(54) **Title**: METHODS AND COMPOSITIONS FOR MODULATING ANGIOGENESIS AND PERICYTE COMPOSITION
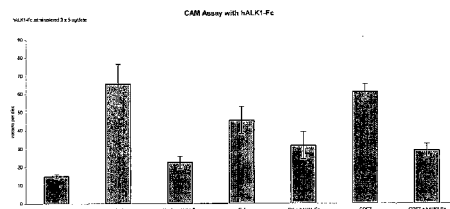
FIGURE 7

(57) **Abstract**: In certain aspects, the present disclosure relates to the insight that a polypeptide comprising a ligand-binding por-
tion of the extracellular domain of activin-like kinase I (ALK1) polypeptide may be used to inhibit angiogenesis in vivo, particu-
larly in mammals suffering angiogenesis-related disorders. Additionally, the disclosure demonstrates that inhibitors of ALK1 may
be used to increase pericyte coverage in vascularized tissues, including tumors and the retina. The disclosure also identifies lig-
ands for ALK1 and demonstrates that such ligands have pro-angiogenic activity, and describes antibodies that inhibit receptor-lig-
and interaction

METHODS AND COMPOSITIONS FOR MODULATING ANGIOGENESIS AND PERICYTE COMPOSITION

RELATED APPLICATIONS

This application claims the benefit of the filing date under 35 USC § 119 of U.S. provisional application 61/050,168 filed on May 2, 2008, and provisional application 61/144,131 filed on January 12, 2009, the contents of both of which are incorporated herein by reference.

BACKGROUND

Angiogenesis, the process of forming new blood vessels, is critical in many normal and abnormal physiological states. Under normal physiological conditions, humans and animals undergo angiogenesis in specific and restricted situations. For example, angiogenesis is normally observed in wound healing, fetal and embryonic development and formation of the corpus luteum, endometrium and placenta.

Undesirable or inappropriately regulated angiogenesis occurs in many disorders, in which abnormal endothelial growth may cause or participate in the pathological process. For example, angiogenesis participates in the growth of many tumors. Deregulated angiogenesis has been implicated in pathological processes such as rheumatoid arthritis, retinopathies, hemangiomas, and psoriasis. The diverse pathological disease states in which unregulated angiogenesis is present have been categorized as angiogenesis-associated diseases.

Both controlled and uncontrolled angiogenesis are thought to proceed in a similar manner. Capillary blood vessels are composed primarily of endothelial cells and pericytes, surrounded by a basement membrane. Angiogenesis begins with the erosion of the basement membrane by enzymes released by endothelial cells and leukocytes. The endothelial cells, which line the lumen of blood vessels, then protrude through the basement membrane. Angiogenic factors induce the endothelial cells to migrate through the eroded basement membrane. The migrating cells form a "sprout" protruding from the parent blood vessel, where the endothelial

cells undergo mitosis and proliferate. Endothelial sprouts merge with each other to form capillary loops, creating the new blood vessel.

Agents that inhibit angiogenesis have proven to be effective in treating a variety of disorders. Avastin™ (bevacizumab), a monoclonal antibody that binds to Vascular Endothelial Growth Factor (VEGF), has proven to be effective in the treatment of a variety of cancers. Macugen™, an aptamer that binds to VEGF has proven to be effective in the treatment of neovascular (wet) age-related macular degeneration. Antagonists of the SDF/CXCR4 signaling pathway inhibit tumor neovascularization and are effective against cancer in mouse models (Guleng et al. Cancer Res. 2005 Jul 1;65(13):5864-71). The isocoumarin 2-(8-hydroxy-6-methoxy-1-oxo-1 H-2-benzopyran-3-yl) propionic acid (NM-3) has completed phase I clinical evaluation as an orally bioavailable angiogenesis inhibitor. NM-3 directly kills both endothelial and tumor cells in vitro and is effective in the treatment of diverse human tumor xenografts in mice (Agata et al. Cancer Chemother Pharmacol. 2005 Dec;56(6):610-4.). Thalidomide and related compounds have shown beneficial effects in the treatment of cancer, and although the molecular mechanism of action is not clear, the inhibition of angiogenesis appears to be an important component of the anti-tumor effect (see, e.g., Dredge et al. Microvasc Res. 2005 Jan;69(1-2):56-63). The success of TNF-alpha antagonists in the treatment of rheumatoid arthritis is partially attributed to anti-angiogenic effects on the inflamed joint tissue (Feldmann et al. Annu Rev Immunol. 2001;19:163-96). Anti-angiogenic therapies are widely expected to have beneficial effects on other inflammatory diseases, particularly psoriasis. Although many anti-angiogenic agents have an effect on angiogenesis regardless of the tissue that is affected, other angiogenic agents may tend to have a tissue-selective effect.

Pericytes are one of the component cell types of the vasculature, along with endothelial cells and smooth muscle cells. The ratio of pericytes to endothelial cells is greatest in the central nervous system, and pericytes are thought to play a significant role in the blood-brain barrier. Diabetic retinopathy is marked by a loss of pericytes in the retinal microvasculature, and this loss of pericytes is thought to have an important pathophysiological effect on the progression of the disease.

It is desirable to have additional compositions and methods for inhibiting angiogenesis and for increasing pericyte coverage in vascularized tissues. These include methods and compositions which can inhibit the unwanted growth of blood vessels, either generally or in certain tissues and/or disease states.

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SUMMARY

In part, the present disclosure presents a characterization of an activin-like kinase 1 (ALK1)-mediated regulatory system and the role of this system in
10   angiogenesis and the regulation of pericyte coverage in vascularized tissues in vivo. In certain aspects, the disclosure provides antagonists of ALK-1 ligands and the use of such antagonists as anti-angiogenic agents or to increase pericyte coverage. Additionally, the disclosure provides antagonists of ALK-1 itself, and the use of such antagonists as anti-angiogenic agents. As described herein, ALK1 is a receptor
15   for the GDF5 group of ligands, which includes GDF6 and GDF7, and also for the BMP9 group of ligands, which includes BMP10. This disclosure demonstrates that signaling mediated by ALK1 and the ligands described above is involved in angiogenesis in vivo, and that inhibition of this regulatory system has a potent anti-angiogenic effect. Additionally, this disclosure demonstrates that inhibition of the
20   ALK1 regulatory system causes increased pericyte coverage in vascularized tissue. Thus, in certain aspects, the disclosure provides antagonists of the ALK1 regulatory system, including antagonists of the receptor or one or more of the ligands, for use in inhibiting angiogenesis. In certain aspects, the disclosure provides antagonists of ALK1 ligands for the treatment of cancers, particularly multiple myeloma,
25   melanoma, lung cancer, pancreatic cancer (particularly tumors of the pancreatic endocrine tissue), breast cancer (e.g., primary breast cancer or metastatic breast cancer; Estrogen receptor positive (ER+) or estrogen receptor negative (ER-)), rheumatoid arthritis, disorders associated with pathological angiogenesis in the eye and disorders associated with the loss of pericytes in vascularized tissue, such as
30   diabetic retinopathy.

In certain aspects, the disclosure provides polypeptides comprising a ligand binding portion of the extracellular domain of ALK1 ("ALK1 ECD polypeptides") for use in inhibiting angiogenesis. While not wishing to be bound to any particular mechanism of action, it is expected that such polypeptides act by binding to ligands

5   of ALK1 and inhibiting the ability of these ligands to interact with ALK1 as well as other receptors. In certain embodiments, an ALK1 ECD polypeptide comprises an amino acid sequence that is at least 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99% or 100% identical to the sequence of amino acids 22-118 of the human ALK1 sequence of SEQ ID NO:1. An ALK1 ECD polypeptide may be used as a small monomeric

10 protein or in a dimerized form (e.g., expressed as a fusion protein), particularly for local administration into tissues such as the eye. An ALK1 ECD may also be fused to a second polypeptide portion to provide improved properties, such as an increased half-life or greater ease of production or purification. Fusions to an Fc portion of an immunoglobulin or linkage to a polyoxyethylene moiety (e.g., polyethylene glycol)

15 may be particularly useful to increase the serum half-life of the ALK1 ECD polypeptide in systemic administration (e.g., intravenous, intra-arterial and intra-peritoneal administration). As demonstrated herein, a systemically administered ALK1-Fc polypeptide has a potent anti-angiogenic effect in the eye and also provides positive effects in murine models of rheumatoid arthritis and various

20 tumors. In certain embodiments, an ALK1-Fc fusion protein comprises a polypeptide having an amino acid sequence that is at least 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99% or 100% identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide is fused, either with or without an intervening linker, to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion

25 protein binds to GDF5, GDF7 and BMP9 with a K_D of less than 1×10^{-7} M and binds to TGFβ-1 with a K_D of greater than 1×10^{-6}. An Fc portion may be selected so as to be appropriate to the organism. Optionally, the Fc portion is an Fc portion of a human IgG1. In a preferred embodiment, the ALK1-Fc fusion protein comprises amino acids 22-118 of SEQ ID NO:1. Optionally, the ALK1-Fc fusion

30 protein comprises the amino acid sequence of SEQ ID NO: 3. Optionally, the ALK1-Fc fusion protein is the protein produced by expression of the nucleic acid of SEQ ID NO:4 in a mammalian cell line, particularly a Chinese Hamster Ovary

(CHO) cell line. ALK1-ECD polypeptides may be formulated as a pharmaceutical preparation that is substantially pyrogen free. The pharmaceutical preparation may be prepared for systemic delivery (e.g., intravenous, intra-arterial or subcutaneous delivery) or local delivery (e.g., to the eye).

5   In certain aspects, the disclosure identifies difficulties in developing relatively homogeneous preparations of ALK1-Fc fusion protein for use in a therapeutic setting. As described herein, the ALK1-Fc fusion protein tends to aggregate into higher order multimers. The disclosure provides solutions to these difficulties and therefore provides pharmaceutical preparations comprising ALK1-Fc

10   fusion proteins wherein such preparations are at least 85%, 90%, 95%, 96%, 97%, 98% or 99% composed of dimeric ALK1-Fc fusion protein. Therefore, in certain aspects, the disclosure provides pharmaceutical preparations comprising an ALK1-Fc fusion protein comprising: a polypeptide having an amino acid sequence that is at least 97% identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which

15   polypeptide is fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion protein binds to GDF5, GDF7 and BMP9 with a KD of less than 1×10^{-7} M and binds to TGFβ-1 with a KD of greater than 1×10^{-6} and wherein at least 85%, 90%, 95%, 96%, 97%, 98%, or 99% of the ALK1-Fc fusion protein is present in a dimeric form. The Fc portion of the ALK1-Fc fusion protein may be an Fc portion

20   of a human IgG1. The ALK1-Fc fusion protein may comprise the amino acid sequence of SEQ ID NO: 3. The ALK1-Fc fusion protein may be produced by expression of the nucleic acid of SEQ ID NO:4 in a mammalian cell line, particularly a Chinese Hamster Ovary (CHO) cell line. Such pharmaceutical preparations may be formulated so as to be appropriate for administration to the eye,

25   particularly by injection. The disclosed pharmaceutical preparations may be used for a variety of therapeutic purposes described herein, including inhibiting angiogenesis, treating tumors, treating rheumatoid arthritis, treating ocular disorders associated with angiogenesis and treating disorders associated with the loss of pericyte coverage in vascularized tissue, such as diabetic retinopathy. The ALK1-Fc

30   pharmaceutical preparations may be used in conjunction with a second agent that inhibits angiogenesis, such as a VEGF antagonist (e.g., Avastin, sorafenib, and VEGF receptor traps).

The disclosure demonstrates that antagonists of the ALK1 signaling pathway increase pericyte coverage in vascularized tissue. Therefore, the disclosure provides methods for promoting an increase in pericyte coverage in a vascularized tissue of a mammal. Such antagonist may be any of the antagonists described herein, including

5   ALK1 ECD proteins (e.g., ALK1-Fc), DAN proteins, and antibodies directed to ALK1 and any of its ligands, including BMP9, BMP10, GDF5, GDF6 and GDF7. In certain aspects, the disclosure provides methods for promoting an increase in pericyte coverage in a vascularized tissue of a mammal in need thereof, the method comprising administering to the mammal an effective amount of an ALK1 ECD

10   protein. The ALK1 ECD protein may be an ALK1-Fc fusion protein, and the ALK1-Fc fusion protein may comprise a polypeptide having an amino acid sequence that is at least 90% identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide is fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion protein binds to TGFβ-1 with a K_D of greater than 1 x

15   10^{-6}. The ALK1 ECD protein may bind to one or more ALK1 ligands selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10. The ALK1 ECD polypeptide may comprise an amino acid sequence that is at least 85%, 90%, 95%, 96%, 97%, 98% or 99% identical to the sequence of amino acids corresponding to amino acids 34-95 of SEQ ID NO:1. The ALK1 ECD may comprise an amino acid

20   sequence encoded by a nucleic acid that hybridizes under stringent hybridization conditions to nucleotides 100-285 of SEQ ID NO:2 or a variant of nucleotides 100-285 of SEQ ID NO:2 that encodes the same amino acid sequence. The ALK1-Fc fusion protein may have the sequence of SEQ ID NO:3. The ALK1 ECD fusion protein may be delivered intravenously or locally to the eye. In certain aspects, the

25   disclosure provides methods for promoting an increase in pericyte coverage in a vascularized tissue of a mammal in need thereof, the method comprising administering to the mammal an effective amount of an antibody that binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of:

30   GDF5, GDF6, GDF7, BMP9 and BMP10. The antibody may bind to the ALK1 polypeptide with a K_D of less than 5 x 10^{-8} M, less than 1 x 10^{-9} M or less than 1 x 10^{-10} M. The antibody may inhibit binding of ALK1 to an ALK1 ligand, wherein

the ALK1 ligand is selected from the group consisting of: BMP9 and BMP10. The antibody may be delivered intravenously or intraocularly. Antibodies described in WO 2007/040912 may be useful in such methods. ALK1 signaling antagonists may be administered with a second agent that inhibits angiogenesis, such as a VEGF antagonist. The mammal to be treated may have diabetic retinopathy or other retinal disorder characterized by a loss of pericyte coverage in the retinal vasculature, or a tumor selected from the group consisting of: melanoma, a lung tumor, multiple myeloma, a pancreatic tumor, such as a tumor of the pancreatic endocrine tissue, and breast cancer (e.g., primary breast cancer or metastatic breast cancer; Estrogen receptor positive (ER+) or estrogen receptor negative (ER-)).

In certain aspects, the disclosure provides methods for inhibiting angiogenesis in a mammal by administering any of the ALK1 ECD polypeptides described generally or specifically herein. In one embodiment, a method comprises administering to the mammal an effective amount of an ALK1-Fc fusion protein, wherein the ALK1 Fc fusion protein comprises a polypeptide having an amino acid sequence that is at least 90% identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide is fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion protein binds to TGFβ-1 with a K_D of greater than 1 x 10^{-6}. Optionally, the ALK1-Fc fusion protein binds to one or more ALK1 ligands selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10. Optionally, the ALK1-Fc fusion protein has a sequence of SEQ ID NO:3. The ALK1 ECD polypeptide may be delivered locally (e.g., to the eye) or systemically (e.g., intravenously, intra-arterially or subcutaneously). In a particular embodiment, the disclosure provides a method for inhibiting angiogenesis in the eye of a mammal by administering an ALK1-Fc protein to the mammal at a location distal to the eye, e.g. by systemic administration.

In certain aspects, the disclosure provides antibodies that bind to ALK1, particularly an epitope situated in the extracellular domain, amino acids 22-118 of SEQ ID NO:1, and inhibit the binding of ALK1 to at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10. Based on the affinity of these ligands for ALK1, an antibody may bind with a K_D of less than 5 x 10^{-8} M, and optionally between 5 x 10^{-8} and 1 x 10^{-10}. An antibody with affinity

within this range would be expected to inhibit signaling by one or more of GDF5, 6 and 7 while having less effect on signaling by BMP9 and 10. Such an antibody preferably inhibits angiogenesis stimulated by at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6 and GDF7. While not wishing to be bound to a particular mechanism, it is expected that such antibodies will act by inhibiting ALK1 activity directly, which should be contrasted to the activity of an ALK1-Fc fusion protein, which is expected to inhibit the activity of ALK1 ligands. An anti-ALK1 antibody is not expected to interfere with the ability of GDF5, GDF6, GDF7, BMP10 or BMP10 to signal through alternative receptor systems, such as the BMPR1a, BMPR1b and BMPRII complexes. However, an anti-ALK1 antibody is expected to interfere with the ability of low affinity ligands for ALK1 (e.g., TGF-β, which is generally recognized as triggering significant signaling events through ALK-1 even though binding is relatively weak) to signal through ALK1, even though an ALK1 ECD may not bind to or inhibit such low affinity ligands. An antibody may bind to the ALK1 polypeptide with a K_D of less than 1×10^{-10} M. An antibody with affinity within this range would be expected to inhibit signaling by BMP9 or 10. Such an antibody preferably inhibits binding of BMP9 and BMP10 to ALK1. Notably, based on the data disclosed herein, an antibody that binds relatively poorly to ALK1 may inhibit TGFβ binding to ALK1 while failing to inhibit the tighter binding ligands such as GDF5 or BMP9. The antibodies described herein are preferably recombinant antibodies, meaning an antibody expressed from a nucleic acid that has been constructed using the techniques of molecular biology, such as a humanized antibody or a fully human antibody developed from a single chain antibody. Fv, Fab and single chain antibodies are also included within the term "recombinant antibody". Antibodies may also be polyclonal or non-recombinant monoclonal antibodies (including human or murine forms, as well as human antibodies obtained from transgenic mice). Antibodies and ALK1-ECD polypeptides may be formulated as a pharmaceutical preparation that is substantially pyrogen free. The pharmaceutical preparation may be prepared for systemic delivery (e.g., intravenous, intra-arterial or subcutaneous delivery) or local delivery (e.g., to the eye). Antibodies described in WO 2007/040912 may be useful in the various methods described herein.

In certain aspects, the disclosure provides methods for inhibiting angiogenesis in a mammal by administering to the mammal an effective amount of an antibody that binds to an ALK1 polypeptide, described herein either generally or specifically. An antibody useful for this purpose may bind to the extracellular

5   domain of ALK1 (e.g., bind to a polypeptide consisting of amino acids 22-118 of SEQ ID NO:1) or another portion of ALK1. The antibody may bind to a polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10. The antibody may bind to the ALK1 polypeptide

10   with a K_D of less than 5 x 10^{-8} M, and optionally between 5 x 10^{-8} and 1 x 10^{-10}. The antibody may inhibit angiogenesis stimulated by at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6 and GDF7. An antibody that selectively inhibits signaling mediated by GDF5, 6 or 7 relative to signaling by BMP9 or 10 may be used as a selective inhibitor of angiogenesis that occurs in tissues where

15   GDF5, 6 or 7 are localized: primarily bone or joints. The antibody may bind to the ALK1 polypeptide with a K_D of less than 1 x 10^{-10} M. The antibody may inhibit the binding of ALK1 to an ALK1 ligand, wherein the ALK1 ligand is selected from the group consisting of: BMP9 and BMP10. The anti-ALK1 antibody may be delivered locally (e.g., to the eye) or systemically (e.g., intravenously, intra-arterially or

20   subcutaneously). In a particular embodiment, the disclosure provides a method for inhibiting angiogenesis in the eye of a mammal by administering an anti-ALK1 antibody. In another particular embodiment, the disclosure provides a method for treating patients with multiple myeloma. In a particular embodiment, the disclosure provides a method for inhibiting angiogenesis in disorders that are associated with

25   pathological angiogenesis as a consequence of multiple pro-angiogenic factors, such as VEGF, PDGF and/or FGF.

In certain aspects, the disclosure provides antibodies that bind to an ALK1 ligand disclosed herein and inhibit the binding of the ALK1 ligand to ALK1. While not wishing to be bound to any particular mechanism, it is expected that antibodies

30   that bind to ALK1 ligands will have effects that are similar in nature to ALK1 ECD polypeptides, because both types of agent bind to the ligands rather than the receptor itself. In certain embodiments, the antibody binds to a ligand selected from the

group consisting of GDF5, GDF6 and GDF7. The antibody may bind to the ALK1 ligand with a K_D of less than 5×10^{-8} M. The antibody may be selected for inhibition of angiogenesis stimulated by the ALK1 ligand. A CAM assay is an appropriate assay system for selection of desirable antibodies. Such antibodies are

5   preferably recombinant antibodies, and may be formulated as a pharmaceutical preparation that is substantially pyrogen free. The pharmaceutical preparation may be prepared for systemic delivery (e.g., intravenous, intra-arterial or subcutaneous delivery) or local delivery (e.g., to the eye).

In certain aspects, the disclosure provides antibodies that bind to an ALK1

10   ligand and inhibit the binding of the ALK1 ligand to ALK1, wherein the ALK1 ligand is selected from the group consisting of BMP9 and BMP10. The antibody may bind to the ALK1 ligand with a K_D of less than 1×10^{-10} M. Such antibodies are preferably recombinant antibodies, and may be formulated as a pharmaceutical preparation that is substantially pyrogen free. The pharmaceutical preparation may

15   be prepared for systemic delivery (e.g., intravenous, intra-arterial or subcutaneous delivery) or local delivery (e.g., to the eye).

In certain aspects, the disclosure provides methods for inhibiting angiogenesis in a mammal, the method comprising, administering to the mammal an effective amount of an antibody that binds to an ALK1 ligand and inhibits the

20   binding of the ALK1 ligand to ALK1, wherein the ALK1 ligand is selected from the group consisting of GDF5, GDF6, GDF7, BMP9 and BMP10. The antibody may inhibit angiogenesis stimulated by at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6 and GDF7.

Members of the BMP/GDF family, including BMP9, BMP10, GDF5, GDF6

25   and GDF7 bind to a type I and a type II receptor in order to form a functional signaling complex. The binding sites for these receptors are different. Accordingly, in certain embodiments, an antibody that binds to an ALK1 ligand and inhibits the ligand to ALK1 is an antibody that binds at or near the type I receptor binding site of the ligand.

