SMALL PEPTIDES HAVING POTENT ANTI-ANGIOGENIC ACTIVITY

FIELD OF THE INVENTION

The invention involves small peptides that function as potent angiogenic inhibitors. In particular, the invention relates to small peptides that can be synthesized by enzymatic or chemical methods. In addition, the invention relates to use of the small peptides to inhibit angiogenesis, to treat angiogenesis-related diseases and in angiogenesis research.

BACKGROUND OF THE INVENTION

Angiogenesis is the process of new blood vessel formation from pre-existing vessels. It plays important roles in many normal physiological functions such as embryonic development and wound healing (1). In addition, inappropriate angiogenesis is also associated with various pathological conditions including solid tumor growth and metastasis, rheumatoid arthritis and psoriasis (2). Many molecules that inhibit tumor angiogenesis have been shown to inhibit tumor growth including antibodies against angiogenic factors, natural and synthetic compounds that inhibit angiogenesis, and the natural angiogenic inhibitors like the angiostatin and endostatin proteins produced by tumor cells (3-8). Anti-cancer therapy by inhibiting tumor angiogenesis is called anti-angiogenic therapy and has shown great potential as an effective new method for treating cancer, especially solid tumors (9).

Plasminogen is a plasma glycoprotein synthesized mainly in the liver. It is the precursor of the serum protease plasmin that plays important roles in the fibrinolytic system and clot dissolution (10). At the amino terminus, plasminogen

contains five homologous repeats that form looped "kringle" structures held together by disulfide bonds. Plasminogen binds to fibrin through lysine binding sites located on the five kringle domains (k1 through k5) (10). A naturally occurring fragment of plasminogen containing the first four kringle domains (k1-k4) has been isolated from serum and urine of mice bearing a low metastic Lewis lung carcinoma. This plasminogen fragment has been named angiostatin (equivalent to amino acids 98-440 of murine plasminogen) and is a potent angiogenesis inhibitor that can inhibit endothelial cell proliferation as well as tumor growth and metastasis in mice with no obvious toxicity (5, 6, 11). Furthermore, recombinant individual kringle domains of human plasminogen produced in *E. coli* have been found to be able to inhibit endothelial cell proliferation to various degrees with k5 the most potent, followed by k1 and k3 (12, 13). The k5 domain is not present in the naturally existing angiostatin protein.

Endostatin is a protein first identified from a hemangioendothelioma cell line in 1997 (17). It is a 20kDa C-terminal fragment of collagen XVIII, a novel collagen that consists of a N-terminal region, a series of collagen-like domains with interruptions and a 35kDa C-terminal noncollagenous domain (18, 19, 20). Recombinant endostatin functions as a potent angiogenesis inhibitor *in vitro* as well as *in vivo* (17). Systemic administration of endostatin to tumor bearing mice regressed the primary tumor without inducing drug resistance (21). Recently, endostatin was found to be a zinc-binding protein and the zinc-binding is essential for its antiangiogenic activity (22, 23). Human trials of endostatin are expected to be undertaken.

VEGF is a potent endothelial specific mitogen. VEGF functions through two high affinity tyrosine kinase

receptors: FLT-1/VEGFR1 and FLK-1/VEGFR2 (26). Both receptors are specifically expressed in endothelial cells. FLT-1 and KDR/FLK-1 stimulate endothelial cell proliferation and migration by binding to these two tyrosine kinase receptors (24). VEGF is also known as vascular permeability factor due to its ability to induce vascular leakage (24). The ligand binding domains of the two receptors as well as the receptor binding sites of VEGF have been studied by site-directed mutagenesis and X-ray crystallography (25, 26, 27, 28). VEGF binds its two receptors through different amino acid contacts (25). The first three immunoglobulin loops of the FLT-1 receptor seem to be the main area responsible for VEGF binding (29, 30). The signal transduction triggered by VEGF through its receptors play critical roles in both physiological angiogenesis as well as pathological angiogenesis such as solid tumor growth and metastasis by stimulating embryonic angiogenesis and tumor angiogenesis. An anti-VEGF monoclonal antibody has been shown to inhibit tumor growth in mice by reducing the vessel density of the tumor (14). Likewise, trans-dominant mutants of both receptors have been shown to inhibit tumor growth in mice (15).

