Fc:ActRIIB-Fc heterodimer displays enhanced binding to activin B compared with either homodimer, retains strong binding to activin A, GDF8, and GDF11 as observed with ActRIIB-Fc homodimer, and exhibits substantially reduced binding to BMP9, BMP10, and GDF3. In particular, BMP9 displays low or no observable affinity for ALK4-Fc:ActRIIB-Fc heterodimer, whereas this ligand binds strongly to ALK4-Fc:ActRIIB-Fc heterodimer. Like the ActRIIB-Fc homodimer, the heterodimer retains intermediate-level binding to BMP6. See Figure 4.

In addition, an A-204 Reporter Gene Assay was used to evaluate the effects of ALK4-Fc:ActRIIB-Fc heterodimer and ActRIIB-Fc:ActRIIB-Fc homodimer on signaling by activin A, activin B, GDF11, GDF8, BMP10, and BMP9. Cell line: Human Rhabdomyosarcoma (derived from muscle). Reporter vector: pGL3(CAGA)12 (as described in Dennler et al, 1998, EMBO 17: 3091-3100). The CAGA12 motif is present in TGF-beta responsive genes (PAI-1 gene), so this vector is of general use for factors signaling through Smad2 and 3. An exemplary A-204 Reporter Gene Assay is outlined below.

Day 1: Split A-204 cells into 48-well plate.

Day 2: A-204 cells transfected with 10 ug pGL3(CAGA)12 or pGL3(CAGA)12(10 ug)+pRLCMV (1 ug) and Fugene.

Day 3: Add factors (diluted into medium+0.1% BSA). Inhibitors need to be pre-incubated with Factors for about one hr before adding to cells. About six hrs later, cells are rinsed with PBS and then lysed.

Following the above steps, applicant performed a Luciferase assay.

5 Both the ALK4-Fc:ActRIIB-Fc heterodimer and ActRIIB-Fc:ActRIIB-Fc homodimer were determined to be potent inhibitors of activin A, activin B, GDF11, and GDF8 in this assay. In particular, as can be seen in the comparative homodimer/heterodimer IC₅₀ data illustrated in Figure 7, ALK4-Fc:ActRIIB-Fc heterodimer inhibits activin A, activin B, GDF8, and GDF11 signaling pathways similarly to the ActRIIB-Fc:ActRIIB-Fc homodimer.

10 However, ALK4-Fc:ActRIIB-Fc heterodimer inhibition of BMP9 and BMP10 signaling pathways is significantly reduced compared to the ActRIIB-Fc:ActRIIB-Fc homodimer. This data is consistent with the above-discussed binding data in which it was observed that both the ALK4-Fc:ActRIIB-Fc heterodimer and ActRIIB-Fc:ActRIIB-Fc homodimer display strong binding to activin A, activin B, GDF8, and GDF11, but BMP10 and BMP9 have

15 significantly reduced affinity for the ALK4-Fc:ActRIIB-Fc heterodimer compared to the ActRIIB-Fc:ActRIIB-Fc homodimer.

Together, these data therefore demonstrate that ALK4-Fc:ActRIIB-Fc heterodimer is a more selective antagonist of activin B, activin A, GDF8, and GDF11 compared to ActRIIB-Fc homodimer. Accordingly, an ALK4-Fc:ActRIIB-Fc heterodimer will be more useful than

20 an ActRIIB-Fc homodimer in certain applications where such selective antagonism is advantageous. Examples include therapeutic applications where it is desirable to retain antagonism of one or more of activin A, activin B, activin AB, GDF8, and GDF11 but minimize antagonism of one or more of BMP9, BMP10, GDF3, and BMP6.

25 **Example 3. Activity profile of ALK4-Fc:ActRIIB-Fc heterodimer in mice compared to ActRIIB-Fc homodimer**

Homodimeric and heterodimeric complexes were tested in mice to investigate differences in their activity profiles in vivo. Wild-type C57BL/6 mice were dosed subcutaneously with ActRIIB-Fc homodimer (10 mg/kg), ALK4-Fc:ActRIIB-Fc heterodimer

30 (3 or 10 mg/kg), or vehicle (phosphate-buffered saline, PBS) twice per week for 4 weeks

beginning at approximately 10 weeks of age (n = 9 mice per group). ALK4-Fc homodimer was not tested in vivo due to its inability to bind ligands with high affinity under cell-free conditions as determined by surface plasmon resonance. Study endpoints included: body weight; total lean mass and total adipose mass as determined by nuclear magnetic resonance (NMR) at baseline and study completion (4 weeks); total bone mineral density as determined by dual energy x-ray absorptiometry (DEXA) at baseline and 4 weeks; and weights of the gastrocnemius, rectus femoris, and pectoralis muscles determined at 4 weeks.

Activity of ActRIIB-Fc and ALK4-Fc Complexes in Wild-Type Mice				
Endpoint (4 wk)	Vehicle	ActRIIB-Fc homodimer 10 mg/kg	ALK4-Fc:ActRIIB-Fc heterodimer	
			10 mg/kg	3 mg/kg
Change in body weight from baseline	↑ 15%	↑ 38% **	↑ 41% **	↑ 33% **
Change in total lean mass from baseline	↓ 1%	↑ 5% **	↑ 5% **	↑ 5% **
Change in total adipose mass from baseline	↑ 5%	↓ 3.6% **	↓ 3.5% **	↓ 3.5% **
Change in total bone mineral density from baseline	↑ 8%	↑ 14% *	↑ 12% *	↑ 11%
Gastrocnemius weight †	23	36 **	35 **	30 **
Femoris weight †	11.5	17 **	16 **	14 **
Pectoralis weight †	15	23 **	28 **	23 **
* <i>P</i> < 0.05 vs. vehicle ** <i>P</i> < 0.01 vs. vehicle † Combined left and right muscle weights normalized to femur length (mg/mm) to control for body size				

Study results are summarized in the table above. As expected, ActRIIB-Fc homodimer caused marked changes in body composition, many consistent with known effects of GDF8 and activin inhibition. Treatment of wild-type mice with ActRIIB-Fc homodimer more than doubled body weight gain over the course of the study compared to vehicle-treated controls. Accompanying this net weight gain were significant increases in total lean mass and total bone mineral density, as well as a significant reduction in total adipose mass, compared to vehicle. It should be recognized that normalized (percentage-based) changes in lean and adipose tissues differ in their correspondence to absolute changes because lean mass (typically about 70% of body weight in a mouse) is much larger than adipose mass (typically about 10% of body weight). Individual skeletal muscles examined,

including the gastrocnemius, femoris, and pectoralis all increased significantly in weight compared to vehicle controls over the course of treatment with ActRIIB-Fc homodimer.

The ALK4-Fc:ActRIIB-Fc heterodimer produced certain effects strikingly similar to those of the ActRIIB-Fc homodimer despite differential ligand selectivity of the two
5 complexes. As shown in the table above, treatment of mice with the ALK4-Fc:ActRIIB-Fc heterodimer at a dose level of 10 mg/kg matched, nearly matched, or exceeded the effects of ActRIIB-Fc homodimer at the same dose level for all endpoints listed. Effects of the ALK4-Fc:ActRIIB-Fc heterodimer at 3 mg/kg were mildly attenuated for several endpoints compared to 10 mg/kg, thus providing evidence for a dose-effect relationship.

10 Thus, an ALK4-Fc:ActRIIB-Fc heterodimer exerts beneficial anabolic effects on skeletal muscle and bone, and catabolic effects on adipose tissue, very similar to those of ActRIIB-Fc homodimer. However, unlike ActRIIB homodimer, ALK4-Fc:ActRIIB-Fc heterodimer exhibits only low-affinity or transient binding to BMP9 and BMP10 and so should have little to no concurrent inhibition on processes mediated by those ligands, such as
15 angiogenesis. This novel selectivity will be useful, for example, in treating patients in need of stimulatory effects on muscle and bone, and inhibitory effects on fat, but not in need of altered angiogenesis.

**Example 4. ALK4:ActRIIB heteromultimer treatment suppresses kidney fibrosis and
20 inflammation and reduces kidney injury.**

The effects of the ALK4-Fc:ActRIIB-Fc heterodimer described in Example 2 on kidney disease was assessed in a mouse unilateral ureteral obstruction model. See, e.g., Klahr and Morrissey (2002) Am J Physiol Renal Physiol 283: F861-F875.

Twenty-four C57BL/6 male mice 12 weeks of age underwent left unilateral ureteral
25 ligation twice at the level of the lower pole of kidney. After 3 days, eight mice were euthanized and kidneys from individual animals were harvested to assess kidney injury. The remaining mice were randomized into two groups: i) eight mice were injected subcutaneously with the ALK4-Fc:ActRIIB-Fc heterodimer at a dose of 10mg/kg at day 3, day 7, day 10, and day 14 after surgery and a ii) eight mice were injected subcutaneously with vehicle control,
30 phosphate buffered saline (PBS), at day 3, day 7, day 10, and day 14 after surgery. Both groups were sacrificed at day 17 in accordance with the relevant Animal Care Guidelines.

Half kidneys from individual animals were collected for histology analysis (H&E, and Masson's Trichrome stain), from both the UUO kidney and contralateral kidney, and 1/4 kidneys were used for RNA extraction (RNeasy Midi Kit, Qiagen, IL).

Gene expression analysis on UUO kidney samples was performed to assess levels of various genes. QRT-PCR was performed on a CFX Connect™ Real-time PCR detection system (Bio-Rad, CA) to evaluate the expression of various fibrotic genes (Colla1, Fibronectin, PAI-1, CTGF, and α -SMA), inflammatory genes (TNF α , and MCP1), cytokines (TGF β 1, TGF β 2, TGF β 3, and activin A), and kidney injury genes (NGAL. See Figure 8. Treatment of mice with ALK4-Fc:ActRIIB-Fc heterodimer significantly suppressed the expression of fibrotic and inflammatory genes, inhibited the upregulation of TGF β 1/2/3 and reduced kidney injury. Histology data confirmed that ALK4-Fc:ActRIIB-Fc heterodimer treatment significantly inhibited kidney fibrosis and reduced kidney injury in the UUO model.

Together, these data demonstrate that ALK4:ActRIIB heteromultimer treatment suppresses kidney fibrosis and inflammation and reduces kidney injury. Moreover, these data indicate that other ALK4:ActRIIB antagonists may be useful in the treatment or preventing of kidney disease including, for example, antagonists of ALK4 and/or ActRIIB-binding ligands, antagonists of ALK4 and/or ActRIIB receptors, antagonists of ALK4 and/or ActRIIB downstream signaling mediators (e.g., Smads), and antagonists of TGF β superfamily co-receptors associated with ALK4 and/or ActRIIB.

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Example 5. ALK4:ActRIIB heteromultimer treatment suppresses kidney fibrosis and reduces proteinuria in Alport mouse models.

The effects of the ALK4-Fc:ActRIIB-Fc heterodimer described in Example 2 on kidney disease was assessed in Col4a3^{-/-} and Col4a5 Alport mouse models. See, e.g., Cosgrove D et al, (1996) Genes Dev. 10(23): 2981-92; Rheault MN et al, (2004) J Am Soc Nephrol. 15(6): 1466-74.

Sixteen Col4a3^{-/-} male mice 2 weeks of age were randomized into two groups: i) eight mice were biweekly injected subcutaneously with the ALK4-Fc:ActRIIB-Fc heterodimer at a dose of 10mg/kg for 5 weeks ii) eight mice were injected subcutaneously with vehicle control, phosphate buffered saline (PBS) for 5 weeks. Urine samples from individual animals were collected by metabolic cages at 4 weeks, 5 weeks, 6 weeks, and 7

30

weeks of age respectively. Both groups were sacrificed at 7 weeks of age and kidneys from individual animals were harvested to assess kidney injury. Half kidneys from individual animals were collected for histology analysis (H&E, and Masson's Trichrome stain), and urine samples from individual animals were used to evaluate albuminuria, a hallmark of glomerular damage in Alport syndrome (Mouse Albumin Antigen Assay, Molecular Innovation, MI; QuantiChrom Creatinine Assay Kit, BioAssay System, CA).

Albuminuria analysis was performed to assess levels of albumin in urine after normalized to urine creatinine (ACR: albumin-to-creatinine ratio). Treatment of mice with ALK4-Fc:ActRIIB-Fc heterodimer significantly reduced albuminuria (Figure 9A) and suppressed extracellular matrix deposition measured by immunofluorescent staining of Collagen-I (Figure 10A). In line with the albuminuria result, histology data confirmed that ALK4-Fc:ActRIIB-Fc heterodimer treatment significantly inhibited kidney fibrosis (Figure 10B) and reduced sclerotic glomeruli (Figure 10C) in Col4a3^{-/-} mice.

To confirm the suppression of albuminuria in Alport mouse model, ALK4-Fc:ActRIIB-Fc heterodimer was evaluated in Col4a5 X-linked Alport mouse model. Thirty Col4a5 hemizygous male mice 17 weeks of age were randomized into two groups: i) fifteen mice were biweekly injected subcutaneously with the ALK4-Fc:ActRIIB-Fc heterodimer at a dose of 10mg/kg for 12 weeks ii) fifteen mice were injected subcutaneously with vehicle control, phosphate buffered saline (PBS) for 12 weeks. Urine samples from individual animals were collected by metabolic cages at 17 weeks, 20 weeks, 23 weeks, 26 weeks, and 29 weeks of age respectively for albuminuria analysis. Consistent with the result in Col4a3^{-/-} mice, treatment of Col4a5 hemizygous mice with ALK4-Fc:ActRIIB-Fc heterodimer significantly reduced albuminuria (Figure 9B).

Together, these data demonstrate that ALK4:ActRIIB heterodimer treatment suppresses kidney fibrosis and reduces sclerotic glomeruli, associated with the improvement of albuminuria in Alport mouse models. Moreover, these data indicate that other ALK4:ActRIIB antagonists may be useful in the treatment or preventing of kidney dysfunction in Alport syndrome.

Example 6. ALK4:ActRIIB heteromultimer treatment improves muscle mass and strength in a mouse model of amyotrophic lateral sclerosis (ALS).

The effects of the ALK4-Fc:ActRIIB-Fc heterodimer described in Example 2 on muscle mass and strength in a disease condition was assessed in the SOD1 mouse model of amyotrophic lateral sclerosis (ALS). See, e.g., Gurney et al. (1994) Science 264(5166): 1772-1775. In the SOD1 model, mice develop mild disease symptoms, muscle weakness
 5 and/or stiffness, around 12 weeks of age, and they develop more severe symptoms, muscle paralysis and/or respiratory failure, around 16 weeks of age. In this study, SOD1 mice were examined at 8 weeks (“pre-symptomatic” stage), 12 weeks (“disease-onset” stage), and 16 weeks (“disease-progression” stage) of age.

SOD1 [B6SJL-Tg(SOD1*G93A)1Gur/J] mice at 5 weeks of age were separated into
 10 separate groups: i) mice subcutaneously injected with vehicle control, phosphate buffered saline, twice weekly; and ii) mice subcutaneously injected with the ALK4-Fc:ActRIIB-Fc heterodimer at a dose of 10mg/kg twice weekly. These two treatment groups were also compared to wild-type mice at 5 weeks of age, receiving subcutaneous injects of vehicle control, phosphate buffered saline, twice weekly. Mice were observed for changes in muscle
 15 mass, muscle fiber area, and changes in muscle tetanic force over the course of 11 weeks. Compared to wild-type mice, SOD1 mice receiving vehicle displayed significantly decreased tibialis anterior (TA) muscle mass at 12 weeks (approximately 55 mg vs. 40 mg muscle mass) and 16 weeks approximately 60 mg vs. 35 mg muscle mass) of age. In contrast, SOD1 mice receiving ALK4-Fc:ActRIIB-Fc surprisingly displayed significantly TA more muscle mass
 20 than wild-type mice at 8 weeks (approximately 55 mg vs. 80 mg muscle mass) and 12 weeks (approximately 60 mg vs. 85 mg muscle mass) of age. In disease-progression stage mice, SOD1 mice receiving ALK4-Fc:ActRIIB-Fc displayed slightly reduced TA muscle mass compared to wild-type animals, but ALK4-Fc:ActRIIB-Fc treated animals had significantly more (>80%) TA muscle mass compared to SOD1 mice receiving vehicle. Similar trends
 25 were observed upon examining TA muscle fiber area (μm^2). In particular, compared to wild-type mice, SOD1 mice receiving vehicle displayed slight reductions in TA muscle fiber at 12 weeks of age (approximately $1900 \mu\text{m}^2$ vs. $1700 \mu\text{m}^2$ muscle fiber), and dramatic reductions in TA muscle fiber were observed in disease-progression stage mice (approximately $2200 \mu\text{m}^2$ vs. $1450 \mu\text{m}^2$ muscle fiber). In contrast, SOD1 mice receiving ALK4-Fc:ActRIIB-Fc
 30 displayed significantly more TA muscle mass than wild-type mice 12 weeks of age (approximately $2300 \mu\text{m}^2$ vs. $1900 \mu\text{m}^2$ muscle fiber). In disease-progression stage mice, SOD1 mice receiving ALK4-Fc:ActRIIB-Fc displayed slightly reduced TA muscle fiber concentration compared to wild-type animals, but ALK4-Fc:ActRIIB-Fc treated animals had

significantly (>29%) more TA muscle fiber concentration compared to SOD1 mice receiving vehicle. The increase in TA muscle mass and fiber content correlated with an increase in strength. For example, compared to wild-type mice, SOD1 mice receiving vehicle displayed moderately decreased TA muscle strength, measured by peak tetanic force (mN) of the muscle, at 12 weeks of age (approximately 1300 mN vs. 900 mN peak tetanic force), and dramatic reductions in TA muscle strength were observed in disease-progression stage mice (approximately 1250 mN vs. 600 mN peak tetanic force). SOD1 mice receiving ALK4-Fc:ActRIIB-Fc displayed significantly increased TA muscle strength than SOD1 mice receiving vehicle at 12 weeks of age (>25% increased muscle strength) and 16 weeks of age (>43% increased muscle strength).

Taken together, the data demonstrate that ALK4-mFc:ActRIIB-mFc therapy is able to increase muscle mass and strength in a mouse model of ALS. Therefore, the data indicate that ALK4-mFc:ActRIIB-mFc, and potentially other ALK4:ActRIIB antagonists, may be used to treat other muscle disorders, particularly motor neuron and neuromuscular diseases.

Example 7. ALK4:ActRIIB heteromultimer treatment improves diaphragm strength in a mouse model of muscular dystrophy.

The effects of the ALK4-Fc:ActRIIB-Fc heterodimer described in Example 2 on muscle mass and strength in a disease condition was further assessed in the mdx mouse model of muscular dystrophy. In this mdx model, the phenotype of dystrophin deficiency can be observed at any early age (i.e., around 7 weeks of age).

Mdx (D2.B10-*Dmd*^{mdx}/J) mice at 5 weeks of age were separated into separate groups: i) mice subcutaneously injected with vehicle control, phosphate buffered saline, twice weekly; and ii) mice subcutaneously injected with the ALK4-Fc:ActRIIB-Fc heterodimer at a dose of 10 mg/kg twice weekly. These two treatment groups were also compared to wild-type mice at 5 weeks of age, receiving subcutaneous injects of vehicle control, phosphate buffered saline, twice weekly. Mice were observed for changes in muscle strength after 8 weeks of treatment. Compared to wild-type mice, mdx mice receiving vehicle displayed a significant decreased in diaphragm muscle strength, measured by specific force (kPa) of the muscle, after 8 weeks [i.e., approximately 89 kPa (wild-type) vs. 32 kPa (mdx)]. In contrast, ALK4-

Fc:ActRIIB-Fc treatment was observed to significantly increase diaphragm strength (>63%) compared to mdx mice receiving vehicle control.