30   In certain aspects, the disclosure provides methods for inhibiting angiogenesis in a mammal by administering other inhibitors of the ALK1 signaling

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system disclosed herein. Such inhibitors may include nucleic acids (e.g., antisense
or RNAi constructs) that decrease the production of ALK1, GDF5, GDF6, GDF7,
BMP9 or BMP10). A variety of affinity binding reagents can also be used, such as
aptamers, random peptides, protein scaffolds that can be modified to allow binding

5   to selected targets (examples of such scaffolds include anticalins and FNIII
domains); in each case, an affinity binding reagent would be selected for the ability
to disrupt the ALK1 regulatory system disclosed herein, either by disrupting the
ALK1-ligand interaction or by inhibiting the signaling that occurs after binding.

In a further embodiment, the disclosure describes the role of DAN as a

10   regulator of the ALK1 regulatory system. As shown herein, DAN binds to the
GDF5 group of ligands but fails to bind to the BMP9 group of ligands. Thus, DAN
is expected to inhibit angiogenesis mediated by GDF5, GDF6 or GDF7 but not
angiogenesis mediated by BMP9 or BMP10. DAN may therefore be used as a
selective agent for inhibiting angiogenesis in the bone or joints, where the GDF5

15   group of proteins is primarily expressed. Thus, in certain embodiments the
disclosure provides DAN proteins for use as anti-angiogenic agents in the context of
bone or joint angiogenesis, including rheumatoid arthritis and cancers that involve
the bone or joints (e.g., multiple myeloma and bone metastases). A DAN protein
will generally bind to one or more ALK1 ligands selected from the group consisting

20   of: GDF5, GDF6 and GDF7, while having relatively poor binding to BMP9 or
BMP10. A DAN protein may comprise an amino acid sequence that is at least 70%,
80%, 90%, 95%, 96%, 97%, 98%, 99% or 100% identical to the sequence of amino
acids corresponding to amino acids 17-180 of SEQ ID NO:10 (mature human DAN)
or amino acids 21-125 of SEQ ID NO:10 (conserved cysteine knot domain of DAN).

25   A DAN protein may also be encoded by a nucleic acid that comprises a sequence the
complement of which hybridizes under stringent hybridization conditions to
nucleotides 153-467 of SEQ ID NO:11 or a variant of nucleotides 153-467 of SEQ
ID NO:11 that has the same coding sequence (a "silent" variant, such as a variant
containing one or more alterations at a wobble position in the triplet code), or to

30   nucleotides 93-635 of SEQ ID NO:11 or a silent variant thereof. In certain aspects,
the DAN protein is a fusion protein, such as an Fc fusion protein. While DAN is
expected to be particularly useful for the inhibition of angiogenesis in bone and

joints (including tumors located in the bone or joints, such as multiple myeloma and bone metastases), it may also be useful in other contexts, such as in a tumor located elsewhere, or in the eye.

In certain aspects, the disclosure provides methods for treating rheumatoid
5   arthritis in a mammal, the method comprising, administering to a mammal that has rheumatoid arthritis an effective amount of an agent selected from the group consisting of: an ALK1 ECD protein; an antibody that binds to an ALK1 ligand and inhibits the binding of the ALK1 ligand to ALK1, wherein the ALK1 ligand is selected from the group consisting of GDF5, GDF6, GDF7, BMP9 and BMP10; an
10   antibody that binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10; and a DAN polypeptide.

In certain aspects the disclosure provides methods for treating a tumor in a
15   mammal. Such a method may comprise administering to a mammal that has a tumor an effective amount of an agent selected from the group consisting of: an ALK1 ECD protein (e.g., ALK1-Fc); an antibody that binds to an ALK1 ligand and inhibits the binding of the ALK1 ligand to ALK1, wherein the ALK1 ligand is selected from the group consisting of GDF5, GDF6, GDF7, BMP9 and BMP10; an antibody that
20   binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10; and a DAN polypeptide. A method may further comprise administering a second agent that inhibits angiogenesis. A tumor may be a tumor that is associated with bone, such as a
25   leukemia, a bone marrow tumor, a multiple myeloma or bone metastases, such as those commonly associated with breast or prostate cancer. A tumor may be a melanoma, lung cancer tumor, a pancreatic tumor (e.g., a tumor of the pancreatic endocrine tissue), or breast cancer (e.g., primary breast cancer or metastatic breast cancer). The breast cancer may be estrogen receptor positive (ER+) or estrogen
30   receptor negative (ER-). A tumor may also be one that utilizes multiple pro-angiogenic factors, such as a tumor that is resistant to anti-VEGF therapy.

In certain aspects the disclosure provides ophthalmic formulations. Such formulations may comprise an agent selected from the group consisting of: an ALK1 ECD protein; an antibody that binds to an ALK1 ligand and inhibits the binding of the ALK1 ligand to ALK1, wherein the ALK1 ligand is selected from the group consisting of GDF5, GDF6, GDF7, BMP9 and BMP10; an antibody that binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10; and a DAN polypeptide.

In certain aspects, the disclosure provides methods for treating an angiogenesis related disease of the eye. Such methods may comprise administering systemically or to said eye a pharmaceutical formulation comprising: an effective amount of an agent selected from the group consisting of: an ALK1 ECD protein; an antibody that binds to an ALK1 ligand and inhibits the binding of the ALK1 ligand to ALK1, wherein the ALK1 ligand is selected from the group consisting of GDF5, GDF6, GDF7, BMP9 and BMP10; an antibody that binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10; and a DAN polypeptide.

In each instance, an agent described herein may be administered in conjunction with a second agent that inhibits angiogenesis. Where it is desirable to inhibit angiogenesis of a tumor, the agent may be administered in conjunction with a second agent that has an anti-cancer effect, such as a chemotherapeutic agent or a biologic anti-cancer agent.

The disclosure also provides an ophthalmic pharmaceutical formulation comprising an ALK1-Fc fusion protein having an amino acid sequence that is at least 97%, 98% or 99% identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide is fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion protein binds to GDF5, GDF7 and BMP9 with a K_D of less than 1 x 10^{-7} M and binds to TGFβ-1 with a K_D of greater than 1 x 10^{-6}. In one embodiment, the fusion protein has the sequence of SEQ ID NO: 3. In one embodiment, the Fc portion is from human IgG1. In one embodiment, the fusion

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protein is produced by expression of the nucleic acid of SEQ ID NO:4 in a mammalian cell line. In one embodiment, the cell line is Chinese Hamster Ovary cell line. The formulation may further comprise one or more of the following medicaments: pegaptanib, ranibizumab, or a glucocorticoid. In one embodiment, the

5 formulation is substantially pyrogen free.

The application also provides for an ophthalmic pharmaceutical formulation comprising an antibody that binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10. In

10 one embodiment, the antibody inhibits angiogenesis stimulated by at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6 and GDF7. In one embodiment, the antibody binds to the ALK1 polypeptide with a K_D of less than 5 x 10^{-8} M. In another embodiment, the antibody binds to the ALK1 polypeptide with a K_D of less than 1 x 10^{-10} M. In one embodiment, the antibody inhibits angiogenesis

15 stimulated by GDF5, GDF6, GDF7, BMP9, or BMP10. The formulation may further comprise one or more of the following medicaments: pegaptanib, ranibizumab, or a glucocorticoid. In one embodiment, the formulation is substantially pyrogen free.

In certain aspects, the disclosure provides for an ophthalmic pharmaceutical formulation comprising an antibody that binds to an ALK1 ligand disclosed herein

20 and inhibits the binding of the ALK1 ligand to ALK1. In certain embodiments, the antibody binds to a ligand selected from the group consisting of GDF5, GDF6 and GDF7. The antibody may bind to the ALK1 ligand with a K_D of less than 5 x 10^{-8} M. The antibody may be selected for inhibition of angiogenesis stimulated by the ALK1 ligand. A CAM assay is an appropriate assay system for selection of

25 desirable antibodies. Such antibodies are preferably recombinant antibodies. The formulation may further comprise one or more of the following medicaments: pegaptanib, ranibizumab, or a glucocorticoid. In one embodiment, the formulation is substantially pyrogen free.

The application also provides methods of treating an angiogenesis related

30 disease of the eye comprising administering to said eye an ophthalmic pharmaceutical formulation comprising an ALK1-Fc fusion protein comprising: a polypeptide having an amino acid sequence that is at least 97%, 98% or 99%

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identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide

is fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion

protein binds to GDF5, GDF7 and BMP9 with a K_D of less than 1 x 10^{-7} M and

binds to TGFβ-1 with a K_D of greater than 1 x 10^{-6}. In one embodiment, the fusion

5   protein has the sequence of SEQ ID NO: 3. In one embodiment, the Fc portion is

from human IgG1. In one embodiment, the fusion protein is produced by expression

of the nucleic acid of SEQ ID NO:4 in a mammalian cell line. In one embodiment,

the cell line is Chinese Hamster Ovary cell line. The formulation may further

comprise one or more of the following medicaments: pegaptanib, ranibizumab, or a

10   glucocorticoid. In one embodiment, the formulation is substantially pyrogen free.

The application also provides methods of treating an angiogenesis related

disease of the eye comprising administering to said eye an ophthalmic

pharmaceutical formulation comprising an antibody that binds to an ALK1

polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the

15   binding of at least one ALK1 ligand selected from the group consisting of: GDF5,

GDF6, GDF7, BMP9 and BMP10. In one embodiment, the antibody inhibits

angiogenesis stimulated by at least one ALK1 ligand selected from the group

consisting of: GDF5, GDF6 and GDF7. In one embodiment, the antibody binds to

the ALK1 polypeptide with a K_D of less than 5 x 10^{-8} M. In another embodiment, the

20   antibody binds to the ALK1 polypeptide with a K_D of less than 1 x 10^{-10} M. In one

embodiment, the antibody inhibits angiogenesis stimulated by GDF5, GDF6, GDF7,

BMP9, or BMP10. The formulation may further comprise one or more of the

following medicaments: pegaptanib, ranibizumab, or a glucocorticoid. In one

embodiment, the formulation is substantially pyrogen free.

25   In one embodiment of the disclosed methods, the angiogenesis related

disease is selected from the group consisting of a tumor, a tumor that is resistant to

anti-VEGF therapy, a multiple myeloma tumor, a tumor that has metastasized to the

bone, joint or bone inflammation, rheumatoid arthritis, diabetic retinopathy,

retinopathy of prematurity, macular degeneration, corneal graft rejection,

30   neovascular glaucoma, and retrolental fibroplasias.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the amino acid sequence for the human Activin Like Kinase 1, ALK1 (SEQ ID NO:1). Single underlining shows the predicted extracellular domain. Double underlining shows the intracellular domain. The signal peptide and the transmembrane domain are not underlined.

5   Figure 2 shows the nucleic acid sequence of a human ALK1 cDNA (SEQ ID NO:2). The coding sequence is underlined. The portion encoding the extracellular domain is double underlined.

Figure 3 shows an example of a fusion of the extracellular domain of human ALK1 to an Fc domain (SEQ ID NO:3). The hALK1-Fc protein includes amino
10   acids 22-120 of the human ALK1 protein, fused at the C-terminus to a linker (underlined) and an IgG1 Fc region.

Figure 4 shows the nucleic acid sequence for expression of the hALK1-Fc polypeptide of SEQ ID NO:3. The encoded amino acid sequence is also shown. The leader sequence is cleaved such that Asp 22 is the N-terminal amino acid of the
15   secreted protein.

Figure 5 shows the anti-angiogenic effect of murine ALK1-Fc ("RAP") and human ALK1-Fc ("ACE") in an endothelial cell tube forming assay. All concentrations of RAP and ACE reduced the level of tube formation in response to Endothelial Cell Growth Supplement (ECGF) to a greater degree than the positive
20   control, Endostatin.

Figure 6 shows the angiogenic effect of GDF7 in a chick chorioallantoic membrane (CAM) assay. The GDF7 effect is comparable to that of VEGF.

Figure 7 shows the anti-angiogenic effect of the human ALK1-Fc fusion in the CAM assay. hALK1-Fc inhibits angiogenesis stimulated by VEGF, FGF and
25   GDF7.

Figure 8 shows comparative anti-angiogenic effects of murine ALK1-Fc (mALK1-Fc), hALK1-Fc, a commercially available anti-ALK1 monoclonal antibody (Anti-ALK1 mAb) and a commercially available, neutralizing anti-VEGF monoclonal antibody. The anti-angiogenic effect of the ALK1-Fc constructs is
30   comparable to the effects of the anti-VEGF antibody.

Figure 9 shows the anti-angiogenic effects of hALK1-Fc and the anti-VEGF antibody in vivo. hALK1-Fc and anti-VEGF had comparable effects on angiogenesis in the eye as measured by the mouse corneal micropocket assay.

Figure 10 shows the effects of mALK1-Fc in the murine collagen-induced arthritis (CIA) model of rheumatoid arthritis. The graph shows mean group arthritic scores determined during the 42 day observation period in the collagen-induced male DBA/1 arthritic mice. RAP-041 is mALK1-Fc. Avastin™ is the anti-VEGF antibody bevacizumab.

Figure 11 shows resolution of hALK1-Fc (SEQ ID NO: 3) and an hALK1-Fc fusion protein from R&D Systems (Minneapolis, MN) by Superose 12 10/300 GL Size Exclusion column (Amersham Biosciences, Piscataway, NJ). The R&D Systems material contains approximately 13% aggregated protein, as shown by the peaks on the left hand side of the graph, as well as some lower molecular weight species. The material of SEQ ID NO:3 is greater than 99% composed of dimers of the appropriate molecular size.

Figure 12 shows fluorescent signal from luciferase-expressing Lewis lung cancer (LL/2-luc) cells in mice treated with PBS (circles) and mALK1-Fc (triangles). Tumor cells were injected into the tail vein and treatment (PBS or 10mg/kg mALK1-Fc IP, twice weekly) was initiated on the day of cell administration. PBS-treated mice were sacrificed on day 22 as being moribund. The treatment and control groups each consisted of seven animals (n=7).

Figure 13 shows the levels of ALK1 and BMP9 expression at the various stages of tumor development in the RIP1-Tag2 mouse model of pancreatic endocrine tumors. ALK1 expression peaks during the period of maximal angiogenic activity, while BMP9 expression increases throughout tumor development.

Figure 14 shows the effects of mALK1-Fc treatment on tumor growth in the RIP1-Tag2 mice. Mice were treated with either mALK1-Fc or control Fc (in each case 300 micrograms per mouse, twice weekly) for a period of two weeks beginning at either 10 weeks of age or 12 weeks of age. mALK1-Fc treatment completely arrests tumor growth.

Figure 15 shows the vascular density (CD31$^+$ cells) of tumors from RIP1-Tag2 mice that were treated with mALK1-Fc or control Fc. mALK1-Fc treatment reduced vascular density of the tumors by approximately 50%.

Figure 16 shows the pericyte coverage (ratio of NG2+ cells to CD31+ cells) in vessels of tumors from RIP1-Tag2 mice that were treated with mALK1-Fc or control Fc. mALK1-Fc treatment increased pericyte coverage by approximately 100%.

Figure 17 shows the effects of mALK1-Fc on an orthotopic xenograft model using the MDA-MB-231 cell line, a cell line derived from ER- breast cancer cells. At a dose of 30 mg/kg, the mALK1-Fc has a significant growth delaying effect on the xenograft tumor.

Figure 18 shows the effects of hALK1-Fc on an orthotopic xenograft model using the MCF7 cell line, a cell line derived from ER+ breast cancer cells. At a dose of 10 or 30 mg/kg, the hALK1-Fc has a significant growth delaying effect on the xenograft tumor.

DETAILED DESCRIPTION

1.   Overview

ALK1 is a type I cell-surface receptor for the TGF-β superfamily of ligands and is also known as ACVRL1 and ACVRLK1. ALK1 has been implicated as a receptor for TGF-β1, TGF-β3 and BMP-9 (Marchuk et al., Hum Mol Genet. 2003; Brown et al., J Biol Chem. 2005 Jul 1;280(26):25111-8).

In mice, loss-of-function mutations in ALK1 lead to a variety of abnormalities in the developing vasculature (Oh et al., Proc. Natl Acad. Sci. USA 2000, 97, 2626–2631; Urness et al., Nat. Genet. 2000, 26, 328–331).

In humans, loss-of-function mutations in ALK1 are associated with hereditary hemorrhagic telangiectasia (HHT, or Osler–Rendu–Weber syndrome), in which patients develop arteriovenous malformations that create direct flow (communication) from an artery to a vein (arteriovenous shunt), without an intervening capillary bed. Typical symptoms of patients with HHT include recurrent

epistaxis, gastrointestinal hemorrhage, cutaneous and mucocutaneous telangiectases, and arteriovenous malformations (AVM) in the pulmonary, cerebral, or hepatic vasculature.

5   Recent publications from David et al. (Blood. 2007 Mar 1;109(5):1953-61.) and Scharpfenecker et al. (J Cell Sci. 2007 Mar 15;120(Pt 6):964-72) conclude that BMP9 and BMP10 activate ALK1 in endothelial cells, and that the consequence of this activation is to inhibit endothelial cell proliferation and migration. These effects are directly opposed to those of pro-angiogenic factors such as VEGF. Thus, these publications conclude that BMP9 and BMP10 are themselves anti-angiogenic

10   factors, and further, that ALK1 activation has an anti-angiogenic effect. By contrast, the present disclosure demonstrates that antagonists, rather than agonists, of BMP9 and BMP10 have anti-angiogenic effects.

The disclosure relates to the discovery that polypeptides comprising a portion of the extracellular domain of ALK1 ("ALK1 ECD polypeptides") may be

15   used to inhibit angiogenesis in vivo, including VEGF-independent angiogenesis and angiogenesis that is mediated by multiple angiogenic factors, including VEGF, FGF and PDGF. In part, the disclosure provides the identity of physiological, high affinity ligands for ALK1 and demonstrates that ALK1 ECD polypeptides inhibit angiogenesis. The data demonstrate that an ALK1 ECD polypeptide can exert an

20   anti-angiogenic effect even in the case where the ALK1 ECD polypeptide does not exhibit meaningful binding to TGF-β1. Moreover, ALK1 ECD polypeptides inhibit angiogenesis that is stimulated by many different pro-angiogenic factors, including VEGF, FGF, and GDF7. Thus, the disclosure provides a description of an ALK1 regulatory system, in which ALK1 is a receptor for the GDF5 group of ligands,

25   which includes GDF6 and GDF7, and also for the BMP9 group of ligands, which includes BMP10, with different affinities for the two groups of ligands. Further, the disclosure demonstrates that signaling mediated by ALK1 and the ligands described above is pro-angiogenic in vivo, and that inhibition of this regulatory system has a potent anti-angiogenic effect in vivo. Thus, in certain aspects, the disclosure

30   provides antagonists of the ALK1 regulatory system, including antagonists of the receptor or one or more of the ligands, for use in inhibiting angiogenesis, including both VEGF-dependent angiogenesis and VEGF-independent angiogenesis.

However, it should be noted that antibodies directed to ALK1 itself are expected to have different effects from an ALK1 ECD polypeptide. A pan-neutralizing antibody against ALK1 (one that inhibits the binding of all strong and weak ligands) would be expected to inhibit the signaling of such ligands through ALK1 but would not be

5   expected to inhibit the ability of such ligands to signal through other receptors (e.g., BMPR1a, BMPR1b, BMPRII in the case of GDF5-7 and BMP9-10 and TBRI and TBRII in the case of TGFβ). On the other hand, an ALK1 ECD polypeptide would be expected to inhibit all of the ligands that it binds to tightly, including, for a construct such as that shown in the Examples, GDF5-7 and BMP9-10, but would not

10   affect ligands that it binds to weakly, such as TGF-β. So, while a pan-neutralizing antibody against ALK1 would block BMP9 and TGF-β signaling through ALK1 it would not block BMP9 and TGF-β signaling through another receptor, and while an ALK1 ECD polypeptide may inhibit BMP9 signaling through all receptors (even receptors other than ALK1) it would not be expected to inhibit TGF-β signaling

15   through any receptor, even ALK1.

Proteins described herein are the human forms, unless otherwise specified. Genbank references for the proteins are as follows: human GDF5, CAA56874; human GDF6, AAH43222; human GDF7, NP_878248; human BMP9, Q9UK05; human BMP10, O95393; human DAN, BAA92265. ALK1 sequences are set forth

20   in Figures 1-5.

Human DAN amino acid sequence (SEQ ID NO:10) (Genbank BAA92265):

MLRVLVGAVL PAMLLAAPPP INKLALFPDK SAWCEAKNIT QIVGHSGCEA KSIQNRACLG

QCFSYSVPNT FPQSTESLVH CDSCMPAQSM WEIVTLECPG HEEVPRVDKL VEKILHCSCQ

ACGKEPSHEG LSVYVQGEDG PGSQPGTHPH PHPHPHPGGQ TPEPEDPPGA PHTEEEGAED

25   The mature DAN protein is expected to correspond to amino acids 17-180. The conserved cysteine knot domain of DAN corresponds to amino acids 21-125 (underlined).

