

TITLE OF THE INVENTION
Disintegrin Variants and Pharmaceutical Uses Thereof

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Section 371 of International Application No. PCT/US2015/046322, filed August 21, 2015, which was published in the English language on February 25, 2016, under International Publication No. WO 2016/029131 A1, which claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/040,503, filed August 22, 2014, and the disclosures of which are herein incorporated by reference in their entirety.

REFERENCE TO SEQUENCE LISTING SUBMITTED ELECTRONICALLY

[0002] This application contains a sequence listing, which is submitted electronically via EFS-Web as an ASCII formatted sequence listing with a file name “688947-1PCT Sequence Listing.txt”, creation date of August 20, 2015, and having a size of 157,219 bytes. The sequence listing submitted via EFS-Web is part of the specification and is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0003] The invention relates to disintegrin variants that bind specifically to one or more of $\alpha 5\beta 1$ and αv integrins, such as $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$ and $\alpha v\beta 8$, but with reduced binding activity to $\alpha IIb\beta 3$, and uses of the disintegrin variants for the treatment and prevention of a disease associated with an αv integrin or $\alpha 5\beta 1$ integrin.

BACKGROUND OF THE INVENTION

[0004] Integrins are transmembrane receptors that bind extracellular matrix proteins or other adhesion receptors on neighboring cells. Heterodimeric pairing of integrin α and β subunits confers specificity of binding to one or more substrates (Weis et al., 2011, *Cold Spring Harb Perspect Med*;1:a006478). This family of adhesion molecules plays a pivotal role in broad contexts of biology, including inflammation, innate and antigen specific immunity, homeostasis, wound healing, tissue morphogenesis, and regulation of cell growth and differentiation. Dysregulation of integrins is involved in the pathogenesis of many disease states, from autoimmunity to thrombotic vascular diseases to cancer metastasis. Extensive efforts have been directed towards the discovery and development of integrin antagonists for clinical applications.

[0005] The αv integrins, each having an αv subunit paired with a $\beta 1$, $\beta 3$, $\beta 5$, $\beta 6$ or $\beta 8$ subunit, appear to be particularly important during the tissue remodeling associated with wound repair, angiogenesis, and cancer (Weis et al., 2011, *supra*). The αv integrins are being targeted for cancer, ophthalmological and orthopedic indications. Integrins $\alpha v\beta 3$ and $\alpha v\beta 5$ have

also been associated with tumors, arthritis, psoriasis and age-related macular degeneration (AMD). In particular, $\alpha v \beta 3$ integrin is important in mediating angiogenesis and in inhibiting tumor migration, and $\alpha v \beta 6$ integrin is upregulated in some cancers. The other αv integrins present in the cornea ($\alpha v \beta 5$, $\alpha v \beta 6$, and $\alpha v \beta 8$) mediate transforming growth factor β (TGF β) activation.

[0006] It was reported that the integrins $\alpha 5 \beta 1$, $\alpha v \beta 3$ and $\alpha v \beta 5$ play an important role in the process of angiogenesis and are expressed in a variety of malignancies, including, but not limited to, melanoma, breast cancer, prostate cancer, colon cancer, and gliomas (Staunton et al., 2006, *Adv Immunol.*, 91:111-57). The intratumoral expression of these integrins has been associated with progression and metastasis in tumors, such as melanoma, breast cancer, and prostate cancer (Staunton et al., 2006, *supra*). They have been shown to signal through multiple pathways and contribute to endothelial cell migration and proliferation. *In vivo*, they are overexpressed on tumor neovasculature and on tumor cells themselves, which suggests that their function may potentiate tumor progression by multiple mechanisms. Antagonistic antibodies and small molecules directed against integrins $\alpha 5 \beta 1$, $\alpha v \beta 3$, and $\alpha v \beta 5$ have been shown to inhibit angiogenesis *in vitro* and *in vivo*. Inhibitors of integrins $\alpha 5 \beta 1$, $\alpha v \beta 3$, and $\alpha v \beta 5$ are able to inhibit signaling through ERK, Akt and FAK, resulting in decreased adhesion, migration and proliferation of endothelial and cancer cells. These antagonists have also been found to elicit cell death through caspase-dependent mechanisms. Therefore, the critical role of integrins $\alpha 5 \beta 1$, $\alpha v \beta 3$ and $\alpha v \beta 5$ in angiogenesis and association with tumor progression make them attractive targets for anticancer therapy, and many antagonists of these integrins have been tested in clinical trials.

[0007] The $\alpha v \beta 3$ integrin shares the same $\beta 3$ subunit with the $\alpha IIb \beta 3$ integrin, as well as several macromolecular ligands including fibrinogen, fibronectin, thrombospondin, von Willebrand factor, and vitronectin. These ligands all contain a triple amino acid sequence arginine-glycine-aspartic acid (RGD). Fibronectin and vitronectin are also ligands for $\alpha 5 \beta 1$ and other αv integrins. The $\alpha IIb \beta 3$ integrin is a major membrane protein on platelets and plays an important role in platelet aggregation. Several $\alpha IIb \beta 3$ integrin antagonists have been developed for the treatment of patients with acute coronary syndrome (ACS). However, because extensive inhibition of platelet aggregation are associated with increased risk of bleeding, ongoing studies are focused on reduction of bleeding and other side effects of $\alpha IIb \beta 3$ integrin antagonists. It is essential to design drugs by blocking either a single integrin or multiple αv integrins for different indications (Goodman, 2012. *Trends Pharmacol Sci.* 2012;33:405-412).