It has also been observed that proline residues are sometimes found at the ends of the linear sequences that constitute the site of a protein-protein interaction (14, 15). However, the proline residues are not usually present within the interaction site.

SUMMARY OF THE INVENTION

The invention provides compositions comprising the peptides that are effective in inhibiting undesirable angiogenesis. The invention includes small peptides that have the ability to inhibit bovine aorta endothelial cell

proliferation in the presence of basic Fibroblast Growth Factor (bFGF) *in vitro*. They can also inhibit angiogenesis in the chick chorioallantoic membrane (CAM) *in vivo*. The peptides of the invention are typically less than 20 amino acids in length. They preferably contain proline residues at each end or penultimate thereto. Peptides of the invention can be identified within the kringle domains of plasminogen or within the amino acid sequences of endostatin, VEGF, and VEGF receptors, especially FLT-1 and KDR/FLK-1.

Some preferred peptides of the invention are named Angio-1, Angio-2, Angio-3, Angio-4 and Angio-5 (SEQ. ID. NOs. 1-3, 11 and 12) according to the plasminogen kringle domains they are derived from. Other preferred peptides are shown in Table 1 (SEQ ID NOS. 29-50).

Methods for preventing or treating undesirable angiogenesis, for example to prevent tumor metastasis or inhibit the growth of a primary tumor, by administration of compositions of the anti-angiogenic peptides, are also within the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1. Inhibition of BAE cell proliferation by peptide Angio 3.

Figure 2. Inhibition of BAE cell proliferation by peptides Angio-2 and Angio-4.

Figure 3. Inhibition of chick CAM angiogenesis on 4 day embryo by Angio-3 at 120 ug/cover slip. The arrow indicates the inhibition of the growth of new vessels at the site of peptide application.

Figure 4. Inhibition of chick CAM angiogenesis on 4 day

embryo by Angio-4 at 120 ug/cover slip. Arrows indicate the inhibition of the growth of new vessels at the site of peptide application.

Figure 5. Inhibition of chick CAM angiogenesis on 10 day embryo by Angio-2 at 12 ug/cover slip.

Figure 6. Control cover slip containing PBS on 10 day old chick embryo CAM. The arrow indicates the position of the control cover slip on CAM.

Figure 7. Inhibition of BAE cell proliferation by peptides Endo-1, Endo-2, Endo-3 and Endo-4.

Figure 8. Inhibition of chick CAM angiogenesis in 10 day embryo by Endo-4 at 1.8 μg/coverslip.

Figures 9A-9B. Inhibition of chick CAM angiogenesis in 13 day embryo by mVEGF peptide at various doses as indicated. Arrows indicate the inhibition of growth of new vessels at the site of peptide application. Fig. 9A - 0 hrs incubation; Fig. 9B - 40 hours incubation.

Figure 10. Antiangiogenic effect of peptides in the chick CAM assay. The number of positive inhibitions over the number of CAMs examined for each group are indicated above each bar.

Figure 11. Antiangiogenic effect of peptides in the chick CAM assay. The number of positive inhibitions over the number of CAMs examined for each group are indicated above each bar.

DETAILED DESCRIPTION OF THE INVENTION

Small peptides were designed according to the amino acid sequences of the kringle domains of human plasminogen or from

the amino acid sequences of endostatin, VEGF, FLT-1 or KDR/FLK-1 using the "proline bracket model" described in references 14 and 15. The peptides were synthesized using a peptide synthesizer (Applied Biosystems, Inc., model 473A). The peptides were then purified by typical HPLC methods using a C18 reverse-phase column and eluting with an acetonitrile gradient.

Angiostatin-derived peptides of the present invention represent a portion of a kringle domain of plasminogen. The effective portion of a kringle domain is generally residues 30 to 38 or 39 of a kringle domain, numbered as in reference 13. However, it is acceptable to add additional amino acids to this generally effective core peptide. Thus, peptides representing residues 27 to 40 or 41 of a kringle domain would be expected to be effective. Preferred peptides of the invention are derived from human or mouse plasminogen. The exemplified peptides of SEQ. ID. NOs.: 1-3, 11 and 12 represent residues 29-38 or 29-39 of human plasminogen kringle domains (13).