The data demonstrate that ALK4-mFc:ActRIIB-mFc therapy is able to increase strength in a mouse model of mdx. Therefore, the data indicate that ALK4-mFc:ActRIIB-mFc, and potentially other ALK4:ActRIIB antagonists, may be used to treat other muscle disorders, particularly muscular dystrophies including, for example, DMD and BMD.

We claim:

1. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises one or more amino acid modifications that alter the isoelectric point (pI) of the ALK4-Fc fusion protein and/or wherein the ActRIIB-Fc fusion protein comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.
2. The ALK4:ActRIIB heteromultimer of claim 1, wherein:
 - a) the one or more amino acid modifications in the ALK4-Fc fusion protein confers increased difference in pIs between the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein;
 - b) the one or more amino acid modifications in the ActRIIB-Fc fusion protein confers increased difference in pIs between the ActRIIB-Fc fusion protein and the ALK4-Fc fusion protein; or
 - c) the one or more amino acid modifications in the ALK4-Fc fusion protein confers increased difference in pIs between the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein, and the one or more amino acid modifications in the ActRIIB-Fc fusion protein confers increased difference in pIs between the ActRIIB-Fc fusion protein and the ALK4-Fc fusion protein.
3. The ALK4:ActRIIB heteromultimer of claim 2, wherein:
 - a) the ALK4-Fc fusion protein comprises one or more amino acid modifications that increase the pI of the ALK4-Fc fusion protein; and
 - b) the ActRIIB-Fc fusion protein comprises one or more amino acid modifications that decrease the pI of the ActRIIB-Fc fusion protein.
4. The ALK4:ActRIIB heteromultimer of any one of claims 1-3, wherein ALK4-Fc fusion protein Fc domain is an IgG1 Fc domain, and wherein the IgG1 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

5. The ALK4:ActRIIB heteromultimer of claim 4, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31.
- 5 6. The ALK4:ActRIIB heteromultimer of claim 5, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:
 - a) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31;
 - b) an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31; and
 - c) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31.
- 10 7. The ALK4:ActRIIB heteromultimer of claim 6, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:
 - a) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H);
 - b) an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H); and
 - 20 c) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H) and an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H).
- 25 8. The ALK4:ActRIIB heteromultimer of claim 7, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:
 - a) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R);

b) an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R); and

c) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R) and an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R).

9. The ALK4:ActRIIB heteromultimer of any one of claims 1-3, wherein ALK4-Fc fusion protein Fc domain is an IgG2 Fc domain, and wherein the IgG2 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

10. The ALK4:ActRIIB heteromultimer of any one of claim 9, wherein the ALK4-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

11. The ALK4:ActRIIB heteromultimer of claim 10, wherein the ALK4-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32;

b) an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32; and

c) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32.

12. The ALK4:ActRIIB heteromultimer of claim 11, wherein the ALK4-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H);

b) an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H); and

c) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H) and an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H).

- 5 13. The ALK4:ActRIIB heteromultimer of any one of claims 1-3, wherein ALK4-Fc fusion protein Fc domain is an IgG3 Fc domain, and wherein the IgG3 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.
- 10 14. The ALK4:ActRIIB heteromultimer of claim 13 wherein the ALK4-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33.
- 15 15. The ALK4:ActRIIB heteromultimer of claim 14, wherein the ALK4-Fc fusion protein IgG3Fc domain comprises one or more amino acid substitutions selected from:
 - 15 a) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33;
 - 15 b) an amino acid substitution at the position corresponding to D186 of SEQ ID NO: 33; and
 - 20 c) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to D186 of SEQ ID NO: 33.
- 20 16. The ALK4:ActRIIB heteromultimer of claim 15, wherein the ALK4-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from:
 - 25 a) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H);
 - 25 b) an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H); and
 - 25 c) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H) and an arginine, lysine, or histidine

substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H).

17. The ALK4:ActRIIB heteromultimer of any one of claims 1-3, wherein ALK4-Fc fusion protein Fc domain is an IgG4 Fc domain, and wherein the IgG4 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

18. The ALK4:ActRIIB heteromultimer of claim 17, wherein the ALK4-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

19. The ALK4:ActRIIB heteromultimer of claim 18, wherein the ALK4-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35;

b) an amino acid substitution at the position corresponding to D183 of SEQ ID NO: 35; and

c) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35 and an amino acid substitution at the position corresponding to D183 of SEQ ID NO: 35.

20. The ALK4:ActRIIB heteromultimer of claim 19, wherein the ALK4-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H);

b) an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 35 (D183R, D183K, or D183H); and

c) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H) and an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 32 (D183R, D183K, or D183H).

21. The ALK4:ActRIIB heteromultimer of claim 3, wherein:

a) the ALK4-Fc fusion protein comprises one or more neutral or negatively charged amino acid substitutions with one or more positively charged amino acids [e.g., an arginine (R), lysine (K), or histidine (H)]; and

5 b) the ActRIIB-Fc fusion protein comprises one or more neutral or positively charged amino acid substitutions with one or more negatively charged amino acids [e.g., aspartic acid (E) or glutamic acid (D)].

22. The ALK4:ActRIIB heteromultimer of any one of claims 1-21, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG1 Fc domain, and wherein the IgG1 Fc domain
10 comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

23. The ALK4:ActRIIB heteromultimer of claim 22 wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to
15 the amino acid sequence of SEQ ID NO: 31.

24. The ALK4:ActRIIB heteromultimer of claim 23, wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K138 of SEQ ID NO:
20 31;

b) an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31; and

c) an amino acid substitution at the position corresponding to K138 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to K217 of SEQ ID
25 NO: 31.

25. The ALK4:ActRIIB heteromultimer of claim 24, wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D); and

5 c) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D) and an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D).

26. The ALK4:ActRIIB heteromultimer of claim 25, wherein the ALK4-Fc fusion protein
10 IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E);

b) an aspartic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217D); and

15 c) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E) and an aspartic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217D).

27. The ALK4:ActRIIB heteromultimer of any one of claims 1-21, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG2 Fc domain, and wherein the IgG2 Fc domain
20 comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

28. The ALK4:ActRIIB heteromultimer of claim 27, wherein the ActRIIB-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to
25 the amino acid sequence of SEQ ID NO: 32.

29. The ALK4:ActRIIB heteromultimer of claim 28, wherein the ActRIIB-Fc fusion protein IgG2 fusion Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K136 of SEQ ID NO: 32;

b) an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32; and

5 c) an amino acid substitution at the position corresponding to K136 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32.

30. The ALK4:ActRIIB heteromultimer of claim 29, wherein the ActRIIB-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected
10 from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D); and

15 c) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D) and an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D).

31. The ALK4:ActRIIB heteromultimer of any one of claims 1-21, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG3 Fc domain, and wherein the IgG3 Fc domain
20 comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

32. The ALK4:ActRIIB heteromultimer of claim 31, wherein the ActRIIB-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%,
25 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33.

33. The ALK4:ActRIIB heteromultimer of claim 32, wherein the ActRIIB-Fc fusion protein IgG3 fusion Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K145 of SEQ ID NO: 33;

b) an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33; and

5 c) an amino acid substitution at the position corresponding to K145 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33.

34. The ALK4:ActRIIB heteromultimer of claim 33, wherein the modified ActRIIB-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions
10 selected from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D); and

15 c) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D) and an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D).

35. The ALK4:ActRIIB heteromultimer of any one of claims 1-21, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG4 Fc domain, and wherein the IgG4 Fc domain
20 comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

36. The ALK4:ActRIIB heteromultimer of claim 35, wherein the ActRIIB-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%,
25 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

37. The ALK4:ActRIIB heteromultimer of claim 36, wherein the ActRIIB-Fc fusion protein IgG4 fusion Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35;

b) an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35; and

5 c) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35 and an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35.

38. The ALK4:ActRIIB heteromultimer of claim 37, wherein the ActRIIB-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D); and

15 c) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D) and an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D).

39. The ALK4:ActRIIB heteromultimer of claim 2, wherein:

20 a) the ActRIIB-Fc fusion protein comprises one or more amino acid modifications that increase the pI of the ActRIIB-Fc fusion protein; and

b) the ALK4-Fc fusion protein comprises one or more amino acid modifications that decrease the pI of the ALK4-Fc fusion protein.

40. The ALK4:ActRIIB heteromultimer of claim 39, wherein:

25 a) the ActRIIB-Fc fusion protein comprises one or more neutral or negatively charged amino acid substitutions with one or more positively charged amino acids [e.g., an arginine (R), lysine (K), or histidine (H)]; and

b) the ALK4-Fc fusion protein comprises one or more neutral or positively charged amino acid substitutions with one or more negatively charged amino acids [e.g., aspartic acid (E) or glutamic acid (D)].

41. The ALK4:ActRIIB heteromultimer of claim 39 or 40, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG1 Fc domain, and wherein the IgG1 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

42. The ALK4:ActRIIB heteromultimer of claim 41, wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31.

43. The ALK4:ActRIIB heteromultimer of claim 42, wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31;

b) an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31; and

c) an amino acid substitution at the position corresponding to N162 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to D179 of SEQ ID NO: 31.

44. The ALK4:ActRIIB heteromultimer of claim 43, wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H);

b) an arginine, lysine, or histidine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H); and

c) an arginine, lysine, or histidine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R, N162K, or N162H) and an arginine, lysine, or histidine

substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R, D179K, or D179H).

45. The ALK4:ActRIIB heteromultimer of claim 44, wherein the ActRIIB-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R);

b) an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R); and

c) an arginine substitution at the position corresponding to N162 of SEQ ID NO: 31 (N162R) and an arginine substitution at the position corresponding to D179 of SEQ ID NO: 31 (D179R).

46. The ALK4:ActRIIB heteromultimer of claim 39 or 40, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG2 Fc domain, and wherein the IgG2 Fc domain comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

47. The ALK4:ActRIIB heteromultimer of claim 46, wherein the ActRIIB-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

48. The ALK4:ActRIIB heteromultimer of claim 47, wherein the ActRIIB-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32;

b) an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32; and

c) an amino acid substitution at the position corresponding to N160 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to D177 of SEQ ID NO: 32.

49. The ALK4:ActRIIB heteromultimer of claim 48, wherein the ActRIIB-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H);

b) an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H); and

c) an arginine, lysine, or histidine substitution at the position corresponding to N160 of SEQ ID NO: 32 (N160R, N160K, or N160H) and an arginine, lysine, or histidine substitution at the position corresponding to D177 of SEQ ID NO: 32 (D177R, D177K, or D177H).

50. The ALK4:ActRIIB heteromultimer of claim 39 or 40, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG3 Fc domain, and wherein the IgG3 Fc domain comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

51. The ALK4:ActRIIB heteromultimer of claim 50, wherein the ActRIIB-Fc fusion protein IgG3 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33.

52. The ALK4:ActRIIB heteromultimer of claim 51, wherein the ActRIIB-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33;

b) an amino acid substitution at the position corresponding to D186 of SEQ ID NO: 33; and

c) an amino acid substitution at the position corresponding to S169 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to D186 of SEQ ID NO: 33.

53. The ALK4:ActRIIB heteromultimer of claim 52, wherein the modified ActRIIB-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H);

b) an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H); and

c) an arginine, lysine, or histidine substitution at the position corresponding to S169 of SEQ ID NO: 33 (S169R, S169K, or S169H) and an arginine, lysine, or histidine substitution at the position corresponding to D186 of SEQ ID NO: 33 (D186R, D186K, or D186H).

54. The ALK4:ActRIIB heteromultimer of claim 39 or 40, wherein the ActRIIB-Fc fusion protein Fc domain is an IgG4 Fc domain, and wherein the IgG4 Fc domain comprises one or more amino acid modifications that alter the pI of the ActRIIB-Fc fusion protein.

55. The ALK4:ActRIIB heteromultimer of claim 54, wherein the ActRIIB-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

56. The ALK4:ActRIIB heteromultimer of claim 55, wherein the ActRIIB-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35;

b) an amino acid substitution at the position corresponding to D183 of SEQ ID NO: 35; and

c) an amino acid substitution at the position corresponding to N166 of SEQ ID NO: 35 and an amino acid substitution at position D183 of SEQ ID NO: 35.

57. The ALK4:ActRIIB heteromultimer of claim 56, wherein the ActRIIB-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H);

b) an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 35 (D183R, D183K, or D183H); and

c) an arginine, lysine, or histidine substitution at the position corresponding to N166 of SEQ ID NO: 35 (N166R, N166K, or N166H) and an arginine, lysine, or histidine substitution at the position corresponding to D183 of SEQ ID NO: 35 (D183R, D183K, or D183H).

58. The ALK4:ActRIIB heteromultimer of claim 2, wherein the one or more amino acid modifications in the ALK4-Fc fusion protein decreases the pI of the ALK4-Fc fusion protein.

59. The ALK4:ActRIIB heteromultimer of claim 2 or 39-40, wherein the ALK4-Fc fusion protein Fc domain is an IgG1 Fc domain, and wherein the IgG1 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

60. The ALK4:ActRIIB heteromultimer of claim 59, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31.

61. The ALK4:ActRIIB heteromultimer of claim 59 or 60, wherein the ALK4-Fc fusion protein IgG1 fusion Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K138 of SEQ ID NO: 31;

b) an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31; and

c) an amino acid substitution at the position corresponding to K138 of SEQ ID NO: 31 and an amino acid substitution at the position corresponding to K217 of SEQ ID NO: 31.

62. The ALK4:ActRIIB heteromultimer of claim 61, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D); and

c) an aspartic acid or glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E or K138D) and an aspartic acid or glutamic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217E or K217D).

63. The ALK4:ActRIIB heteromultimer of claim 62, wherein the ALK4-Fc fusion protein IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E);

b) an aspartic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217D); and

c) a glutamic acid substitution at the position corresponding to K138 of SEQ ID NO: 31 (K138E) and an aspartic acid substitution at the position corresponding to K217 of SEQ ID NO: 31 (K217D).

64. The ALK4:ActRIIB heteromultimer of claim 2 or 39-40, wherein the ALK4-Fc fusion protein Fc domain is an IgG2 Fc domain, and wherein the IgG2 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

65. The ALK4:ActRIIB heteromultimer of claim 64, wherein the ALK4-Fc fusion protein IgG2 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.
- 5 66. The ALK4:ActRIIB heteromultimer of claim 64 or 65, wherein the ALK4-Fc fusion protein IgG2 fusion Fc domain comprises one or more amino acid substitutions selected from:
- a) an amino acid substitution at the position corresponding to K136 of SEQ ID NO: 32;
- 10 b) an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32; and
- c) an amino acid substitution at the position corresponding to K136 of SEQ ID NO: 32 and an amino acid substitution at the position corresponding to K215 of SEQ ID NO: 32.
- 15 67. The ALK4:ActRIIB heteromultimer of claim 66, wherein the ALK4-Fc fusion protein IgG2 Fc domain comprises one or more amino acid substitutions selected from:
- a) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D);
- b) an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D); and
- 20 c) an aspartic acid or glutamic acid substitution at the position corresponding to K136 of SEQ ID NO: 32 (K136E or K136D) and an aspartic acid or glutamic acid substitution at the position corresponding to K215 of SEQ ID NO: 32 (K215E or K215D).
- 25 68. The ALK4:ActRIIB heteromultimer of claim 2 or 39-40, wherein the ALK4-Fc fusion protein Fc domain is an IgG3 Fc domain, and wherein the IgG3 Fc domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.
69. The ALK4:ActRIIB heteromultimer of claim 68, wherein the ALK4-Fc fusion protein IgG31 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%,

90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 33.

70. The ALK4:ActRIIB heteromultimer of claim 68 or 69, wherein the ALK4-Fc fusion protein IgG3 fusion Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K145 of SEQ ID NO: 33;

b) an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33; and

c) an amino acid substitution at the position corresponding to K145 of SEQ ID NO: 33 and an amino acid substitution at the position corresponding to K224 of SEQ ID NO: 33.

71. The ALK4:ActRIIB heteromultimer of claim 70, wherein the ALK4-Fc fusion protein IgG3 Fc domain comprises one or more amino acid substitutions selected from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D); and

c) an aspartic acid or glutamic acid substitution at the position corresponding to K145 of SEQ ID NO: 33 (K145E or K145D) and an aspartic acid or glutamic acid substitution at the position corresponding to K224 of SEQ ID NO: 33 (K224E or K224D).

72. The ALK4:ActRIIB heteromultimer of claim 2 or 39-40, wherein the ALK4-Fc fusion protein Fc domain is an IgG4 Fc domain, and wherein the IgG4 domain comprises one or more amino acid modifications that alter the pI of the ALK4-Fc fusion protein.

73. The ALK4:ActRIIB heteromultimer of claim 72, wherein the ALK4-Fc fusion protein IgG4 Fc domain comprises an amino acid sequence that is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

74. The ALK4:ActRIIB heteromultimer of claim 72 or 73, wherein the ALK4-Fc fusion protein IgG4 fusion Fc domain comprises one or more amino acid substitutions selected from:

a) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35;

b) an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35; and

c) an amino acid substitution at the position corresponding to K142 of SEQ ID NO: 35 and an amino acid substitution at the position corresponding to K221 of SEQ ID NO: 35.

75. The ALK4:ActRIIB heteromultimer of claim 74, wherein the ALK4-Fc fusion protein IgG4 Fc domain comprises one or more amino acid substitutions selected from:

a) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D);

b) an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D); and

c) an aspartic acid or glutamic acid substitution at the position corresponding to K142 of SEQ ID NO: 35 (K142E or K142D) and an aspartic acid or glutamic acid substitution at the position corresponding to K221 of SEQ ID NO: 35 (K221E or K221D).

76. The ALK4:ActRIIB heteromultimer of any one of claims 4-8 and 22-26, wherein:

a) the ALK4-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position S132 of SEQ ID NO: 31 (S132C) and a tryptophan substitution at position T144 of SEQ ID NO: 31 (T144W); and

b) the ActRIIB-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position Y127 of SEQ ID NO: 31 (Y127C), a serine substitution at position T144 of SEQ ID NO: 31 (T144S), an alanine substitution at position L146 of SEQ ID NO: 31 (L146A), and a valine substitution at position Y185 of SEQ ID NO: 31 (Y185V).

77. The ALK4:ActRIIB heteromultimer of any one of claims 4-8 and 22-26, wherein:

a) the ActRIIB-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position S132 of SEQ ID NO: 31 (S132C) and a tryptophan substitution at position T144 of SEQ ID NO: 31 (T144W); and

5 b) the ALK4-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position Y127 of SEQ ID NO: 31 (Y127C), a serine substitution at position T144 of SEQ ID NO: 31 (T144S), an alanine substitution at position L146 of SEQ ID NO: 31 (L146A), and a valine substitution at position Y185 of SEQ ID NO: 31 (Y185V).

78. The ALK4:ActRIIB heteromultimer of any one of claims 41-45 and 59-63, wherein:

10 a) the ALK4-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position S132 of SEQ ID NO: 31 (S132C) and a tryptophan substitution at position T144 of SEQ ID NO: 31 (T144W); and

15 b) the ActRIIB-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position Y127 of SEQ ID NO: 31 (Y127C), a serine substitution at position T144 of SEQ ID NO: 31 (T144S), an alanine substitution at position L146 of SEQ ID NO: 31 (L146A), and a valine substitution at position Y185 of SEQ ID NO: 31 (Y185V).