[0008] Disintegrins are a family of low-molecular-weight RGD-containing peptides that

bind to integrins, such as, α Ib β 3, α 5 β 1, and α v β 3 expressed on platelets and other cells, including vascular endothelial cells and some tumor cells. In addition to their potent anti-platelet activity, studies of disintegrins have revealed new uses in the diagnosis of cardiovascular diseases and the design of therapeutic agents in arterial thrombosis, osteoporosis, and angiogenesis-related tumor growth and metastasis. Rhodostomin (Rho), a disintegrin from the venom of *Colloselasma rhodostoma*, has been found to inhibit platelet aggregation *in vitro* and *in vivo* through the blockade of platelet glycoprotein α Ib β 3. It is also found that Rho can bind to integrins α Ib β 3, α 5 β 1, and α v β 3 with high affinity and interact with cancer cells. For example, Rho is reported to inhibit the adhesion of breast and prostate carcinoma cells to both unmineralized and mineralized bone extracellular matrices in a dose-dependent manner, without affecting the viability of tumor cells. Rho also inhibits the migration and invasion of breast and prostate carcinoma cells.

[0009] However, because rhodostomin non-specifically binds to integrins α Ib β 3, α 5 β 1, and α v β 3, the pharmaceutical uses of rhodostomin may cause serious side effects, such as bleeding resulting from the inhibition of platelet aggregation. Therefore, a need exists in the art for a disintegrin variant that is selective for integrins α 5 β 1 and α v β 3, but with reduced binding activity to α Ib β 3. Such a need is met by this invention.

SUMMARY OF THE INVENTION

[0010] The invention relates to disintegrin variants having one or more mutations in one or more of the linker region, the RGD loop and the C-terminus of a disintegrin, such as rhodostomin, that have reduced binding activity to α Ib β 3 integrin, thus a weak inhibition on the platelet aggregation, but bind specifically to one or more of α 5 β 1 and α v integrins, such as α v β 1, α v β 3, α v β 5, α v β 6 and α v β 8.

[0011] Accordingly, in one general aspect, the invention relates to a disintegrin variant, comprising at least one selected from the group consisting of:

- (a) a mutant linker comprising at least one mutation at positions 1 to 5 of the amino acid sequence of SEQ ID NO:332 (SRAGKIC);
- (b) a mutant RGD loop comprising the amino acid sequence selected from the group consisting of SEQ ID NOs: 329 to 331; and
- (c) a mutant C-terminus comprising at least one mutation at positions 1-4 of the amino acid sequence of SEQ ID NO: 334 (PRYH),

wherein the disintegrin variant has reduced binding activity to α Ib β 3 integrin as compared to a disintegrin not having the at least one selected from the group consisting of the mutant linker, the mutant RGD loop and the mutant C-terminus. Preferably, the disintegrin

variant also has increased binding activity to at least one of $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha v\beta 8$ and $\alpha 5\beta 1$ integrins as compared to a disintegrin not having the at least one selected from the group consisting of the mutant linker, the mutant RGD loop and the mutant C-terminus.

[0012] According to embodiments of the invention, the disintegrin variant can be a variant of any disintegrin, including, but not limited to a disintegrin selected from the group consisting of rhodostomin, albolabrin, applagin, basilicin, batroxostatin, bitistatin, cereberin, cerastin, crotatroxin, durissin, elegantin, flavoridin, flavostatin, halysin, halystatin, jararacin, jarastatin, kistrin, lachesin, lutosin, molossin, salmosin, saxatilin, tergeminin, trimestatin, trimucrin, trimutase, ussuristatin, and viridin. Preferably, the disintegrin variant is a variant of a disintegrin having the amino acid sequence selected from the group consisting of SEQ ID NOs: 1 to 6. More preferably, the disintegrin variant is a variant of rhodostomin having the amino acid sequence of SEQ ID NO: 1.

[0013] In a preferred embodiment, the disintegrin variant comprises a mutant RGD loop comprising at least one mutation at positions 1-3, 5, 7 and 8 of the amino acid sequence of SEQ ID NO: 333 (RIPRGDMP) and at least one of the mutant linker and the mutant C-terminus described herein.

[0014] In another preferred embodiment of the invention, the disintegrin variant comprises a mutant linker having the amino acid sequence selected from the group consisting of SEQ ID NO:306 to SEQ ID NO: 317.

[0015] In yet another preferred embodiment of the invention, the disintegrin variant comprises a mutant C-terminus having the amino acid sequence selected from the group consisting of SEQ ID NO: 319 to SEQ ID NO:328.

[0016] In a preferred embodiment of the invention, the disintegrin variant comprises a mutant RGD loop having the amino acid sequence selected from the group consisting of SEQ ID NO: 329 to SEQ ID NO: 331, and at least one of a mutant linker having the amino acid sequence selected from the group consisting of SEQ ID NO:306 to SEQ ID NO: 317, and a mutant C-terminus having the amino acid sequence selected from the group consisting of SEQ ID NO:319 to SEQ ID NO: 328. More preferably, the disintegrin variant comprises the mutant RGD loop, the mutant linker and the mutant C-terminus described herein.