Human DAN cDNA sequence (SEQ ID NO:11) (Genbank BC012037):

30
```
gccgagcctc ctggggcgcc cgggcccgcg accccgcac  ccagctccgc aggaccggcg
ggcgcgcgcg ggctctggag gccacgggca tgatgcttcg ggtcctggtg ggggctgtcc
tccctgccat gctactggct gccccaccac ccatcaacaa gctggcactg ttcccagata
agagtgcctg gtgcgaagcc aagaacatca cccagatcgt gggccacagc ggctgtgagg
```

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     ccaagtccat ccagaacagg gcgtgcctag gacagtgctt cagctacagc gtccccaaca
     ccttcccaca gtccacagag tccctggttc actgtgactc ctgcatgcca gcccagtcca
     tgtgggagat tgtgacgctg gagtgcccgg gccacgagga ggtgcccagg gtggacaagc
     tggtggagaa gatcctgcac tgtagctgcc aggcctgcgg caaggagcct agtcacgagg
  5  ggctgagcgt ctatgtgcag ggcgaggacg ggccgggatc ccagcccggc acccaccctc
     acccccatcc ccaccccat cctggcgggc agacccctga gcccgaggac ccccctgggg
     cccccacac agaggaagag ggggctgagg actgaggccc cccaactct tcctcccctc
     tcatcccct gtggaatgtt gggtctcact ctctggggaa gtcaggggag aagctgaagc
     ccccctttgg cactggatgg acttggcttc agactcggac ttgaatgctg cccggttgcc
 10  atggagatct gaaggggcgg ggttagagcc aagctgcaca atttaatata ttcaagagtg
     gggggaggaa gcagaggtct tcagggctct tttttgggg ggggggtggt ctcttcctgt
     ctggcttcta gagatgtgcc tgtgggaggg ggaggaagtt ggctgagcca ttgagtgctg
     ggggaggcca tccaagatgg catgaatcgg gctaaggtcc ctgggggtgc agatggtact
     gctgaggtcc cgggcttagt gtgagcatct tgccagcctc aggcttgagg gagggctggg
 15  ctagaaagac cactggcaga aacaggaggc tccggcccca caggtttccc caaggcctct
     caccccactt cccatctcca gggaagcgtc gccccagtgg cactgaagtg gccctccctc
     agcggagggg tttgggagtc aggcctgggc aggaccctgc tgactcgtgg cgcgggagct
     gggagccagg ctctccgggc ctttctctgg cttccttggc ttgcctggtg ggggaagggg
     aggaggggaa gaaggaaagg gaagagtctt ccaaggccag aaggaggggg acaacccccc
 20  aagaccatcc ctgaagacga gcatcccct cctctccctg ttagaaatgt tagtgccccg
     cactgtgccc caagttctag gccccccaga aagctgtcag agccggccgc cttctcccct
     ctcccaggga tgctctttgt aaatatcgga tgggtgtggg agtgaggggt tacctccctc
     gccccaaggt tccagaggcc ctaggcggga tgggctcgct gaacctcgag gaactccagg
     acgaggagga catgggactt gcgtggacag tcagggttca cttgggctct ctctagctcc
 25  ccaattctgc ctgcctcctc cctcccagct gcactttaac cctagaaggt ggggacctgg
     ggggagggac agggcaggcg ggcccatgaa gaaagcccct cgttgcccag cactgtctgc
     gtctgctctt ctgtgcccag ggtggctgcc agcccactgc ctcctgcctg gggtggcctg
     gccctcctgg ctgttgcgac gcgggcttct ggagcttgtc accattggac agtctccctg
     atggaccctc agtcttctca tgaataaatt ccttcaacgc caaaaaaaaa aaaaaaaaaa
 30  aaaaaaaaaa aaaaaaaaaa aaa
```

The coding sequence for DAN precursor corresponds to nucleic acids 93-
635. The coding sequence for the mature DAN protein corresponds to nucleic acids
141-632. The coding sequence for the conserved cysteine knot portion of DAN
corresponds to nucleic acids 153-467.

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 in the specification, to provide additional
guidance to the practitioner in describing the compositions and methods disclosed
herein and how to make and use them. The scope or meaning of any use of a term
will be apparent from the specific context in which the term is used.

2.   Soluble ALK1 Polypeptides

Naturally occurring ALK1 proteins are transmembrane proteins, with a
portion of the protein positioned outside the cell (the extracelluar portion) and a
portion of the protein positioned inside the cell (the intracellular portion). Aspects of
the present disclosure encompass polypeptides comprising a portion of the
5   extracellular domain of ALK1.

In certain embodiments, the disclosure provides "ALK1 ECD polypeptides".
The term "ALK1 ECD polypeptide" is intended to refer to a polypeptide consisting
of or comprising an amino acid sequence of an extracellular domain of a naturally
occurring ALK1 polypeptide, either including or excluding any signal sequence and
10   sequence N-terminal to the signal sequence, or an amino acid sequence that is at
least 33 percent identical to an extracellular domain of a naturally occurring ALK1
polypeptide, and optionally at least 60%, at least 70%, at least 80%, at least 85%, at
least 90%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% or
100% identical to the sequence of an extracellular domain of a naturally occurring
15   ALK1 polypeptide, as exemplified by the cysteine knot region of amino acids 34-95
of SEQ ID NO:1 or the cysteine knot plus additional amino acids at the N- and C-
termini of the extracellular domain, such as amino acids 22-118 of SEQ ID NO. 1.
Likewise, an ALK1 ECD polypeptide may comprise a polypeptide that is encoded
by nucleotides 100-285 of SEQ ID NO:2, or silent variants thereof or nucleic acids
20   that hybridize to the complement thereof under stringent hybridization conditions
(generally, such conditions are known in the art but may, for example, involve
hybridization in 50% v/v formamide, 5x SSC, 2% w/v blocking agent, 0.1% N-
lauroylsarcosine, 0.3% SDS at 65 C° overnight and washing in, for example, 5xSSC
at about 65 C°). Additionally, an ALK1 ECD polypeptide may comprise a
25   polypeptide that is encoded by nucleotides 64-384 of SEQ ID NO:2, or silent
variants thereof or nucleic acids that hybridize to the complement thereof under
stringent hybridization conditions (generally, such conditions are known in the art
but may, for example, involve hybridization in 50% v/v formamide, 5x SSC, 2%
w/v blocking agent, 0.1% N-lauroylsarcosine, 0.3% SDS at 65 C° overnight and
30   washing in, for example, 5xSSC at about 65 C°). The term "ALK1 ECD
polypeptide" accordingly encompasses isolated extracellular portions of ALK1
polypeptides, variants thereof (including variants that comprise, for example, no

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more than 2, 3, 4, 5 or 10 amino acid substitutions, additions or deletions in the
sequence corresponding to amino acids 22-118 of SEQ ID NO:1 and including
variants that comprise no more than 2, 3, 4, 5, or 10 amino acid substitutions,
additions or deletions in the sequence corresponding to amino acids 34-95 of SEQ

5   ID NO:1), fragments thereof and fusion proteins comprising any of the preceding,
but in each case preferably any of the foregoing ALK1 ECD polypeptides will retain
substantial affinity for one or more of GDF5, GDF6, GDF7, BMP9 or BMP10. The
term "ALK1 ECD polypeptide" is explicitly intended to exclude any full-length,
naturally occurring ALK1 polypeptide. Generally, an ALK1 ECD polypeptide will

10   be designed to be soluble in aqueous solutions at biologically relevant temperatures,
pH levels and osmolarity.

As described above, the disclosure provides ALK1 ECD polypeptides
sharing a specified degree of sequence identity or similarity to a naturally occurring
ALK1 polypeptide. To determine the percent identity of two amino acid sequences,

15   the sequences are aligned for optimal comparison purposes (e.g., gaps can be
introduced in one or both of a first and a second amino acid or nucleic acid sequence
for optimal alignment and non-homologous sequences can be disregarded for
comparison purposes). The amino acid residues at corresponding amino acid
positions are then compared. When a position in the first sequence is occupied by

20   the same amino acid residue as the corresponding position in the second sequence,
then the molecules are identical at that position (as used herein amino acid "identity"
is equivalent to amino acid "homology"). The percent identity between the two
sequences is a function of the number of identical positions shared by the sequences,
taking into account the number of gaps, and the length of each gap, which need to be

25   introduced for optimal alignment of the two sequences.

The comparison of sequences and determination of percent identity and
similarity between two sequences can be accomplished using a mathematical
algorithm. (Computational Molecular Biology, Lesk, A. M., ed., Oxford University
Press, New York, 1988; Biocomputing: Informatics and Genome Projects, Smith, D.

30   W., ed., Academic Press, New York, 1993; Computer Analysis of Sequence Data,
Part 1, Griffin, A. M., and Griffin, H. G., eds., Humana Press, New Jersey, 1994;
Sequence Analysis in Molecular Biology, von Heinje, G., Academic Press, 1987;

and Sequence Analysis Primer, Gribskov, M. and Devereux, J., eds., M Stockton Press, New York, 1991).

In one embodiment, the percent identity between two amino acid sequences is determined using the Needleman and Wunsch (J Mol. Biol. (48):444-453 (1970)) algorithm which has been incorporated into the GAP program in the GCG software package (available at http://www.gcg.com). In a specific embodiment, the following parameters are used in the GAP program: either a Blosum 62 matrix or a PAM250 matrix, and a gap weight of 16, 14, 12, 10, 8, 6, or 4 and a length weight of 1, 2, 3, 4, 5, or 6. In yet another embodiment, the percent identity between two nucleotide sequences is determined using the GAP program in the GCG software package (Devereux, J., et al., Nucleic Acids Res. 12(1):387 (1984)) (available at http://www.gcg.com). Exemplary parameters include using a NWSgapdna.CMP matrix and a gap weight of 40, 50, 60, 70, or 80 and a length weight of 1, 2, 3, 4, 5, or 6. Unless otherwise specified, percent identity between two amino acid sequences is to be determined using the GAP program using a Blosum 62 matrix, a GAP weight of 10 and a length weight of 3, and if such algorithm cannot compute the desired percent identity, a suitable alternative disclosed herein should be selected.

In another embodiment, the percent identity between two amino acid sequences is determined using the algorithm of E. Myers and W. Miller (CABIOS, 4:11-17 (1989)) which has been incorporated into the ALIGN program (version 2.0), using a PAM120 weight residue table, a gap length penalty of 12 and a gap penalty of 4.

Another embodiment for determining the best overall alignment between two amino acid sequences can be determined using the FASTDB computer program based on the algorithm of Brutlag et al. (Comp. App. Biosci., 6:237-245 (1990)). In a sequence alignment the query and subject sequences are both amino acid sequences. The result of said global sequence alignment is presented in terms of percent identity. In one embodiment, amino acid sequence identity is performed using the FASTDB computer program based on the algorithm of Brutlag et al. (Comp. App. Biosci., 6:237-245 (1990)). In a specific embodiment, parameters employed to

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calculate percent identity and similarity of an amino acid alignment comprise: Matrix=PAM 150, k-tuple=2, Mismatch Penalty=1, Joining Penalty=20, Randomization Group Length=0, Cutoff Score=1, Gap Penalty=5 and Gap Size Penalty=0.05.

5   In certain embodiments, ALK1 ECD polypeptides comprise an extracellular portion of a naturally occurring ALK1 protein such as a sequence of SEQ ID NO:1, and preferably a ligand binding portion of the ALK1 extracellular domain. In certain embodiments, a soluble ALK1 polypeptide comprises an amino acid sequence that is at least 60%, 70%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99%
10   identical to an amino acid sequence of amino acids 22-118 of the SEQ ID NO:1. In certain embodiments, a truncated extracellular ALK1 polypeptide comprises at least 30, 40 or 50 consecutive amino acids of an amino acid sequence of an extracellular portion of SEQ ID NO:1.

            In preferred embodiments, an ALK1 ECD polypeptide binds to one or more
15   of GDF5, GDF6, GDF7, BMP9 and BMP10. Optionally the ALK1 polypeptide does not show substantial binding to TGF-β1 or TGF-β3. Binding may be assessed using purified proteins in solution or in a surface plasmon resonance system, such as a Biacore™ system. Preferred soluble ALK1 polypeptides will exhibit an anti-angiogenic activity. Bioassays for angiogenesis inhibitory activity include the chick
20   chorioallantoic membrane (CAM) assay, the mouse corneal micropocket assay, an assay for measuring the effect of administering isolated or synthesized proteins on implanted tumors. The CAM assay is described by O'Reilly, et al. in "Angiogenic Regulation of Metastatic Growth" Cell, vol. 79 (2), Oct. 1, 1994, pp. 315-328. Briefly, 3 day old chicken embryos with intact yolks are separated from the egg and
25   placed in a petri dish. After 3 days of incubation, a methylcellulose disc containing the protein to be tested is applied to the CAM of individual embryos. After 48 hours of incubation, the embryos and CAMs are observed to determine whether endothelial growth has been inhibited. The mouse corneal micropocket assay involves implanting a growth factor-containing pellet, along with another pellet
30   containing the suspected endothelial growth inhibitor, in the cornea of a mouse and observing the pattern of capillaries that are elaborated in the cornea. Other assays are described in the Examples.

ALK1 ECD polypeptides may be produced by removing the cytoplasmic tail and the transmembrane region of an ALK1 polypeptide. Alternatively, the transmembrane domain may be inactivated by deletion, or by substitution of the normally hydrophobic amino acid residues which comprise a transmembrane

5   domain with hydrophilic ones. In either case, a substantially hydrophilic hydropathy profile is created which will reduce lipid affinity and improve aqueous solubility. Deletion of the transmembrane domain is preferred over substitution with hydrophilic amino acid residues because it avoids introducing potentially immunogenic epitopes.

10   ALK1 ECD polypeptides may additionally include any of various leader sequences at the N-terminus. Such a sequence would allow the peptides to be expressed and targeted to the secretion pathway in a eukaryotic system. See, e.g., Ernst et al., U.S. Pat. No. 5,082,783 (1992). Alternatively, a native ALK1 signal sequence may be used to effect extrusion from the cell. Possible leader sequences

15   include native, tPa and honeybee mellitin leaders (SEQ ID NOs. 7-9, respectively). Processing of signal peptides may vary depending on the leader sequence chosen, the cell type used and culture conditions, among other variables, and therefore actual N-terminal start sites for mature ALK1 ECD polypeptides, including that of SEQ ID NO:5, may shift by 1-5 amino acids in either the N-terminal or C-terminal direction.

20   In certain embodiments, the present disclosure contemplates specific mutations of the ALK1 polypeptides 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

25   sequence, asparagine-X-threonine (or asparagines-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 wild-type ALK1 polypeptide (for O-linked glycosylation sites). A variety of amino acid substitutions

30   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 an ALK1 polypeptide is by chemical or enzymatic coupling of glycosides to the ALK1 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

5   cysteine; (d) free hydroxyl groups such as those of serine, threonine, or hydroxyproline; (e) aromatic residues such as those of phenylalanine, tyrosine, or tryptophan; or (f) the amide group of glutamine. These methods are described in WO 87/05330 published Sep. 11, 1987, and in Aplin and Wriston (1981) CRC Crit. Rev. Biochem., pp. 259-306, incorporated by reference herein. Removal of one or

10   more carbohydrate moieties present on an ALK1 polypeptide may be accomplished chemically and/or enzymatically. Chemical deglycosylation may involve, for example, exposure of the ALK1 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

15   N-acetylgalactosamine), while leaving the amino acid sequence intact. Chemical deglycosylation is further described by Hakimuddin et al. (1987) Arch. Biochem. Biophys. 259:52 and by Edge et al. (1981) Anal. Biochem. 118:131. Enzymatic cleavage of carbohydrate moieties on ALK1 polypeptides can be achieved by the use of a variety of endo- and exo-glycosidases as described by Thotakura et al.

20   (1987) Meth. Enzymol. 138:350. The sequence of an ALK1 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, ALK1 proteins for use in humans will be expressed in a mammalian cell line that

25   provides proper glycosylation, such as HEK293 or CHO cell lines, although other mammalian expression cell lines, yeast cell lines with engineered glycosylation enzymes and insect cells are expected to be useful as well.

       This disclosure further contemplates a method of generating mutants, particularly sets of combinatorial mutants of an ALK1 polypeptide, as well as

30   truncation mutants; pools of combinatorial mutants are especially useful for identifying functional variant sequences. The purpose of screening such combinatorial libraries may be to generate, for example, ALK1 polypeptide variants

which can act as either agonists or antagonist, or alternatively, which possess novel
activities all together. A variety of screening assays are provided below, and such
assays may be used to evaluate variants. For example, an ALK1 polypeptide variant
may be screened for ability to bind to an ALK1 ligand, to prevent binding of an
5   ALK1 ligand to an ALK1 polypeptide or to interfere with signaling caused by an
ALK1 ligand. The activity of an ALK1 polypeptide or its variants may also be
tested in a cell-based or in vivo assay, particularly any of the assays disclosed in the
Examples.

Combinatorially-derived variants can be generated which have a selective or
10   generally increased potency relative to an ALK1 ECD polypeptide comprising an
extracellular domain of a naturally occurring ALK1 polypeptide. Likewise,
mutagenesis can give rise to variants which have serum half-lives dramatically
different than the corresponding a wild-type ALK1 ECD polypeptide. For example,
the altered protein can be rendered either more stable or less stable to proteolytic
15   degradation or other processes which result in destruction of, or otherwise
elimination or inactivation of a native ALK1 ECD polypeptide. Such variants, and
the genes which encode them, can be utilized to alter ALK1 ECD polypeptide levels
by modulating the half-life of the ALK1 polypeptides. For instance, a short half-life
can give rise to more transient biological effects and can allow tighter control of
20   recombinant ALK1 ECD polypeptide levels within the patient. In an Fc fusion
protein, mutations may be made in the linker (if any) and/or the Fc portion to alter
the half-life of the protein.

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
25   potential ALK1 polypeptide sequences. For instance, a mixture of synthetic
oligonucleotides can be enzymatically ligated into gene sequences such that the
degenerate set of potential ALK1 polypeptide nucleotide sequences are expressible
as individual polypeptides, or alternatively, as a set of larger fusion proteins (e.g.,
for phage display).

30   There are many ways by which the library of potential ALK1 ECD variants
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 then be ligated into an appropriate vector for expression. The synthesis of degenerate oligonucleotides is well known in the art (see for example, Narang, SA (1983) Tetrahedron 39:3; Itakura et al., (1981) Recombinant

5 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; Ike et al., (1983) Nucleic Acid Res. 11:477). Such techniques have been employed in the directed evolution of other proteins (see, for example, Scott et al., (1990) Science 249:386-390; Roberts et al., (1992) PNAS

10 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, ALK1 polypeptide variants can be generated

15 and isolated from a library by screening using, for example, alanine scanning mutagenesis and the like (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;

20 and Cunningham et al., (1989) Science 244:1081-1085), by linker scanning mutagenesis (Gustin et al., (1993) Virology 193:653-660; 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

25 chemical mutagenesis, etc. (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 ALK1 polypeptides.

30 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 screening cDNA libraries for gene products having a certain property.

29

Such techniques will be generally adaptable for rapid screening of the gene libraries generated by the combinatorial mutagenesis of ALK1 polypeptides. The most widely used techniques for screening large gene libraries typically comprises cloning the gene library into replicable expression vectors, transforming appropriate

5   cells with the resulting library of 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 ALK1 ligand binding assays and ligand-mediated cell signaling assays.

10   In certain embodiments, the ALK1 ECD polypeptides of the disclosure may further comprise post-translational modifications in addition to any that are naturally present in the ALK1 polypeptides. Such modifications include, but are not limited to, acetylation, carboxylation, glycosylation, phosphorylation, lipidation, and acylation. As a result, the modified ALK1 ECD polypeptides may contain non-

15   amino acid elements, such as polyethylene glycols, lipids, poly- or mono-saccharide, and phosphates. Effects of such non-amino acid elements on the functionality of an ALK1 ECD polypeptide may be tested as described herein for other ALK1 ECD polypeptide variants. When an ALK1 ECD polypeptide is produced in cells by cleaving a nascent form of the ALK1 polypeptide, post-translational processing may

20   also be important for correct folding and/or function of the protein. Different cells (such as CHO, HeLa, MDCK, 293, WI38, NIH-3T3 or HEK293) have specific cellular machinery and characteristic mechanisms for such post-translational activities and may be chosen to ensure the correct modification and processing of the ALK1 polypeptides.

25   In certain aspects, functional variants or modified forms of the ALK1 ECD polypeptides include fusion proteins having at least a portion of the ALK1 ECD polypeptides and one or more fusion domains. Well known examples of such fusion domains include, but are not limited to, polyhistidine, Glu-Glu, glutathione S transferase (GST), thioredoxin, protein A, protein G, an immunoglobulin heavy

30   chain constant region (Fc), maltose binding protein (MBP), or human serum albumin. A fusion domain may be selected so as to confer a desired property. For example, some fusion domains are particularly useful for isolation of the fusion

30

proteins by affinity chromatography. For the purpose of affinity purification, relevant matrices for affinity chromatography, such as glutathione-, amylase-, and nickel- or cobalt- conjugated resins are used. Many of such matrices are available in "kit" form, such as the Pharmacia GST purification system and the QIAexpress™

5   system (Qiagen) useful with (HIS₆) fusion partners. As another example, a fusion domain may be selected so as to facilitate detection of the ALK1 ECD 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

10   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

15   domain by subsequent chromatographic separation. In certain preferred embodiments, an ALK1 ECD polypeptide is fused with a domain that stabilizes the ALK1 polypeptide in vivo (a "stabilizer" domain). By "stabilizing" is meant anything that increases serum half life, regardless of whether this is because of decreased destruction, decreased clearance by the kidney, or other pharmacokinetic

20   effect. Fusions with the Fc portion of an immunoglobulin are known to confer desirable pharmacokinetic properties on a wide range of proteins. Likewise, fusions to human serum albumin can confer desirable properties. Other types of fusion domains that may be selected include multimerizing (e.g., dimerizing, tetramerizing) domains and functional domains.

25   As a specific example, the present disclosure provides a fusion protein comprising a soluble extracellular domain of ALK1 fused to an Fc domain (e.g., SEQ ID NO: 6).

       THTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVD (A) VSHEDPEVKF
       NWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCK (A) VSNKAL

30   PVPIEKTISKAKGQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESN
       GQPENNYKTTPPVLDSDGPFFLYSKLTVDKSRWQQGNVFSCSVMHEALHN (A) HYT
       QKSLSLSPGK*

Optionally, the Fc domain has one or more mutations at residues such as
Asp-265, lysine 322, and Asn-434. 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
5   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.

It is understood that different elements of the fusion proteins may be
arranged in any manner that is consistent with the desired functionality. For
10   example, an ALK1 ECD polypeptide may be placed C-terminal to a heterologous
domain, or, alternatively, a heterologous domain may be placed C-terminal to an
ALK1 ECD polypeptide. The ALK1 ECD 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
15   domains.

As used herein, the term, "immunoglobulin Fc region" or simply "Fc" is
understood to mean the carboxyl-terminal portion of an immunoglobulin chain
constant region, preferably an immunoglobulin heavy chain constant region, or a
portion thereof. For example, an immunoglobulin Fc region may comprise 1) a CH1
20   domain, a CH2 domain, and a CH3 domain, 2) a CH1 domain and a CH2 domain, 3)
a CH1 domain and a CH3 domain, 4) a CH2 domain and a CH3 domain, or 5) a
combination of two or more domains and an immunoglobulin hinge region. In a
preferred embodiment the immunoglobulin Fc region comprises at least an
immunoglobulin hinge region a CH2 domain and a CH3 domain, and preferably
25   lacks the CH1 domain.

In one embodiment, the class of immunoglobulin from which the heavy
chain constant region is derived is IgG (Igγ) (γ subclasses 1, 2, 3, or 4). Other
classes of immunoglobulin, IgA (Igα), IgD (Igδ), IgE (Igε) and IgM (Igμ), may be
used. The choice of appropriate immunoglobulin heavy chain constant region is
30   discussed in detail in U.S. Pat. Nos. 5,541,087, and 5,726,044. The choice of
particular immunoglobulin heavy chain constant region sequences from certain

immunoglobulin classes and subclasses to achieve a particular result is considered to be within the level of skill in the art. The portion of the DNA construct encoding the immunoglobulin Fc region preferably comprises at least a portion of a hinge domain, and preferably at least a portion of a CH3 domain of Fc γ or the homologous

5   domains in any of IgA, IgD, IgE, or IgM.

Furthermore, it is contemplated that substitution or deletion of amino acids within the immunoglobulin heavy chain constant regions may be useful in the practice of the methods and compositions disclosed herein. One example would be to introduce amino acid substitutions in the upper CH2 region to create an Fc variant

10   with reduced affinity for Fc receptors (Cole *et al.* (1997) J. Immunol. 159:3613).

In certain embodiments, the present disclosure makes available isolated and/or purified forms of the ALK1 ECD polypeptides, which are isolated from, or otherwise substantially free of (e.g., at least 80%, 90%, 95%, 96%, 97%, 98% or 99% free of), other proteins and/or other ALK1 ECD polypeptide species. ALK1

15   polypeptides will generally be produced by expression from recombinant nucleic acids.

In certain embodiments, the disclosure includes nucleic acids encoding soluble ALK1 polypeptides comprising the coding sequence for an extracellular portion of an ALK1 proteins. In further embodiments, this disclosure also pertains

20   to a host cell comprising such nucleic acids. The host cell may be any prokaryotic or eukaryotic cell. For example, a polypeptide of the present disclosure may be expressed in bacterial cells such as *E. coli*, insect cells (e.g., using a baculovirus expression system), yeast, or mammalian cells. Other suitable host cells are known to those skilled in the art. Accordingly, some embodiments of the present disclosure

25   further pertain to methods of producing the ALK1 ECD polypeptides. It has been established that an ALK1-Fc fusion protein set forth in SEQ ID NO:3 and expressed in CHO cells has potent anti-angiogenic activity.

DAN polypeptides, including variants of wild type DAN, and fusion proteins containing DAN proteins may be generated and characterized as described above

30   with respect to ALK1 ECD proteins.

3.   <u>Nucleic Acids Encoding ALK1 Polypeptides</u>

In certain aspects, the disclosure provides isolated and/or recombinant nucleic acids encoding any of the ALK1 polypeptides (e.g., ALK1 ECD polypeptides), including fragments, functional variants and fusion proteins disclosed herein. For example, SEQ ID NO: 2 encodes the naturally occurring human ALK1 precursor polypeptide, while SEQ ID NO: 4 encodes the precursor of an ALK1 extracellular domain fused to an IgG1 Fc domain. The subject nucleic acids may be single-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 ALK1 polypeptides or as direct therapeutic agents (e.g., in an antisense, RNAi or gene therapy approach).

In certain aspects, the subject nucleic acids encoding ALK1 polypeptides are further understood to include nucleic acids that are variants of SEQ ID NO: 2 or 4. Variant nucleotide sequences include sequences that differ by one or more nucleotide substitutions, additions or deletions, such as allelic variants.

In certain embodiments, the disclosure provides isolated or recombinant nucleic acid sequences that are at least 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99% or 100% identical to SEQ ID NO: 2 or 4. One of ordinary skill in the art will appreciate that nucleic acid sequences complementary to SEQ ID NO: 2 or 4, and variants of SEQ ID NO: 2 or 4 are also within the scope of this 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.

In other embodiments, nucleic acids of the disclosure also include nucleotide sequences that hybridize under highly stringent conditions to the nucleotide sequence designated in SEQ ID NO: 2 or 4, complement sequence of SEQ ID NO: 2 or 4, or fragments thereof. As discussed above, one of ordinary skill in the art will understand readily that appropriate stringency conditions which promote DNA hybridization can be varied. One of ordinary skill in the art will understand readily that appropriate stringency conditions which promote DNA hybridization can be varied. For example, one could perform the hybridization at 6.0 x sodium

34

chloride/sodium citrate (SSC) at about 45 °C, followed by a wash of 2.0 x SSC at 50

°C. For example, the salt concentration in the wash step can be selected from a low

stringency of about 2.0 x SSC at 50 °C to a high stringency of about 0.2 x SSC at 50

°C. In addition, the temperature in the wash step can be increased from low

5   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

10   SSC at room temperature.

Isolated nucleic acids which differ from the nucleic acids as set forth in SEQ

ID NOs: 2 or 4 due 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

15   and CAC are synonyms for histidine) may result in "silent" mutations 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

20   nucleotides) of the nucleic acids encoding a particular protein may exist among

individuals of a given species 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

25   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

30   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

5   present in a cell on an episome, such as a plasmid, or the expression construct may be inserted in a chromosome. In a preferred embodiment, the expression vector contains a selectable marker gene to allow the selection of transformed host cells. Selectable marker genes are well known in the art and will vary with the host cell used.

10   In certain aspects disclosed herein, the subject nucleic acid is provided in an expression vector comprising a nucleotide sequence encoding an ALK1 polypeptide and operably linked to at least one regulatory sequence. Regulatory sequences are art-recognized and are selected to direct expression of the ALK1 polypeptide. Accordingly, the term regulatory sequence includes promoters, enhancers, and other

15   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 an ALK1

20   polypeptide. Such useful expression control sequences, include, for example, the early and late promoters of SV40, tet promoter, adenovirus or cytomegalovirus immediate early promoter, RSV promoters, the lac system, the trp system, the TAC or TRC system, T7 promoter whose expression is directed by T7 RNA polymerase, the major operator and promoter regions of phage lambda , the control regions for fd

25   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

30   the design of the expression vector may depend on such factors as the choice of the host cell to be transformed and/or the type of protein desired to be expressed. Moreover, the vector's copy number, the ability to control that copy number and the

expression of any other protein encoded by the vector, such as antibiotic markers, should also be considered.

A recombinant nucleic acid included in the disclosure can be produced by ligating the cloned gene, or a portion thereof, into a vector suitable for expression in
5   either prokaryotic cells, eukaryotic cells (yeast, avian, insect or mammalian), or both. Expression vehicles for production of a recombinant ALK1 polypeptide include plasmids and other vectors. For instance, suitable vectors include plasmids of the types: pBR322-derived plasmids, pEMBL-derived plasmids, pEX-derived plasmids, pBTac-derived plasmids and pUC-derived plasmids for expression in
10 prokaryotic cells, such as E. coli.

Some mammalian expression vectors contain both prokaryotic sequences to facilitate the propagation of the vector in bacteria, and one or more eukaryotic transcription units that are expressed in eukaryotic cells. The pcDNAI/amp, pcDNAI/neo, pRc/CMV, pSV2gpt, pSV2neo, pSV2-dhfr, pTk2, pRSVneo, pMSG,
15 pSVT7, pko-neo and pHyg derived vectors are examples of mammalian expression vectors suitable for transfection of eukaryotic cells. Some of these vectors are modified with sequences from bacterial plasmids, such as pBR322, to facilitate replication and drug resistance selection in both prokaryotic and eukaryotic cells. Alternatively, derivatives of viruses such as the bovine papilloma virus (BPV-1), or
20 Epstein-Barr virus (pHEBo, pREP-derived and p205) can be used for transient expression of proteins in eukaryotic cells. Examples of other viral (including retroviral) expression systems can be found below in the description of gene therapy delivery systems. The various methods employed in the preparation of the plasmids and in transformation of host organisms are well known in the art. For other suitable
25 expression systems for both prokaryotic and eukaryotic cells, as well as general recombinant procedures, see 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
30 expression systems include pVL-derived vectors (such as pVL1392, pVL1393 and pVL941), pAcUW-derived vectors (such as pAcUW1), and pBlueBac-derived vectors (such as the ß-gal containing pBlueBac III).

In a preferred embodiment, a vector will be designed for production of the subject ALK1 polypeptides in CHO cells, such as a Pcmv-Script vector (Stratagene, La Jolla, Calif.), pcDNA4 vectors (Invitrogen, Carlsbad, Calif.) and pCI-neo vectors (Promega, Madison, Wisc.). As will be apparent, the subject gene constructs can be used to cause expression of the subject ALK1 polypeptides in cells propagated in culture, e.g., to produce proteins, including fusion proteins or variant proteins, for purification.

This disclosure also pertains to a host cell transfected with a recombinant gene including a coding sequence (e.g., SEQ ID NO: 2 or 4) for one or more of the subject ALK1 polypeptides. The host cell may be any prokaryotic or eukaryotic cell. For example, an ALK1 polypeptide disclosed herein may be expressed in bacterial cells such as E. coli, insect cells (e.g., using a baculovirus expression system), yeast, or mammalian cells. Other suitable host cells are known to those skilled in the art.

Accordingly, the present disclosure further pertains to methods of producing the subject ALK1 polypeptides, including ALK1 ECD polypeptides. For example, a host cell transfected with an expression vector encoding an ALK1 polypeptide can be cultured under appropriate conditions to allow expression of the ALK1 polypeptide to occur. The ALK1 polypeptide may be secreted and isolated from a mixture of cells and medium containing the ALK1 polypeptide. Alternatively, the ALK1 polypeptide may be retained cytoplasmically or in a membrane fraction and the cells harvested, lysed and the protein isolated. A cell culture includes host cells, media and other byproducts. Suitable media for cell culture are well known in the art. The subject ALK1 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 the ALK1 polypeptides and affinity purification with an agent that binds to a domain fused to the ALK1 polypeptide (e.g., a protein A column may be used to purify an ALK1-Fc fusion). In a preferred embodiment, the ALK1 polypeptide is a fusion protein containing a domain which facilitates its purification. In a preferred embodiment, purification is 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 cation exchange chromatography. The purification could be completed with viral filtration and buffer exchange.

5   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 ALK1 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
10   treatment with enterokinase to provide the purified ALK1 polypeptide (e.g., see Hochuli et al., (1987) *J. Chromatography* 411:177; and Janknecht et al., *PNAS USA* 88:8972).

          Techniques for making fusion genes are well known. Essentially, the joining of various DNA fragments coding for different polypeptide sequences is performed
15   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
20   DNA synthesizers. Alternatively, PCR amplification of gene fragments can be carried out using anchor primers which give rise to complementary overhangs between two consecutive gene fragments which can subsequently be annealed to generate a chimeric gene sequence (see, for example, *Current Protocols in Molecular Biology*, eds. Ausubel et al., John Wiley & Sons: 1992).

25   Examples of categories of nucleic acid compounds that are antagonists of ALK1, BMP9, BMP10, GDF5, GDF6 or GDF7 include antisense nucleic acids, RNAi constructs and catalytic nucleic acid constructs. A nucleic acid compound may be single or double stranded. A double stranded compound may also include regions of overhang or non-complementarity, where one or the other of the strands is
30   single stranded. A single stranded compound may include regions of self-complementarity, meaning that the compound forms a so-called "hairpin" or "stem-

39

loop" structure, with a region of double helical structure. A nucleic acid compound
may comprise a nucleotide sequence that is complementary to a region consisting of
no more than 1000, no more than 500, no more than 250, no more than 100 or no
more than 50, 35, 30, 25, 22, 20 or 18 nucleotides of the full-length ALK1 nucleic

5   acid sequence or ligand nucleic acid sequence. The region of complementarity will
preferably be at least 8 nucleotides, and optionally at least 10 or at least 15
nucleotides, and optionally between 15 and 25 nucleotides. A region of
complementarity may fall within an intron, a coding sequence or a noncoding
sequence of the target transcript, such as the coding sequence portion. Generally, a

10   nucleic acid compound will have a length of about 8 to about 500 nucleotides or
base pairs in length, and optionally the length will be about 14 to about 50
nucleotides. A nucleic acid may be a DNA (particularly for use as an antisense),
RNA or RNA:DNA hybrid. Any one strand may include a mixture of DNA and
RNA, as well as modified forms that cannot readily be classified as either DNA or

15   RNA. Likewise, a double stranded compound may be DNA:DNA, DNA:RNA or
RNA:RNA, and any one strand may also include a mixture of DNA and RNA, as
well as modified forms that cannot readily be classified as either DNA or RNA. A
nucleic acid compound may include any of a variety of modifications, including one
or modifications to the backbone (the sugar-phosphate portion in a natural nucleic

20   acid, including internucleotide linkages) or the base portion (the purine or
pyrimidine portion of a natural nucleic acid). An antisense nucleic acid compound
will preferably have a length of about 15 to about 30 nucleotides and will often
contain one or more modifications to improve characteristics such as stability in the
serum, in a cell or in a place where the compound is likely to be delivered, such as

25   the stomach in the case of orally delivered compounds and the lung for inhaled
compounds. In the case of an RNAi construct, the strand complementary to the
target transcript will generally be RNA or modifications thereof. The other strand
may be RNA, DNA or any other variation. The duplex portion of double stranded or
single stranded "hairpin" RNAi construct will preferably have a length of 18 to 40

30   nucleotides in length and optionally about 21 to 23 nucleotides in length, so long as
it serves as a Dicer substrate. Catalytic or enzymatic nucleic acids may be
ribozymes or DNA enzymes and may also contain modified forms. Nucleic acid

compounds may inhibit expression of the target by about 50%, 75%, 90% or more
when contacted with cells under physiological conditions and at a concentration
where a nonsense or sense control has little or no effect. Preferred concentrations
for testing the effect of nucleic acid compounds are 1, 5 and 10 micromolar. Nucleic
5   acid compounds may also be tested for effects on, for example, angiogenesis.

Nucleic acids encoding DAN polypeptides, including variants of wild type
DAN, and those encoding fusion proteins containing DAN proteins may be
generated and characterized as described above with respect to nucleic acids
encoding ALK1 ECD proteins.

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4.   Antibodies

Another aspect of the disclosure pertains to an antibody reactive with an
extracellular portion of an ALK1 polypeptide, preferably antibodies that are
specifically reactive with ALK1 polypeptide. In a preferred embodiment, such
15   antibody may interfere with ALK1 binding to a ligand such as GDF5, GDF6, GDF7
BMP-9 or BMP-10 – it will be understood that an antibody against a ligand of
ALK1 should bind to the mature, processed form of the relevant protein. The
disclosure also provides antibodies that bind to GDF5, GDF6, GDF7, BMP9 and/or
BMP10 and inhibit ALK1 binding to such ligands. Preferred antibodies will exhibit
20   an anti-angiogenic activity in a bioassay, such as a CAM assay or corneal
micropocket assay (see above).

The term "antibody" as used herein is intended to include whole antibodies,
e.g., of any isotype (IgG, IgA, IgM, IgE, etc), and includes fragments or domains of
immunoglobulins which are reactive with a selected antigen. Antibodies can be
25   fragmented using conventional techniques and the fragments screened for utility
and/or interaction with a specific epitope of interest. Thus, the term includes
segments of proteolytically-cleaved or recombinantly-prepared portions of an
antibody molecule that are capable of selectively reacting with a certain protein.
Non-limiting examples of such proteolytic and/or recombinant fragments include
30   Fab, F(ab')2, Fab', Fv, and single chain antibodies (scFv) containing a V[L] and/or
V[H] domain joined by a peptide linker. The scFv's may be covalently or non-

covalently linked to form antibodies having two or more binding sites. The term antibody also includes polyclonal, monoclonal, or other purified preparations of antibodies and recombinant antibodies. The term "recombinant antibody", means an antibody, or antigen binding domain of an immunoglobulin, expressed from a

5   nucleic acid that has been constructed using the techniques of molecular biology, such as a humanized antibody or a fully human antibody developed from a single chain antibody. Single domain and single chain antibodies are also included within the term "recombinant antibody".

Antibodies may be generated by any of the various methods known in the
10   art, including administration of antigen to an animal, administration of antigen to an animal that carries human immunoglobulin genes, or screening with an antigen against a library of antibodies (often single chain antibodies or antibody domains). Once antigen binding activity is detected, the relevant portions of the protein may be grafted into other antibody frameworks, including full-length IgG frameworks. For
15   example, by using immunogens derived from an ALK1 polypeptide or an ALK1 ligand, anti-protein/anti-peptide antisera or monoclonal antibodies can be made by standard protocols (See, for example, Antibodies: A Laboratory Manual ed. by Harlow and Lane (Cold Spring Harbor Press: 1988)). A mammal, such as a mouse, a hamster or rabbit can be immunized with an immunogenic form of the peptide
20   (e.g., a ALK1 polypeptide or an antigenic fragment which is capable of eliciting an antibody response, or a fusion protein). Techniques for conferring immunogenicity on a protein or peptide include conjugation to carriers or other techniques well known in the art. An immunogenic portion (preferably an extracellular portion) of an ALK1 polypeptide can be administered in the presence of adjuvant. The progress
25   of immunization can be monitored by detection of antibody titers in plasma or serum. Standard ELISA or other immunoassays can be used with the immunogen as antigen to assess the levels of antibodies.

Following immunization of an animal with an antigenic preparation of an ALK1 polypeptide, anti-ALK1 antisera can be obtained and, if desired, polyclonal
30   anti-ALK1 antibodies can be isolated from the serum. To produce monoclonal antibodies, antibody-producing cells (lymphocytes) can be harvested from an immunized animal and fused by standard somatic cell fusion procedures with

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immortalizing cells such as myeloma cells to yield hybridoma cells. Such techniques are well known in the art, and include, for example, the hybridoma technique (originally developed by Kohler and Milstein, (1975) Nature, 256: 495-497), the human B cell hybridoma technique (Kozbar et al., (1983) Immunology

5   Today, 4: 72), and the EBV-hybridoma technique to produce human monoclonal antibodies (Cole et al., (1985) Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, Inc. pp. 77-96). Hybridoma cells can be screened immunochemically for production of antibodies specifically reactive with a mammalian ALK1 polypeptide of the present disclosure and monoclonal antibodies isolated from a culture

10   comprising such hybridoma cells.

The term antibody as used herein is intended to include fragments thereof which are also specifically reactive with one of the subject ALK1 polypeptides. Antibodies can be fragmented using conventional techniques and the fragments screened for utility in the same manner as described above for whole antibodies. For

15   example, $F(ab)_2$ fragments can be generated by treating antibody with pepsin. The resulting $F(ab)_2$ fragment can be treated to reduce disulfide bridges to produce Fab fragments. The antibody of the present disclosure is further intended to include bispecific, single-chain, and chimeric and humanized molecules having affinity for an ALK1 polypeptide conferred by at least one CDR region of the antibody. In

20   preferred embodiments, the antibody further comprises a label attached thereto and is able to be detected, (e.g., the label can be a radioisotope, fluorescent compound, enzyme or enzyme co-factor).

In certain preferred embodiments, an antibody of the disclosure is a recombinant antibody, particularly a humanized monoclonal antibody or a fully

25   human recombinant antibody.

The adjective "specifically reactive with" as used in reference to an antibody is intended to mean, as is generally understood in the art, that the antibody is sufficiently selective between the antigen of interest (e.g. an ALK1 polypeptide or an ALK1 ligand) and other antigens that are not of interest that the antibody is useful

30   for, at minimum, detecting the presence of the antigen of interest in a particular type of biological sample. In certain methods employing the antibody, a higher degree of

specificity in binding may be desirable. For example, an antibody for use in detecting a low abundance protein of interest in the presence of one or more very high abundance protein that are not of interest may perform better if it has a higher degree of selectivity between the antigen of interest and other cross-reactants.

5   Monoclonal antibodies generally have a greater tendency (as compared to polyclonal antibodies) to discriminate effectively between the desired antigens and cross-reacting polypeptides. In addition, an antibody that is effective at selectively identifying an antigen of interest in one type of biological sample (e.g. a stool sample) may not be as effective for selectively identifying the same antigen in a

10   different type of biological sample (e.g. a blood sample). Likewise, an antibody that is effective at identifying an antigen of interest in a purified protein preparation that is devoid of other biological contaminants may not be as effective at identifying an antigen of interest in a crude biological sample, such as a blood or urine sample. Accordingly, in preferred embodiments, the application provides antibodies that

15   have demonstrated specificity for an antigen of interest in a sample type that is likely to be the sample type of choice for use of the antibody.

One characteristic that influences the specificity of an antibody:antigen interaction is the affinity of the antibody for the antigen. Although the desired specificity may be reached with a range of different affinities, generally preferred

20   antibodies will have an affinity (a dissociation constant) of about 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9} or less. Given the apparently low binding affinity of TGFβ for ALK1, it is expected that many anti-ALK1 antibodies will inhibit TGFβ binding. However, the GDF5,6,7 group of ligands bind with a K_D of approximately 5×10^{-8} M and the BMP9,10 ligands bind with a K_D of approximately 1×10^{-10} M. Thus, antibodies of appropriate

25   affinity may be selected to interfere with the signaling activities of these ligands.

In addition, the techniques used to screen antibodies in order to identify a desirable antibody may influence the properties of the antibody obtained. For example, an antibody to be used for certain therapeutic purposes will preferably be able to target a particular cell type. Accordingly, to obtain antibodies of this type, it

30   may be desirable to screen for antibodies that bind to cells that express the antigen of interest (e.g. by fluorescence activated cell sorting). Likewise, if an antibody is to be used for binding an antigen in solution, it may be desirable to test solution

binding. A variety of different techniques are available for testing antibody:antigen interactions to identify particularly desirable antibodies. Such techniques include ELISAs, surface plasmon resonance binding assays (e.g. the Biacore binding assay, Bia-core AB, Uppsala, Sweden), sandwich assays (e.g. the paramagnetic bead

5   system of IGEN International, Inc., Gaithersburg, Maryland), western blots, immunoprecipitation assays and immunohistochemistry.

5.   Alterations in antibodies and Fc-fusion proteins

        The application further provides antibodies, ALK1-Fc fusion proteins and

10   DAN-Fc fusion proteins with engineered or variant Fc regions. Such antibodies and Fc fusion proteins may be useful, for example, in modulating effector functions, such as, antigen-dependent cytotoxicity (ADCC) and complement-dependent cytotoxicity (CDC). Additionally, the modifications may improve the stability of the antibodies and Fc fusion proteins. Amino acid sequence variants of the

15   antibodies and Fc fusion proteins are prepared by introducing appropriate nucleotide changes into the DNA, or by peptide synthesis. Such variants include, for example, deletions from, and/or insertions into and/or substitutions of, residues within the amino acid sequences of the antibodies and Fc fusion proteins disclosed herein. Any combination of deletion, insertion, and substitution is made to arrive at the final