79. The ALK4:ActRIIB heteromultimer of any one of claims 41-45 and 59-63, wherein:

20 a) the modified ActRIIB-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position S132 of SEQ ID NO: 31 (S132C) and a tryptophan substitution at position T144 of SEQ ID NO: 31 (T144W); and

25 b) the modified ALK4-Fc fusion protein IgG1 Fc domain comprises a cysteine substitution at position Y127 of SEQ ID NO: 31 (Y127C), a serine substitution at position T144 of SEQ ID NO: 31 (T144S), an alanine substitution at position L146 of SEQ ID NO: 31 (L146A), and a valine substitution at position Y185 of SEQ ID NO: 31 (Y185V).

80. The ALK4:ActRIIB heteromultimer of any one of claims 9-12 and 27-30, wherein:

a) the ALK4-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position S130 of SEQ ID NO: 32 (S130C) and a tryptophan substitution at position T142 of SEQ ID NO: 32 (T142W); and

b) the ActRIIB-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position Y125 of SEQ ID NO: 32 (Y125C), a serine substitution at position T142 of SEQ ID NO: 32 (T142S), an alanine substitution at position L144 of SEQ ID NO: 32 (L144A), and a valine substitution at position Y183 of SEQ ID NO: 32 (Y183V).

5 81. The ALK4:ActRIIB heteromultimer of any one of claims 9-12 and 27-30, wherein:

a) the ActRIIB-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position S130 of SEQ ID NO: 32 (S130C) and a tryptophan substitution at position T142 of SEQ ID NO: 32 (T142W); and

10 b) the ALK4-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position Y125 of SEQ ID NO: 32 (Y125C), a serine substitution at position T142 of SEQ ID NO: 32 (T142S), an alanine substitution at position L144 of SEQ ID NO: 32 (L144A), and a valine substitution at position Y183 of SEQ ID NO: 32 (Y183V).

82. The ALK4:ActRIIB heteromultimer of any one of claims 46-49 and 64-67, wherein:

15 a) the ALK4-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position S130 of SEQ ID NO: 32 (S130C) and a tryptophan substitution at position T142 of SEQ ID NO: 32 (T142W); and

20 b) the ActRIIB-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position Y125 of SEQ ID NO: 32 (Y125C), a serine substitution at position T142 of SEQ ID NO: 32 (T142S), an alanine substitution at position L144 of SEQ ID NO: 32 (L144A), and a valine substitution at position Y183 of SEQ ID NO: 32 (Y183V).

83. The ALK4:ActRIIB heteromultimer of any one of claims 46-49 and 64-67, wherein:

a) the modified ActRIIB-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position S130 of SEQ ID NO: 32 (S130C) and a tryptophan substitution at position T142 of SEQ ID NO: 32 (T142W); and

25 b) the modified ALK4-Fc fusion protein IgG2 Fc domain comprises a cysteine substitution at position Y125 of SEQ ID NO: 32 (Y125C), a serine substitution at position T142 of SEQ ID NO: 32 (T142S), an alanine substitution at position L144 of SEQ ID NO: 32 (L144A), and a valine substitution at position Y183 of SEQ ID NO: 32 (Y183V).

84. The ALK4:ActRIIB heteromultimer of any one of claims 13-16 and 31-34, wherein:

a) the ALK4-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position S139 of SEQ ID NO: 33 (S139C) and a tryptophan substitution at position T151 of SEQ ID NO: 33 (T151W); and

5 b) the ActRIIB-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position Y134 of SEQ ID NO: 33 (Y134C), a serine substitution at position T151 of SEQ ID NO: 33 (T151S), an alanine substitution at position L153 of SEQ ID NO: 33 (L153A), and a valine substitution at position Y192 of SEQ ID NO: 33 (Y192V).

85. The ALK4:ActRIIB heteromultimer of any one of claims 13-16 and 31-34, wherein:

10 a) the ActRIIB-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position S139 of SEQ ID NO: 33 (S139C) and a tryptophan substitution at position T151 of SEQ ID NO: 33 (T151W); and

15 b) the ALK4-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position Y134 of SEQ ID NO: 33 (Y134C), a serine substitution at position T151 of SEQ ID NO: 33 (T151S), an alanine substitution at position L153 of SEQ ID NO: 33 (L153A), and a valine substitution at position Y192 of SEQ ID NO: 33 (Y192V).

86. The ALK4:ActRIIB heteromultimer of any one of claims 50-53 and 68-71, wherein:

20 a) the ALK4-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position S139 of SEQ ID NO: 33 (S139C) and a tryptophan substitution at position T151 of SEQ ID NO: 33 (T151W); and

b) the ActRIIB-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position Y134 of SEQ ID NO: 33 (Y134C), a serine substitution at position T151 of SEQ ID NO: 33 (T151S), an alanine substitution at position L153 of SEQ ID NO: 33 (L153A), and a valine substitution at position Y192 of SEQ ID NO: 33 (Y192V).

25 87. The ALK4:ActRIIB heteromultimer of any one of claims 50-53 and 68-71, wherein:

a) the ActRIIB-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position S139 of SEQ ID NO: 33 (S139C) and a tryptophan substitution at position T151 of SEQ ID NO: 33 (T151W); and

b) the ALK4-Fc fusion protein IgG3 Fc domain comprises a cysteine substitution at position Y134 of SEQ ID NO: 33 (Y134C), a serine substitution at position T151 of SEQ ID NO: 33 (T151S), an alanine substitution at position L153 of SEQ ID NO: 33 (L153A), and a valine substitution at position Y192 of SEQ ID NO: 33 (Y192V).

5 88. The ALK4:ActRIIB heteromultimer of any one of claims 17-20 and 35-38, wherein:

a) the ALK4-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position S136 of SEQ ID NO: 35 (S136C) and a tryptophan substitution at position T148 of SEQ ID NO: 35 (T148W); and

10 b) the ActRIIB-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position Y131 of SEQ ID NO: 35 (Y131C), a serine substitution at position T148 of SEQ ID NO: 35 (T148S), an alanine substitution at position L150 of SEQ ID NO: 35 (L150A), and a valine substitution at position Y189 of SEQ ID NO: 35 (Y189V).

89. The ALK4:ActRIIB heteromultimer of any one of claims 17-20 and 35-38, wherein:

15 a) the ActRIIB-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position S136 of SEQ ID NO: 35 (S136C) and a tryptophan substitution at position T148 of SEQ ID NO: 35 (T148W); and

20 b) the ALK4-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position Y131 of SEQ ID NO: 35 (Y131C), a serine substitution at position T148 of SEQ ID NO: 35 (T148S), an alanine substitution at position L150 of SEQ ID NO: 35 (L150A), and a valine substitution at position Y189 of SEQ ID NO: 35 (Y189V).

90. The ALK4:ActRIIB heteromultimer of any one of claims 54-58 and 72-75, wherein:

a) the ALK4-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position S136 of SEQ ID NO: 35 (S136C) and a tryptophan substitution at position T148 of SEQ ID NO: 35 (T148W); and

25 b) the ActRIIB-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position Y131 of SEQ ID NO: 35 (Y131C), a serine substitution at position T148 of SEQ ID NO: 35 (T148S), an alanine substitution at position L150 of SEQ ID NO: 35 (L150A), and a valine substitution at position Y189 of SEQ ID NO: 35 (Y189V).

91. The ALK4:ActRIIB heteromultimer of any one of claims 54-58 and 72-75, wherein:

a) the ActRIIB-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position S136 of SEQ ID NO: 35 (S136C) and a tryptophan substitution at position T148 of SEQ ID NO: 35 (T148W); and

b) the ALK4-Fc fusion protein IgG4 Fc domain comprises a cysteine substitution at position Y131 of SEQ ID NO: 35 (Y131C), a serine substitution at position T148 of SEQ ID NO: 35 (T148S), an alanine substitution at position L150 of SEQ ID NO: 35 (L150A), and a valine substitution at position Y189 of SEQ ID NO: 35 (Y189V).

92. The ALK4:ActRIIB heteromultimer of claim 22 or 59, wherein the IgG1 Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of SEQ ID NO: 66.

93. The ALK4:ActRIIB heteromultimer of claim 92, wherein the IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) a glutamic acid at the position corresponding to 138 of SEQ ID NO: 66;

b) an aspartic acid at the position corresponding to 217 of SEQ ID NO: 66; and

c) a glutamic acid at the position corresponding to 138 of SEQ ID NO: 66 and an aspartic acid at the position corresponding to 217 of SEQ ID NO: 66.

94. The ALK4:ActRIIB heteromultimer of claim 92 or 93, wherein the modified IgG1 Fc domain comprises a cysteine at the position corresponding to 132 of SEQ ID NO: 66 and a tryptophan at the position corresponding to 144 of SEQ ID NO: 66

95. The ALK4:ActRIIB heteromultimer of claim 4 or 41, wherein the IgG1 Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to the amino acid sequence of SEQ ID NO: 67.

96. The ALK4:ActRIIB heteromultimer of claim 95, wherein the IgG1 Fc domain comprises one or more amino acid substitutions selected from:

a) an arginine at the position corresponding to 162 of SEQ ID NO: 67;

b) an arginine at the position corresponding to 179 of SEQ ID NO: 67; and

c) an arginine at the position corresponding to 162 of SEQ ID NO: 67 and an arginine at the position corresponding to 179 of SEQ ID NO: 67.

97. The ALK4:ActRIIB heteromultimer of claim 95 or 96, wherein the modified IgG1 Fc domain comprises a cysteine at the position corresponding to 127 of SEQ ID NO: 67, a serine at the position corresponding to 144 of SEQ ID NO: 67, an alanine at the position corresponding to 146 of SEQ ID NO: 67, and a valine at the position corresponding to 185 of SEQ ID NO: 67.
98. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :
- a) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31; and
- b) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), and a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V).
99. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :
- a) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31; and
- b) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), and a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V).
100. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), and a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W); and

b) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31.

101. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ActRIIB-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to S132 of SEQ ID NO: 31 (S132C), and a tryptophan at the position corresponding to T144 of SEQ ID NO: 31 (T144W); and

b) the ALK4-Fc fusion protein comprises an IgG1 Fc domain comprising a cysteine at the position corresponding to Y127 of SEQ ID NO: 31 (Y127C), a serine at the position corresponding to T144 of SEQ ID NO: 31 (T144S), an alanine at the position corresponding to L146 of SEQ ID NO: 31 (L146A), and a valine at the position corresponding to Y185 of SEQ ID NO: 31 (Y185V), and an acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31.

102. The ALK4:ActRIIB heteromultimer of any one of claims 98-101, wherein the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is an aspartic acid.

103. The ALK4:ActRIIB heteromultimer of any one of claims 98-101, wherein the acidic amino acid at the position corresponding to H213 of SEQ ID NO: 31 is a glutamic acid.

104. The ALK4:ActRIIB heteromultimer of any one of claims 98-103, wherein the IgG1 Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 31.

105. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :
- a) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32; and
- b) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), and a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V).
106. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :
- a) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32; and
- b) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), and a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V).
107. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :
- a) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), and a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W); and
- b) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position

corresponding to L144 of SEQ ID NO: 32 (L144A), a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32.

108. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ActRIIB-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to S130 of SEQ ID NO: 32 (S130C), and a tryptophan at the position corresponding to T142 of SEQ ID NO: 32 (T142W); and

b) the ALK4-Fc fusion protein comprises an IgG2 Fc domain comprising a cysteine at the position corresponding to Y125 of SEQ ID NO: 32 (Y125C), a serine at the position corresponding to T142 of SEQ ID NO: 32 (T142S), an alanine at the position corresponding to L144 of SEQ ID NO: 32 (L144A), a valine at the position corresponding to Y183 of SEQ ID NO: 32 (Y183V), and an acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32.

109. The ALK4:ActRIIB heteromultimer of any one of claims 105-108, wherein the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is an aspartic acid.

110. The ALK4:ActRIIB heteromultimer of any one of claims 105-108, wherein the acidic amino acid at the position corresponding to H211 of SEQ ID NO: 32 is a glutamic acid.

111. The ALK4:ActRIIB heteromultimer of any one of claims 105-110, wherein the modified IgG2 Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 32.

112. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35; and

b) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), and a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V).

113. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35; and

b) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), and a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V).

114. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), and a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W); and

b) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35.

115. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein :

a) the ActRIIB-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to S136 of SEQ ID NO: 35 (S136C), and a tryptophan at the position corresponding to T148 of SEQ ID NO: 35 (T148W); and

b) the ALK4-Fc fusion protein comprises an IgG4 Fc domain comprising a cysteine at the position corresponding to Y131 of SEQ ID NO: 35 (Y131C), a serine at the position corresponding to T148 of SEQ ID NO: 35 (T148S), an alanine at the position corresponding to L150 of SEQ ID NO: 35 (L150A), a valine at the position corresponding to Y189 of SEQ ID NO: 35 (Y189V), and an acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35.

116. The ALK4:ActRIIB heteromultimer of any one of claims 112-115, wherein the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is an aspartic acid.

117. The ALK4:ActRIIB heteromultimer of any one of claims 112-115, wherein the acidic amino acid at the position corresponding to H217 of SEQ ID NO: 35 is a glutamic acid.

118. The ALK4:ActRIIB heteromultimer of any one of claims 112-117, wherein the modified IgG4 Fc domain is at least 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to the amino acid sequence of SEQ ID NO: 35.

119. The ALK4:ActRIIB heteromultimer of any one of claims 1-118, wherein the ALK4-Fc fusion protein comprises an ALK4 polypeptide domain comprising an amino acid sequence selected from:

a) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to a polypeptide that

i) begins at any one of amino acids of 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, or 34 SEQ ID NO: 9, and

ii) ends at any one of amino acids 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, or 126 of SEQ ID NO: 9;

5 b) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 34-101 of SEQ ID NO: 9;.

c) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 10;

10 d) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to a polypeptide that

i) begins at any one of amino acids of 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, or 34 SEQ ID NO: 19, and

15 ii) ends at any one of amino acids 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, or 126 of SEQ ID NO: 19;

e) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 34-101 of SEQ ID NO: 19; and

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f) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 20.

120. The ALK4:ActRIIB heteromultimer of any one of claims, wherein the ActRIIB-Fc fusion protein comprises an ActRIIB polypeptide domain comprising an amino acid sequence selected from:

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a) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to a polypeptide that:

i) begins at any one of amino acids of 20, 21, 22, 23, 24, 25, 26, 27, 28, or 29

5 SEQ ID NO: 1, and

ii) ends at any one of amino acids 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, or 134 of SEQ ID NO: 1;

10 b) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 29-109 of SEQ ID NO: 1;

c) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to amino acids 25-131 of SEQ ID NO: 1;

15 d) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 2;

20 e) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 3;

f) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 5; and

25 g) an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 6.

121. The ALK4:ActRIIB heteromultimer of claim 120, wherein the ActRIIB polypeptide domain does not comprise an acidic amino acid at the position corresponding to L79 of SEQ ID NO: 1.
122. The ALK4:ActRIIB heteromultimer of any one of claims 1-121, wherein the ALK4-Fc fusion protein further comprises a linker domain positioned between the ALK4 domain and the Fc domain and/or the ActRIIB fusion protein further comprises a linker domain positioned between the ActRIIB domain and the Fc domain.
123. The ALK4:ActRIIB heteromultimer of claim 122, wherein the linker domain is selected from: TGGG (SEQ ID NO: 17), TGGGG (SEQ ID NO: 15), SGGGG (SEQ ID NO: 16), GGGGS (SEQ ID NO: 58), GGG (SEQ ID NO: 13), GGGG (SEQ ID NO: 14), SGGG (SEQ ID NO: 18), and GGGGS (SEQ ID NO: 58).
124. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 76, and wherein the ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 72.
125. The ALK4:ActRIIB heteromultimer of claim 124, wherein the ALK4-Fc fusion protein comprises one or more amino acid selected from:
- a) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76;
 - b) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76;
 - c) a positively charged amino acid at the position corresponding to D286 of SEQ ID NO: 76;

d) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76 and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76;

e) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at the position corresponding to 292 of SEQ ID NO: 76 (Y292V), and a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76;

f) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at position 292 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76; and

g) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76, a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76.

126. The ALK4:ActRIIB heteromultimer of claim 124 or 125, wherein the ActRIIB-Fc fusion protein comprises one or more amino acid selected from:

a) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, and a tryptophan at position 262 of SEQ ID NO: 72;

b) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72;

c) a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72;

d) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72 and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72;

e) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72;

f) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; and

g) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72.

127. A recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 76.

128. The ALK4-Fc fusion protein of claim 127, wherein the fusion protein comprises one or more amino acid selected from:

a) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76;

b) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76;

c) a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76;

d) a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76 and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76;

e) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at position 292 of SEQ ID NO: 76,

and a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76;

f) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, a valine at the position corresponding to 292 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76; and

g) a cysteine at the position corresponding to 234 of SEQ ID NO: 76, a serine at the position corresponding to 251 of SEQ ID NO: 76, an alanine at the position corresponding to 253 of SEQ ID NO: 76, and a valine at the position corresponding to 292 of SEQ ID NO: 76, a positively charged amino acid at the position corresponding to 269 of SEQ ID NO: 76, and a positively charged amino acid at the position corresponding to 286 of SEQ ID NO: 76.

129. A recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 72.

130. The ActRIIB-Fc fusion protein of claim 129, wherein the fusion protein comprises one or more amino acid selected from:

a) a cysteine at the position corresponding to 250 of SEQ ID NO: 72 and a tryptophan at the position corresponding to 262 of SEQ ID NO: 72;

b) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72;

c) a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72;

d) a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72 and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72;

e) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72;

f) a cysteine at the position corresponding to 250 of SEQ ID NO: 72, a tryptophan at position 262 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72; and

g) a cysteine at the position corresponding to 250 of SEQ ID NO: 7, a tryptophan at position 262 of SEQ ID NO: 72, a negatively charged amino acid at the position corresponding to 256 of SEQ ID NO: 72, and a negatively charged amino acid at the position corresponding to 335 of SEQ ID NO: 72.

131. A recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 74.

132. The ALK4-Fc fusion protein of claim 131, wherein the fusion protein comprises one or more amino acid selected from:

a) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, and a valine at position 316 of SEQ ID NO: 74;

b) a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74;

c) a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74;

d) a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74 and a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74;

e) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, a valine at position 316 of SEQ ID NO: 74,

and a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74;

f) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, a valine at the position corresponding to 316 of SEQ ID NO: 74, and a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74

g) a cysteine at the position corresponding to 258 of SEQ ID NO: 74, a serine at the position corresponding to 275 of SEQ ID NO: 74, an alanine at the position corresponding to 277 of SEQ ID NO: 74, a valine at the position corresponding to 316 of SEQ ID NO: 74, a positively charged amino acid at the position corresponding to 293 of SEQ ID NO: 74, and a positively charged amino acid at the position corresponding to 310 of SEQ ID NO: 74.

133. A recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 70.

134. The ActRIIB-Fc fusion protein of claim 133, wherein the fusion protein comprises one or more amino acid selected from:

a) a cysteine at the position corresponding to 275 of SEQ ID NO: 70 and a tryptophan at the position corresponding to 287 of SEQ ID NO: 70;

b) a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70;

c) a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70;

d) a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70 and a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70;

e) a cysteine at the position corresponding to 275 of SEQ ID NO: 70, a tryptophan at the position corresponding to 287 of SEQ ID NO: 70, and a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70;

f) a cysteine at the position corresponding to 275 of SEQ ID NO: 70, a tryptophan at the position corresponding to 287 of SEQ ID NO: 70, and a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70; and

g) a cysteine at the position corresponding to 275 of SEQ ID NO: 70, a tryptophan at the position corresponding to 287 of SEQ ID NO: 70, a negatively charged amino acid at the position corresponding to 281 of SEQ ID NO: 70, and a negatively charged amino acid at the position corresponding to 360 of SEQ ID NO: 70.