[0017] According to embodiments of the invention, the disintegrin variant comprises the amino acid sequence selected from the group consisting of SEQ ID NO: 7 to SEQ ID NO:179. Preferably, the disintegrin variant according to an embodiment of the invention comprises the

amino acid sequence selected from the group consisting of SEQ ID NOs: 123, 124, 147, 149 and 171.

[0018] Preferably, the disintegrin variant according to an embodiment of the invention is modified, e.g., for improved delivery or stability. For example, the disintegrin variant is pegylated or is conjugated with a fusion partner, such as an albumin or Fc.

[0019] Another general aspect of the invention relates to a polynucleotide encoding a disintegrin variant of the invention, which can be an expression vector comprising a regulatory sequence, such as a promoter, operably linked to a DNA sequence encoding the disintegrin variant.

[0020] The invention also relates to a recombinant host cell comprising a polynucleotide encoding a disintegrin variant of the invention. The host cell can be a prokaryotic cell, a yeast cell, an insect cell or a mammalian cell.

[0021] The invention further relates to a process of making a disintegrin variant of the invention, comprising producing the disintegrin variant from a recombinant host cell according to an embodiment of the invention.

[0022] Also provided is a pharmaceutical composition comprising a disintegrin variant of the invention and a pharmaceutically acceptable carrier.

[0023] Yet another general aspect of the invention relates to a method for treating a disease associated with at least one of $\alpha\text{v}\beta 1$, $\alpha\text{v}\beta 3$, $\alpha\text{v}\beta 5$, $\alpha\text{v}\beta 6$, $\alpha\text{v}\beta 8$ and $\alpha 5\beta 1$ integrins, preferably a disease associated with at least one of integrins $\alpha 5\beta 1$ and $\alpha\text{v}\beta 3$, in a subject in need thereof. The method comprises administering to the subject a pharmaceutical composition of the invention.

[0024] In one embodiment of the invention, the integrin-associated disease is an angiogenesis-related eye disease selected from the group consisting of age-related macular degeneration, diabetic retinopathy, corneal neovascularizing diseases, ischaemia-induced neovascularizing retinopathy, high myopia, and retinopathy of prematurity.

[0025] In another embodiment of the invention, the integrin-associated disease is a cancer selected from the group consisting of metastatic melanoma, metastatic prostate cancer, metastatic breast cancer, colorectal carcinoma, liver cancer, ovarian cancer, cervical cancer, pancreatic cancer, non-small-cell lung cancer, and glioblastoma multiforme.

[0026] Another general aspect of the invention relates to use of a disintegrin variant of the invention in the manufacture of a medicament for the treatment of a disease associated with at least one of $\alpha\text{v}\beta 1$, $\alpha\text{v}\beta 3$, $\alpha\text{v}\beta 5$, $\alpha\text{v}\beta 6$, $\alpha\text{v}\beta 8$ and $\alpha 5\beta 1$ integrins in a subject in need thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The foregoing summary, as well as the following detailed description of the invention, will be better understood when read in conjunction with the appended drawings. It should be understood that the invention is not limited to the precise embodiments shown in the drawings.

[0028] In the drawings:

[0029] Figure 1 illustrates the interaction map of rhodostomin: (A) illustration of the interactions among the linker region, RGD loop, and C-terminal region of rhodostomin; and (B) the amino acid sequences of the regions involved in the interactions between rhodostomin and integrins, where the residues that can be mutated in a disintegrin variant according to an embodiment of the invention are marked as “X”;

[0030] Figure 2 shows the inhibitory activity of various tested agents on the migration of A375 human melanoma cells: (A) the wild-type Rho, (B) AR-NP, a disintegrin variant according to an embodiment of the invention, and (C) phosphate buffered saline (PBS);

[0031] Figure 3A are photographs showing a reduced blood vessel density in MATRIGEL™ plugs from C57BL/6 mice treated with AR-NP protein or ARLDDL, in comparison with untreated control mice;

[0032] Figure 3B is a graph showing a reduced hemoglobin content in MATRIGEL™ plugs from C57BL/6 mice treated with AR-NP protein or ARLDDL protein twice daily after 5 days in comparison with untreated control mice;

[0033] Figure. 3C is a graph showing a reduced hemoglobin content in MATRIGEL™ plugs from C57BL/6 mice treated with AR-NP protein or ARLDDL protein administrated once daily for 5 days in comparison with untreated control mice;

[0034] Figure 4A are photographs showing angiogenesis in a mouse model of retinopathy of prematurity (ROP), and reduced angiogenesis in a ROP mouse treated with AR-NP protein, arrows indicate blood vessel profiles (BVPs) of new vessels;

[0035] Figure 4B is a graph showing reduced BVPs of the new vessels in a mouse model of retinopathy of prematurity (ROP) treated with AR-NP protein;

[0036] Figure 4C is a graph showing reduced BVPs of the endothelial cells in a mouse model of retinopathy of prematurity (ROP) treated with AR-NP protein;

[0037] Figure 5 shows the inhibition of mice aortic ring by AR-NP protein (0.1 μ M) for 7 days in comparison with untreated control: upper panel: images taken at magnification x20; Lower panel: image taken at magnification x100;