20   construct, provided that the final construct possesses the desired characteristics. The amino acid changes also may alter post-translational processes of the antibodies and Fc fusion proteins, such as changing the number or position of glycosylation sites.

        Antibodies and Fc fusion proteins with reduced effector function may be produced by introducing changes in the amino acid sequence, including, but are not

25   limited to, the Ala-Ala mutation described by Bluestone et al. (see WO 94/28027 and WO 98/47531; also see Xu et al. 2000 Cell Immunol 200; 16-26). Thus in certain embodiments, antibodies and Fc fusion proteins of the disclosure with mutations within the constant region including the Ala-Ala mutation may be used to reduce or abolish effector function. According to these embodiments, antibodies

30   and Fc fusion proteins may comprise a mutation to an alanine at position 234 or a mutation to an alanine at position 235, or a combination thereof. In one embodiment, the antibody or Fc fusion protein comprises an IgG4 framework,

wherein the Ala-Ala mutation would describe a mutation(s) from phenylalanine to alanine at position 234 and/or a mutation from leucine to alanine at position 235. In another embodiment, the antibody or Fc fusion protein comprises an IgG1 framework, wherein the Ala-Ala mutation would describe a mutation(s) from leucine to alanine at position 234 and/or a mutation from leucine to alanine at position 235. The antibody or Fc fusion protein may alternatively or additionally carry other mutations, including the point mutation K322A in the CH2 domain (Hezareh et al. 2001 J Virol. 75: 12161-8).

In particular embodiments, the antibody or Fc fusion protein may be modified to either enhance or inhibit complement dependent cytotoxicity (CDC). Modulated CDC activity may be achieved by introducing one or more amino acid substitutions, insertions, or deletions in an Fc region (see, e.g., U.S. Pat. No. 6,194,551). Alternatively or additionally, cysteine residue(s) may be introduced in the Fc region, thereby allowing interchain disulfide bond formation in this region. The homodimeric antibody thus generated may have improved or reduced internalization capability and/or increased or decreased complement-mediated cell killing. See Caron et al., J. Exp Med. 176:1191-1195 (1992) and Shopes, B. J. Immunol. 148:2918-2922 (1992), WO99/51642, Duncan & Winter Nature 322: 738-40 (1988); U.S. Pat. No. 5,648,260; U.S. Pat. No. 5,624,821; and WO94/29351.

6. Methods and compositions for modulating angiogenesis, pericyte coverage and certain disorders

The disclosure provides methods of inhibiting angiogenesis and/or increasing pericyte coverage in a mammal by administering to a subject an effective amount of a an ALK1 ECD polypeptide, such as an ALK1-Fc fusion protein, a DAN protein, such as a DAN-Fc fusion protein, or an antibody disclosed herein, such as an antibody against GDF5, GDF6, GDF7, BMP9, BMP10, or the ECD of ALK1, or nucleic acid antagonists (e.g., antisense or siRNA) of any of the foregoing hereafter collectively referred to as "therapeutic agents". The data presented indicate specifically that the anti-angiogenic therapeutic agents disclosed herein may be used to inhibit angiogenesis in the eye of a mammal. It is expected that these therapeutic

agents will also be useful in inhibiting angiogenesis in bones and joints, and in tumors, particularly tumors associated with bones and joints.

Angiogenesis associated diseases include, but are not limited to, angiogenesis-dependent cancer, including, for example, solid tumors, blood born

5   tumors such as leukemias, and tumor metastases; benign tumors, for example hemangiomas, acoustic neuromas, neurofibromas, trachomas, and pyogenic granulomas; rheumatoid arthritis; psoriasis; rubeosis; Osler-Webber Syndrome; myocardial angiogenesis; plaque neovascularization; telangiectasia; hemophiliac joints; and angiofibroma.

10   In particular, polypeptide therapeutic agents of the present disclosure are useful for treating or preventing a cancer (tumor), and particularly such cancers as are known to rely on angiogenic processes to support growth. Unlike most anti-angiogenic agents, ALK1 ECD polypeptides affect angiogenesis that is stimulated by multiple factors. This is highly relevant in cancers, where a cancer will

15   frequently acquire multiple factors that support tumor angiogenesis. Thus, the therapeutic agents disclosed herein will be particularly effective in treating tumors that are resistant to treatment with a drug that targets a single angiogenic factor (e.g., bevacizumab, which targets VEGF). As demonstrated herein, an ALK1-Fc fusion protein is effective in reducing the pathological effects of melanoma, lung cancer,

20   pancreatic cancer (e.g., tumors of the pancreatic endocrine tissue), multiple myeloma and breast cancer (e.g., primary breast cancer or metastatic breast cancer; Estrogen receptor positive (ER+) or estrogen receptor negative (ER-)).

Multiple myeloma is widely recognized as a cancer that includes a significant angiogenic component. Accordingly, it is expected that ALK1-Fc fusion

25   proteins and other therapeutic agents disclosed herein will be useful in treating multiple myeloma and other tumors associated with the bone. As demonstrated herein, therapeutic agents disclosed herein may be used to ameliorate the bone damage associated with multiple myeloma, and therefore may be used to ameliorate bone damage associated with bone metastases of other tumors, such as breast or

30   prostate tumors. As noted herein, the GDF5-7 ligands are highly expressed in bone,

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and, while not wishing to be limited to any particular mechanism, interference with these ligands may disrupt processes that are required for tumor development in bone.

In certain embodiments of such methods, one or more polypeptide therapeutic agents can be administered, together (simultaneously) or at different times (sequentially). In addition, polypeptide therapeutic agents can be administered with another type of compound for treating cancer or for inhibiting angiogenesis.

In certain embodiments, the subject methods of the disclosure can be used alone. Alternatively, the subject methods may be used in combination with other conventional anti-cancer therapeutic approaches directed to treatment or prevention of proliferative disorders (e.g., tumor). For example, such methods can be used in prophylactic cancer prevention, prevention of cancer recurrence and metastases after surgery, and as an adjuvant of other conventional cancer therapy. The present disclosure recognizes that the effectiveness of conventional cancer therapies (e.g., chemotherapy, radiation therapy, phototherapy, immunotherapy, and surgery) can be enhanced through the use of a subject polypeptide therapeutic agent.

A wide array of conventional compounds have been shown to have anti-neoplastic activities. These compounds have been used as pharmaceutical agents in chemotherapy to shrink solid tumors, prevent metastases and further growth, or decrease the number of malignant cells in leukemic or bone marrow malignancies. Although chemotherapy has been effective in treating various types of malignancies, many anti-neoplastic compounds induce undesirable side effects. It has been shown that when two or more different treatments are combined, the treatments may work synergistically and allow reduction of dosage of each of the treatments, thereby reducing the detrimental side effects exerted by each compound at higher dosages. In other instances, malignancies that are refractory to a treatment may respond to a combination therapy of two or more different treatments.

When a polypeptide therapeutic agent disclosed herein is administered in combination with another conventional anti-neoplastic agent, either concomitantly or sequentially, such therapeutic agent may enhance the therapeutic effect of the anti-neoplastic agent or overcome cellular resistance to such anti-neoplastic agent. This allows decrease of dosage of an anti-neoplastic agent, thereby reducing the

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undesirable side effects, or restores the effectiveness of an anti-neoplastic agent in resistant cells.

According to the present disclosure, the antiangiogenic agents described herein may be used in combination with other compositions and procedures for the treatment of diseases. For example, a tumor may be treated conventionally with surgery, radiation or chemotherapy combined with the ALK1 or ALK1 ligand antagonist and then the antagonist may be subsequently administered to the patient to extend the dormancy of micrometastases and to stabilize any residual primary tumor.

Angiogenesis-inhibiting agents can also be given prophylactically to individuals known to be at high risk for developing new or re-current cancers. Accordingly, an aspect of the disclosure encompasses methods for prophylactic prevention of cancer in a subject, comprising administrating to the subject an effective amount of an ALK1 or ALK1 ligand antagonist and/or a derivative thereof, or another angiogenesis-inhibiting agent of the present disclosure.

As demonstrated herein, ALK1-Fc is effective for diminishing the phenotype of a murine model of rheumatoid arthritis. Accordingly, therapeutic agents disclosed herein may be used for the treatment of rheumatoid arthritis and other type of bone or joint inflammation.

Certain normal physiological processes are also associated with angiogenesis, for example, ovulation, menstruation, and placentation. The angiogenesis inhibiting proteins of the present disclosure are useful in the treatment of disease of excessive or abnormal stimulation of endothelial cells. These diseases include, but are not limited to, intestinal adhesions, atherosclerosis, scleroderma, and hypertrophic scars, i.e., keloids. They are also useful in the treatment of diseases that have angiogenesis as a pathologic consequence such as cat scratch disease (Rochele minalia quintosa) and ulcers (Helicobacter pylori).

General angiogenesis inhibiting proteins can be used as a birth control agent by reducing or preventing uterine vascularization required for embryo implantation. Thus, the present disclosure provides an effective birth control method when an amount of the inhibitory protein sufficient to prevent embryo implantation is

administered to a female. In one aspect of the birth control method, an amount of the inhibiting protein sufficient to block embryo implantation is administered before or after intercourse and fertilization have occurred, thus providing an effective method of birth control, possibly a "morning after" method. While not wanting to be bound

5   by this statement, it is believed that inhibition of vascularization of the uterine endometrium interferes with implantation of the blastocyst. Similar inhibition of vascularization of the mucosa of the uterine tube interferes with implantation of the blastocyst, preventing occurrence of a tubal pregnancy. Administration methods may include, but are not limited to, pills, injections (intravenous, subcutaneous,

10 intramuscular), suppositories, vaginal sponges, vaginal tampons, and intrauterine devices. It is also believed that administration of angiogenesis inhibiting agents of the present disclosure will interfere with normal enhanced vascularization of the placenta, and also with the development of vessels within a successfully implanted blastocyst and developing embryo and fetus.

15   In the eye, angiogenesis is associated with, for example, diabetic retinopathy, retinopathy of prematurity, macular degeneration, corneal graft rejection, neovascular glaucoma, and retrolental fibroplasias. The therapeutic agents disclosed herein may be administered intra-ocularly or by other local administration to the eye. Furthermore, as shown in the Examples, ALK1-Fc may be administered

20 systemically and yet have the desired effect on ocular angiogenesis.

Other diseases associated with angiogenesis in the eye include, but are not limited to, epidemic keratoconjunctivitis, Vitamin A deficiency, contact lens overwear, atopic keratitis, superior limbic keratitis, pterygium keratitis sicca, sjogrens, acne rosacea, phylectenulosis, syphilis, Mycobacteria infections, lipid

25 degeneration, chemical burns, bacterial ulcers, fungal ulcers, Herpes simplex infections, Herpes zoster infections, protozoan infections, Kaposi sarcoma, Mooren ulcer, Terrien's marginal degeneration, mariginal keratolysis, rheumatoid arthritis, systemic lupus, polyarteritis, trauma, Wegeners sarcoidosis, Scleritis, Steven's Johnson disease, periphigoid radial keratotomy, and corneal graft rejection, sickle

30 cell anemia, sarcoid, pseudoxanthoma elasticum, Pagets disease, vein occlusion, artery occlusion, carotid obstructive disease, chronic uveitis/vitritis, mycobacterial infections, Lyme's disease, systemic lupus erythematosis, retinopathy of prematurity,

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Eales disease, Bechets disease, infections causing a retinitis or choroiditis, presumed ocular histoplasmosis, Bests disease, myopia, optic pits, Stargarts disease, pars planitis, chronic retinal detachment, hyperviscosity syndromes, toxoplasmosis, trauma and post-laser complications. Other diseases include, but are not limited to,

5   diseases associated with rubeosis (neovasculariation of the angle) and diseases caused by the abnormal proliferation of fibrovascular or fibrous tissue including all forms of proliferative vitreoretinopathy.

Conditions of the eye can be treated or prevented by, e.g., systemic, topical, intraocular injection of a therapeutic agent, or by insertion of a sustained release

10   device that releases a therapeutic agent. A therapeutic agent may be delivered in a pharmaceutically acceptable ophthalmic vehicle, such that the compound is maintained in contact with the ocular surface for a sufficient time period to allow the compound to penetrate the corneal and internal regions of the eye, as for example the anterior chamber, posterior chamber, vitreous body, aqueous humor, vitreous

15   humor, cornea, iris/ciliary, lens, choroid/retina and sclera. The pharmaceutically-acceptable ophthalmic vehicle may, for example, be an ointment, vegetable oil or an encapsulating material. Alternatively, the therapeutic agents of the disclosure may be injected directly into the vitreous and aqueous humour. In a further alternative, the compounds may be administered systemically, such as by intravenous infusion

20   or injection, for treatment of the eye.

One or more therapeutic agents can be administered. The methods of the disclosure also include co-administration with other medicaments that are used to treat conditions of the eye. When administering more than one agent or a combination of agents and medicaments, administration can occur simultaneously or

25   sequentially in time. The therapeutic agents and/or medicaments may be administered by different routes of administration or by the same route of administration. In one embodiment, a therapeutic agent and a medicament are administered together in an ophthalmic pharmaceutical formulation.

In one embodiment, a therapeutic agent is used to treat a disease associated

30   with angiogenesis in the eye by concurrent administration with other medicaments that act to block angiogenesis by pharmacological mechanisms. Medicaments that

can be concurrently administered with a therapeutic agent of the disclosure include, but are not limited to, pegaptanib (Macugen™), ranibizumab (Lucentis™), squalamine lactate (Evizon™), heparinase, and glucocorticoids (e.g. Triamcinolone). In one embodiment, a method is provided to treat a disease

5   associated with angiogenesis is treated by administering an ophthalmic pharmaceutical formulation containing at least one therapeutic agent disclosed herein and at least one of the following medicaments: pegaptanib (Macugen™), ranibizumab (Lucentis™), squalamine lactate (Evizon™), heparinase, and glucocorticoids (e.g. Triamcinolone).

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7.   Formulations and Effective Doses

The therapeutic agents described herein may be formulated into pharmaceutical compositions. Pharmaceutical compositions for use in accordance with the present disclosure may be formulated in conventional manner using one or

15   more physiologically acceptable carriers or excipients. Such formulations will generally be substantially pyrogen free, in compliance with most regulatory requirements.

In certain embodiments, the therapeutic method of the disclosure includes administering the composition systemically, or locally as an implant or device.

20   When administered, the therapeutic composition for use in this disclosure is in a pyrogen-free, physiologically acceptable form. Therapeutically useful agents other than the ALK1 signaling antagonists which may also optionally be included in the composition as described above, may be administered simultaneously or sequentially with the subject compounds (e.g., ALK1 ECD polypeptides or any of

25   the antibodies disclosed herein) in the methods disclosed herein.

Typically, protein therapeutic agents disclosed herein will be administered parentally, and particularly intravenously or subcutaneously. Pharmaceutical compositions suitable for parenteral administration may comprise one or more ALK1 ECD polypeptides or other antibodies in combination with one or more

30   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, which may contain antioxidants, buffers, bacteriostats, solutes which render the formulation isotonic with the blood of the intended recipient or suspending or thickening agents. Examples of suitable aqueous and nonaqueous carriers which

5   may be employed in the pharmaceutical compositions of the disclosure include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), and suitable mixtures thereof, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials, such as lecithin, by the maintenance of the

10 required particle size in the case of dispersions, and by the use of surfactants.

In one embodiment, the antibodies and ALK1 ECD proteins disclosed herein are administered in an ophthalmic pharmaceutical formulation. In some embodiments, the ophthalmic pharmaceutical formulation is a sterile aqueous solution, preferable of suitable concentration for injection, or a salve or ointment.

15 Such salves or ointments typically comprise one or more antibodies or ALK1 ECD proteins disclosed herein dissolved or suspended in a sterile pharmaceutically acceptable salve or ointment base, such as a mineral oil-white petrolatum base. In salve or ointment compositions, anhydrous lanolin may also be included in the formulation. Thimerosal or chlorobutanol are also preferably added to such ointment

20 compositions as antimicrobial agents. In one embodiment, the sterile aqueous solution is as described in U.S. Pat. No. 6,071,958.

The disclosure provides formulations that may be varied to include acids and bases to adjust the pH; and buffering agents to keep the pH within a narrow range. Additional medicaments may be added to the formulation. These include, but are not

25 limited to, pegaptanib, heparinase, ranibizumab, or glucocorticoids. The ophthalmic pharmaceutical formulation according to the disclosure is prepared by aseptic manipulation, or sterilization is performed at a suitable stage of preparation.

The compositions and formulations may, if desired, be presented in a pack or dispenser device which may contain one or more unit dosage forms containing the

30 active ingredient. The pack may for example comprise metal or plastic foil, such as a blister pack. The pack or dispenser device may be accompanied by instructions for

administration.

EXAMPLES:

Example 1: Expression of ALK1-Fc fusion proteins

5   Applicants constructed a soluble ALK1 fusion protein that has the

extracellular domain of human ALK1 fused to a human Fc or mouse ALK1 fused to

a murine Fc domain with a minimal linker in between. The constructs are referred

to as hALK1-Fc and mALK1-Fc, respectively.

         hALK1-Fc is shown as purified from CHO cell lines in Figure 3 (SEQ ID

10   NO: 3). Notably, while the conventional C-terminus of the extracellular domain of

human ALK1 protein is amino acid 118 of SEQ ID NO:1, we have determined that

it is desirable to avoid having a domain that ends at a glutamine residue.

Accordingly, the portion of SEQ ID NO:3 that derives from human ALK1

incorporates two residues c-terminal to Q118, a leucine and an alanine. The

15   disclosure therefore provides ALK1 ECD polypeptides (including Fc fusion

proteins) having a c-terminus of the ALK1 derived sequence that is anywhere from 1

to 5 amino acids upstream (113-117 relative to SEQ ID NO:1) or downstream (119-

123) of Q118.

         The hALK1-Fc and mALK1-Fc proteins were expressed in CHO cell lines.

20   Three different leader sequences were considered:

(i) Honey bee mellitin (HBML): MKFLVNVALVFMVVYISYIYA (SEQ ID NO:

7)

(ii) Tissue Plasminogen Activator (TPA): MDAMKRGLCCVLLLCGAVFVSP

(SEQ ID NO: 8)

25   (iii) Native: MTLGSPRKGLLMLLMALVTQG (SEQ ID NO: 9).

         The selected form employs the TPA leader and has the unprocessed amino

acid sequence shown in Figure 4 (SEQ ID NO:5).

         This polypeptide is encoded by the nucleic acid sequence shown in Figure 4

(SEQ ID NO:4).

       Purification can 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 cation exchange chromatography. The

5   purification can be completed with viral filtration and buffer exchange. The hALK1-Fc protein was purified to a purity of >98% as determined by size exclusion chromatography and >95% as determined by SDS PAGE.

       In the course of protein production and purification, we observed that hALK1-Fc tends to be expressed in a mixture of dimers and higher order aggregates

10   which, while appearing pure under denaturing, reducing conditions (e.g., reducing SDS-PAGE), are problematic for administration to a patient. The aggregates may be immunogenic or poorly bioavailable, and because of their heterogeneity, these aggregates make it difficult to characterize the pharmaceutical preparation at a level that is desirable for drug development. Thus, various approaches were tested to

15   reduce the amount of aggregate in final preparations.

       In one approach, a number of different cell culture media were tested. IS CHO-CD (Cat. No. 91119, Irvine Scientific, Santa Ana, CA) showed a remarkable reduction in the production of aggregated products, while maintaining high level production of the hALK1-Fc. Additionally, elution of the material from a

20   hydrophobic interaction column (e.g., phenylsepharose) at a pH of 8.0 resulted in further resolution of the aggregated product. The resulting material is comprised of greater than 99% dimers. A comparison to an ALK1-Fc fusion protein sold by R&D Systems (cat. no. 370-AL, Minneapolis, MN) shows that this protein, produced in NSO cells, is 84% dimers, with the remaining protein appearing as high molecular

25   weight species by size exclusion chromatography. A comparison of the sizing column profile for the preparations is shown in Figure 11. Having identified aggregate formation as a significant problem in ALK1-Fc production, it is expected that other approaches may be developed, including approaches that involve additional purification steps (although such approaches may result in lower yield of

30   purified protein).

Example 2: Identification of ALK1-Fc Ligands

ALK1 is a type 1 receptors for members of the TGFβ family. A variety of members of the TGFβ family were tested for binding to a human ALK1-Fc fusion protein, using a Biacore™ system. TGFβ itself, GDF8, GDF11, BMP2 and BMP4 all failed to show substantial binding to the hALK1-Fc protein. BMP2 and BMP4 showed limited binding. GDF5, GDF7 and BMP9 showed binding with K_D values of approximately 5×10^{-8} M, 5×10^{-8} M and 1×10^{-10} M, respectively. Based on the similarity of GDF5 and GDF7 to GDF6, it is expected that GDF6 will bind with similar affinity. BMP10 is closely related to BMP9 and is also expected to bind with similar affinity.

Example 3: Characterization of ALK1-Fc and anti-ALK1 Antibody Effects on Endothelial Cells

Using a luciferase reporter construct under the control of four sequential consensus SBE sites (SBE4-luc), which are responsive to Smad1/5/8-mediated signaling, we measured BMP-9 mediated activity in the presence and absence of hALK1-Fc drug or neutralizing ALK1 specific monoclonal antibody in HMVEC cells. HMVEC cells were stimulated with rhBMP-9 (50ng/ml), which induced Smad1/5/8-mediated transcriptional activation, evidenced here by the increase in SBE4-luc modulated transcriptional upregulation. When added, the hALK1-Fc compound (10μg/ml) or antibody (10μg/ml) diminished this transcriptional response, each by nearly 60%, indicating that the presence of ALK1-Fc significantly reduces BMP9 signaling, and moreover, that the BMP9 signaling is related to ALK1 activity.

Activation of SMAD phosphorylation is commonly used to assay activation of upstream activin receptors. ALK1 is known to modulate phosphorylation of SMAD proteins 1,5 and 8 upon activation by its ligand. Here, we added rhBMP-9 (50ng/ml) to initiate SMAD phosphorylation in HUVEC cells, a human endothelial cell line which innately expresses ALK1 receptor, over a timecourse of 30 minutes. Phosphorylation of SMAD 1/5/8 was seen 5 minutes after treatment of cells with ligand and phosphorylation was maintained for the entirety of the 30 minute period.

In the presence of relatively low concentrations of hALK1-Fc (250ng/ml), SMAD 1/5/8 phosphorylation was reduced, confirming that this agent inhibits Smad1/5/8 activation in endothelial cells.

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In order to evaluate the angiogenic effect of ALK1-Fc in an in vitro system, we assayed the effectiveness of the compound in reducing tube formation of endothelial cells on a Matrigel substrate. This technique is commonly used to assess neovascularization, giving both rapid and highly reproducible results. Endothelial Cell Growth Supplement (ECGS) is used to induce the formation of microvessels from endothelial cells on Matrigel, and the efficacy of anti-angiogenic compounds are then gauged as a reduction of cord formation in the presence of both the drug and ECGS over an 18 hour timecourse. As expected, addition of ECGS (200ng/ml) induced significant cord formation, as compared to the negative control (no treatment added), which indicates basal levels of endothelial cell cord formation produced on Matrigel substrate (Figure 5). Upon addition of either hALK1-Fc (100 ng/ml) or mALK1-Fc (100ng/ml), cord formation was visibly reduced. Final quantification of vessel length in all samples revealed that every concentration of hALK1-fc or mALK1-Fc reduced neovascularization to basal levels. Additionally, hALK1-Fc and mALK1-Fc in the presence of the strongly pro-angiogenic factor ECGS maintained strong inhibition of neovascularization demonstrating even more potent anti-angiogenic activity than the negative control endostatin (100ng/ml).

Example 4: CAM Assays

25
VEGF and FGF are well-known to stimulate angiogenesis. A CAM (chick chorioallantoic membrane) assay system was used to assess the angiogenic effects of GDF7. As shown in Figure 6, GDF7 stimulates angiogenesis with a potency that is similar to that of VEGF. Similar results were observed with GDF5 and GDF6.

30
ALK1-Fc fusions were tested for anti-angiogenic activity in the CAM assay. These fusion proteins showed a potent anti-angiogenic effect on angiogenesis stimulated by VEGF, FGF and GDF7. See Figure 7. BMP9 and PDGF showed a relatively poor capability to induce angiogenesis in this assay, but such angiogenesic effect of these factors was nonetheless inhibited by ALK1.

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ALK1-Fc proteins and a commercially available, anti-angiogenic anti-VEGF monoclonal antibody were compared in the CAM assay. The ALK1-Fc proteins had similar potency as compared to anti-VEGF. The anti-VEGF antibody bevacizumab is currently used in the treatment of cancer and macular degeneration in humans. See

5   Figure 8.

Interestingly, an anti-ALK1 antibody (R&D Systems) failed to significantly inhibit angiogenesis in this assay system. We expect that this may reflect the difference in the ALK1 sequence in different species.

10   Example 5: Mouse Corneal Micropocket Assay

The mouse corneal micropocket assay was used to assess the effects of ALK1-Fc on angiogenesis in the mouse eye. hALK1-Fc, administered intraperitoneally, significantly inhibited ocular angiogenesis. As shown in Figure 9, hALK1-Fc inhibited ocular angiogenesis to the same degree as anti-VEGF. hALK1-

15   Fc and anti-VEGF were used at identical weight/weight dosages. Similar data were obtained when a Matrigel plug impregnated with VEGF was implanted in a non-ocular location.

These data demonstrate that high affinity ligands for ALK1 promote angiogenesis and that an ALK1-Fc fusion protein has potent anti-angiogenic

20   activity. The ligands for ALK1 fall into two categories, with the GDF5,6,7 grouping having an intermediate affinity for ALK1 and the BMP9,10 grouping having a high affinity for ALK1.

GDF5, 6 and 7 are primarily localized to bone and joints, while BMP9 is circulated in the blood. Thus, there appears to be a pro-angiogenic system of the

25   bones and joints that includes ALK1, GDF5, 6 and 7 and a systemic angiogenic system that includes ALK1 and BMP9 (and possibly BMP10).

Example 6: Murine Model of Rheumatoid Arthritis

The murine collagen-induced arthritis model is a well-accepted model of

30   rheumatoid arthritis. In this study, groups of 10 mice were treated with vehicle, anti-

VEGF (bevacizumab – as a negative control, because bevacizumab does not inhibit murine VEGF), or doses of mALK1-Fc ("RAP-041") at 1 mg/kg, 10 mg/kg or 25 mg/kg. Following the collagen boost on day 21 arthritic scores (see Figure 10) and paw swelling steadily increased in all groups, peaking around day 38. Mice treated

5   with mALK1-Fc ("RAP-041") showed reduced scores for both characteristics, particularly at the highest dose (25mg/kg), although the reduction did not achieve statistical significance. Nonetheless, a dose-related trend is apparent.

By study termination at day 42 the incidence of arthritis had reached 10/10 in the vehicle control treated mice, 9/10 in the bevacizumab treated mice, 8/10 in the

10   mALK1-Fc at 1mg/kg treated group and 9/10 in the mALK1-Fc 10mg/kg treated group. In the mALK1-Fc 25mg/kg treated group disease incidence was lower at 6/10.

Example 7: Ligand Binding Characteristics of DAN

15   DAN is a member of a family of secreted cystine knot proteins that inhibit BMP activity. DAN is known to bind to and antagonize GDF5. We determined that DAN also binds tightly to GDF7, but not to BMP9. Thus, we conclude that DAN inhibits the suite of bone and joint localized ligands for ALK1, and DAN is expected to be a potent antagonist of bone and joint related angiogenesis. Thus DAN may be

20   useful in treating cancers of the bone, e.g., multiple myeloma and bone metastases, as well as rheumatoid arthritis and osteoarthritis.

Taken together, the findings disclosed in these Examples provide numerous reagents, described herein, for inhibiting angiogenesis in vivo, and particularly ocular angiogenesis. These findings also indicate that agents targeted to GDF5, 6

25   and 7 can be used to selectively inhibit bone and joint angiogenesis. These findings further indicate that such agents can be used to treat cancers and rheumatoid arthritis.

Example 8: ALK1-Fc Reduces Tumor Angiogenesis in a CAM Assay

Tumors, as with any tissue, have a basic nutrient and oxygen requirement. Although small tumors are capable of acquiring adequate amounts via diffusion from neighboring blood vessels, as the tumor increases in size, it must secure

5   nutrients by recruiting and maintaining existing capillaries. In order to test the capacity of ALK1-Fc proteins to limit tumor growth through vessel inhibition, we tested varying concentrations of mALK1-Fc in a melanoma explant CAM assay. As with CAM assays described above, small windows were made in the surface of each egg through which 5×10^5 B16 melanoma cells were implanted. Eggs were then

10   treated daily with 0.02 mg/ml mALK1-Fc, 0.2 mg/ml mALK1-Fc, or left untreated for a period of a week. At the end of the experiment, tumors were carefully removed, weighed and digital images were captured. Tumors originating from CAMs treated with mALK1-Fc showed a significant decrease in size as compared to untreated CAM tumors. Quantification of tumor weight demonstrated that weight of

15   tumors treated daily with either 0.02 mg/ml or 0.2 mg/ml mALK1-Fc showed a reduction of 65% and 85% compared to the untreated CAMs (Fig 6E). In conclusion, neovascularization and tumor growth was significantly suppressed upon addition of ALK1-Fc in a dose-responsive manner, indicating that ALK1-Fc is a powerful anti-angiogenic agent.

20

Example 9: Lung Cancer Experimental Model

To further confirm the effects of ALK1-Fc on tumor progression, a mouse model of lung cancer was tested. Fluorescently labeled murine Lewis lung cancer cells (LL/2-luc) were administered to albino Black 6 mice through the tail vein. On

25   the same day, the mice began treatment with either PBS control (n=7) or 10mg/kg mALK1-Fc (n=7) administered intraperitoneally. In-life fluorescent imaging showed substantial development of tumors localized to the lungs in the control mice, to the point that the mice became moribund and had to be sacrificed by day 22 post-implantation. By contrast, the ALK1-Fc treated mice showed a substantially

30   delayed growth of lung tumors and exhibited 100% survival as of day 22. See Figure 12.

60

These data demonstrate that ALK1-Fc has substantial effect on tumor growth in a mouse model of lung cancer and provides a survival benefit.

Example 10. Effects of ALK1-Fc Protein on a Pancreatic Tumor Model

5   The SV40 large T antigen is an oncogene that can be expressed in a variety of different tissues in mice to stimulate the formation of spontaneous, orthotopic tumors in the mice. These tumors may bear a greater resemblance to naturally occurring tumors than the commonly used xengraft models. In the RIP1-Tag2 mice, the mice are genetically modified to express the T antigen under control of an
10   insulin promoter, such that the mice develop tumors specifically in the endocrine tissue of the pancreas. We tested the effects of ALK1-Fc on the RIP1-Tag2 tumors.

We observed that the pancreatic tissue of a RIP1-Tag2 mouse goes through a series of stages, beginning with normal tissue, which then develops a hyperplastic appearance, undergoes angiogenesis to develop a substantial de novo blood vessel
15   system and finally becomes a fully formed tumor. ALK-1 and BMP9 expression was monitored in tissues at these various stages. The results are shown in Figure 13. The expression of ALK1 peaked during the angiogenic stage of development, while BMP9 expression increased throughout tumor development.

RIP1-Tag2 mice were treated with mALK1-Fc or control Fc (300
20   micrograms per mouse, or roughly 12mg/kg, twice weekly for two weeks) starting at 10 weeks (early tumor development) or 12 weeks of age (mature tumor development). In either case, the treatment with mALK1-Fc essentially halted tumor growth. See Figure 14. Note that the tumor volume of mice treated at 10 weeks of age failed to increase from 10 weeks to 12 weeks, while mice treated with a control
25   Fc protein showed a tripling of tumor volume during the same period of time. Similarly, the tumor volume of mice treated at 12 weeks of age failed to increase from 12 weeks to 14 weeks, while the control group showed an additional 30% increase in tumor volume.

Fluorescent staining of the treated and control tumors showed a decrease in
30   vascularization caused by mALK1-Fc treatment, as measured by staining for CD31,

a marker of endothelial cells. Figure 15. Remarkably, mALK1-Fc treatment caused an increase in the pericyte coverage of tumor vasculature, as measured by the ratio of NG2 positive cells (pericytes) to CD31 positive cells. Figure 16. Pericytes are cells that form part of blood vessels and play a role in modulating vessel stability and permeability. Similar increases in pericyte coverage were observed in response to ALK1-Fc treatment of xenograft tumor models with the CaLu6 non-small cell lung cancer cell line.

Collectively, these data show that ALK1-Fc is a potent inhibitor of tumor growth in the spontaneous, orthotopic pancreatic tumors formed in the RIP1-Tag2 mice, and that the tumor inhibition is correlated with a marked decrease in tumor vascularization and a marked increase in the pericyte coverage of tumor vasculature. The significance of the latter with respect to tumor biology remains to be determined. However, it should be noted that the pathology of diabetic retinopathy is largely attributed to a loss of pericytes and a leakage of fluid from the vessels of the diabetic retina. Thus, these data demonstrate that ALK1-Fc can be used as anti-tumor/anti-angiogenic agent, and further, that this agent can be used to promote the formation of pericytes in vascularized tissue.

Example 11. Effects of ALK1-Fc Fusion Protein on Breast Cancer Tumor Models

mALK1-Fc was effective in delaying the growth of breast cancer tumor cell lines derived from both estrogen receptor positive (ER+) and estrogen receptor negative tumor cells (ER-).

The MDA-MB-231 breast cancer cell line (derived from ER- cells) was stably transfected with the luciferase gene to allow for the in vivo detection of tumor growth and potential metastasis. In this study, 1×10^6 MDA-MB-231-Luc cells were implanted orthotopically in the mammary fat pad of athymic nude mice (Harlan). Tumor progression was followed by bioluminescent detection using an IVIS Spectrum imaging system (Caliper Life Sciences). An increase in the luminescence (number of photons detected) corresponds to an increase in tumor burden.

Thirty female nude mice were injected with 1 x 10^6 tumor cells into the mammary fat pad. Three days after tumor implantation the mice were treated with either vehicle control or mALK1-Fc (30 mg/kg) twice per week by subcutaneous (SC) injection. Treatment was continued and tumor progression was monitored by bioluminescent imaging for 10 weeks. mALK1-Fc treatment at 30 mg/kg slowed tumor progression as determined by bioluminescent detection when compared to vehicle treated controls (Figure 17). Treatment with mALK1-Fc delayed, but did not reverse tumor growth in this model. This may be expected of an antiangiogenic compound in that tumors may be able to survive to a certain size before requiring new blood vessel formation to support continued growth. In a similar experiment, hALK1-Fc produced similar, if slightly lesser, effects at dose levels as low as 3 mg/kg.

The estrogen-receptor-positive (ER+), luciferase expressing cell line, MCF-7, was also tested in an orthotopic implantation model. In this model, female nude mice are implanted subcutaneously with a 60 day slow release pellet of 17β-estradiol. Two days following pellet implantation, 5 x 10^6 MCF-7 tumor cells were implanted into the mammary fat pad. Mice were treated twice per week with hALK1-Fc at 3, 10 and 30 mg/kg, or vehicle control, by the IP route. Tumor progression was followed by bioluminescent imaging on a weekly basis with an IVIS-Spectrum imager (Caliper Life Sciences). In vehicle treated mice tumors progressed rapidly until study day 26 (Figure 18). After day 26 there were fluctuations in tumor luminescence until the conclusion of the study at day 60 (when the estradiol pellets were depleted). These fluctuations are due to a common feature of this model in that the rapid tumor growth can exceed the angiogenic response of the host animals leading to tumor necrosis and a concomitant drop-off in luminescent signal. The remaining cells continue to grow leading to an increased signal. Mice treated with 10 or 30 mg/kg of hALK1-Fc were able to maintain tumor size at a constant level during the study, compared to vehicle-treated controls, indicating a potent effect of this molecule on tumor growth.

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. In case of conflict, the

5   present application, including any definitions herein, will control.

EQUIVALENTS

While specific embodiments of the subject inventions are explicitly disclosed herein, the above specification is illustrative and not restrictive. Many variations of

10   the inventions will become apparent to those skilled in the art upon review of this specification and the claims below. The full scope of the inventions should be determined by reference to the claims, along with their full scope of equivalents, and the specification, along with such variations.

WE CLAIM:

1. A pharmaceutical preparation comprising an ALK1-Fc fusion protein

   comprising: a polypeptide having an amino acid sequence that is at least 97%

   identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which

   polypeptide is fused to an Fc portion of an immunoglobulin, and wherein the

   ALK1-Fc fusion protein binds to GDF5, GDF7 and BMP9 with a K_D of less

   than 1×10^{-7} M and binds to TGFβ-1 with a K_D of greater than 1×10^{-6}.and

   wherein at least 90% of the ALK1-Fc fusion protein is present in a dimeric

   form.

2. The pharmaceutical preparation of claim 1, wherein the Fc portion of the

   ALK1-Fc fusion protein is an Fc portion of a human IgG1.

3. The pharmaceutical preparation of claim 1, wherein the ALK1-Fc fusion

   protein comprises the amino acid sequence of SEQ ID NO: 3.

4. The pharmaceutical preparation of claim 1, wherein the ALK1-Fc fusion

   protein is produced by expression of the nucleic acid of SEQ ID NO:4 in a

   mammalian cell line.

5. The pharmaceutical preparation of claim 4, wherein the ALK1-Fc fusion

   protein is produced by expression of the nucleic acid of SEQ ID NO:4 in a

   Chinese Hamster Ovary (CHO) cell line.

6. The pharmaceutical preparation of claim 1, wherein the pharmaceutical

   preparation is a pharmaceutical preparation that is suitable for administration

   to the eye.

7. The pharmaceutical preparation of any of claims 1-6, wherein at least 95% of

   the ALK1-Fc fusion protein is present in a dimeric form.

8. The pharmaceutical preparation of any of claims 1-6, wherein at least 99% of the ALK1-Fc fusion protein is present in a dimeric form.

9. A method for inhibiting angiogenesis in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a pharmaceutical preparation of claim 1.

10. A method for treating a tumor in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a pharmaceutical preparation of claim 1.

11. A method of treating an ocular disorder associated with angiogenesis in a mammal in need thereof, the method comprising administering to the mammal an effective amount of a pharmaceutical preparation of claim 1.

12. A method for treating rheumatoid arthritis in a mammal in need thereof, the method comprising, administering to the mammal an effective amount of a pharmaceutical preparation of claim 1.

13. The method of any of claims 9-12, wherein the method further comprises administering a second agent that inhibits angiogenesis.

14. A method of promoting an increase in pericyte coverage in a vascularized tissue of a mammal in need thereof, the method comprising administering to the mammal an effective amount of an ALK1 ECD protein.

15. The method of claim 14, wherein the ALK1 ECD protein is an ALK1-Fc fusion protein.

16. The method of claim 15, wherein the ALK1-Fc fusion protein comprises a polypeptide having an amino acid sequence that is at least 90% identical to the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide is

fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc

fusion protein binds to TGFβ-1 with a K_D of greater than 1×10^{-6}.

17. The method of claim 14, wherein the ALK1 ECD protein binds to one or

more ALK1 ligands selected from the group consisting of: GDF5, GDF6,

GDF7, BMP9 and BMP10.

18. The method of claim 14, wherein the ALK1 ECD polypeptide comprises an

amino acid sequence that is at least 90% identical to the sequence of amino

acids corresponding to amino acids 34-95 of SEQ ID NO:1.

19. The method of claim 14, wherein the ALK1 ECD comprises an amino acid

sequence encoded by a nucleic acid that hybridizes under stringent

hybridization conditions to nucleotides 100-285 of SEQ ID NO:2 or a variant

of nucleotides 100-285 of SEQ ID NO:2 that encodes the same amino acid

sequence.

20. The method of claim 15, wherein the ALK1-Fc fusion protein has a sequence

of SEQ ID NO:3.

21. The method of claim 15, wherein the ALK1-Fc fusion protein is

administered in a pharmaceutical preparation wherein at least 90% of the

ALK1-Fc fusion protein is in a dimeric form.

22. The method of claim 14, wherein the ALK1 ECD fusion protein is delivered

intravenously or locally to the eye.

23. The method of claim 14, wherein the method further comprises

administering a second agent that inhibits angiogenesis.

24. The method of claim 14, wherein the vascularized tissue is selected from the

group consisting of: the eye of the mammal, a tumor, a bone and a joint.

25. The method of claim 14, wherein the mammal has diabetic retinopathy or other retinal disorder characterized by a loss of pericyte coverage in the retinal vasculature.

26. The method of claim 14, wherein the mammal has a tumor selected from the group consisting of: melanoma, a lung tumor, multiple myeloma and breast cancer.

27. The method of claim 14, wherein the mammal has a pancreatic tumor.

28. The method of claim 27, wherein the mammal has a tumor of the pancreatic endocrine tissue.

29. A method of promoting an increase in pericyte coverage in a vascularized tissue of a mammal in need thereof, the method comprising, administering to the mammal an effective amount of an antibody that binds to an ALK1 polypeptide consisting of amino acids 22-118 of SEQ ID NO:1 and inhibits the binding of at least one ALK1 ligand selected from the group consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10.

30. The method of claim 29, wherein the antibody binds to the ALK1 polypeptide with a K_D of less than 5×10^{-8} M.

31. The method of claim 29, wherein the antibody binds to the ALK1 polypeptide with a K_D of less than 1×10^{-10} M.

32. The method of claim 29, wherein the antibody inhibits binding of ALK1 to an ALK1 ligand, wherein the ALK1 ligand is selected from the group consisting of: BMP9 and BMP10.

33. The method of claim 29, wherein the antibody is delivered intravenously.

34. The method of claim 29, wherein the method further comprises

administering a second agent that inhibits angiogenesis.

35. The method of claim 29, wherein the vascularized tissue is selected from the

group consisting of: the eye of the mammal, a tumor, a bone and a joint.

36. The method of claim 29, wherein the mammal has diabetic retinopathy or

other retinal disorder characterized by a loss of pericyte coverage in the

retinal vasculature.

37. The method of claim 29, wherein the mammal has a tumor selected from the

group consisting of: melanoma, a lung tumor, multiple myeloma, and breast

cancer.

38. The method of claim 29, wherein the mammal has a pancreatic tumor.

39. The method of claim 38, wherein the mammal has a tumor of the pancreatic

endocrine tissue.

40. A method for treating a tumor in a mammal, the method comprising,

administering to a mammal that has a tumor an effective amount of an agent

selected from the group consisting of:

    (a) an ALK1 ECD protein;

    (b) an antibody that binds to an ALK1 ligand and inhibits the

        binding of the ALK1 ligand to ALK1, wherein the ALK1

        ligand is selected from the group consisting of GDF5,

        GDF6, GDF7, BMP9 and BMP10;

    (c) an antibody that binds to an ALK1 polypeptide consisting of

        amino acids 22-118 of SEQ ID NO:1 and inhibits the

        binding of at least one ALK1 ligand selected from the group

consisting of: GDF5, GDF6, GDF7, BMP9 and BMP10;

and

(d) a DAN polypeptide,

wherein the tumor is selected from the group consisting of: melanoma, multiple

myeloma, a tumor associated with bone, a tumor that has metastasized to bone, a

lung tumor, a pancreatic tumor and breast cancer.

41. The method of claim 40, wherein the ALK-1 ECD protein is an ALK1-Fc

    fusion protein.

42. The method of claim 41, wherein the ALK1-Fc fusion protein comprises a

    polypeptide having an amino acid sequence that is at least 90% identical to

    the sequence of amino acids 22-118 of SEQ ID NO:1, which polypeptide is

    fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc

    fusion protein binds to TGFβ-1 with a K_D of greater than 1 x 10^{-6}.

43. The method of claim 40, wherein the ALK1 ECD protein binds to one or

    more ALK1 ligands selected from the group consisting of: GDF5, GDF6,

    GDF7, BMP9 and BMP10.

44. The method of claim 41, wherein the ALK1-Fc fusion protein has a sequence

    of SEQ ID NO:3.

45. The method of claim 40, wherein the ALK1 ECD polypeptide comprises an

    amino acid sequence that is at least 90% identical to the sequence of amino

    acids corresponding to amino acids 34-95 of SEQ ID NO:1.

46. The method of claim 40, wherein the ALK1 ECD comprises an amino acid

    sequence encoded by a nucleic acid that hybridized under stringent

hybridization conditions to nucleotides 100-285 of SEQ ID NO:2 or a variant

of nucleotides 100-285 of SEQ ID NO:2 that has the same coding sequence.

47. The method of claim 40, wherein the antibody of (b) binds to the ALK1

polypeptide with a K_D of less than 5 x 10^{-8} M.

48. The method of claim 40, wherein the antibody of (b) binds to the ALK1

polypeptide with a K_D of less than 1 x 10^{-10} M.

49. The method of claim 40, wherein the antibody of (b) inhibits angiogenesis

stimulated by at least one ALK1 ligand selected from the group consisting

of: GDF5, GDF6 and GDF7.

50. The method of claim 40, wherein the antibody of (b) inhibits binding of

ALK1 to an ALK1 ligand, wherein the ALK1 ligand is selected from the

group consisting of: BMP9 and BMP10.

51. The method of claim 40, wherein the antibody of (c) inhibits angiogenesis

stimulated by at least one ALK1 ligand selected from the group consisting

of: GDF5, GDF6 and GDF7.

52. The method of claim 40, wherein the antibody of (c) inhibits angiogenesis

stimulated by at least one ALK1 ligand selected from the group consisting

of: BMP9 and BMP10.

53. The method of claim 40, wherein the DAN protein is a DAN-Fc fusion

protein.

54. The method of claim 53, wherein the DAN-Fc fusion protein comprises a

polypeptide having an amino acid sequence that is at least 90% identical to

the sequence of amino acids 21-125 of SEQ ID NO:10, which polypeptide is

fused to an Fc portion of an immunoglobulin, and wherein the ALK1-Fc fusion protein binds to TGFβ-1 with a K_D of greater than 1×10^{-6}.

55. The method of claim 40, wherein the DAN protein binds to one or more ALK1 ligands selected from the group consisting of: GDF5, GDF6 and GDF7.

56. The method of claim 40, wherein the DAN protein comprises an amino acid sequence that is at least 90% identical to the sequence of amino acids corresponding to amino acids 17-180 of SEQ ID NO:10.

57. The method of claim 40, wherein the DAN protein comprises an amino acid sequence encoded by a nucleic acid that hybridizes under stringent hybridization conditions to nucleotides 153-467 of SEQ ID NO:11 or a variant of nucleotides 153-467 of SEQ ID NO:11 that has the same coding sequence.

58. The method of claim 40, wherein the agent is delivered intravenously.

59. The method of claim 40, wherein the method further comprises administering a second agent that inhibits angiogenesis.

60. The method of claim 10, wherein the tumor is selected from the group consisting of: melanoma, a lung tumor, multiple myeloma, pancreatic tumor, and breast cancer.

Figure 1: Amino acid sequence for Human Activin receptor-like kinase 1 (ALK-1)

(gi:3915750; SEQ ID NO:1)