135. The heteromultimer or fusion protein of any one of claims 125, 128, and 132, wherein the positively charged amino acid residue is a modified or naturally occurring (e.g., R, K, or H) amino acid.

136. The heteromultimer or fusion protein of claim 135, wherein the positively charged amino acid residue is R.

137. The heteromultimer or fusion protein of any one of claims 126, 130, and 134 negatively charged amino acid residue is a modified or naturally occurring (e.g., D or E) amino acid.

138. The heteromultimer or fusion protein of claim 137, wherein the negatively charged amino acid residue is D.

139. The heteromultimer or fusion protein of claim 137, wherein the negatively charged amino acid residue is E.

140. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 48, and wherein the ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 80.

141. The ALK4:ActRIIB heteromultimer of claim 140, wherein the ALK4-Fc fusion protein comprises a cysteine at the position corresponding to 234 of SEQ ID NO: 48, a serine at the position corresponding to 251 of SEQ ID NO: 48, an alanine at the position corresponding to 253 of SEQ ID NO: 48, and a valine at position 292 of SEQ ID NO: 48.
142. The ALK4:ActRIIB heteromultimer of claim 140 or 141, wherein the ActRIIB-Fc fusion protein comprises a cysteine at the position corresponding to 250 of SEQ ID NO: 80, a tryptophan at the position corresponding to 262 of SEQ ID NO: 80, and a arginine at the position corresponding to 331 of SEQ ID NO: 80.
143. A recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 48.
144. The ALK4-Fc fusion protein of claim 143, wherein the ALK4-Fc fusion protein comprises a cysteine at the position corresponding to 234 of SEQ ID NO: 48, a serine at the position corresponding to 251 of SEQ ID NO: 48, an alanine at the position corresponding to 253 of SEQ ID NO: 48, and a valine at position 292 of SEQ ID NO: 48.
145. A recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 80.
146. The ActRIIB-Fc fusion protein of claim 145, wherein the ActRIIB-Fc fusion protein comprises a cysteine at the position corresponding to 250 of SEQ ID NO: 80, a tryptophan at the position corresponding to 262 of SEQ ID NO: 80, and a arginine at the position corresponding to 331 of SEQ ID NO: 80.
147. A recombinant ALK4-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 47.
148. The ALK4-Fc fusion protein of claim 147, wherein the ALK4-Fc fusion protein comprises a cysteine at the position corresponding to 258 of SEQ ID NO: 47, a serine at the position corresponding to 275 of SEQ ID NO: 47, an alanine at the position

corresponding to 277 of SEQ ID NO: 47, and a valine at position 316 of SEQ ID NO: 47.

149. A recombinant ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%,
5 96%, 97%, 98%, 99%, or 100% to the amino acid sequence of SEQ ID NO: 78.
150. The ActRIIB-Fc fusion protein of claim 145, wherein the ActRIIB-Fc fusion protein comprises a cysteine at the position corresponding to 275 of SEQ ID NO: 78, a tryptophan at the position corresponding to 287 of SEQ ID NO: 78, and a arginine at the position corresponding to 356 of SEQ ID NO: 78.
- 10 151. The ALK4:ActRIIB heteromultimer, ALK4-Fc fusion protein, or ActRIIB-Fc fusion protein of any one of claims 1-150, wherein the heteromultimer or fusion protein comprises one or more modified amino acid residues selected from the group consisting of: a glycosylated amino acid, a PEGylated amino acid, a farnesylated amino acid, an acetylated amino acid, a biotinylated amino acid, and an amino acid
15 conjugated to a lipid moiety.
152. The ALK4:ActRIIB heteromultimer, ALK4-Fc fusion protein, or ActRIIB-Fc fusion protein of claim 151, wherein the heteromultimer or fusion protein is glycosylated and has a glycosylation pattern obtainable from a Chinese hamster ovary (CHO) cell line.
153. The ALK4:ActRIIB heteromultimer, ALK4-Fc fusion protein, or ActRIIB-Fc fusion
20 protein of any one of claims 1-152, wherein the heteromultimer or fusion protein binds to one or more ligands selected from the group consisting of: activin (e.g., activin A and/or activin B), GDF8, GDF11, BMP6, BMP10, and GDF3.
154. The ALK4:ActRIIB heteromultimer, ALK4-Fc fusion protein, or ActRIIB-Fc fusion
25 protein of any one of claims 1-153, wherein the heteromultimer or fusion protein does not substantially bind to BMP9.
155. The heteromultimer of any one of claims 1-126, 135-142, and 151-154, wherein the heteromultimer binds to BMP10 with weaker affinity compared to a corresponding ActRIIB homomultimer.

156. The heteromultimer of any one of claims 1-126, 135-142, and 151-155, wherein the heteromultimer binds to BMP9 with weaker affinity compared to a corresponding ActRIIB homomultimer.
157. The heteromultimer of any one of claims 1-126, 135-142, and 151-156, wherein the heteromultimer binds to GDF3 with weaker affinity compared to a corresponding ActRIIB homomultimer.
158. The heteromultimer of any one of claims 1-126, 135-142, and 151-157, wherein the heteromultimer binds to activin B with stronger affinity compared to a corresponding ActRIIB homomultimer.
159. The ALK4:ActRIIB heteromultimer, ALK4-Fc fusion protein, or ActRIIB-Fc fusion protein of any one of claims 1-158, wherein the heteromultimer or fusion protein inhibits signaling by one or more ligands selected from the group consisting of: activin (e.g., activin A and/or activin B), GDF8, GDF11, BMP6, BMP10, and GDF3.
160. The heteromultimer of any one of claims 1-126, 135-142, and 151-154, wherein the heteromultimer does not sustainably inhibit BMP9 signaling.
161. The heteromultimer of any one of claims 1-126, 135-142, and 151-160, wherein the heteromultimer is a weaker inhibitor of BMP10 signaling compared to a corresponding ActRIIB homomultimer.
162. The heteromultimer of any one of claims 1-126, 135-142, and 151-161, wherein the heteromultimer is a weaker inhibitor of BMP9 signaling compared to a corresponding ActRIIB homomultimer.
163. The heteromultimer of any one of claims 1-126, 135-142, and 151-162, wherein the heteromultimer is a weaker inhibitor of GDF3 signaling compared to a corresponding ActRIIB homomultimer.
164. The heteromultimer of any one of claims 1-126, 135-142, and 151-163, wherein the heteromultimer is a stronger inhibitor of activin B compared to a corresponding ActRIIB homomultimer.

165. The heteromultimer of any one of claims 159-164, wherein the ligand signaling is measured in a cell-based assay.
166. The heteromultimer of any one of claims 1-126, 135-142, and 160-165, wherein the heteromultimer is a heterodimer.
- 5 167. The heteromultimer or Fc fusion protein of any one of claims 1-166, wherein the one or more amino acid modifications alters pI by at least 0.1 (e.g., by at least 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.8, 0.9, 1.0, 1.3, 1.5, 1.7, 2.0, 2.3, 2.5, 2.7, 3.0, 3.3, 3.5, 3.7, or at least by 4.0).
168. The heteromultimer of any proceeding claim, wherein:
- 10 a) the one or more amino acid modifications in the ALK4-Fc fusion protein confers increased difference in isoelectric points between the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein;
- b) the one or more amino acid modifications in the ActRIIB-Fc fusion protein confers increased difference in isoelectric points between the ActRIIB-Fc fusion protein and
- 15 the ALK4-Fc fusion protein; or
- c) the one or more amino acid modifications in the ALK4-Fc fusion protein confers increased difference in isoelectric points between the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein, and the one or more amino acid modifications in the ActRIIB-Fc fusion protein confers increased difference in isoelectric points between
- 20 the ActRIIB-Fc fusion protein and the ALK4-Fc fusion protein.
169. The heteromultimer of claim 167, wherein the ALK4-Fc fusion protein and the ActRIIB-Fc fusion protein have at least a 0.7 difference in pI (e.g., at least 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, or at least 4.0 difference in pI).
- 25 170. A pharmaceutical preparation comprising the heteromultimer of any one of claims 1-126, 135-142, and 160-169 and a pharmaceutically acceptable carrier.
171. The pharmaceutical preparation of claim 170, wherein the pharmaceutical preparation is substantially pyrogen-free.

172. The pharmaceutical preparation of any one of claims 170 or 171, wherein the pharmaceutical preparation comprises less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ALK4 homomultimers.
173. The pharmaceutical preparation of any one of claims 170-172, wherein the pharmaceutical preparation comprises less than about 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or less than about 1% ActRIIB homomultimers.
174. A recombinant nucleic acid comprising a coding sequence for an ALK4-Fc fusion protein as described in any one of claim 1-169.
175. The recombinant nucleic acid of claim 174, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 75.
176. The recombinant nucleic acid of claim 174, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 77.
177. The recombinant nucleic acid of claim 174, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 82.
178. The recombinant nucleic acid of claim 174, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 83.
179. A recombinant nucleic acid comprising a coding sequence for an ActRIIB-Fc fusion protein as described in any one of claim 1-169.
180. The recombinant nucleic acid of claim 179, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%,

90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 71.

181. The recombinant nucleic acid of claim 179, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%,
5 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 73.

182. The recombinant nucleic acid of claim 179, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%,
10 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 79.

183. The recombinant nucleic acid of claim 179, wherein the nucleic acid comprises a nucleic acid sequence that is at least 70%, 75%, 80%, 85%, 86%, 87%, 88%, 89%,
90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO: 81.

15 184. A recombinant polynucleotide comprising a promoter sequence operably linked to the coding sequence of the ALK4 polypeptide of any one of claims 174-178.

185. A recombinant polynucleotide comprising a promoter sequence operably linked to the coding sequence of the ActRIIB polypeptide of any one of claims 179-183.

186. A recombinant polynucleotide comprising a promoter sequence operably linked to the
20 coding sequence of the ALK4 polypeptide according to any one of claims 174-178 and the coding sequence of the ActRIIB polypeptide according to any one of claims 179-183.

187. A vector comprising the recombinant polynucleotide of any one of claims 174-186.

188. A cell transformed with the recombinant polynucleotide any one of claims 174-186 or
25 the vector of claim 187.

189. The cell of claim 186, wherein the cell is a CHO cell.

190. A method of making a heteromultimer comprising an ALK4 polypeptide and an ActRIIB polypeptide comprising culturing a cell under conditions suitable for

expression of an ALK4 polypeptide and an ActRIIB polypeptide, wherein the cell comprises the recombinant polynucleotides of any one of claims 174-176 and the recombinant polynucleotides of any one of claims 179-183.

191. A method of making a heteromultimer comprising an ALK4 polypeptide and an ActRIIB polypeptide comprising culturing a cell under conditions suitable for expression of an ALK4 polypeptide and an ActRIIB polypeptide, wherein the cell comprises the recombinant polynucleotide of claims 186.

192. A method of making a heteromultimer comprising an ALK4 polypeptide and an ActRIIB polypeptide comprising:

a) culturing a first cell under conditions suitable for expression of an ALK4 polypeptide, wherein the first cell comprises the recombinant polynucleotide of any one of claims 174-178;

b) recovering the ALK4 polypeptide so expressed;

c) culturing a second cell under conditions suitable for expression of an ActRIIB polypeptide, wherein the second cell comprises the recombinant polynucleotide of any one of claims 179-183;

d) recovering the ActRIIB polypeptide so expressed;

e) combining the recovered ALK4 polypeptide and the recovered ActRIIB polypeptide under conditions suitable for ALK4:ActRIIB heteromultimer formation.

193. The method of any one of claims 190-192, wherein the method further comprises a step of recovering the heteromultimer.

194. The method of any one of claims 190-193, wherein the ALK4 polypeptide is expressed using a TPA leader sequence.

195. The method of any one of claims 190-193, wherein the ActRIIB polypeptide is expressed using a TPA leader sequence.

196. The method of claim 194 or 195, wherein the TPA leader comprises a coding sequence for SEQ ID NO: 38.

197. The method of any one of claims 190-196, wherein the cell is a CHO cell.

198. The method of any one of claims 190-197, wherein the heteromultimer is a heterodimer.

199. A recombinant ALK4:ActRIIB heteromultimer comprising at least one ALK4-Fc fusion protein and at least one ActRIIB-Fc fusion protein, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 90%, 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 76, and wherein the ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 90%, 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 72.

200. The recombinant ALK4:ActRIIB heteromultimer of claim 199, wherein the ALK4-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 76, and wherein the ActRIIB-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 72.

201. The recombinant ALK4:ActRIIB heteromultimer of claim 199, wherein the ActRIIB-Fc fusion protein comprises the leader sequence of SEQ ID NO: 38.

202. The recombinant ALK4:ActRIIB heteromultimer of any one of claims 199-201, wherein the ActRIIB-Fc fusion protein comprises an amino acid sequence that is at least 90%, 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 70.

203. The recombinant ALK4:ActRIIB heteromultimer of any one of claims 199-202, wherein the ActRIIB-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 70.

204. The recombinant ALK4:ActRIIB heteromultimer of any one of claims 199-203, wherein the ALK4-Fc fusion protein comprises the leader sequence of SEQ ID NO: 38.

205. The recombinant ALK4:ActRIIB heteromultimer of any one of claims 199-201, wherein the ALK4-Fc fusion protein comprises an amino acid sequence that is at least 90%, 95%, 97% or 99% identical to the amino acid sequence of SEQ ID NO: 74.

206. The recombinant ALK4:ActRIIB heteromultimer, wherein the ALK4-Fc fusion protein comprises the amino acid sequence of SEQ ID NO: 74.

207. A method for treating a patient having a disorder associated with muscle loss or insufficient muscle growth, comprising administering to a patient in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169 and 199-206.
- 5 208. The method of claim 207, wherein the patient has muscle atrophy.
209. The method of claim 207, wherein the patient has a muscular dystrophy.
210. The method of claim 208, wherein the muscular dystrophy is Duchenne muscular dystrophy.
- 10 211. The method of claim 210, wherein the patient is a juvenile and treatment begins within one to five years of the date of diagnosis with Duchenne muscular dystrophy.
212. The method of claim 208, wherein the muscular dystrophy is Becker muscular dystrophy.
- 15 213. The method of any one of claims 210-212, wherein the heteromultimer is administered in combination with one or more of: eteplirsen, a corticosteroid (*e.g.*, deflazacourt), steroids (*e.g.*, prednisone), a blood pressure and/or heart medication (*e.g.*, angiotensin converting enzyme inhibitors, beta blockers, and diuretics), an anti-asthmatic (*e.g.*, albuterol), vitamins/neutrients (*e.g.*, amino acids, carnitine, coenzyme Q10, creatine, fish oil, green tea extracts, vitamin E), stem cell therapy, gene therapy, assisted ventilation, surgery, physical therapy, diet and/or exercise.
- 20 214. The method of claim 209, wherein the muscular dystrophy is facioscapulohumeral muscular dystrophy.
- 25 215. The method of claim 214, wherein the heteromultimer is administered in combination with one or more of: albuterol, speech therapy, surgery, walking aids, back braces, T-cell inhibitors (*e.g.*, truncated histidyl-tRNA synthetase), stem cell therapy, gene therapy, and/or foot support devices.
216. The method of claim 207, wherein the patient has amyotrophic lateral sclerosis.
217. The method of claim 216, wherein the patient receives treatment after diagnosis with amyotrophic lateral sclerosis.

218. The method of claim 216 or 217, wherein the heteromultimer is administered in combination with one or more of: riluzole, edaravone, masitinib, antioxidants, physical therapy, speech therapy, nutritional support, breathing support (*e.g.*, a non-invasive ventilator), stem cell therapy, and/or gene therapy.
- 5 219. The method of claim 207, wherein the disorder is cachexia associated with cancer or cancer therapy.
220. The method of claim 207, wherein the disorder is sarcopenia.
221. The method of claim 220, wherein the heteromultimer is administered in combination with urocortin II, hormone replacement therapy (*e.g.*, testosterone or human growth hormone), creatine, vitamin D, exercise, diet, and/or strength training.
- 10 222. The method of claim 207, wherein the disorder is sporadic inclusion body myositis.
223. The method of claim 222, wherein the heteromultimer is administered in combination with one or more of: corticosteroids, prednisone, oxandrolone, methotrexate, mycophenolate mofetil, intravenous immunoglobulin, beta interferon-1a, etanercept, alemtuzumab, follistatin, lithium, bimagrumab, arimoclomol, rapamycin, antioxidants, carnitine, coenzyme Q10, physical therapy, occupational therapy, stem cell therapy, and/or gene therapy.
- 15 224. A method for treating a patient having a disorder associated with neurodegeneration, comprising administering to the patient in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, , 151-169 and 199-207.
- 20 225. The method of claim 224, wherein the disorder is amyotrophic lateral sclerosis.
226. The method of claim 225, wherein the heteromultimer is administered in combination with one or more of: riluzole, edaravone, masitinib, antioxidants, physical therapy, speech therapy, nutritional support, breathing support (*e.g.*, a non-invasive ventilator), stem cell therapy, and/or gene therapy.
- 25 227. A method for treating fibrosis or a disorder or condition associated with fibrosis comprising administering to the patient in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169 and 199-207.

228. The method of claim 227, wherein the disorder or condition associated with fibrosis is selected from: pulmonary fibrosis, hypersensitivity pneumonitis, idiopathic fibrosis, tuberculosis, pneumonia, cystic fibrosis, asthma, chronic obstructive pulmonary disease (COPD), emphysema, renal (kidney) fibrosis, renal (kidney) failure, chronic renal (kidney) disease, bone fibrosis, myelofibrosis, rheumatoid arthritis, systemic lupus erythematosus, scleroderma, sarcoidosis, granulomatosis with polyangiitis, Peyronie's disease, liver fibrosis, Wilson's disease, glycogen storage diseases (particularly types III, IV, IX, and X), iron-overload, Gaucher disease, Zellweger syndrome, nonalcoholic and alcoholic steatohepatitis, biliary cirrhosis, sclerosing cholangitis, Budd-Chiari syndrome, surgery-associated fibrosis, Crohn's disease, Duputren's contracture, mediastinal fibrosis, nephrogenic fibrosis, retroperitoneal fibrosis, atrial fibrosis, endomyocardial fibrosis, pancreatic fibrosis.
229. The method of claim 227, wherein the disorder or condition associated with fibrosis is idiopathic pulmonary fibrosis.
230. A method for reducing body weight in a subject, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.
231. A method for reducing body weight gain in a subject, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169 and 199-207.
232. A method for treating or preventing diabetes, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.
233. The method of claim 232, wherein the subject has type II diabetes.
234. A method for treating or preventing obesity, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.