- [0038]** Figure 6 shows that both ARLDDL (0.1 μ M & 1 μ M) and AR-NP (0.1 μ M & 1 μ M) inhibited colony formation of 4-T1 breast cancer cells;
- [0039]** Figure 7 shows that AR-NP protein or ARLDDL protein inhibited RANKL-induced osteoclastogenesis in comparison with untreated control: AR-NP protein (B and C); ARLDDL protein (D); control (A);
- [0040]** Figure 8 shows that both ARLDDL (0.1 μ M) and AR-NP (0.1 μ M) markedly inhibited glioma invasion;
- [0041]** Figure 9 shows that AR-NP at 5 mg/kg did not significantly affect blood pressure and heart rate in Wistar rat;
- [0042]** Figure 10 shows the inhibition of A375 melanoma growth by AR-NP in SCID mice, scale bar: 1 cm;
- [0043]** Figure 11 shows the inhibition of tumor growth by AR-NP (KG) in K-rasG12D transgenic mice; and
- [0044]** Figure 12 shows the inhibition of brain tumor growth in U87-bearing mice by AR-NP (KG).

DETAILED DESCRIPTION OF THE INVENTION

[0045] Various publications, articles and patents are cited or described in the background and throughout the specification; each of these references is herein incorporated by reference in its entirety. Discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is for the purpose of providing context for the invention. Such discussion is not an admission that any or all of these matters form part of the prior art with respect to any inventions disclosed or claimed.

[0046] Unless defined otherwise, all technical and scientific terms used herein have the same meaning commonly understood to one of ordinary skill in the art to which this invention pertains. Otherwise, certain terms used herein have the meanings as set in the specification. All patents, published patent applications and publications cited herein are incorporated by reference as if set forth fully herein. It must be noted that as used herein and in the appended claims, the singular forms “a,” “an,” and “the” include plural reference unless the context clearly dictates otherwise.

[0047] As used herein, a “disintegrin” refers to a class of cysteine-rich proteins that are potent soluble ligands of integrins and are involved in regulating many processes such as cell-cell and cell-extracellular matrix adhesion, migration and invasion, cell cycle progression, differentiation and cell type speciation during development of many metazoan organisms, cell death and apoptosis. The amino acid motif RGD (Arg-Gly-Asp) is conserved in most monomeric disintegrins and is located at the tip of a flexible loop, the integrin-binding loop,

which is stabilized by disulfide bonds and protruding from the main body of the polypeptide chain. All disintegrins purified from snake venom selectively bind to or target the fibrinogen receptors, such as αv -integrins, $\alpha 5\beta 1$ integrin, and integrin $\alpha IIb\beta 3$, the binding of which results in the inhibition of fibrinogen-dependent platelet aggregation as well as other biological activities mediated by these fibrinogen receptors. Examples of disintegrins useful in the invention include, but are not limited to, rhodostomin, triflavin, rehistan trimucrin, elegantin, trigramin and applaggin. Exemplary peptide sequences of disintegrins useful in the invention are provided in SEQ ID NOs: 1 to 6.

[0048] As used herein, a “disintegrin variant” refers to an engineered, functionally active protein, or a polypeptide or any derivatives thereof, that comprises an amino acid sequence derived or modified or mutated from a wild-type disintegrin. A disintegrin variant contains one or more mutations compared to a naturally occurring disintegrin. The one or more mutations can be a substitution, deletion, or insertion of one or more amino acids to the naturally occurring disintegrin. In one embodiment, a disintegrin variant has a reduced binding activity to $\alpha IIb\beta 3$ integrin as compared to the naturally occurring disintegrin not having the one or more mutations. More preferably, a disintegrin variant binds specifically to one or more of integrins $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$ and $\alpha v\beta 8$, and integrin $\alpha 5\beta 1$. Most preferably, the disintegrin variant has increased binding activity to one or both of integrin $\alpha v\beta 3$ and integrin $\alpha 5\beta 1$ as compared to the naturally occurring disintegrin without the one or more mutations.

[0049] In certain embodiments, a disintegrin variant comprises a modified Rho protein from venom that contains at least one amino acid substitution, insertion or deletion compared with the naturally occurring Rho. Modified Rho variants and/or different disintegrin can further comprise post translational modifications.

[0050] In one embodiment, a disintegrin variant of the invention comprises a mutant RGD loop. As used herein, a “mutant RGD loop” or “mutant RGD region” refers to a peptide comprising one or more mutations in the amino acid sequence that spans the RGD loop of a disintegrin. The RGD loop of a wild-type disintegrin comprises the RGD residues that bind to integrins. For example, the RGD loop of Rho comprises the amino acid sequence of SEQ ID NO: 333 (RIPRGDMP). In preferred embodiments of the invention, a mutant RGD loop comprises at least one mutation at positions 1-3, 5, 7 and 8 of the amino acid sequence of SEQ ID NO: 333. More preferably, a mutant RGD loop comprises the amino acid sequence selected from the group consisting of SEQ ID NOs: 329 to 331.

[0051] In another embodiment, a disintegrin variant of the invention comprises a mutant linker. As used herein, a “mutant linker” or “mutant linker region” refers to a peptide

comprising one or more mutations in the amino acid sequence that spans the linker region of a disintegrin. The linker region of a disintegrin is located immediately N-terminal to the RGD loop. For example, the linker region of Rho comprises the amino acid sequence of SEQ ID NO:332 (SRAGKIC). In preferred embodiments of the invention, a mutant linker comprises at least one mutation at positions 1 to 5 of the amino acid sequence of SEQ ID NO:332. More preferably, a mutant linker comprises the amino acid sequence selected from the group consisting of SEQ ID NO:306 to SEQ ID NO: 317.