The peptides of the invention preferably range from 8 to 20 amino acids long. Peptides of the invention typically range from 7-20, more typically from 10-15 amino acids in length. The peptides are often about 10 amino acids in length. The peptides are more preferably 8, 9 or 10 residues long, most preferably 10 residues long.

The peptides of the invention may contain a single cysteine residue. In such a case, it is desirable that the cysteine residue be derivatized to block disulfide bond formation. Most preferably, peptides of the invention lack cysteine residues altogether.

The peptides also preferably contain a pair of proline

residues. Each proline residue of the pair is preferably the residue penultimate to a terminus of a peptide, but either or both of the proline residues can be a terminal residue. Imino acids similar to proline, in that their side chains form a ring containing the peptide bonding nitrogen and α-carbon, and that will "break" an α-helix or β-sheet secondary structure, can be substituted for one or more of the proline residues. Exemplary peptides are shown as SEQ. ID. Nos. 1-50. The more preferred peptides are those of SEQ. ID. NOs. 1-3, 11, 12, 29-33, 35-38, 40-41 and 44-50.

The peptides of the invention are active in inhibiting angiogenesis in the *in vitro* bovine aorta endothelial (BAE) cell proliferation assay with an IC_{50} of 20 μM or less, preferably 5 μM or less, more preferably 1 μM or less and most preferably below 0.1 μM. Much preferred peptides of the invention are active in the *in vitro* BAE cell proliferation assay with an IC_{50} of about 20 pM.

Alternatively, preferred peptides of the invention will exhibit inhibition of angiogenesis in a chick chorioallantoic membrane assay of at least 30% (i.e. inhibition is observed under at least 3 of 10 coverslips applied) at a dose of 50 μg/coverslip. More preferably at least 50% inhibition is observed at a dose of 25 μg/coverslip. Most preferably, inhibition in the range of 50-80% is observed for a dose ranging from 10-25 μg/coverslip.

Also, the peptides of the invention encompass peptides that have been derivatized, for example to improve transport across membranes by attachment of hydrophobic groups or that are carboxy-terminal amidated to improve resistance to serum proteases. Methods for accomplishing such derivatizations are known in the art.

Formulation of the peptides for administration is standard in the art. It is anticipated that optimization of formulation, dosages and schedule of administration is also standard in the art. Reference 16, especially at parts 4, 5 and 7, provides guidance in these matters. Administration of the peptides for anti-tumor treatment can be by any route, preferably oral, intravenous, intradermal, subcutaneous or aerosol. It is expected that subcutaneous administration is especially effective when anti-metastatic activity is desired (*see*, reference 6).

The dosage of the peptides will depend upon the therapeutic index of the compound. It is noted that angiostatin has been administered to mice in amounts of 100 mg/kg/day without observable toxicity. Inhibition of metastasis by angiostatin is observed at doses of about 1 mg/kg/day and inhibition of primary tumor growth is observed at about 10 mg/kg/day (6). Thus, it is expected that effective doses of the peptides of the present invention will be about 0.2 µg/kg/day to about 2 mg/kg/day for inhibition of metastasis. Preferred dosages are in the 2-200 µg/kg/day range, most preferred dosages are in the 20-50 µg/kg/day range. It is expected that the dosage ranges will be about 10-fold higher for inhibition of primary tumor growth.

Example 1: Anti-proliferative Activity of Peptides Derived from Angiostatin

The peptides were tested in an *in vitro* bovine aorta endothelial cell (BAE) proliferation assay for their ability to inhibit BAE cell proliferation. Cells were plated into 24-well culture plates at 1.25×10^4 cells/well in complete SFM-endothelial medium (Gibco, USA). After 24 h, the medium was removed and various amounts of peptides were added into the