235. A method for treating or preventing fatty liver disease, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.
236. The method of claim 235, wherein the subject has non-alcoholic fatty liver disease.
- 5 237. A method for reducing cholesterol and/or triglycerides in a subject, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, , 151-169, and 199-207.
238. The method of any one of claims 230-237, wherein the subject is has a body mass index (BMI) of 25 kg/m^2 or greater.
- 10 239. The method of any one of claims 230-237, wherein the subject is obese.
240. The method of claim 239, wherein the subject has a body mass index (BMI) of 30 kg/m^2 or greater.
241. The method of any one of claims 230-240, wherein the subject has insulin resistance.
242. The method of any one of claims 230-241, wherein the subject has type 2 diabetes.
- 15 243. The method of any one of claims 230-242, wherein the subject has a disease or condition selected from the group consisting of: dyslipidemia, hyperlipidemia, hypercholesterolemia, low HDL serum level, high LDL serum level, and hypertriglyceridemia.
- 20 244. The method of any one of claims 230-243, wherein the subject has a disease or condition selected from the group consisting of: hypertension (high blood pressure), myocardial infarction, peripheral artery disease, vasoregulation dysfunction, arteriosclerosis, congestive heart failure, atherosclerosis, coronary heart disease, or microvascular disease.
245. The method of any one of claims 230-244, wherein the subject has fatty liver disease.
- 25 246. The method of claim 245, wherein the subject has non-alcoholic fatty liver disease.
247. A method for treating or preventing a disorder or condition associated with undesirable body weight gain and/or a metabolic disorder, comprising administering

to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.

248. The method of claim 247, wherein the disorder or condition is selected from the group consisting of: hyperglycemia, a lipid metabolism disease, disorder, dislipidemia, low HDL levels, high LDL levels, high triglyceride levels, hyperlipidemia, a lipoprotein aberration, a glucose metabolism disease, glucose intolerance, insulin resistance, impaired glucose tolerance (IGT), impaired fasting glucose (IFG), high uric acid levels, NAFLD, fatty liver, NASH, polycystic ovarian syndrome, hyperinsulinemia, obesity, type II diabetes, heart disease, high blood pressure, atherosclerosis, Syndrome X, metabolic syndrome, and hypertension .

249. A method for treating fibrosis or a disorder or condition associated with fibrosis in a subject, comprising administering to a subject in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.

250. The method of claim 248, wherein the disorder or condition associated with fibrosis is selected from: pulmonary fibrosis, hypersensitivity pneumonitis, idiopathic fibrosis, tuberculosis, pneumonia, cystic fibrosis, asthma, chronic obstructive pulmonary disease (COPD), emphysema, renal (kidney) fibrosis, renal (kidney) failure, chronic renal (kidney) disease, bone fibrosis, myelofibrosis, rheumatoid arthritis, systemic lupus erythematosus, scleroderma, sarcoidosis, granulomatosis with polyangiitis, Peyronie's disease, liver fibrosis, Wilson's disease, glycogen storage diseases (particularly types III, IV, IX, and X), iron-overload, Gaucher disease, Zellweger syndrome, nonalcoholic and alcoholic steatohepatitis, biliary cirrhosis, sclerosing cholangitis, Budd-Chiari syndrome, surgery-associated fibrosis, Crohn's disease, Duputren's contracture, mediastinal fibrosis, nephrogenic fibrosis, retroperitoneal fibrosis, atrial fibrosis, endomyocardial fibrosis, and pancreatic fibrosis.

251. The method of claim 249, wherein the disorder or condition associated with fibrosis is idiopathic pulmonary fibrosis.

252. A method for treating kidney disease or a complication of kidney disease, comprising administering to a patient in need thereof an effective amount of a heteromultimer of any one of claims 1-126, 135-142, 151-169, and 199-207.

253. The method of claim 252, where in the patient has chronic kidney disease or failure.
254. The method of claim 252, wherein the patient has acute kidney disease or failure.
255. The method of claim 252, wherein the patient has stage 1, stage 2, stage 3, stage 4, or stage 5 kidney disease.
- 5 256. The method of claim 255, wherein the method delays or prevents progression from: stage 1 to stage 2 kidney disease, stage 2 to stage 3 kidney disease, stage 3 to stage 4 kidney disease, or stage 4 to stage 5 kidney disease.
257. The method of any one of claims 252-256, wherein the method prevents or reduces kidney inflammation.
- 10 258. The method of any one of claims 252-257, wherein the method prevents or reduces kidney tissue damage.
259. The method of any one of claims 252-258, wherein the method prevents or reduces kidney fibrosis.
- 15 260. The method of any one of claims 252-259, wherein the patient has one or more of: non-diabetic kidney diseases, glomerulonephritis, interstitial nephritis, diabetic kidney diseases, diabetic nephropathy, glomerulosclerosis, rapid progressive glomerulonephritis, renal fibrosis, Alport syndrome, IDDM nephritis, mesangial proliferative glomerulonephritis, membranoproliferative glomerulonephritis, crescentic glomerulonephritis, renal interstitial fibrosis, focal segmental
- 20 glomerulosclerosis, membranous nephropathy, minimal change disease, pauci-immune rapid progressive glomerulonephritis, IgA nephropathy, polycystic kidney disease, Dent's disease, nephrocytinosis, Heymann nephritis, autosomal dominant (adult) polycystic kidney disease, autosomal recessive (childhood) polycystic kidney disease, acute kidney injury, nephrotic syndrome, renal ischemia, podocyte diseases
- 25 or disorders, proteinuria, glomerular diseases, membranous glomerulonephritis, focal segmental glomerulonephritis, pre-eclampsia, eclampsia, kidney lesions, collagen vascular diseases, benign orthostatic (postural) proteinuria, IgM nephropathy, membranous nephropathy, sarcoidosis, diabetes mellitus, kidney damage due to drugs, Fabry's disease, aminoaciduria, Fanconi syndrome, hypertensive nephrosclerosis,

interstitial nephritis, sickle cell disease, hemoglobinuria, myoglobinuria, Wegener's
 Granulomatosis, Glycogen Storage Disease Type 1, chronic kidney disease, chronic
 renal failure, low Glomerular Filtration Rate (GFR), nephroangiosclerosis, lupus
 nephritis, ANCA-positive pauci-immune crescentic glomerulonephritis, chronic
 5 allograft nephropathy, nephrotoxicity, renal toxicity, kidney necrosis, kidney damage,
 glomerular and tubular injury, kidney dysfunction, nephritic syndrome, acute renal
 failure (acute kidney injury), chronic renal failure, proximal tubal dysfunction, acute
 kidney transplant rejection, chronic kidney transplant rejection, non-IgA
 mesangioproliferative glomerulonephritis, postinfectious glomerulonephritis,
 10 vasculitides with renal involvement of any kind, any hereditary renal disease, any
 interstitial nephritis, renal transplant failure, kidney cancer, kidney disease associated
 with other conditions (e.g., hypertension, diabetes, and autoimmune disease), Dent's
 disease, nephrocytosis, Heymann nephritis, a primary kidney disease, a collapsing
 glomerulopathy, a dense deposit disease, a cryoglobulinemia-associated
 15 glomerulonephritis, an Henoch-Schonlein disease, a postinfectious glomerulonephritis,
 a bacterial endocarditis, a microscopic polyangitis, a Churg-Strauss syndrome, an
 anti-GBM-antibody mediated glomerulonephritis, amyloidosis, a monoclonal
 immunoglobulin deposition disease, a fibrillary glomerulonephritis, an immunotactoid
 glomerulopathy, ischemic tubular injury, a medication-induced tubulo-interstitial
 20 nephritis, a toxic tubulo-interstitial nephritis, an infectious tubulo-interstitial nephritis,
 a bacterial pyelonephritis, a viral infectious tubulo-interstitial nephritis which results
 from a polyomavirus infection or an HIV infection, a metabolic-induced tubulo-
 interstitial disease, a mixed connective disease, a cast nephropathy, a crystal
 nephropathy which may results from urate or oxalate or drug-induced crystal
 25 deposition, an acute cellular tubulo-interstitial allograft rejection, a tumoral infiltrative
 disease which results from a lymphoma or a post-transplant lymphoproliferative
 disease, an obstructive disease of the kidney, vascular disease, a thrombotic
 microangiopathy, a nephroangiosclerosis, an atheroembolic disease, a mixed
 connective tissue disease, a polyarteritis nodosa, a calcineurin-inhibitor induced-
 30 vascular disease, an acute cellular vascular allograft rejection, an acute humoral
 allograft rejection, early renal function decline (ERFD), end stage renal disease
 (ESRD), renal vein thrombosis, acute tubular necrosis, renal occlusion, acute
 interstitial nephritis, established chronic kidney disease, renal artery stenosis,
 ischemic nephropathy, uremia, drug and toxin-induced chronic tubulointerstitial

- nephritis, reflux nephropathy, kidney stones, Goodpasture's syndrome, normocytic normochromic anemia, renal anemia, diabetic chronic kidney disease, IgG4-related disease, von Hippel-Lindau syndrome, tuberous sclerosis, nephronophthisis, medullary cystic kidney disease, renal cell carcinoma, adenocarcinoma,
- 5 nephroblastoma, lymphoma, leukemia, hyposialylation disorder, chronic cyclosporine nephropathy, renal reperfusion injury, renal dysplasia, azotemia, bilateral arterial occlusion, acute uric acid nephropathy, hypovolemia, acute bilateral obstructive uropathy, hypercalcemic nephropathy, hemolytic uremic syndrome, acute urinary retention, malignant nephrosclerosis, postpartum glomerulosclerosis, scleroderma,
- 10 non-Goodpasture's anti-GBM disease, microscopic polyarteritis nodosa, allergic granulomatosis, acute radiation nephritis, post-streptococcal glomerulonephritis, Waldenstrom's macroglobulinemia, analgesic nephropathy, arteriovenous fistula, arteriovenous graft, dialysis, ectopic kidney, medullary sponge kidney, renal osteodystrophy, solitary kidney, hydronephrosis, microalbuminuria, uremia,
- 15 haematuria, hyperlipidemia, hypoalbuminaemia, lipiduria, acidosis, and hyperkalemia.
261. The method of claim 260, wherein the patient has Alport Syndrome.
262. The method of claim 261, wherein the heteromultimer is administered in combination with one or more of: an angiotensin converting enzyme (ACE) inhibitor (*e.g.*, benazepril, cilazapril, enalapril, fosinopril, lisinopril, perinopril, ramapril and
- 20 quinapril), an angiotensin receptor blocker (*e.g.*, candesartan, epresartan, irbesartan, losartan, telmisartan and valsartan), a statin (*e.g.*, fluvastatin), a non-dihydropyridine calcium channel blocker (*e.g.*, diltiazem), cyclosporine, and/or aldosterone inhibitors.
263. A method of treating pulmonary arterial hypertension, comprising administering to a patient in need thereof an effective amount of the ALK4:ActRIIB heteromultimer as
- 25 described in any preceding claim.
264. A method of treating pulmonary hypertension, comprising administering to a patient in need thereof an effective amount of the ALK4:ActRIIB heteromultimer as described in any preceding claim.
265. A method of treating, preventing, or reducing the progression rate and/or severity of
- 30 one or more complications of pulmonary hypertension, comprising administering to a patient

in need thereof an effective amount of the ALK4:ActRIIB heteromultimer as described in any preceding claim.

266. The method of claim 265, wherein the one or more complications of pulmonary hypertension is selected from the group consisting of: smooth muscle and/or endothelial cell proliferation in the pulmonary artery, angiogenesis in the pulmonary artery, dyspnea, chest pain, pulmonary vascular remodeling, right ventricular hypertrophy, and pulmonary fibrosis.

267. The method of any one of claims 264-266, wherein the pulmonary hypertension is pulmonary arterial hypertension.

268. A method of treating, preventing, or reducing the progression rate and/or severity of one or more complications of an interstitial lung disease, comprising administering to a patient in need thereof an effective amount of the ALK4:ActRIIB heteromultimer as described in any preceding claim.

269. The method of claim 269, wherein the interstitial lung disease is idiopathic pulmonary fibrosis.

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ActRIIa	ILGRSETQEC	LEFNANWEKD	RTNQTV	EPC	YGD	KDKRRHC	FATWKNISGS
ActRIIb	GRGEAETREC	IYYNANWELE	RTNQSGLE	ERC	EGEQDKRLHC	YASWRNSSGT	
	IEIVKQGGWL	DDINCYDRTD	CV	EKKDSPEV	YFCCCEGNMC	NEKFSYFPPEM	
	IELVKKGGWL	DDFNICYDRQE	CV	ATEENPQV	YFCCCEGNFC	NERFTHLPEA	
	EVTQPTSNPV	TPKPPT					
	GGPEVTYEPP	PTAPT					

FIGURE 1

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Rat IIb	M	T	A	P	W	A	-	L	A	L	L	W	G	S	L	C	A	G	S	G	R	G	E	A	E	T	R	E	C	I	Y	N	A	N	W	E	L	E	R	T	N	Q	S	G	L	E	R	-	C	E	G	E	Q	D	K	R	
Pig IIb	M	T	A	P	W	A	-	L	A	L	L	W	G	S	L	C	V	G	S	G	R	G	E	A	E	T	R	E	C	I	Y	N	A	N	W	E	L	E	R	T	N	Q	S	G	L	E	R	-	C	E	G	E	Q	D	K	R	
Mouse IIb	M	T	A	P	W	A	-	L	A	L	L	W	G	S	L	C	A	G	S	G	R	G	E	A	E	T	R	E	C	I	Y	N	A	N	W	E	L	E	R	T	N	Q	S	G	L	E	R	-	C	E	G	E	Q	D	K	R	
Human IIb	M	T	A	P	W	V	A	-	L	A	L	L	W	G	S	L	C	A	G	S	G	R	G	E	A	E	T	R	E	C	I	Y	N	A	N	W	E	L	E	R	T	N	Q	S	G	L	E	R	-	C	E	G	E	Q	D	K	R
Bovine IIb	M	T	A	P	W	A	-	L	A	L	L	W	G	S	L	C	A	G	S	G	R	G	E	A	E	T	R	E	C	I	Y	N	A	N	W	E	L	E	R	T	N	Q	S	G	L	E	R	-	C	E	G	E	R	D	K	R	
Xenopus IIb	M	G	A	S	V	A	L	T	F	L	L	L	A	T	F	R	A	G	S	G	H	D	E	V	E	T	R	E	C	I	Y	N	A	N	W	E	L	E	K	T	N	Q	S	G	V	E	R	L	V	E	G	K	K	D	K	R	
Human IIA	M	G	A	A	K	L	A	F	A	V	F	L	I	S	C	S	S	G	A	I	L	G	R	S	E	T	Q	E	C	L	F	F	N	A	N	W	E	K	D	R	T	N	Q	T	G	V	E	P	-	C	Y	G	D	K	D	K	R

Consensus	M	t	A	p	w	a	X	I	a	I	I	w	g	s	I	c	a	G	s	g	r	g	e	a	E	T	r	E	C	r	y	y	N	A	N	W	E	I	e	r	T	N	Q	s	G	I	E	r	L	c	e	G	e	q	D	K	R
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Rat IIb	L	H	C	Y	A	S	W	P	N	S	S	G	T	I	E	L	V	K	K	G	C	W	L	D	D	F	N	C	Y	D	R	Q	E	C	V	A	T	E	E	N	P	Q	V	Y	F	C	C	E	G	N	F	C	N	E	R	F	T
Pig IIb	L	H	C	Y	A	S	W	R	N	S	S	G	T	I	E	L	V	K	K	G	C	W	L	D	D	F	N	C	Y	D	R	Q	E	C	V	A	T	E	E	N	P	Q	V	Y	F	C	C	E	G	N	F	C	N	E	R	F	T
Mouse IIb	L	H	C	Y	A	S	W	R	N	S	S	G	T	I	E	L	V	K	K	G	C	W	L	D	D	F	N	C	Y	D	R	Q	E	C	V	A	T	E	E	N	P	Q	V	Y	F	C	C	E	G	N	F	C	N	E	R	F	T
Human IIb	L	H	C	Y	A	S	W	R	N	S	S	G	T	I	E	L	V	K	K	G	C	W	L	D	D	F	N	C	Y	D	R	Q	E	C	V	A	T	E	E	N	P	Q	V	Y	F	C	C	E	G	N	F	C	N	E	R	F	T
Bovine IIb	L	H	C	Y	A	S	W	R	N	S	S	G	T	I	E	L	V	K	K	G	C	W	L	D	D	F	N	C	Y	D	R	Q	E	C	V	A	T	E	E	N	P	Q	V	Y	F	C	C	E	G	N	F	C	N	E	R	F	T
Xenopus IIb	L	H	C	Y	A	S	W	R	N	N	S	G	F	I	E	L	V	K	K	G	C	W	L	D	D	F	N	C	Y	D	R	Q	E	C	I	A	K	E	E	N	P	Q	V	F	F	C	C	E	G	N	Y	C	N	K	K	F	T
Human IIA	R	H	C	F	A	T	W	K	N	I	S	G	S	I	E	I	V	K	Q	G	C	W	L	D	D	I	N	C	Y	D	R	T	D	C	V	E	K	K	D	S	P	E	V	Y	F	C	C	E	G	N	M	C	N	E	K	F	S

Consensus	I	H	C	y	A	s	W	r	N	s	S	G	t	I	E	I	V	K	k	G	C	W	L	D	D	f	N	C	Y	D	R	q	e	C	v	a	t	e	e	n	P	q	V	y	F	C	C	E	G	N	f	C	N	e	r	F	t
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Rat IIb	H	L	P	E	P	G	G	P	E	V	T	Y	E	P	-	P	P	T	A	P	T	L	L	T	V	L	A	Y	S	L	L	P	I	G	G	L	S	-
Pig IIb	H	L	P	E	A	G	G	P	E	V	T	Y	E	P	-	P	P	T	A	P	T	L	L	T	V	L	A	Y	S	L	L	P	I	G	G	L	S	-
Mouse IIb	H	L	P	E	P	G	G	P	E	V	T	Y	E	P	-	P	P	T	A	P	T	L	L	T	V	L	A	Y	S	L	L	P	I	G	G	L	S	-
Human IIb	H	L	P	E	A	G	G	P	E	V	T	Y	E	P	-	P	P	T	A	P	T	L	L	T	V	L	A	Y	S	L	L	P	I	G	G	L	S	-
Bovine IIb	H	L	P	E	A	G	G	P	E	V	T	Y	E	P	-	P	P	T	A	P	T	L	L	T	V	L	A	Y	S	L	L	P	V	G	G	L	S	-
Xenopus IIb	H	L	P	E	V	-	-	-	E	T	F	D	P	K	P	Q	P	S	A	S	V	L	N	I	L	I	Y	S	L	L	P	I	V	G	L	S	M	
Human IIA	Y	F	P	E	M	E	V	T	Q	P	T	S	N	P	-	V	T	P	K	P	P	Y	N	I	L	L	Y	S	L	V	P	L	M	L	I	-	-	

Consensus	h	I	P	E	X	g	g	p	e	v	T	y	e	P	K	p	p	t	a	p	t	I	I	t	v	L	a	Y	S	L	I	P	i	g	g	I	S	M
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FIGURE 2

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IgG1	----- <u>THTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVDVSHEDPEVKF</u>	53
IgG4	--- <u>ESKYGPPCPSCPAPEFLGGPSVFLFPPKPKDTLMISRTPEVTCVVDVSQEDPEVQF</u>	57
IgG2	----- <u>VECPPCPAPPVAG-PSVFLFPPKPKDTLMISRTPEVTCVVDVSHEDPEVQF</u>	51
IgG3	<u>EPKSCDTPPPCPRCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVDVSHEDPEVQF</u>	60
	** **** . * *****:****:*	
IgG1	NWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKT	113
IgG4	NWYVDGVEVHNAKTKPREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKGLPSSIEKT	117
IgG2	NWYVDGVEVHNAKTKPREEQFNSTFRVSVLTVVHQDWLNGKEYKCKVSNKGLPAPIEKT	111
IgG3	KWYVDGVEVHNAKTKPREEQYNSTFRVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKT	120
	:*****:***:*****:*****.***:****	
IgG1	ISKAKGQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTP	173
IgG4	<u>ISKAKGQPREPQVYTLPPS</u> <u>QEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTP</u>	177
IgG2	ISKTKGQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTP	171
IgG3	ISKTKGQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESSGQPENNYNTTP	180
	:**:*****:*****.*****:***	
IgG1	PVLDSGDSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK	225
IgG4	<u>PVLDSGDSFFLYSRLTVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLSLGK</u>	229
IgG2	<u>PMLDSGDSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK</u>	223
IgG3	<u>PMLDSGDSFFLYSKLTVDKSRWQQGNIFSCSVMHEALHNRFTQKSLSLSPGK</u>	232
	*:*****:*****:***:*****:***** **	