[0052] In yet another embodiment, a disintegrin variant of the invention comprises a mutant C-terminus. As used herein, a “mutant C-terminus” or “mutant C-terminal region” refers to a peptide comprising one or more mutations in the amino acid sequence of the C-terminal region of a disintegrin. The C-terminal region of a disintegrin is located at the carboxyl end of the disintegrin. For example, the C-terminus of Rho comprises the amino acid sequence of SEQ ID NO: 334 (PRYH). In preferred embodiments of the invention, a mutant C-terminus comprises at least one mutation at positions 1-4 of the amino acid sequence of SEQ ID NO:334. More preferably, a mutant C-terminus comprises the amino acid sequence selected from the group consisting of SEQ ID NO:319 to SEQ ID NO: 328.

[0053] In preferred embodiments, a disintegrin variant of the invention comprises a mutant RGD loop and at least one of a mutant linker and a mutant C-terminus of a disintegrin.

[0054] In more preferred embodiments, a disintegrin variant of the invention comprises a mutant RGD loop, a mutant linker and a mutant C-terminus of a disintegrin described herein.

[0055] A disintegrin variant of invention can include naturally-occurring and non-naturally occurring amino acids. Examples of naturally-occurring amino acid include, but are not limited to, any of the twenty primary, naturally occurring amino acids which typically form peptides, polypeptides, and proteins. The following table 1 is a tabulation of 20 naturally occurring amino acids.

[0056] Table 1

Naturally Occurring Amino Acids		
Amino Acid	Three-letter abbreviation	One-letter symbol
Alanine	Ala	A
Arginine	Arg	R
Asparagine	Asn	N
Aspartic Acid	Asp	D
Cysteine	Cys	C
Glutamine	Gln	Q
Glutamic acid	Glu	E
Glycine	Gly	G
Histidine	His	H
Isoleucine	Ile	I
Leucine	Leu	L
Lysine	Lys	K
Methionine	Met	M
Phenylalanine	Phe	F
Proline	Pro	P
Serine	Ser	S
Threonine	Thr	T
Tryptophan	Trp	W
Tyrosine	Tyr	Y
Valine	Val	V

[0057] Non-naturally occurring amino acids are non-proteinogenic amino acids that either occur naturally or are chemically synthesized. Examples of non-naturally occurring amino acids include, but are not limited to, β -amino acids ($\beta 3$ and $\beta 2$), homo-amino acids, proline and pyruvic acid derivatives, 3-substituted alanine derivatives, glycine derivatives, ring-substituted phenylalanine and tyrosine derivatives, linear core amino acids, N-methyl amino acids, etc.

[0058] As used herein, “conservative substitution” is the replacement of an amino acid with another amino acid that has the same net electronic charge and approximately the same size and shape. Amino acids with aliphatic or substituted aliphatic amino acid side chains have approximately the same size when the total number carbon and heteroatoms in their side chains differs by no more than about four. They have approximately the same shape when the number of branches in their side chains differs by no more than one. Amino acids with phenyl or substituted phenyl groups in their side chains are considered to have about the same size and shape. Listed below are five groups of amino acids. Replacing an amino acid in a polypeptide with another amino acid from the same group results in a conservative substitution: Group I: glycine, alanine, valine, leucine, isoleucine, serine, threonine, cysteine, and non-naturally occurring amino acids with C1-C4 aliphatic or C1-C4 hydroxyl substituted aliphatic

side chains (straight chained or monobranched); Group II: glutamic acid, aspartic acid and non-naturally occurring amino acids with carboxylic acid substituted C1-C4 aliphatic side chains (unbranched or one branch point); Group III: lysine, ornithine, arginine and non-naturally occurring amino acids with amine or guanidino substituted C1-C4 aliphatic side chains (unbranched or one branch point); Group IV: glutamine, asparagine and non-naturally occurring amino acids with amide substituted C1-C4 aliphatic side chains (unbranched or one branch point); and Group V: phenylalanine, phenylglycine, tyrosine and tryptophan.

[0059] As used herein, “highly conservative substitution” is the replacement of an amino acid with another amino acid that has the same functional group in the side chain and nearly the same size and shape. Amino acids with aliphatic or substituted aliphatic amino acid side chains have nearly the same size when the total number carbon and heteroatoms in their side chains differs by no more than two. They have nearly the same shape when they have the same number of branches in their side chains. Examples of highly conservative substitutions include valine for leucine, threonine for serine, aspartic acid for glutamic acid and phenylglycine for phenylalanine.

[0060] The term “isolated protein” or “isolated polypeptide” as used herein refers to a protein encoded by a nucleic acid including, inter alia, genomic DNA, cDNA, recombinant DNA, recombinant RNA, or nucleic acid of synthetic origin or some combination thereof, which (1) is free of at least some proteins with which it would normally be found, (2) is essentially free of other proteins from the same source, e.g., from the same cell or species, (3) is expressed by a cell from a different species, (4) has been separated from at least about 50 percent of polynucleotides, lipids, carbohydrates, or other materials with which it is naturally found when isolated from the source cell, (5) is not linked (by covalent or noncovalent interaction) to all or a portion of a polypeptide to which the “isolated protein” is linked in nature, (6) is operatively linked (by covalent or noncovalent interaction) to a polypeptide with which it is not linked in nature, or (7) does not occur in nature. Preferably, the isolated protein is substantially free from other contaminating proteins or polypeptides or other contaminants that are found in its natural environment that would interfere with its therapeutic, diagnostic, prophylactic or research use.