```
  1 MTLGSPRKGL LMLLMALVTQ GDPVKPSRGP LVTCTCESPH CKGPTCRGAW CTVVLVREEG
 61 RHPQEHRGCG NLHRELCRGR PTEFVNHYCC DSHLCNHNVS LVLEATQPPS EQPGTDGQLA
121 LILGPVLALL ALVALGVLGL WHVRRRQEKQ RGLHSELGES SLILKASEQG DSMLGDLLDS
181 DCTTGSGSGL PFLVQRTVAR QVALVECVGK GRYGEVWRGL WHGESVAVKI FSSRDEQSWF
241 RETEIYNTVL LRHDNILGFI ASDMTSRNSS TQLWLITHYH EHGSLYDFLQ RQTLEPHLAL
301 RLAVSAACGL AHLHVEIFGT QGKPAIAHRD FKSRNVLVKS NLQCCIADLG LAVMHSQGSD
361 YLDIGNNPRV GTKRYMAPEV LDEQIRTDCF ESYKWTDIWA FGLVLWEIAR RTIVNGIVED
421 YRPPFYDVVP NDPSFEDMKK VVCVDQQTPT IPNRLAADPV LSGLAQMMRE CWYPNPSARL
481 TALRIKKTLQ KISNSPEKPK VIQ
```

FIGURE 1

Figure 2: Nucleic acid sequence for Human Activin receptor-like kinase 1 (ALK-1)

(SEQ ID NO:2)