FIGURE 3

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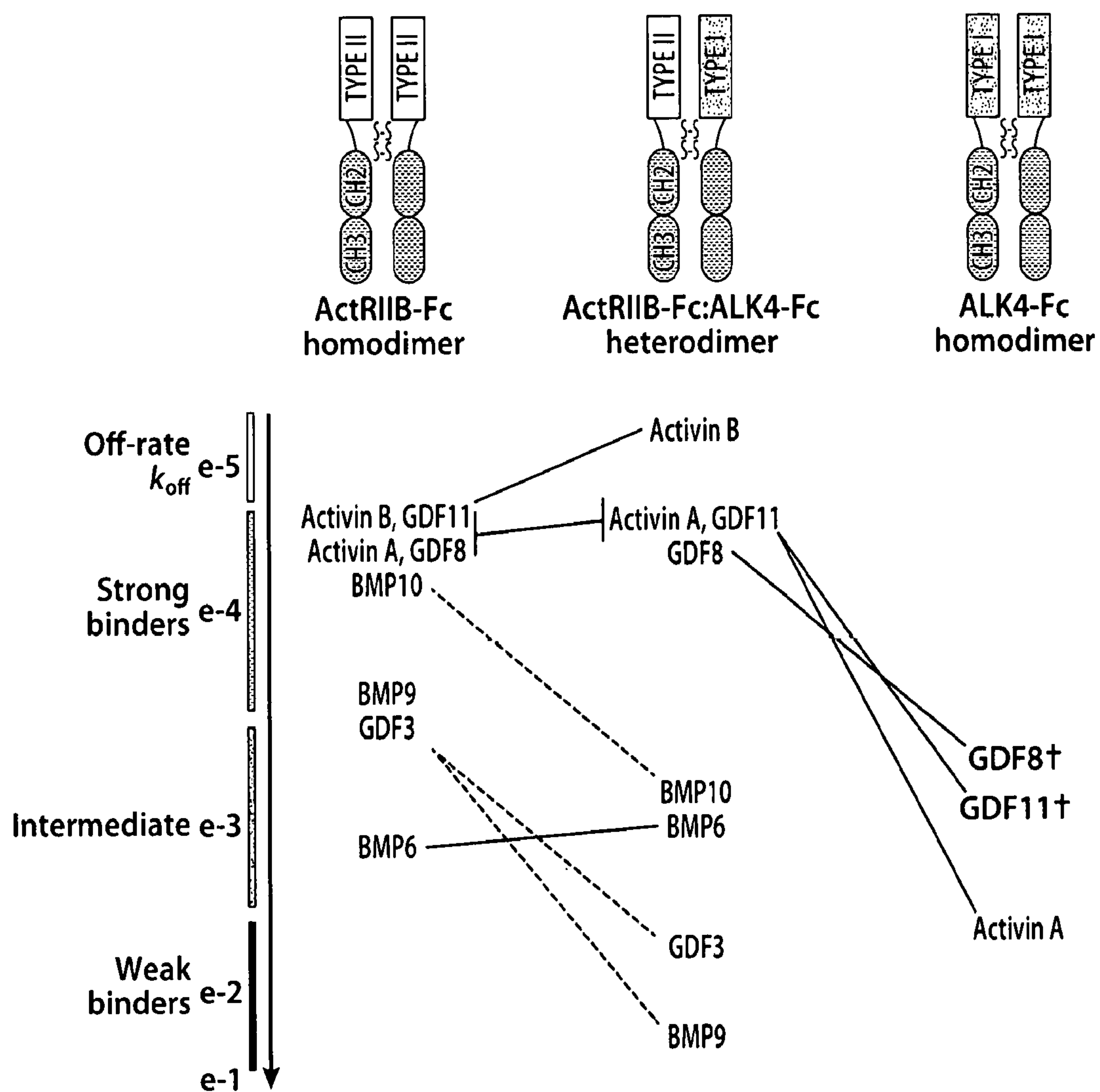


FIGURE 4

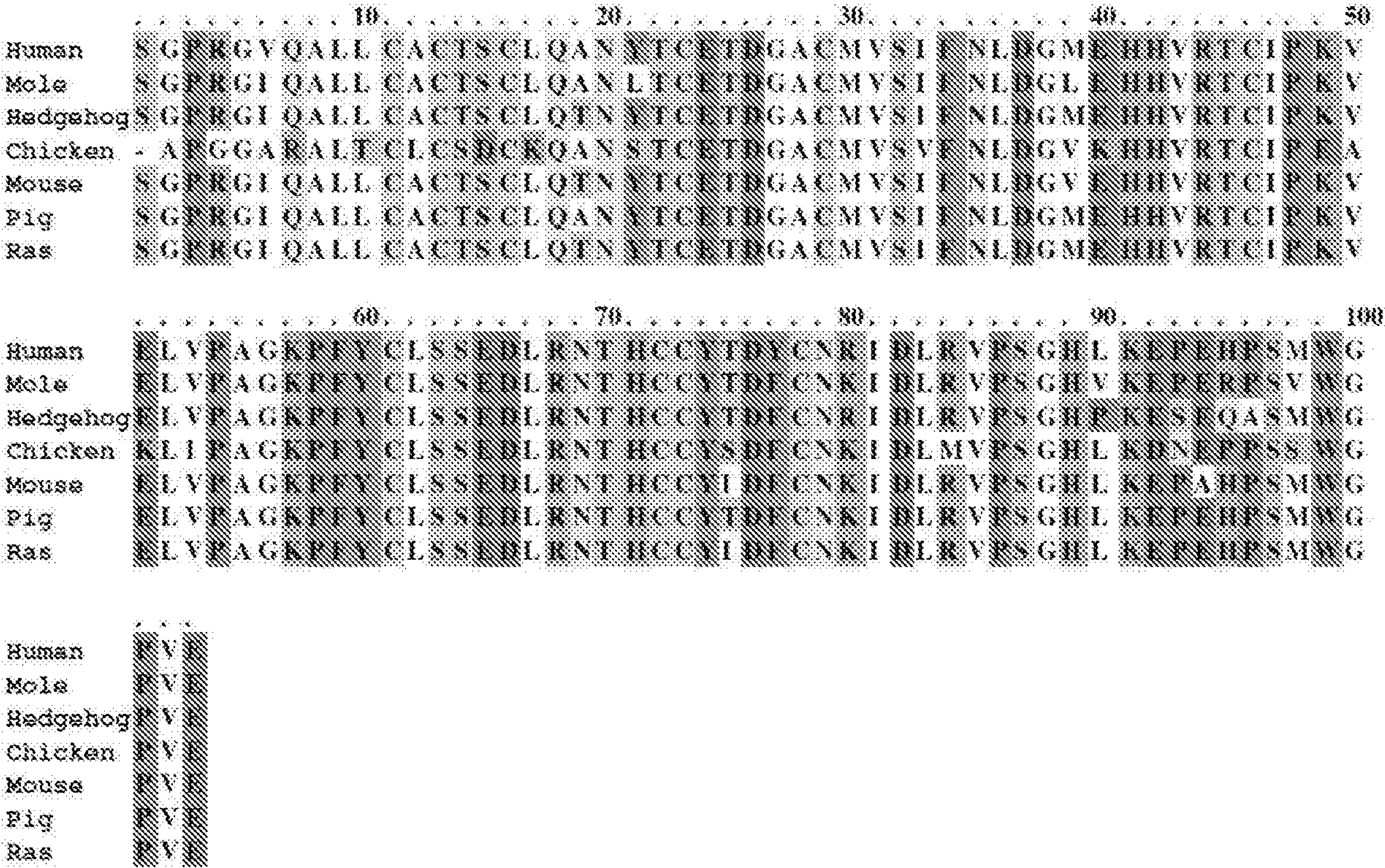


FIGURE 5

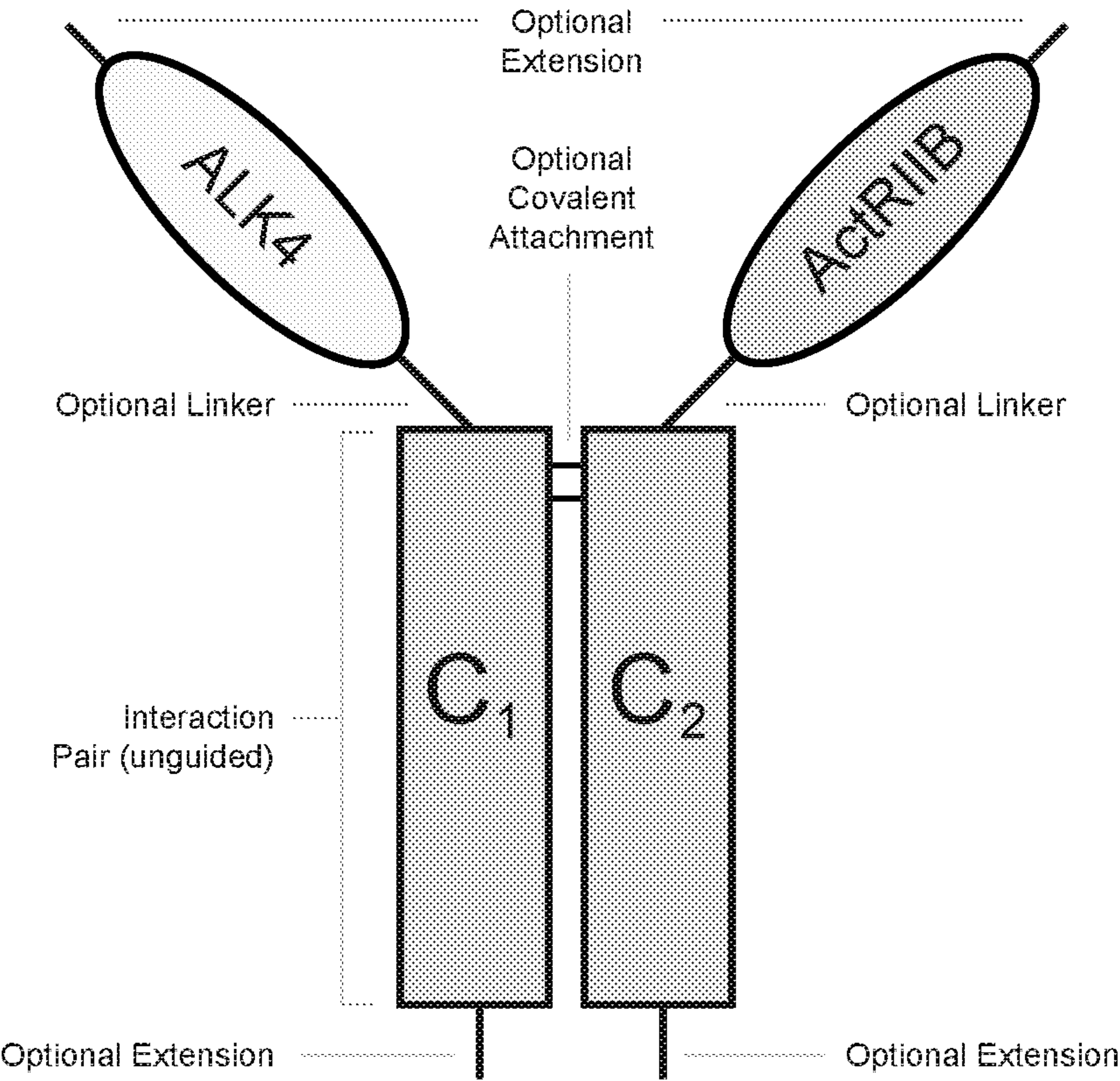


FIGURE 6A

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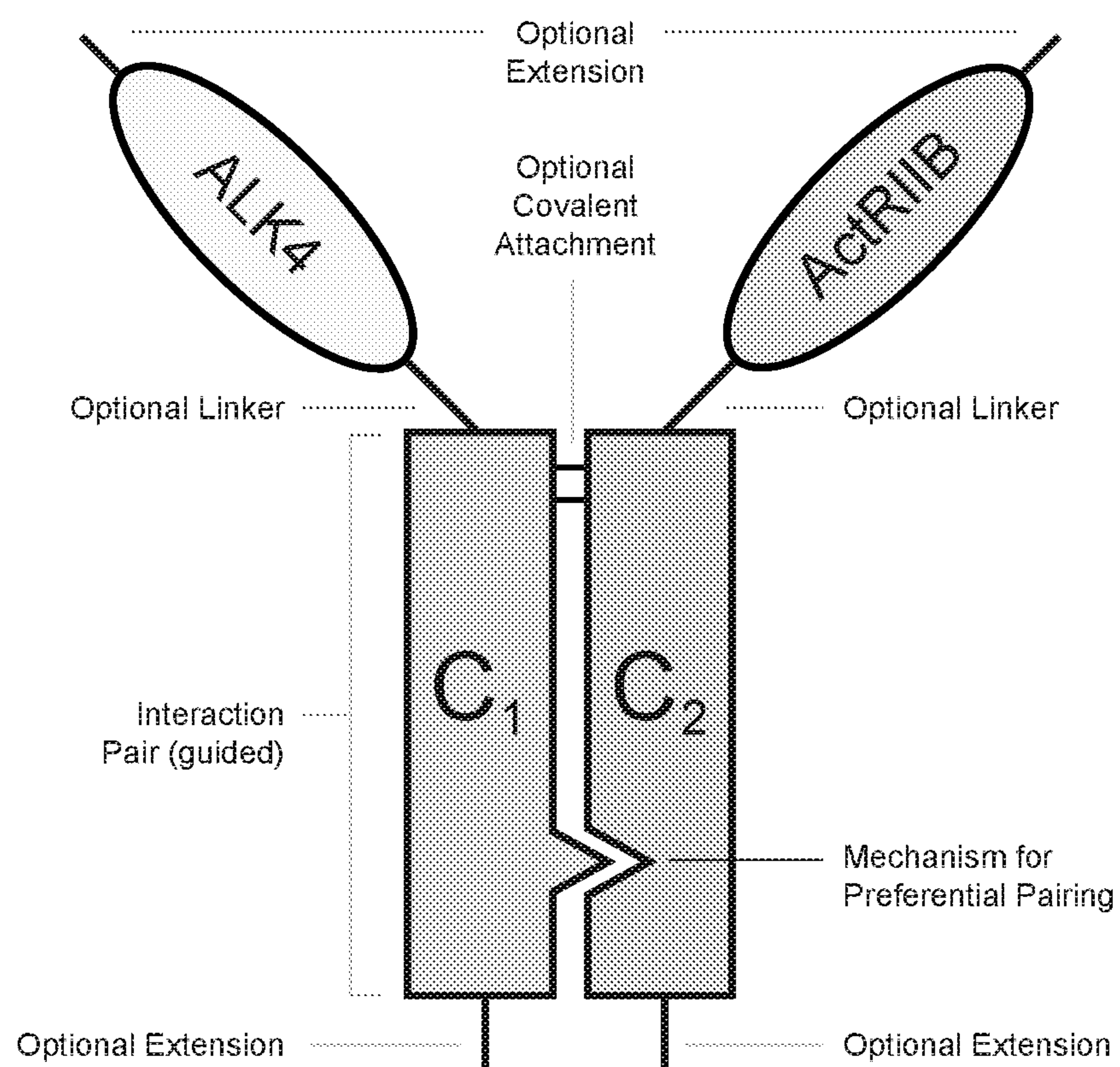