[0061] As used herein, the terms “polynucleotide,” “nucleotide,” “oligonucleotide,” and “nucleic acid” may be used interchangeably to refer to nucleic acid comprising DNA, RNA, derivative thereof, or combination thereof.

[0062] As used herein, the terms “polypeptide” and “protein” may be used interchangeably to refer to proteins produced by naturally-occurring and non-recombinant cells, by genetically-

engineered or recombinant cells, or by chemical synthesis, and comprise molecules having the amino acid sequence of the native protein, or sequences that have deletions, additions, and/or substitutions of one or more amino acids of the native sequence. In accordance with the instant invention, the disintegrins are polypeptide or protein specifically encompasses modified Rho protein or fragments thereof or variants thereof. In certain particular embodiments, the disintegrins encompasses Rho protein, the fragments or variants thereof that inhibit integrin activity. In certain particular embodiments, the disintegrin targets α v-integrin isoform, such as any group selected from the α v β 1, α v β 3, α v β 5, α v β 6 and α v β 8, and integrin α 5 β 1. In certain other particular embodiments, the integrin is not α IIb β 3.

[0063] As used herein, a “host cell” is an individual cell or cell culture which can be or has been a recipient of any recombinant vector(s) or polynucleotide. Host cells include progeny of a single host cell, and the progeny may not necessarily be completely identical (in morphology or in total DNA complement) to the original parent cell due to natural, accidental, or deliberate mutation and/or change. A host cell includes cells transfected or infected in vitro or in vivo with a recombinant vector or a polynucleotide of the invention. A host cell which comprises a recombinant vector of the invention may be called a “recombinant host cell.” Suitable host cells include prokaryotic or eukaryotic cells, including, for example, bacterial, yeast, fungal, plant, insect, and mammalian cells.

[0064] As used herein, the term “binding activity” refers to the binding of a disintegrin or a disintegrin variant to an integrin that results in one or more of inhibiting, blocking, neutralizing, reducing, abrogating or interfering with the integrin activities. In certain embodiments, the disintegrin or disintegrin variant inhibits integrin activities by binding to integrin and sequestering integrin from binding to other molecules, for example other ECM proteins. In certain other embodiments, the disintegrin or disintegrin variant inhibits integrin activities by binding to integrin and preventing integrin from triggering downstream signaling events in the cells.

[0065] As used herein, the term “inhibition” or “inhibit” in the context of integrin activity as used herein refers to a property of a disintegrin or disintegrin variant that reduces the activity of integrin as analyzed by various functional assays, including without limitation, binding assays, migration assays, apoptosis assays and cell adhesion assays. In certain embodiments of the invention, the integrin is an α v-integrin isoform, including α v β 1, α v β 3, α v β 5, α v β 6 and α v β 8. In certain other particular embodiments, the integrin is α 5 β 1. In certain further embodiments, the disintegrin or disintegrin variant inhibits integrin activity by from about 0 %

to about 100 % as compared to the control in the absence of the disintegrin or disintegrin variant.

[0066] As used herein, the term “selectively bind”, “selectively inhibit,” “selective binding,” “selective inhibition,” “differentially bind,” “differentially inhibit,” “differential binding,” or “differential inhibition” refers to the property of disintegrin or disintegrin variant that shows differential specificity for a particular target integrin molecule over one or more other integrins. For example, a disintegrin variant of the invention selectively binds to one or more of integrins $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha 5\beta 1$, thus has higher affinity to the one or more of integrins $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha 5\beta 1$ than another integrin, such as $\alpha IIb\beta 3$ integrin. In certain embodiments, the disintegrin variant comprising a modified Rho fragment selectively inhibits the activity of one or more integrins selected from the group consisting of integrins $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$ and integrin $\alpha 5\beta 1$. In preferred embodiments, the disintegrin variant comprising a modified Rho fragment specifically inhibits both integrin $\alpha v\beta 3$ and integrin $\alpha 5\beta 1$, inhibits both integrin $\alpha v\beta 5$ and integrin $\alpha 5\beta 1$, or both integrin $\alpha v\beta 6$ and integrin $\alpha 5\beta 1$ activities. In certain alternative embodiments, the disintegrin variant comprising a modified Rho fragment specifically inhibits all of integrins $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, and integrin $\alpha 5\beta 1$ activities.

[0067] The term “homology” or “homologous” as used herein refers to the level of overall sequence similarity and/or identity between corresponding disintegrin fragments, such as a Rho fragment. High sequence homology suggests conservation of protein activity. A number of publicly available algorithms or software programs can be used to determine sequence homology. It is within the ability of one skilled in the art to determine the suitability of additional conservative or non-conservative amino acid substitutions and the level of sequence homology.