```
   1 atgaccttgg gctcccccag gaaaggcctt ctgatgctgc tgatggcctt ggtgacccag
  61 ggagaccctg tgaagccgtc tcggggcccg ctggtgacct gcacgtgtga gagcccacat
 121 tgcaagggqc ctacctgccg ggggcctgg tgcacagtag tgctggtgcg ggaggagggg
 181 aggcacccc aggaacatcg gggctgcggg aacttgcaca gggagctctg caggggcgc
 241 cccaccgagt tcgtcaacca ctactgctgc gacagccacc tctgcaacca caacgtgtcc
 301 ctggtgctgg aggccaccca acctccttcg gagcagccgg gaacagatgg ccagctggcc
 361 ctgatcctgg gccccgtgct ggccttgctg gccctggtgg ccctgggtgt cctgggcctg
 421 tggcatgtcc gacggaggca ggagaagcag cgtggcctgc acagcgagct gggagagtcc
 481 agtctcatcc tgaaagcatc tgagcagggc gacagcatgt gggggacct cctggacagt
 541 gactgcacca cagggagtgg ctcagggctc cccttcctgg tgcagaggac agtggcacgg
 601 caggttgcct tggtggagtg tgtgggaaaa ggccgctatg gcgaagtgtg gcggggcttg
 661 tggcacggtg agagtgtggc cgtcaagatc ttctcctcga gggatgaaca gtcctggttc
 721 cgggagactg agatctataa cacagtgttg ctcagacacg acaacatcct aggcttcatc
 781 gcctcagaca tgacctcccg caactcgagc acgcagctgt ggctcatcac gcactaccac
 841 gagcacggct ccctctacga ctttctgcag agacagacgc tggagcccca tctggctctg
 901 aggctagctg tgtccgcggc atgcggcctg gcgcacctgc acgtggagat cttcggtaca
 961 cagggcaaac cagccattgc ccaccgcgac ttcaagagcc gcaatgtgct ggtcaagagc
1021 aacctgcagt gttgcatcgc cgacctgggc ctggctgtga tgcactcaca gggcagcgat
1081 tacctggaca tcggcaacaa cccgagagtg ggcaccaagc ggtacatggc acccgaggtg
1141 ctggacgagc agatccgcac ggactgcttt gagtcctaca gtggactga catctgggcc
1201 tttggcctgg tgctgtggga gattgcccgc cggaccatcg tgaatggcat cgtggaggac
1261 tatagaccac ccttctatga tgtggtgccc aatgacccca gctttgagga catgaagaag
1321 gtggtgtgtg tggatcagca gacccccacc atccctaacc ggctggctgc agacccggtc
1381 ctctcaggcc tagctcagat gatgcgggag tgctggtacc caaacccctc tgcccgactc
1441 accgcgctgc ggatcaagaa gacactacaa aaaattagca acagtccaga gaagcctaaa
1501 gtgattcaat ag
```

FIGURE 2

Figure 3: An ALK1-Fc Fusion Protein (SEQ ID NO:3).

DPVKPSRGPLVTCTCESPHCKGPTCRGAWCTVVLVREEGRHPQEHRGCGNLH
RELCRGRPTEFVNHYCCDSHLCNHNVSLVLEATQPPSEQPGTDGQLA_TGGGT_
HTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFN
WYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNK
ALPVPIEKTISKAKGQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVE
WESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEA
LHNHYTQKSLSLSPGK

FIGURE 3

Figure 4: Nucleic Acid Sequence Encoding an ALK1-Fc Expression Construct
(Nucleic acid sequence, SEQ ID NO:4; Amino acid sequence, SEQ ID NO:5)