FIGURE 6B

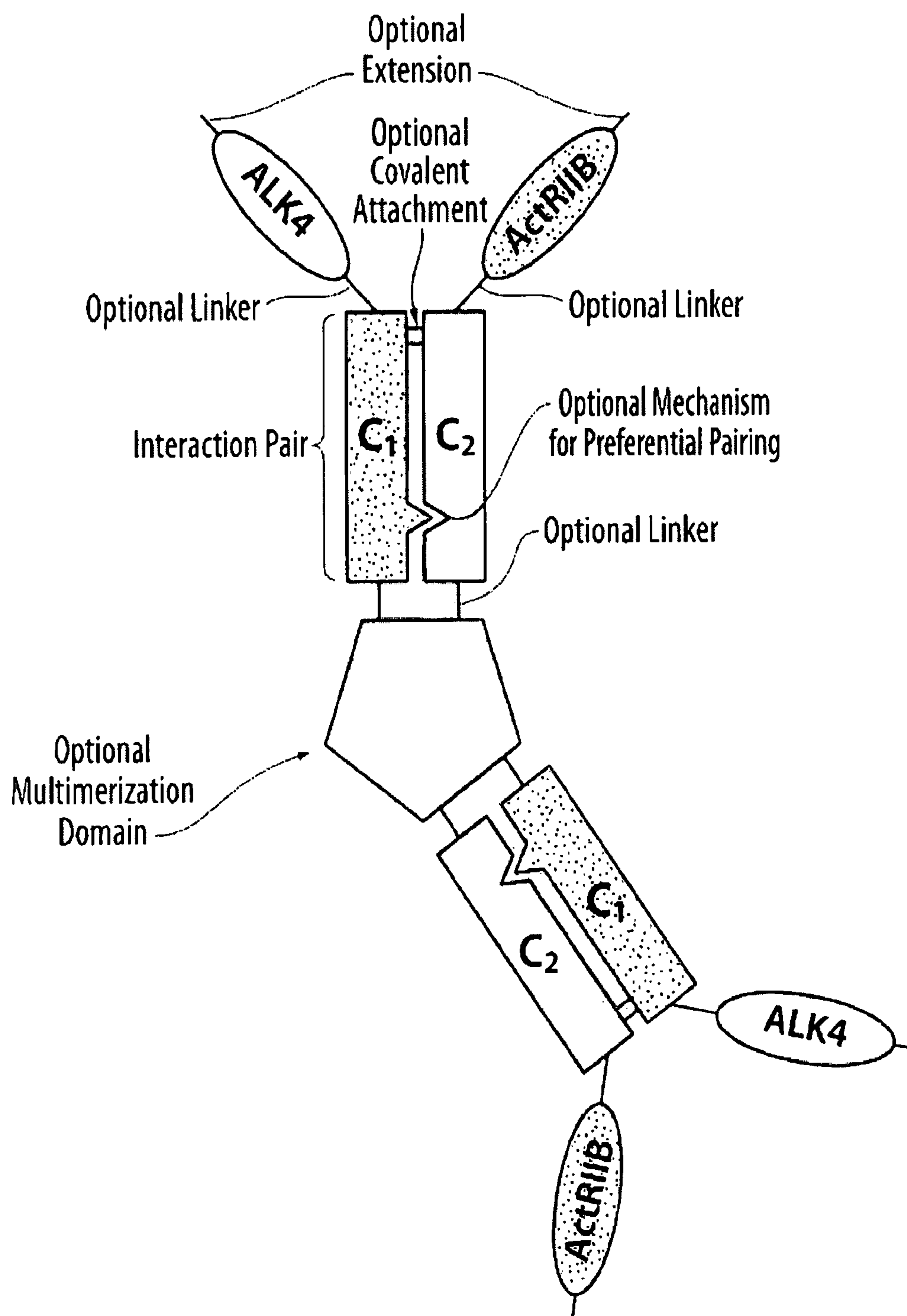


FIGURE 6C

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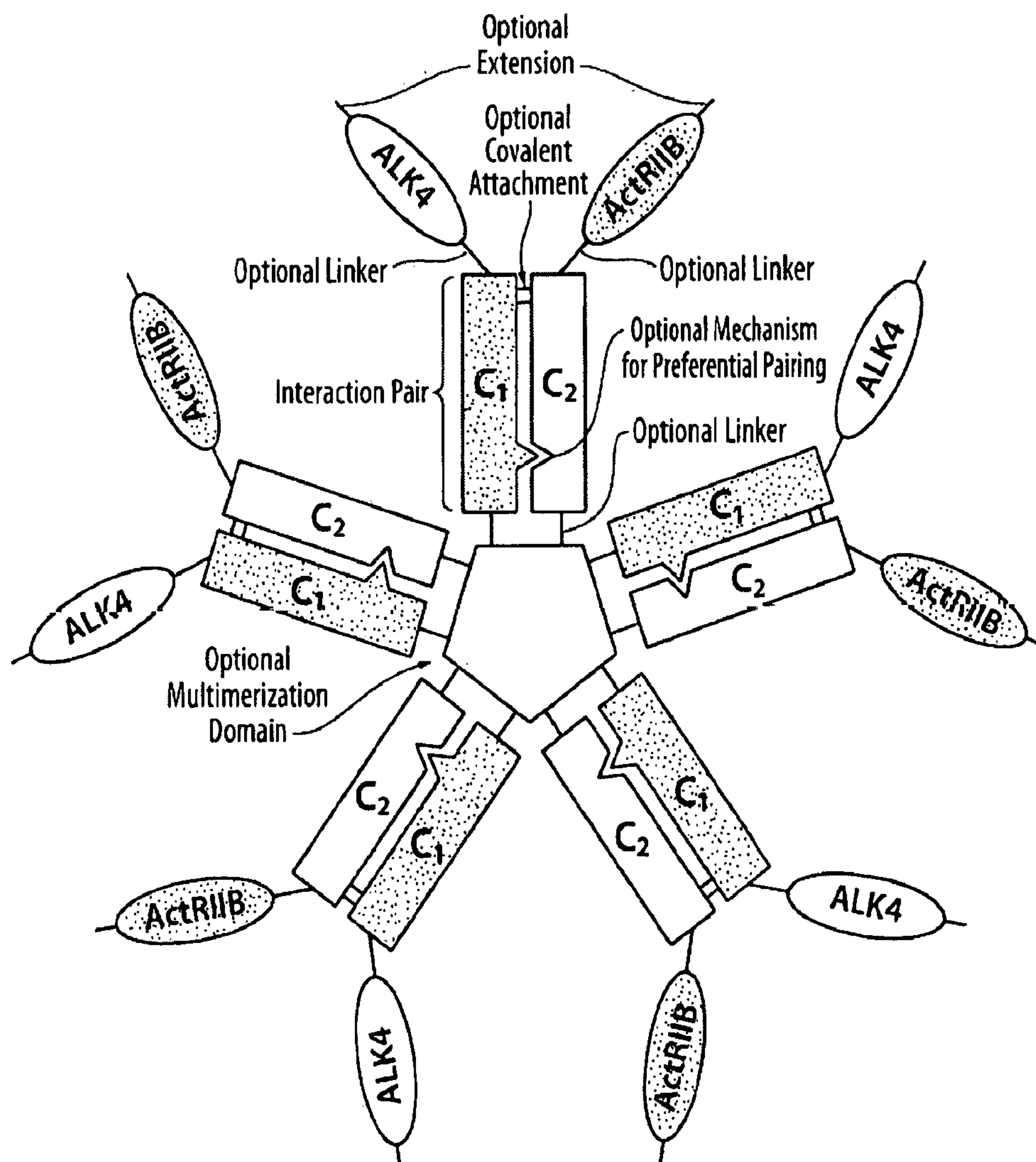


FIGURE 6D

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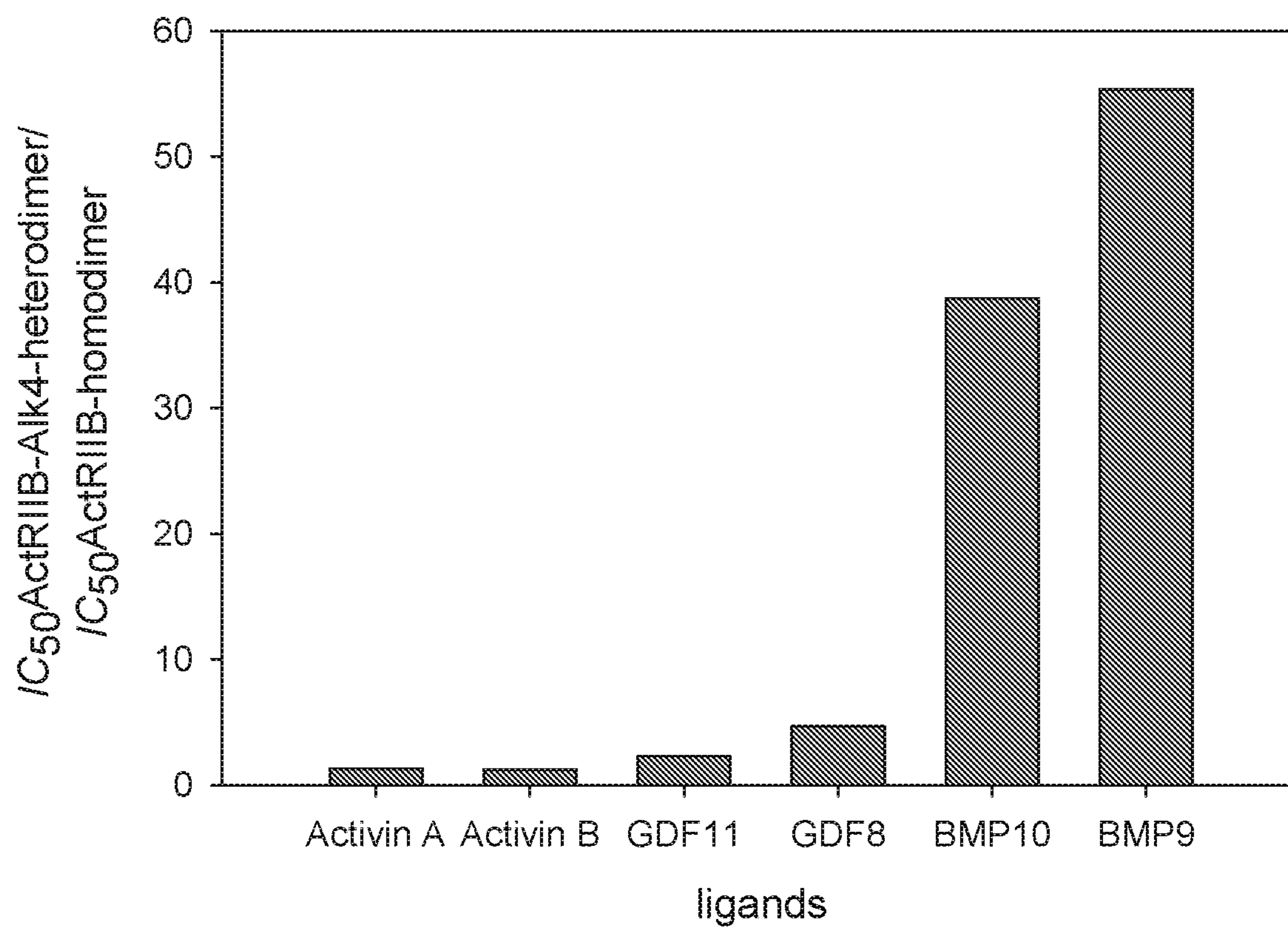


FIGURE 7

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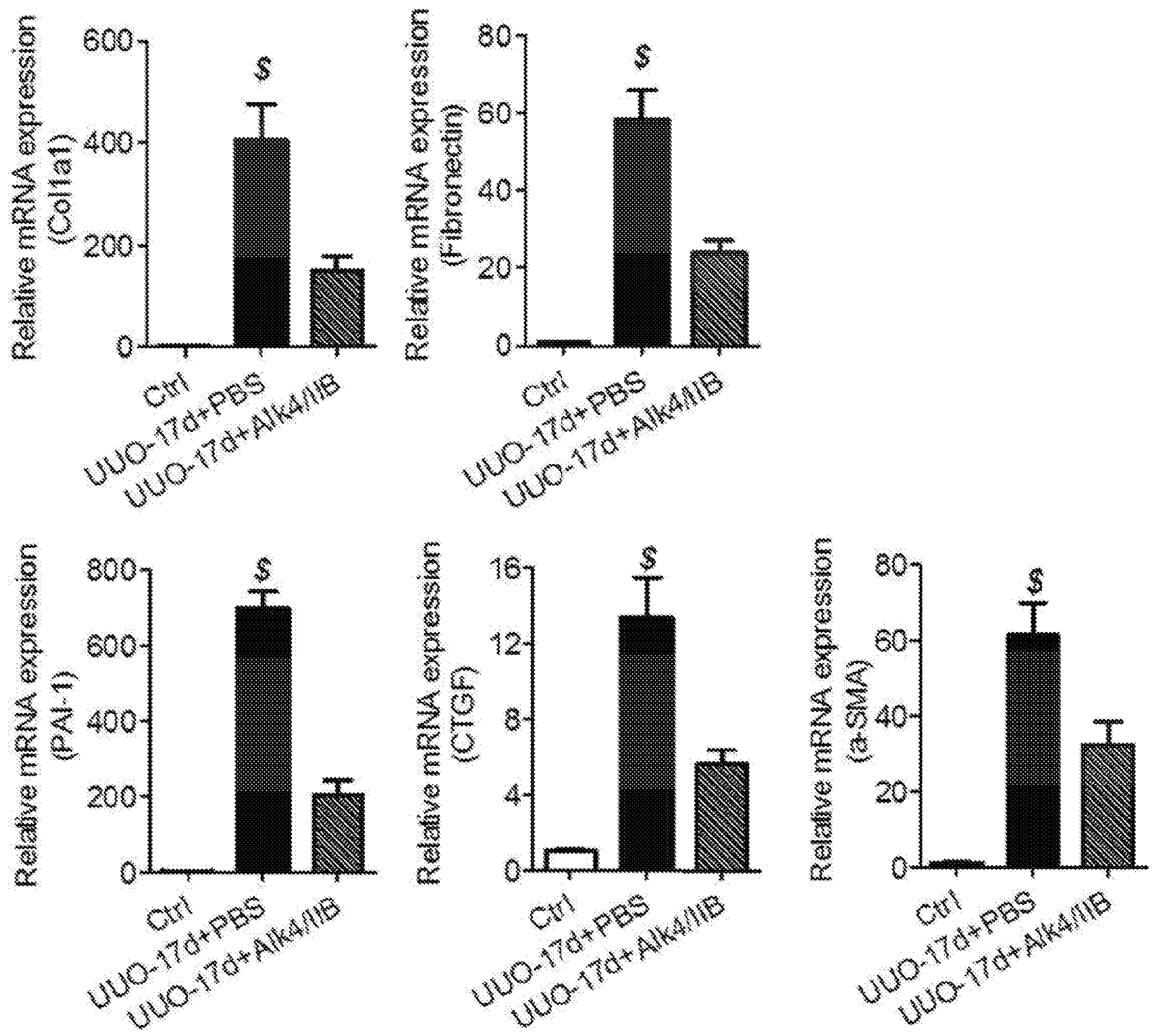


Figure 8A

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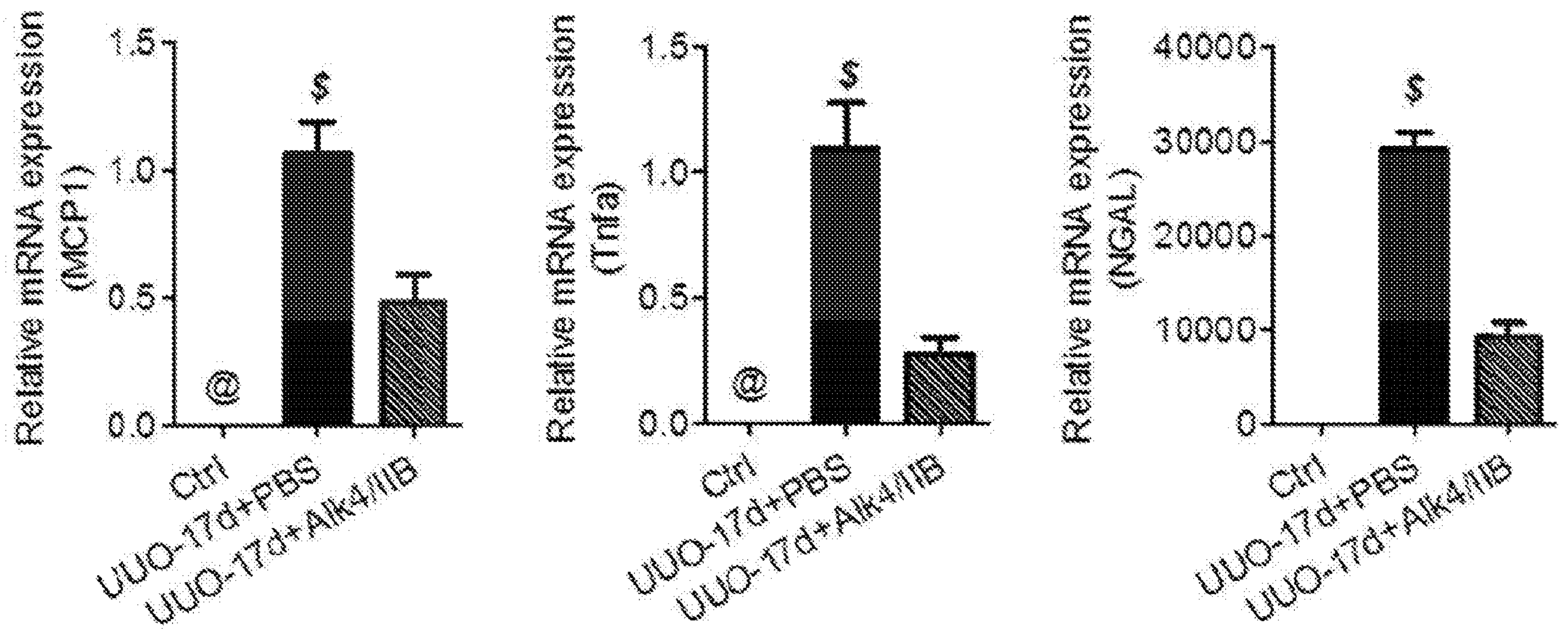