[0068] As used herein, a “subject” refers to any animal including, but not limited to humans and other primates, rodents (e.g., mice, rats, and guinea pigs), lagamorphs (e.g., rabbits), bovines (e.g., cattle), ovines (e.g., sheep), caprines (e.g., goats), porcines (e.g., swine), equines (e.g., horses), canines (e.g., dogs), felines (e.g., cats), domestic fowl (e.g., chickens, turkeys, ducks, geese, other gallinaceous birds, etc.), as well as feral or wild animals, including, but not limited to, such animals as ungulates (e.g., deer), bear, lagamorphs, rodents, birds, etc. It is not intended that the term be limited to a particular age or sex. Thus, adult and newborn subjects, as well as fetuses, whether male or female, are encompassed by the term. Subjects "in need of treatment" are subjects with diseases and/or conditions that can be treated by inhibiting one or more activities of an integrin to achieve a beneficial therapeutic and/or prophylactic result. A beneficial outcome includes a decrease in the severity of symptoms or

delay in the onset of symptoms, increased longevity and/or more rapid or more complete resolution of the disease or condition.

[0069] A “pharmaceutically acceptable carrier” refers to a non-toxic solid, semisolid or liquid filler, diluent, encapsulating material, formulation auxiliary, or excipient of any conventional type. A pharmaceutically acceptable carrier is non-toxic to recipients at the dosages and concentrations employed and is compatible with other ingredients of the formulation.

[0070] As used herein, “pharmaceutically acceptable salts” refer to derivatives of compounds wherein the parent compound is modified by making acid or base salts thereof.

[0071] As used herein, a “disease related to an integrin” refers to any condition, disorder, or syndrome related to the integrin that requires medical intervention or for which medical intervention is desirable. Such medical intervention can include treatment, diagnosis, and/or prevention.

[0072] As used herein, “effective amount” or “sufficient amount” refers to an amount of a disintegrin variant as described herein that can be therapeutically effective to inhibit, prevent, or treat a symptom of a particular disease, disorder, condition, or side effect.

[0073] The term “treat,” “treatment” or “treating” means reducing the frequency, extent, severity and/or duration with a symptom of a particular disease, disorder, condition, or side effect.

[0074] The term “prevent,” “prevention” or “preventing” means inhibition or the averting of symptoms of a particular disease, disorder, condition, or side effect.

Disintegrin Variants

[0075] It is discovered in the invention that variants of disintegrins from snake venom, such as rhodostomin (Rho) from rhodostoma, exhibit different capabilities to selectively bind to one or more α v-integrins, such as one or more of α v β 1, α v β 3, α v β 5, α v β 6 and α v β 8, and other integrins, such as α 5 β 1, with reduced binding activity to α IIb β 3. The capability of selectively binding to certain integrin(s) was enabled by mutating amino acid sequences in one or more of the linker region, the RGD loop and the C-terminus of a disintegrin of interest.

[0076] Accordingly, one general aspect of the invention relates to disintegrin variants. According to one embodiment of the invention, a disintegrin variant has reduced binding activity to α IIb β 3, and binds specifically to at least one of α 5 β 1, α v β 1, α v β 3, α v β 5, α v β 6 and α v β 8.

[0077] Preferably, a disintegrin variant has reduced binding activity to α IIb β 3, but increased binding activity to at least one of α 5 β 1 and α v β 3 as compared to the wild-type disintegrin from which the disintegrin variant derived.

[0078] For example, it was found that a Rho mutation in the RGD loop can increase specificity for $\alpha V\beta 3$ and/or $\alpha 5\beta 1$ integrin, a mutation in the C-terminal region can cause less binding to $\alpha IIb\beta 3$ (thus weaker inhibition on platelet aggregation and less bleeding side effect) and a mutation in the linker region can also reduce binding to $\alpha IIb\beta 3$, wherein each of the three regions are identified by the amino acid residue numbers in the wild-type Rho, and the amino acid residues that can be modified, e.g., by an insertion, deletion, or substitution, according to embodiments of the invention are each independently marked as “X.”

[0079] According to embodiments of the invention, a disintegrin variant comprises a mutation in the RGD loop, i.e., a mutant RGD loop.

[0080] In one embodiment, a disintegrin variant comprises a mutant RGD loop having a consensus sequence of $^{49}RXD^{51}$. Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 7-24.

[0081] In another embodiment, a disintegrin variant comprises a mutant RGD loop having a consensus sequence of $^{48}XRGD^{51}$ (SEQ ID NO: 341). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 25-42.

[0082] In another embodiment, a disintegrin variant comprises a mutant RGD loop having a consensus sequence of $^{48}XRGDXP^{53}$ (SEQ ID NO: 342). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 44-61.

[0083] In another embodiment, a disintegrin variant comprises a mutant RGD loop having a consensus sequence of $^{48}XRGDMX^{53}$ (SEQ ID NO: 343). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 63-78.

[0084] In another embodiment, a disintegrin variant comprises a mutant RGD loop having a consensus sequence of $^{46}XXPRGD^{51}$ (SEQ ID NO: 344). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 79-94.

[0085] In another embodiment, a disintegrin variant comprises a mutant RGD loop having a consensus sequence of $^{48}XRDXP^{53}$ (SEQ ID NO: 345). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 95-101.

[0086] According to other embodiments of the invention, a disintegrin variant comprises a mutation in the C-terminal region, i.e., a mutant C-terminus.

[0087] In one embodiment, a disintegrin variant comprises a mutant C-terminus having a consensus sequence of ⁶⁵PRXXXXX⁷¹ (SEQ ID NO: 346). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 102-107.