```
NheI            |  - - - - - - - - - - - - - CDS - - - - - - - - - - - - - -
   |          M  D  A  M  K  R  G  L  C  C  V  L  L  L  C  G  A  V  F  V
         *    *    *    20   *    *    *    40   *    *    *    60   *    *
GCTAGCACCATGGATGCAATGAAGAGAGGGCTCTGCTGTGTGCTGCTGCTGTGTGGAGCAGTCTTCGTTT
   KasI
      |

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - - - -
   S  P  G  A  D  P  V  K  P  S  R  G  P  L  V  T  C  T  C  E  S  P  H  C
      *    80   *    *    *    100  *    *    *    120  *    *    *    140
CGCCCGGCGCCGACCCTGTGAAGCCGTCTCGGGGCCCGCTGGTGACCTGCACGTGTGAGAGCCCACATTG

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - - -
      K  G  P  T  C  R  G  A  W  C  T  V  V  L  V  R  E  E  G  R  H  P  Q
      *    *    *    160  *    *    *    180  *    *    *    200  *    *
CAAGGGGCCTACCTGCCGGGGGGCCTGGTGCACAGTAGTGCTGGTGCGGGAGGAGGGGAGGCACCCCAG

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - - -
   E  H  R  G  C  G  N  L  H  R  E  L  C  R  G  R  P  T  E  F  V  N  H
      *    220  *    *    *    240  *    *    *    260  *    *    *    280
GAACATCGGGGCTGCGGGAACTTGCACAGGGAGCTCTGCAGGGGCCGCCCCACCGAGTTCGTCAACCACT

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - - -
   Y  C  C  D  S  H  L  C  N  H  N  V  S  L  V  L  E  A  T  Q  P  P  S  E
      *    *    *    300  *    *    *    320  *    *    *    340  *    *
ACTGCTGCGACAGCCACCTCTGCAACCACAACGTGTCCCTGGTGCTGGAGGCCACCCAACCTCCTTCGGA
                 AgeI
                  |

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   Q  P  G  T  D  G  Q  L  A  T  G  G  G  T  H  T  C  P  P  C  P  A  P
      *    360  *    *    *    380  *    *    *    400  *    *    *    420
GCAGCCGGGAACAGATGGCCAGCTGGCCACCGGTGGTGGAACTCACACATGCCCACCGTGCCCAGCACCT

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   E  A  L  G  A  P  S  V  F  L  F  P  P  K  P  K  D  T  L  M  I  S  R
      *    *    *    440  *    *    *    460  *    *    *    480  *    *
GAAGCCCTGGGGGCACCGTCAGTCTTCCTCTTCCCCCCAAAACCCAAGGACACCCTCATGATCTCCCGGA

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   T  P  E  V  T  C  V  V  V  D  V  S  H  E  D  P  E  V  K  F  N  W  Y  V
      *    500  *    *    *    520  *    *    *    540  *    *    *    560
CCCCTGAGGTCACATGCGTGGTGGTGGACGTGAGCCACGAAGACCCTGAGGTCAAGTTCAACTGGTACGT

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   D  G  V  E  V  H  N  A  K  T  K  P  R  E  E  Q  Y  N  S  T  Y  R  V
      *    *    *    580  *    *    *    600  *    *    *    620  *    *
GGACGGCGTGGAGGTGCATAATGCCAAGACAAAGCCGCGGGAGGAGCAGTACAACAGCACGTACCGTGTG

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   V  S  V  L  T  V  L  H  Q  D  W  L  N  G  K  E  Y  K  C  K  V  S  N
      *    640  *    *    *    660  *    *    *    680  *    *    *    700
GTCAGCGTCCTCACCGTCCTGCACCAGGACTGGCTGAATGGCAAGGAGTACAAGTGCAAGGTCTCCAACA

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   K  A  L  P  V  P  I  E  K  T  I  S  K  A  K  G  Q  P  R  E  P  Q  V  Y
      *    *    *    720  *    *    *    740  *    *    *    760  *    *
AAGCCCTCCCAGTCCCCATCGAGAAAACCATCTCCAAAGCCAAAGGGCAGCCCCGAGAACCACAGGTGTA

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   T  L  P  P  S  R  E  E  M  T  K  N  Q  V  S  L  T  C  L  V  K  G  F
      *    780  *    *    *    800  *    *    *    820  *    *    *    840
CACCCTGCCCCCATCCCGGGAGGAGATGACCAAGAACCAGGTCAGCCTGACCTGCCTGGTCAAAGGCTTC

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   Y  P  S  D  I  A  V  E  W  E  S  N  G  Q  P  E  N  N  Y  K  T  T  P
      *    *    *    860  *    *    *    880  *    *    *    900  *    *
TATCCCAGCGACATCGCCGTGGAGTGGGAGAGCAATGGGCAGCCGGAGAACAACTACAAGACCACGCCTC

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   P  V  L  D  S  D  G  P  F  F  L  Y  S  K  L  T  V  D  K  S  R  W  Q  Q
      *    920  *    *    *    940  *    *    *    960  *    *    *    980
CCGTGCTGGACTCCGACGGCCCCTTCTTCCTCTACAGCAAGCTCACCGTGGACAAGAGCAGGTGGCAGCA