Figure 8B

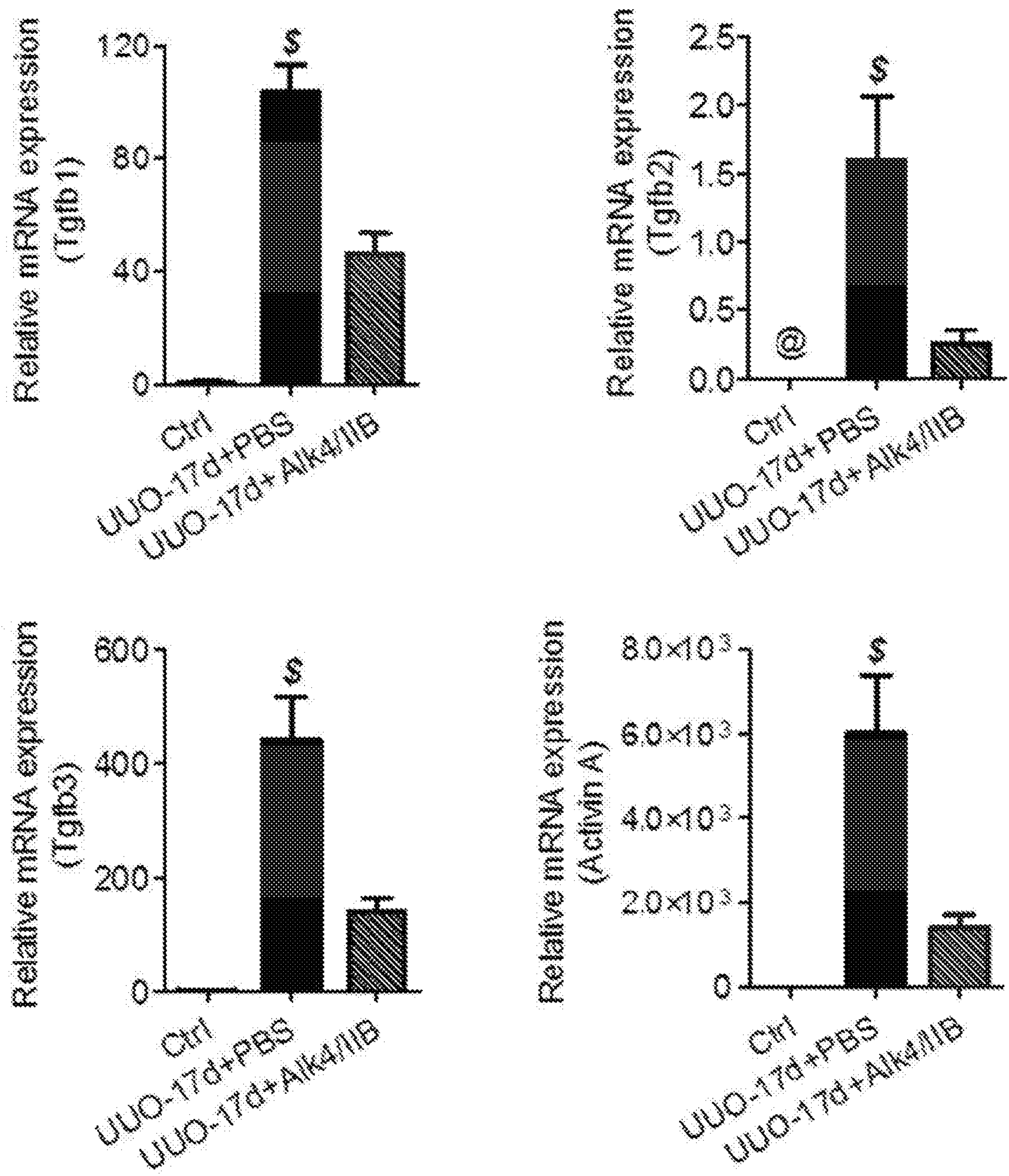


Figure 8C

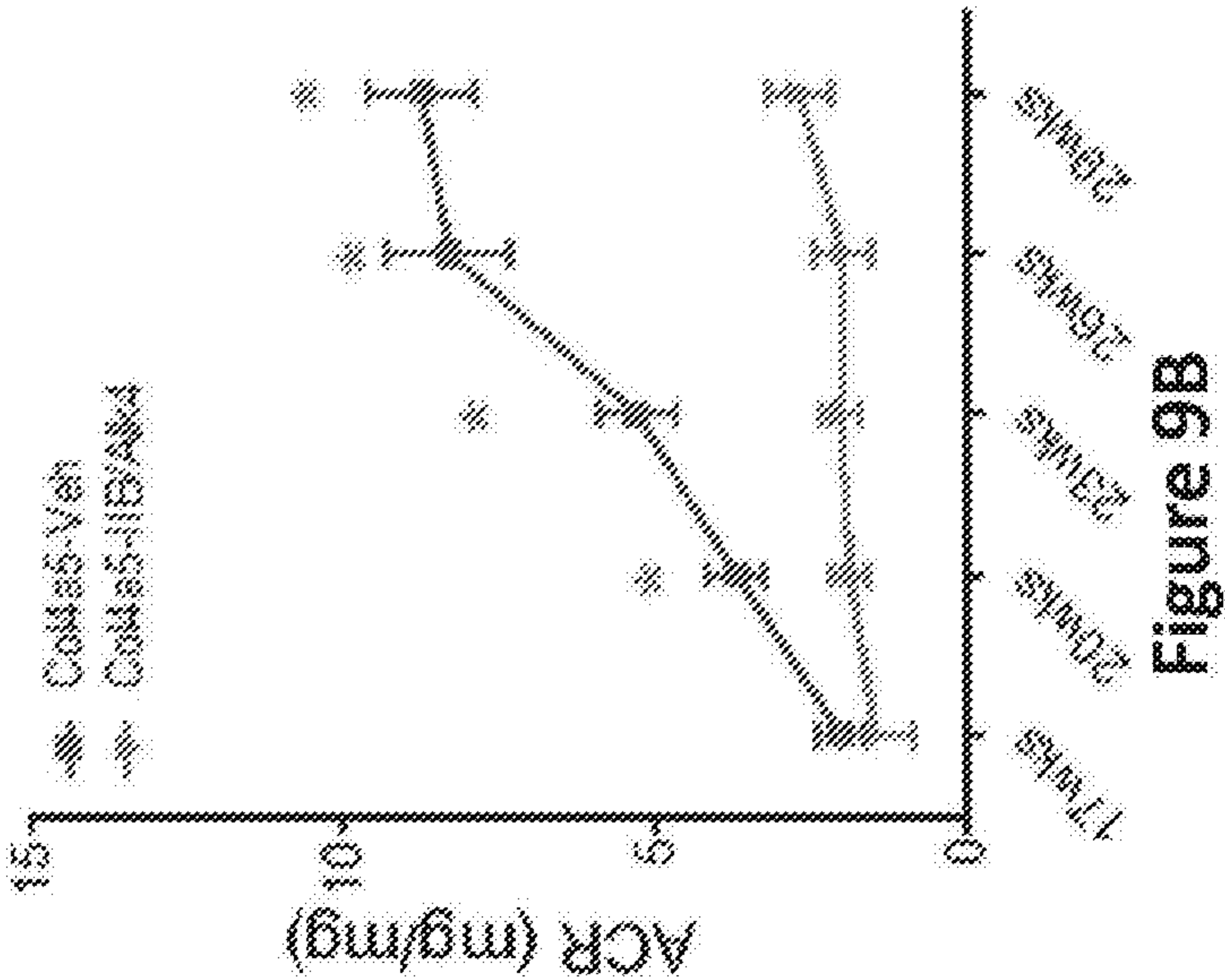


Figure 9B

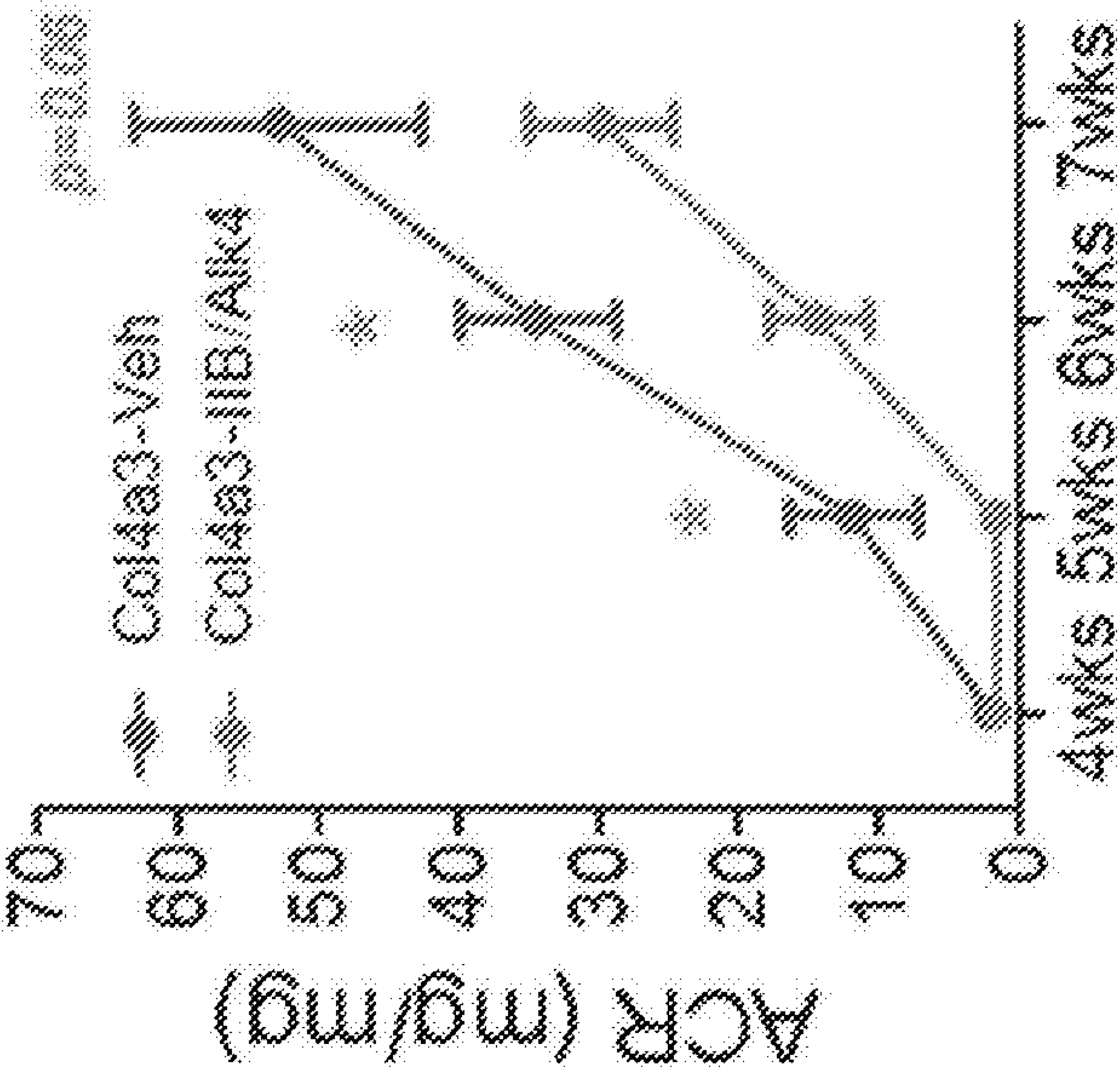


Figure 9A

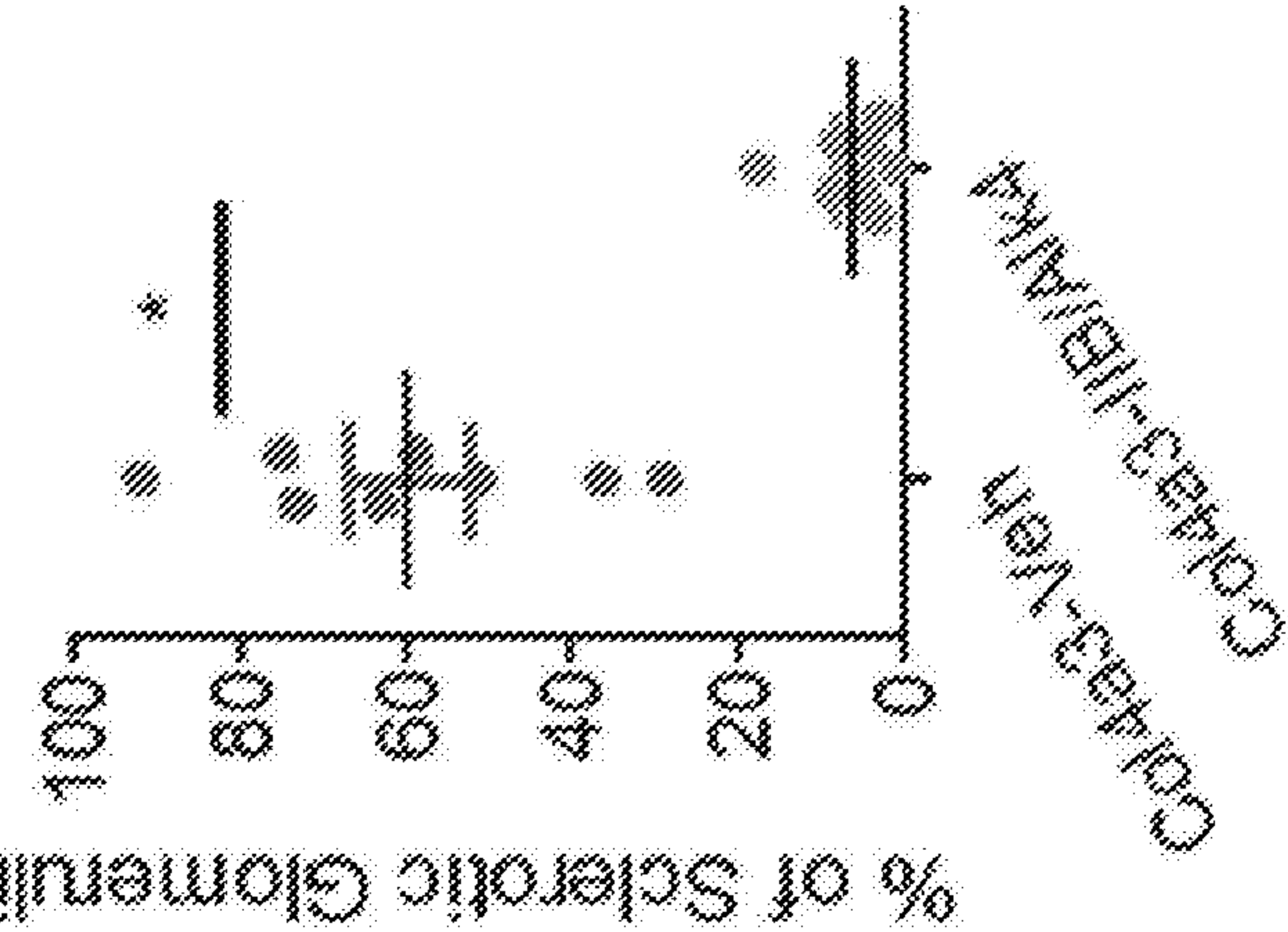


Figure 10A

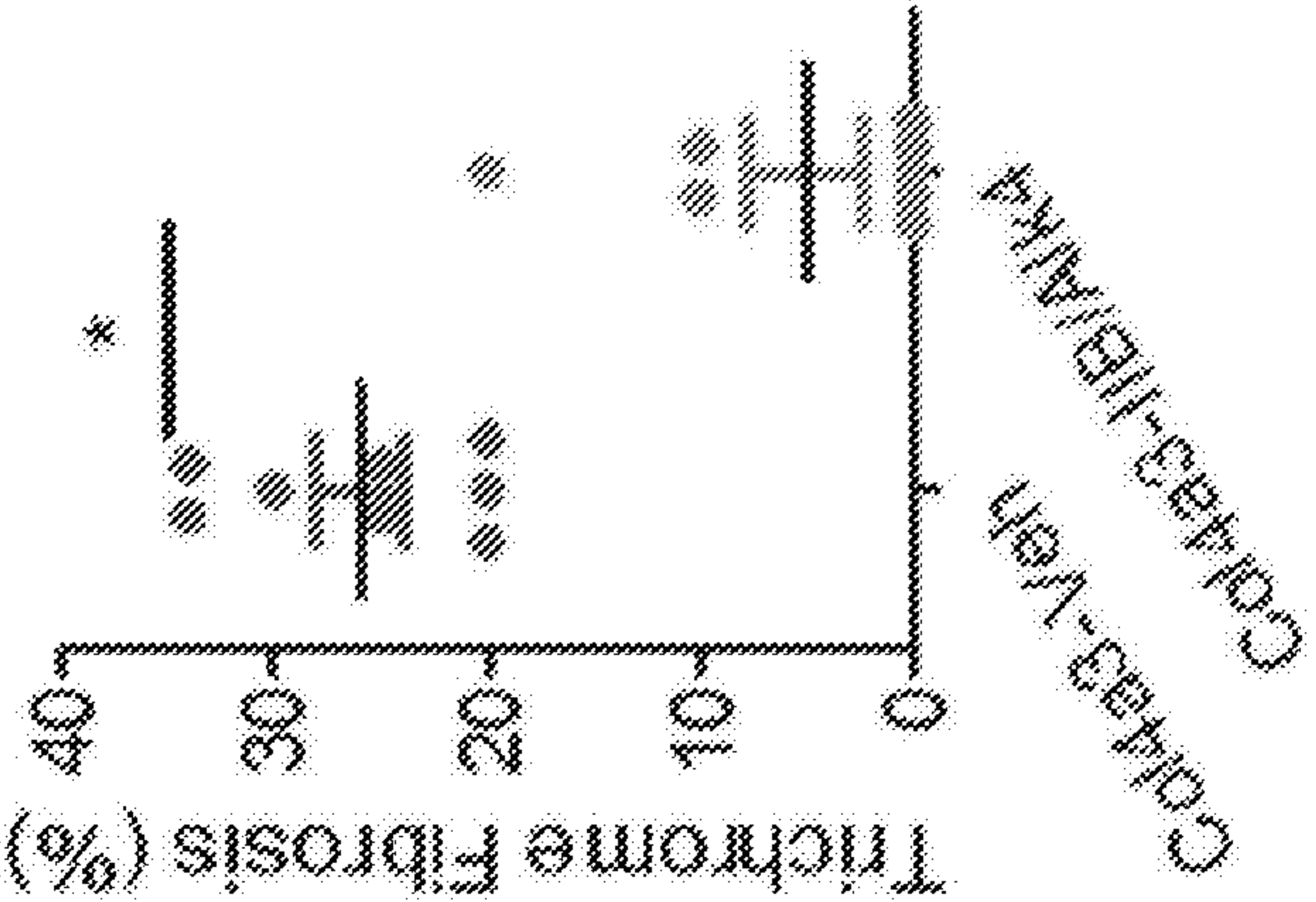


Figure 10B

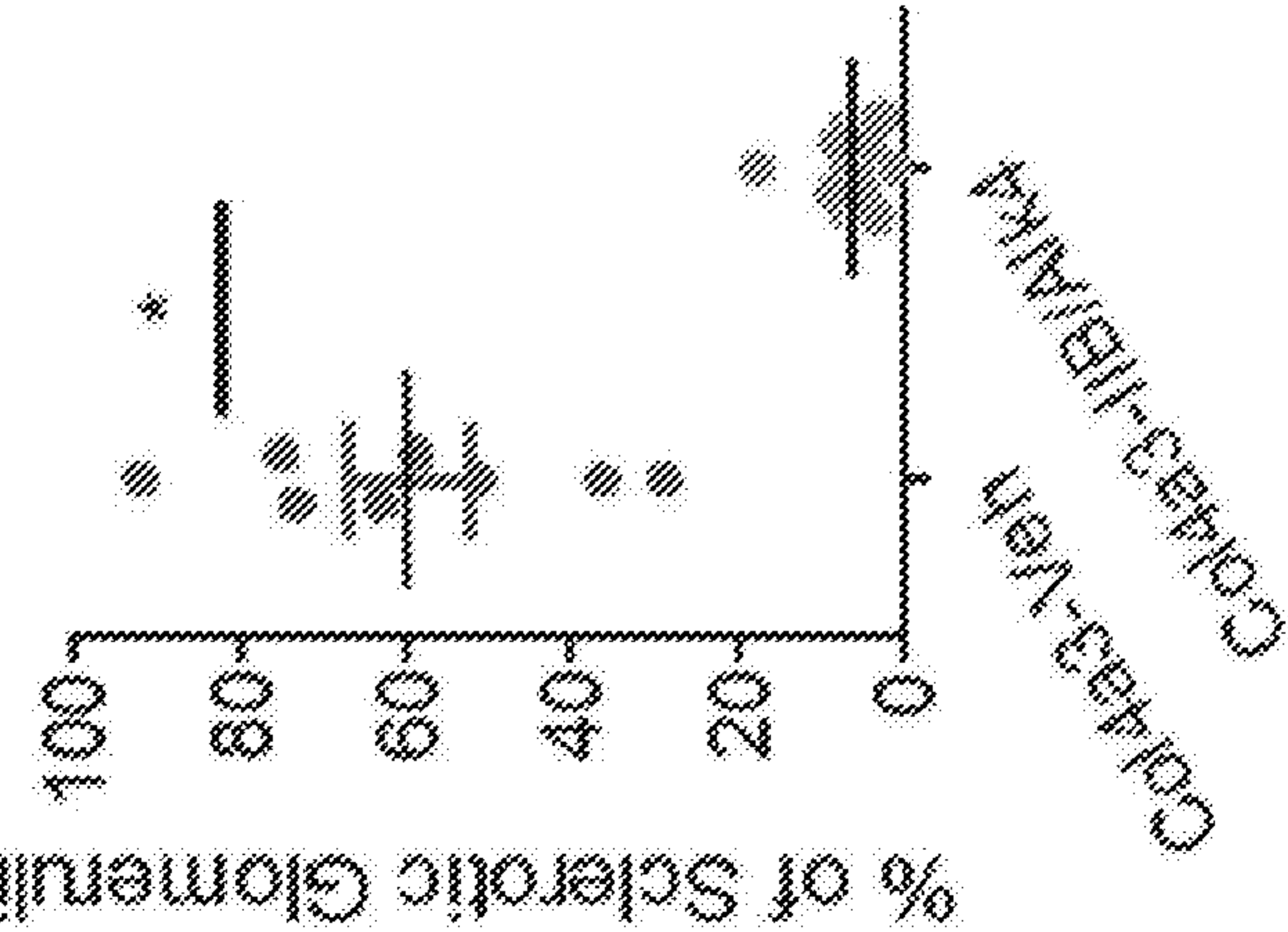


Figure 10C

ActRIIa	ILGRSETQEC	L	F	N	A	N	W	E	K	D	R	T	N	Q	T	G	V	E	P	C	Y	G	D	K	D	K	R	R	H	C	F	A	T	W	K	N	I	S	G	S
ActRIIb	GRGEAETREC	I	Y	N	A	N	W	E	L	E	R	T	N	Q	S	G	L	E	R	C	E	G	E	Q	D	K	R	L	H	C	Y	A	S	W	R	N	S	S	G	T

	I	E	I	V	K	Q	G	O	W	L	D	D	I	N	C	Y	D	R	I	D	C	V	E	K	K	D	S	P	E	V	Y	F	C	C	C	E	G	N	M	C	N	E	K	F	S	Y	F	P	E	M
	I	E	L	V	K	K	G	O	W	L	D	D	F	N	C	Y	D	R	Q	E	C	V	A	T	E	E	N	P	Q	V	Y	F	C	C	C	E	G	N	F	C	N	E	R	F	T	H	L	P	E	A

	E	V	T	Q	P	T	S	N	P	V	T	P	K	P	P	T
	G	G	P	E	V	T	Y	E	P	P	P	T	A	P	T	

FIGURE 1