wells in 0.5 ml of SFM-endothelial medium without bFGF. After 30 minutes incubation, bFGF was added into each well at a final concentration of 1 ng/ml together with another 0.5 ml of SFM-endothelial medium. Seventy-two hours later, cells were trypsinized and counted using a hemocytometer. Commercial *E. coli* recombinant human angiostatin (1 μM) was used as a control in the experiments. Peptides Angio-2, Angio-3 and Angio-4, containing sequences from kringles 2, 3 and 4 of human plasminogen (SEQ. ID. Nos. 2, 3 and 11), all inhibited BAE cell proliferation in a dose-dependent manner (Figures 2 and 3). The IC_{50} of the three peptides are about 20 uM, 20 pm and 2 uM respectively. It is noted that peptide Angio-3 inhibited BAE cell proliferation with an IC_{50} in a range much lower than the reported nanomolar range of angiostatin protein (5). In contrast, a randomly scrambled version of Angio-3 (Angio-3S) in which the same amino acids present in Angio-3 were put in a random order, completely lost angiogenesis inhibition ability (Figure 2). The BAE inhibition assay provides a method for determining the anti-angiogenic activity of peptides. For example, peptides Angio-3A, -3B, -3C, -3D, -3E and -3F (SEQ. ID. Nos. 4-9) are peptides in which the six amino acids surrounded by the two prolines are individually mutated into alanine. The contribution of each of the six amino acids between the proline residues to the biological activity of Angio-3 can be determined by testing these peptides.

Example 2: Anti-angiogenic Activity of Peptides Derived from Angiostatin

Since peptides Angio-2, Angio-3 and Angio-4 all inhibited BAE cell proliferation, they were also tested in the chick embryo chorioallantoic membrane (CAM) *in vivo* angiogenesis assay (7). In this assay, the peptides are

coated onto 2-3 mm glass squares cut from microscope cover slips. All three peptides inhibited chick CAM angiogenesis (Figures 4, 5 and 6). Peptide Angio-3 reduced microvessel density at the very low dose of 12 pg/cover slip (the lowest dose tested, comparing to a PBS control). As a positive control, recombinant angiostatin at the dose of 100 ug/cover slip was tested in the same experiment. The amount of inhibition (judging from the extent of reduction in microvessel density) from 100 ug recombinant angiostatin is equivalent to 1.2 ug of Angio-3 peptide. Based on this, we estimated that Angio-3 is at least as potent as angiostatin in inhibiting chick CAM angiogenesis.

At high doses, e.g., 1 mg/cover slip, the blood vessels under the cover slip containing all three peptides died and circulation was stopped. The color of the blood changed into dark red instead of the bright red of the circulating blood.

The above data demonstrated that Angio-2, Angio-3 and Angio-4, small peptides derived from the sequence of human plasminogen kringle domains 2, 3 and 4 function as potent angiogenesis inhibitors. Importantly, peptide Angio-3 is more potent in inhibiting BAE cell proliferation compared to angiostatin protein and at least as potent as recombinant angiostatin in inhibiting chick CAM angiogenesis.

Cao et al. (12) show that integrity of complete kringle domains is required for anti-angiogenic activity of angiostatin and that a tandem pair of properly folded domains is necessary. Cao et al. (13) also show that, at least with respect to the k5 domain, appropriate disulfide bond formation is necessary for maintaining anti-angiogenic activity. Thus, it is surprising that the exemplified small peptides of the invention, which (1) do not form complete kringle domains and (2) do not contain any cysteine residues and therefore do not

form disulfide bonds, have such high activity.

Example 3: Antiangiogenic Activity of Peptides Derived from Endostatin, VEGF and VEGF Receptors

Peptides were tested in an *in vitro* bovine aorta endothelial cell (BAE) proliferation assay for their ability to inhibit BAE cell proliferation. Cells were plated into 24-well culture plates at the number of 1.25×10^4/well in complete SFM-endothelial media (Gibco, USA). After 24 hours, the medium was removed and various amounts of peptides were added into the wells in 0.5ml of SFM-endothelial medium without bFGF. After 30 minutes incubation, bFGF was added into each well at a final concentration of 1 ng/ml together with another 0.5 ml of SFM-endothelial medium. Seventy-two hours later, cells were trypsinized and counted using a hemocytometer. Peptides Endo-2, Endo-3 and Endo-4 all inhibited BAE cell proliferation in a dose-dependent manner while peptide Endo-1 has only a slight inhibition effect at high doses (Figure 7). The IC_{50} of the Endo-2, -3 and -4 peptides is estimated to be 0.4 uM, 0.3 uM and 2 uM respectively.

All 4 endostatin-derived peptides were also tested in the chick embryo chorioallantoic membrane (CAM) *in vivo* angiogenesis assay. These peptides reduced microvessel density with various efficacy comparing to a PBS control (Figure 8).