       - - - - - - - - - - - - - - CDS - - - - - - - - - - - - - - - -
   G  N  V  F  S  C  S  V  M  H  E  A  L  H  N  H  Y  T  Q  K  S  L  S
      *    *    *    1000 *    *    *    1020 *    *    *    1040 *    *
GGGGAACGTCTTCTCATGCTCCGTGATGCATGAGGCTCTGCACAACCACTACACGCAGAAGAGCCTCTCC
                 EcoRI
                  |
   - - -  CDS  - -  |
   L  S  P  G  K  *
      *    1060 *    *    *
CTGTCTCCGGGTAAATGAGGAATTC
```
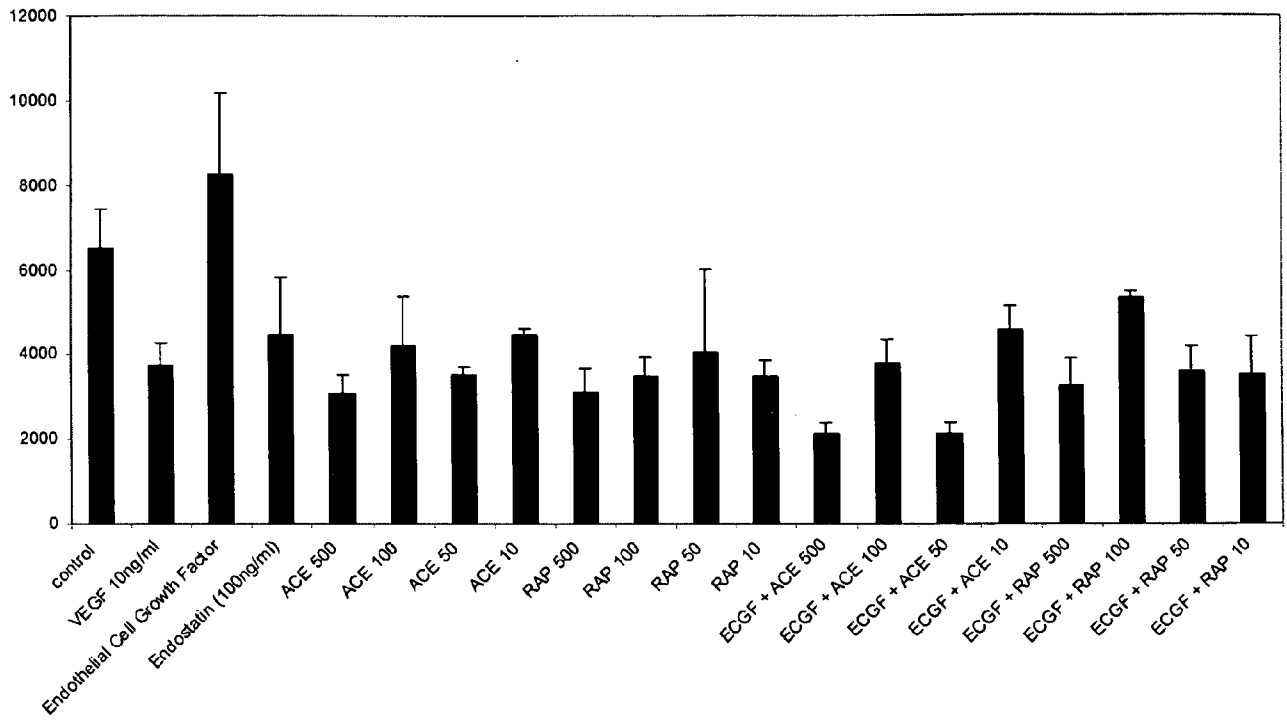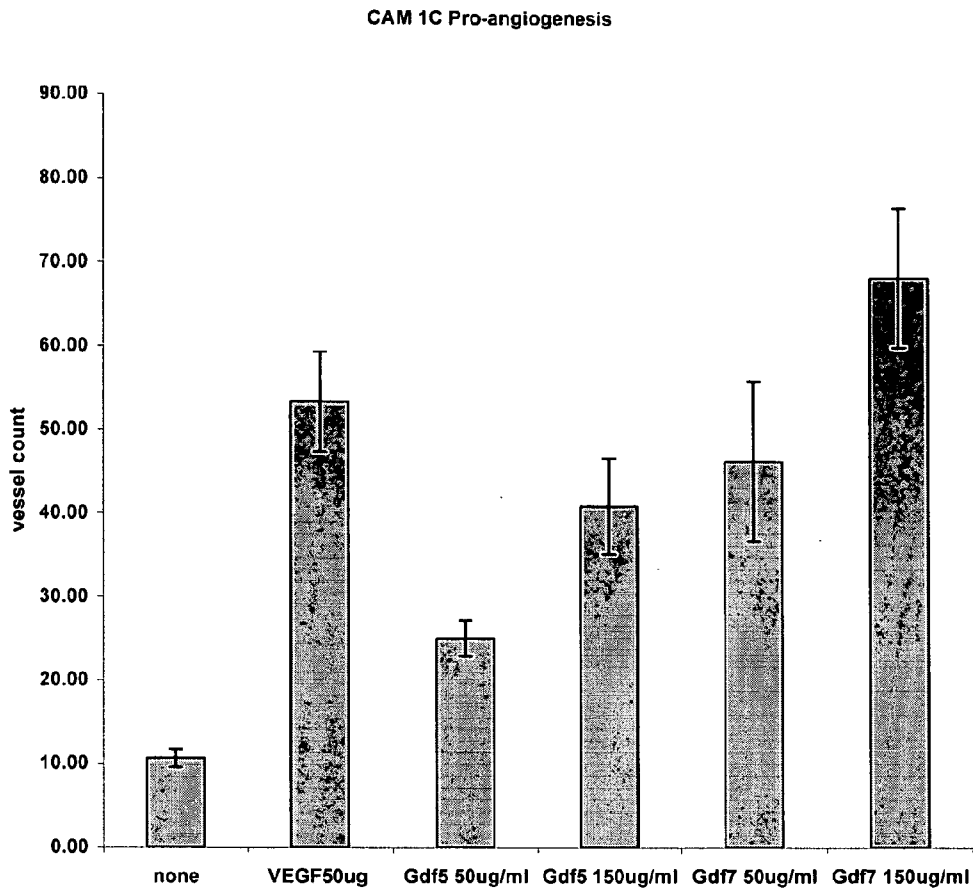
FIGURE 4

Figure 5

CAM 1C Pro-angiogenesis

FIGURE 6
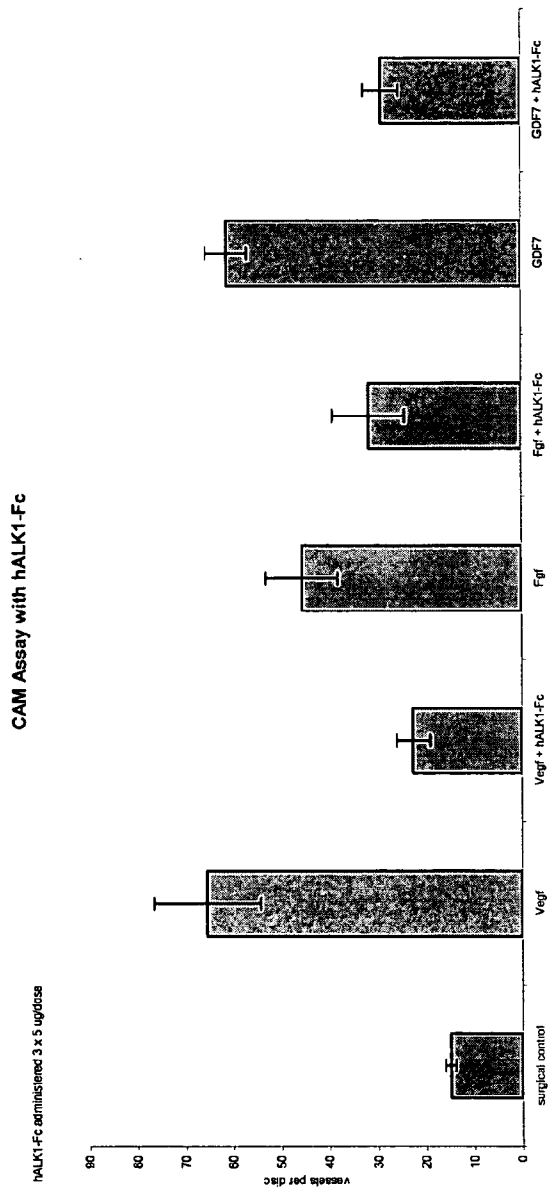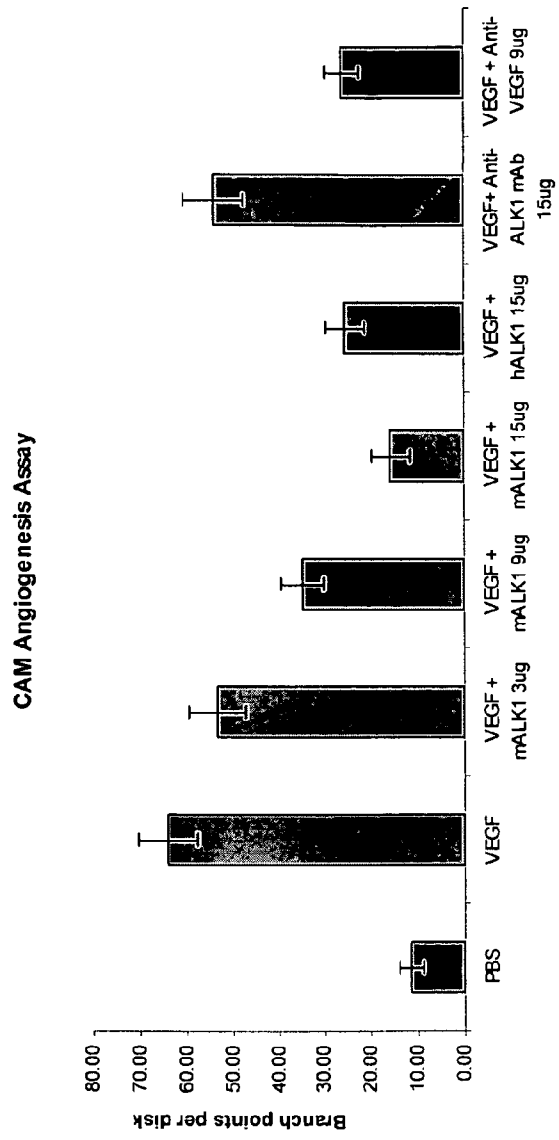
FIGURE 7

FIGURE 8
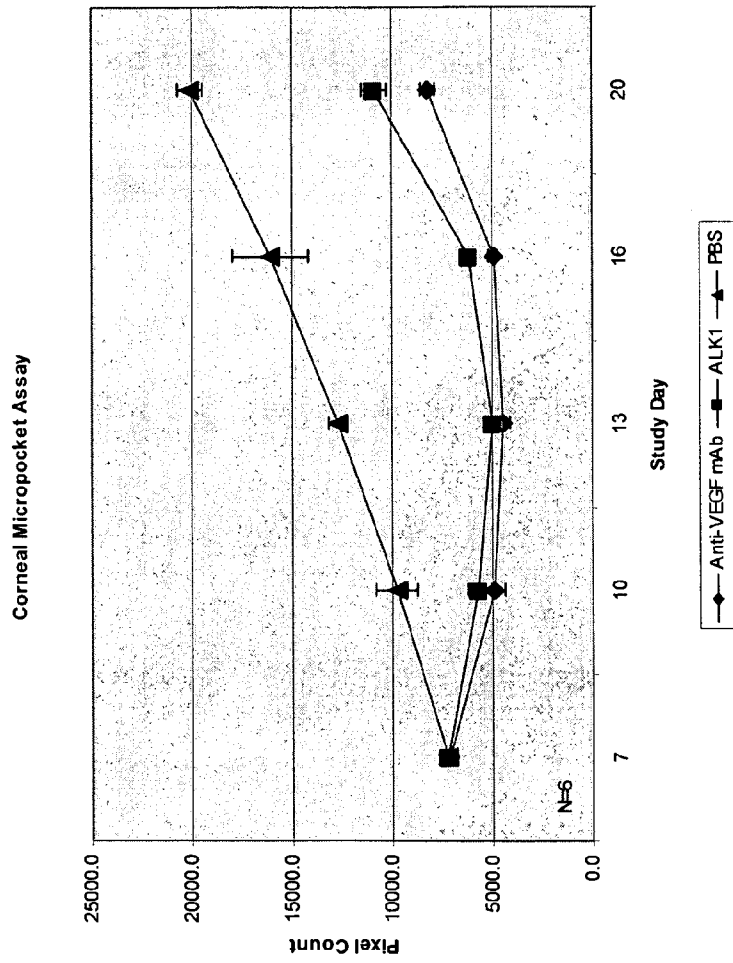
FIGURE 9

MDAC-1 - mean arthritis clinical scores

FIGURE 10

Figure 11

Figure 12
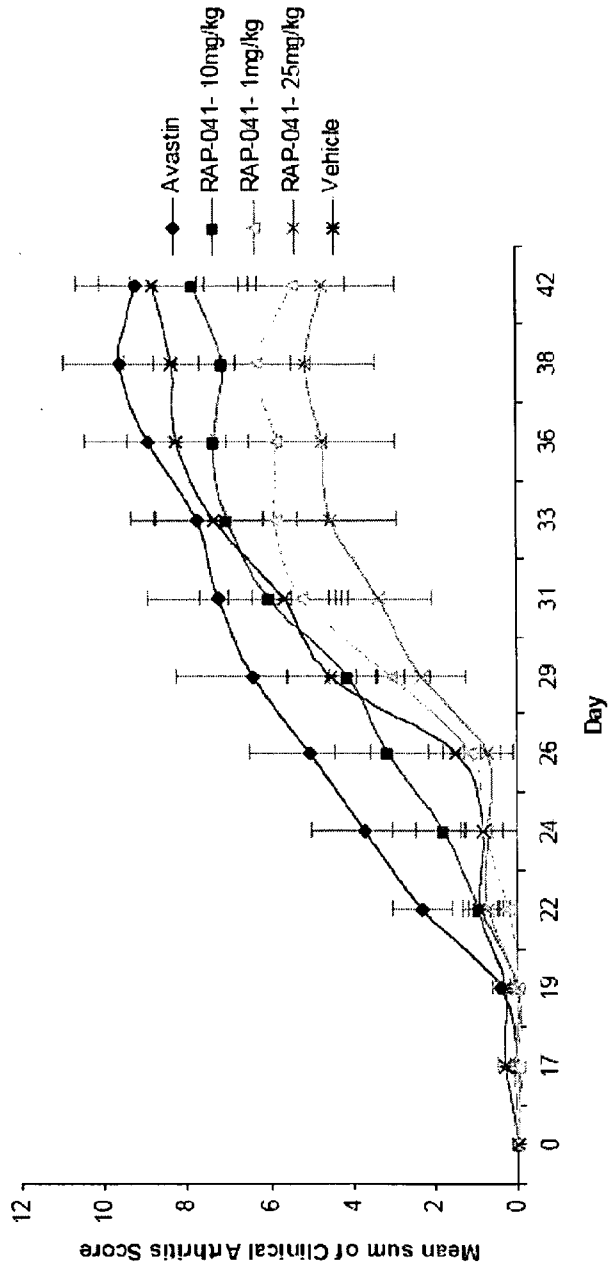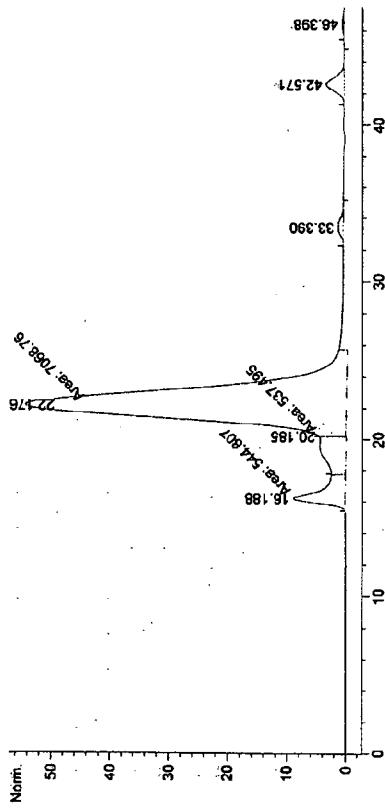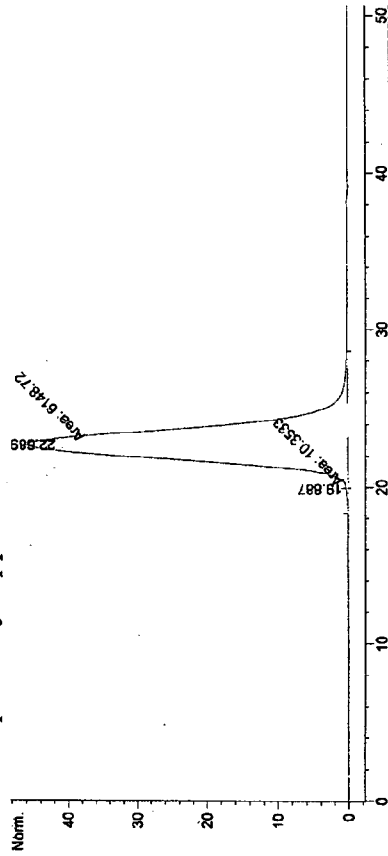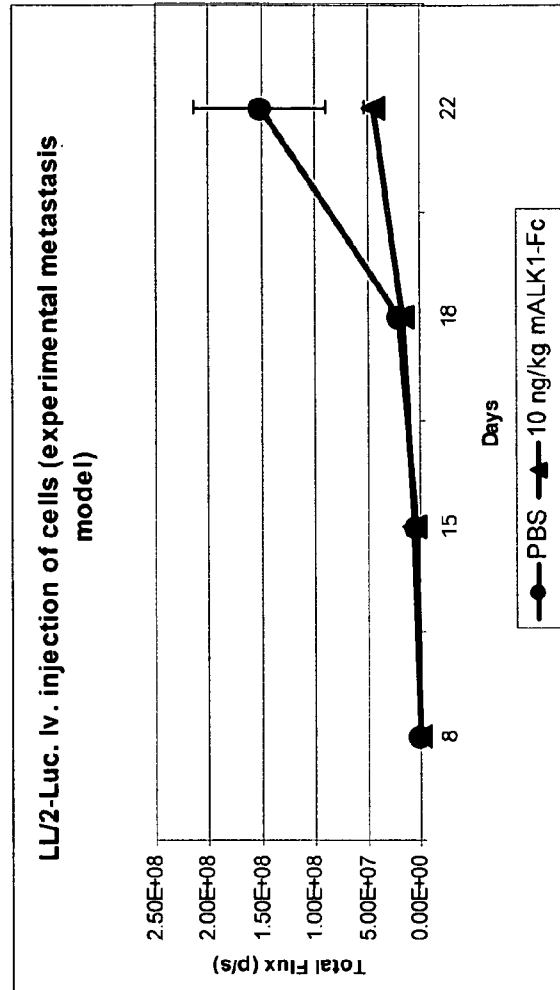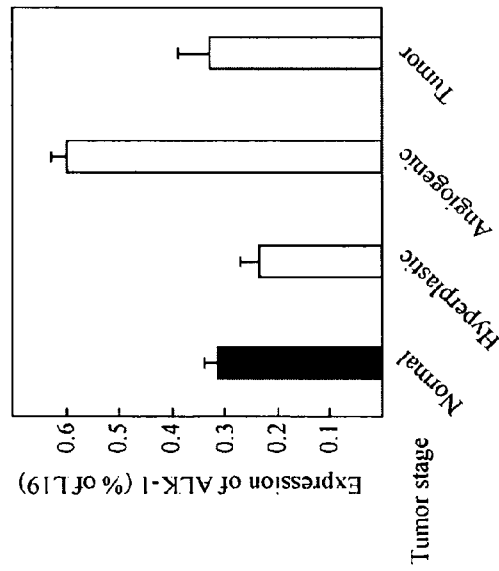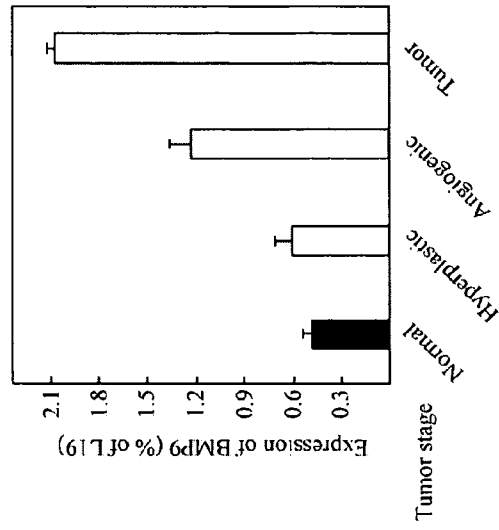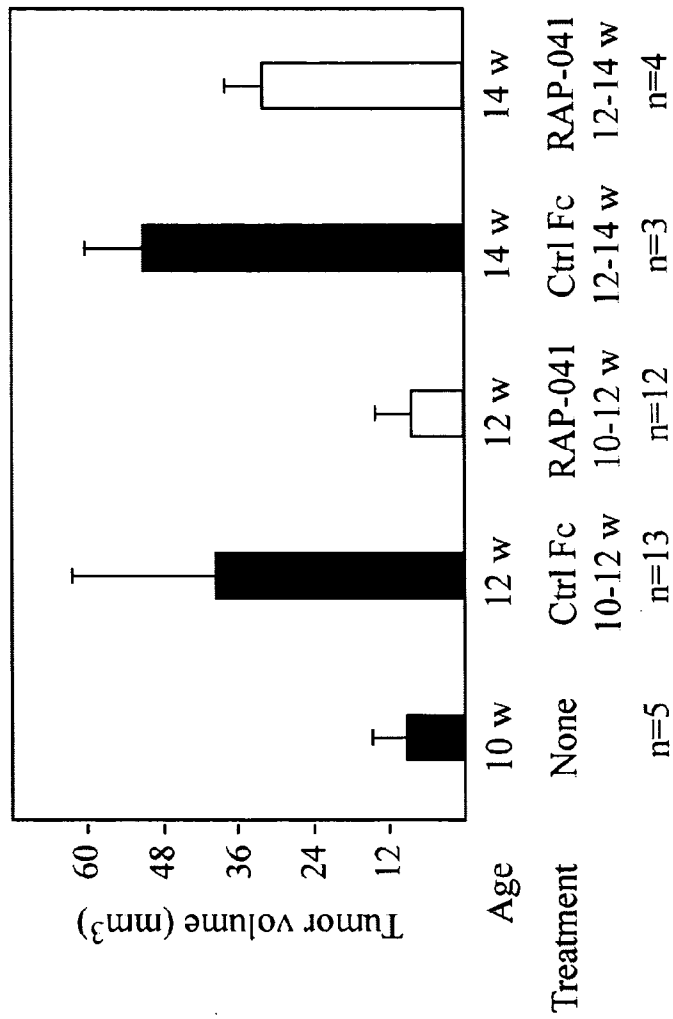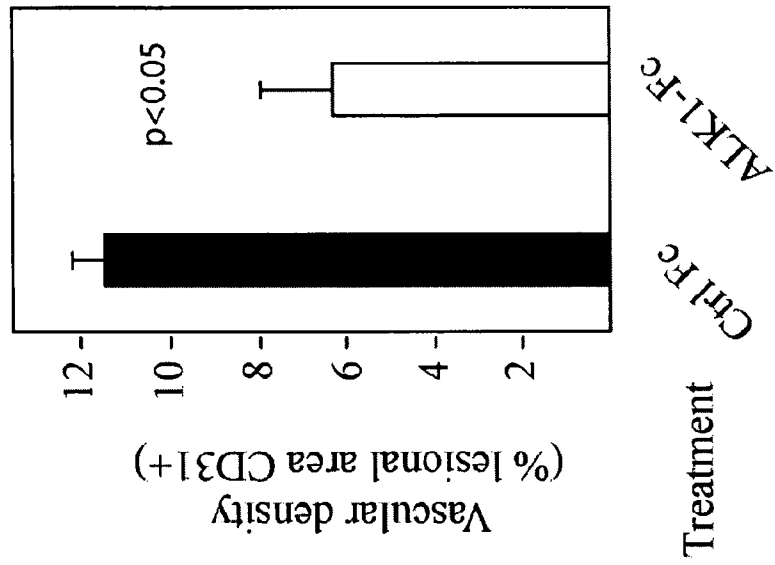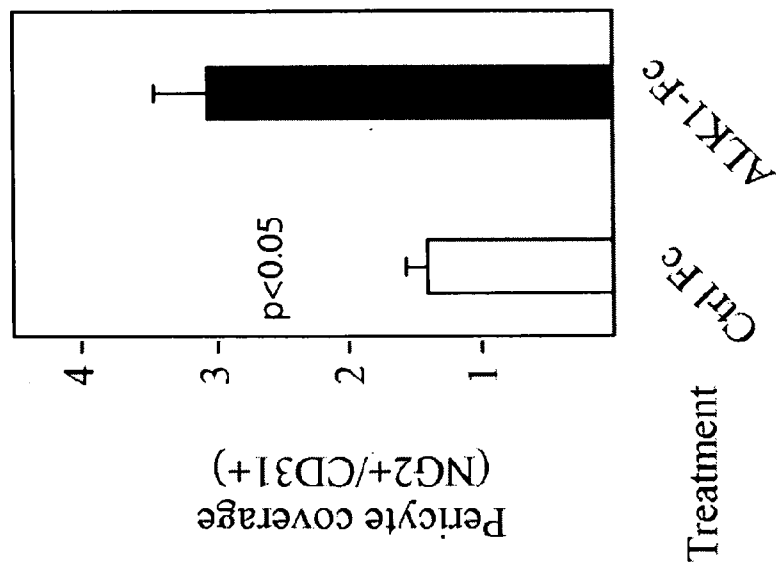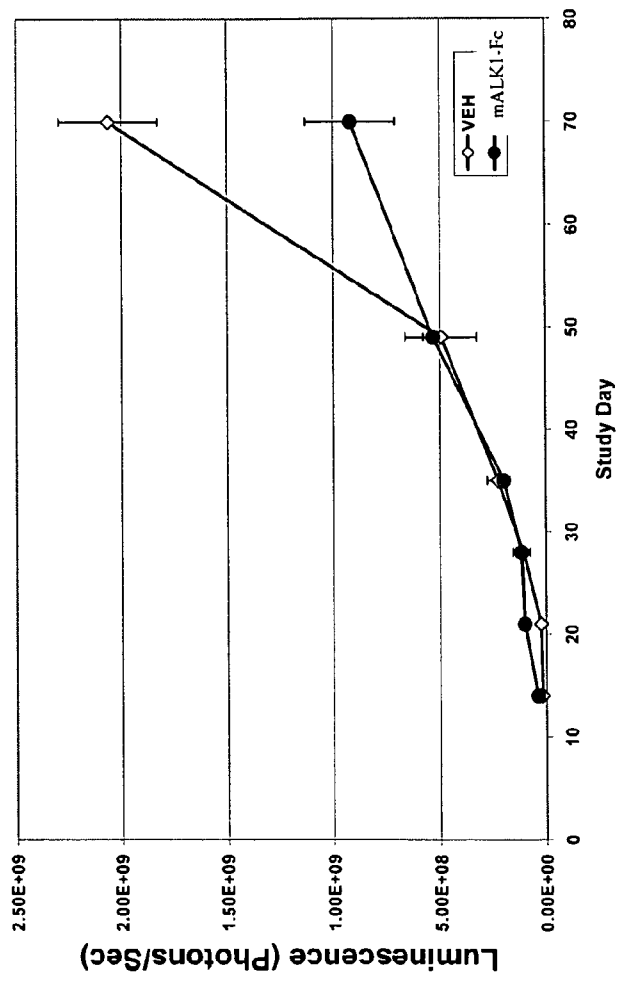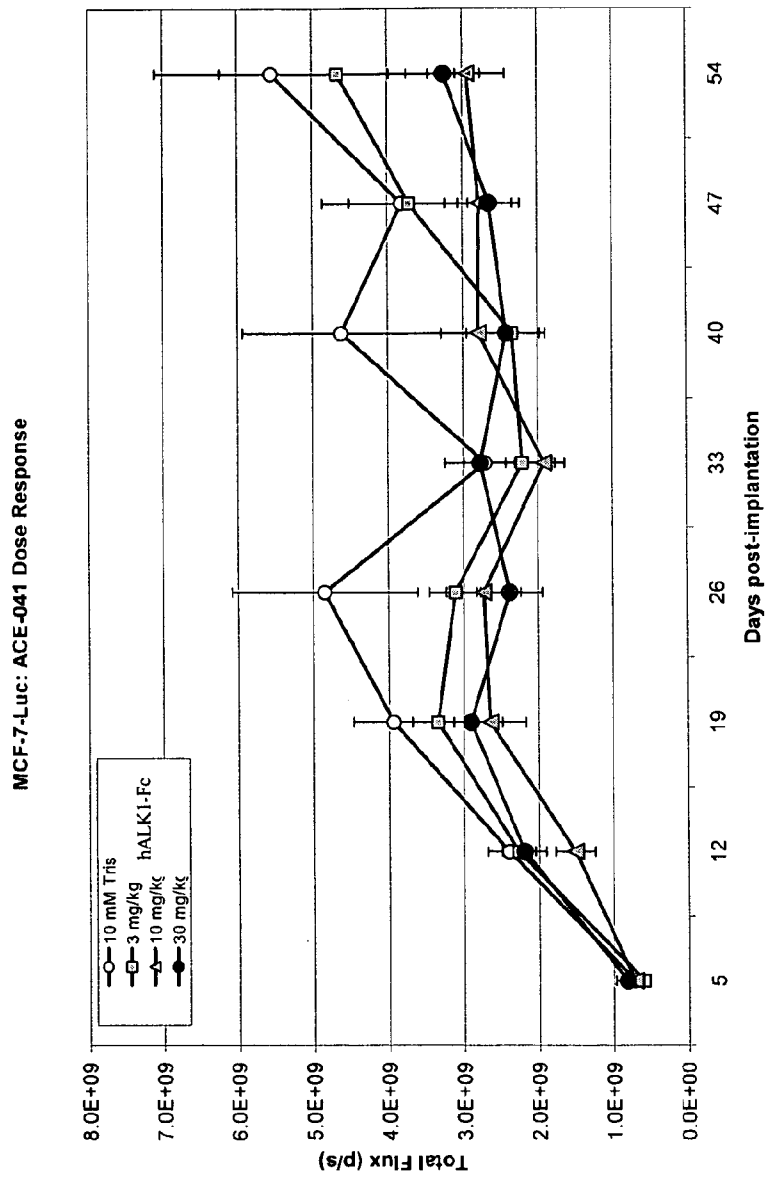
Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18