Peptides designed from mammalian VEGF sequences (mVEGF) and Zebrafish VEGF (fVEGF) showed dose-dependent inhibition of CAM angiogenesis (Figures 9,10). Scrambled mutant peptide where the same amino acids in mVEGF were placed in a random order completely destroyed the angiogenesis inhibition activity of mVEGF peptide.

Two small peptides, hFLT1 and hFLT2, were designed from

the second immunoglobulin domain (Ig domain 2) of the extracellular region of FLT-1. The peptide hFLT2 showed very potent angiogenesis inhibition activity on CAM (Figures 10 and 11). Surprisingly, a truncated version of hFLT2 peptide, hFLT2-11, in which the N-terminal two amino acids have been deleted, showed a even more potent antiangiogenic activity comparing to hFLT2 (Figure 11). However, a single amino acid mutated version of the same peptide, hFLT2-T, in which the second amino acid proline was replaced with threonine, has a much weaker antiangiogenic activity (Figure 11). Peptide hFLT2-9 in which four amino acids were removed from the N-terminal of hFLT2, showed similar level of antiangiogenic activity as the original peptide (Figure 11). Further truncation at the N-terminal of the peptide resulted in non-functional peptide (hFLT2-7 and hFLT2-5).

The above data demonstrated that small peptides derived from the sequence of human endostatin, VEGF and FLT-1 can function as potent angiogenesis inhibitors.

SEQUENCE LISTING

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<120> Small Peptides Having Potent Anti-Angiogenic Activity

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* C L M S *

CLAIMS:

1. A peptide comprising a portion of a protein selected from the group consisting of plasminogen, endostatin, VEGF, FLT-1 and KDR/FLK-1, wherein said peptide is of length from 7-20 amino acids long and wherein said peptide exhibits an IC_{50} of 20 μM or less in a bovine aorta endothelial cell proliferation assay or exhibits inhibition of angiogenesis in a chick chorioallantoic membrane assay of at least 30% at a dose of 50 μg/coverslip.

2. The peptide of claim 1 that exhibits an IC_{50} of 20 pM to 1 μM in a bovine aorta endothelial cell assay or exhibits inhibition of angiogenesis in a chick chorioallantoic membrane assay of at least 50% at a dose of 10 to 25 μg/coverslip.

3. The peptide of claim 1 comprising a portion of a kringle domain of plasminogen.

4. The peptide of claim 3, wherein said portion of a kringle domain is represented by residues 27-41 of a kringle domain of human or mouse plasminogen.

5. The peptide of claim 3, wherein said portion of a kringle domain is represented by residues 29-38 or residues 29-39 of a plasminogen.

6. The peptide of claim 1 that is derived from endostatin, VEGF, FLT-1 and KDR/FLK-1 and has a length of from 9 to 20 amino acids long.

7. The peptide of claim 1, comprising a peptide having an amino acid sequence selected from the group consisting of SEQ. ID. NOs. 1-3, 11-33, 35-38, 40-41 and 44-50.

8. The peptide of claim 1, comprising a peptide having

an amino acid sequence selected from the group consisting of SEQ. ID. NOs. 1-3, 11, 12, 29-36 and 38-39.

9. The peptide of claim 1, comprising a peptide having an amino acid sequence selected from the group consisting of SEQ. ID. NOs.37 and 40-41.

10. A pharmaceutical composition comprising a peptide according to claim 1 and a pharmaceutically acceptable carrier.

11. The composition according to claim 10, wherein said composition provides a unit dose of from 20 µg/kg/day to 2 mg/kg/day.

12. A method for preventing or treating primary tumor growth or metastasis comprising administering to a subject at risk for or presenting a tumor an effective amount of the composition of claim 10.

13. A method for preventing or treating primary tumor growth or metastasis comprising administering the composition of claim 11 to a subject at risk for or presenting a tumor.

14. A method for preventing or treating undesired angiogenesis comprising administering to a subject at risk for or presenting undesired angiogenesis an effective amount of the composition of claim 10 to a subject.

15. A method for preventing or treating undesired angiogenesis comprising administering to a subject at risk for or presenting undesired angiogenesis an effective amount of the composition of claim 11.