[0088] In another embodiment, a disintegrin variant comprises a mutant C-terminus having a consensus sequence of ⁶⁵PRXXXXX⁷¹ (SEQ ID NO: 346), and further comprises a mutant RGD loop, such as those described herein. For example, the mutant RGD loop can have a consensus sequence of ⁴⁸ARGDMP⁵³ (SEQ ID NO: 335). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 115-119.

[0089] According to yet other embodiments of the invention, a disintegrin variant comprises a mutation in the linker region, i.e., a mutant linker.

[0090] In one embodiment, a disintegrin variant comprises a mutant linker having a consensus sequence of ³⁹KKKRTIC⁴⁷ (SEQ ID NO: 306). Preferably, the disintegrin variant further comprises a mutant RGD loop such as those described herein. For example, the mutant RGD loop can have a consensus sequence of ⁴⁸XRDXP⁵³ (SEQ ID NO: 345). Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 108-114.

[0091] According to further embodiments of the invention, a disintegrin variant comprises a mutation in the linker region, a mutation in the RGD loop and a mutation in the C-terminal region. Examples of such variants include, but are not limited to, those having the amino acid sequences selected from the group consisting of SEQ ID NOs: 120-132 and 134-179.

[0092] A disintegrin variant of the invention can be made by any method suitable to the aims of the invention in view of the present disclosure. For example, a disintegrin variant can be constructed by a site-directed mutagenesis method. The disintegrin variant of the invention can be expressed using methods known in the art in view of the present disclosure. Cell-based methods and cell-free methods are suitable for producing peptides of the invention. Cell-based methods generally involve introducing a nucleic acid construct into a host cell in vitro and culturing the host cell under conditions suitable for expression, then harvesting the peptide, either from the culture medium or from the host cell, (for example, by disrupting the host cell),

or both. The invention also provides methods of producing a disintegrin variant using cell-free in vitro transcription/translation methods, which are well known in the art.

[0093] The disintegrin variant can be encoded by a modified disintegrin nucleotide sequence that encodes a modified amino acid sequence resulting in said polypeptide having substantially reduced integrin $\alpha\text{IIb}\beta 3$ receptor-blocking activity, and/or increased specificity to one or more of $\alpha\text{v}\beta 1$, $\alpha\text{v}\beta 3$, $\alpha\text{v}\beta 5$, $\alpha\text{v}\beta 6$ and $\alpha\text{v}\beta 8$, and other integrins, such as $\alpha 5\beta 1$. The coding sequence for a disintegrin variant can be obtained by modifying a coding sequence for a disintegrin derived from a snake venom. The disintegrin can be chosen from one of rhodostomin, albolabrin, applagin, basilicin, batroxostatin, bitistatin, cereberin, cerastin, crotatroxin, durissin, elegantin, flavoridin, flavostatin, halysin, halystatin, jararacin, jarastatin, kistrin, lachesin, lutosin, molossin, salmosin, saxatilin, tergeminin, trimestatin, trimucrin, trimutase, ussuristatin, and viridin.

[0094] Thus, another general aspect of the invention relates to a polynucleotide encoding a disintegrin variant of the invention. Yet another general aspect of the invention relates to host cells comprising a polynucleotide encoding a disintegrin variant of the invention.

[0095] Typically, a heterologous peptide, whether modified or unmodified, may be expressed on its own, as described above, or as a fusion protein, and may include not only secretion signals, but also a secretory leader sequence. A secretory leader sequence of the invention may direct certain proteins to the endoplasmic reticulum (ER) or periplasma. The ER separates the membrane-bound proteins from other proteins. Once localized to the ER, proteins can be further directed to the Golgi apparatus for distribution to vesicles, including secretory vesicles, the plasma membrane, lysosomes, and other organelles. In the case of periplasma, the protein is secreted into the periplasma space of a Gram negative bacterium, such as an *Escherichia coli*.

[0096] Additionally, peptide moieties and/or purification tags can be added to the disintegrin variants. Such regions may be removed prior to final preparation of the polypeptide. The addition of peptide moieties to polypeptides to engender secretion or excretion, to improve stability, and to facilitate purification, among other reasons, are familiar and routine techniques in the art. Suitable purification tags include, for example, V5, polyhistidines, avidin, and biotin. Conjugation of peptides to compounds such as biotin can be accomplished using techniques well known in the art. (Hermanson ed. (1996) *Bioconjugate Techniques*; Academic Press). Peptides can also be conjugated with radioisotopes, toxins, enzymes, fluorescent labels, colloidal gold, nucleic acids, vinorelbine, and doxorubicin using techniques known in the art. (Hermanson ed. (1996) *Bioconjugate Techniques*; Academic Press; Stefano et al. (2006).

[0097] Fusion partners suitable for use in the invention include, for example, fetuin, human serum albumin, immunoglobulin CH2/CH3 domains (Fc), and/or one or more of their fragments. Conjugated proteins, such as polyethylene glycol conjugates, are also provided.

[0098] The peptides of the invention can also be chemically synthesized using techniques known in the art (e.g., see Hunkapiller et al., *Nature*, 310:105-111 (1984); Grant ed. (1992) *Synthetic Peptides, A Users Guide*, W.H. Freeman and Co.; U.S. Pat. No. 6,974,884). For example, a polypeptide corresponding to a fragment of a polypeptide can be synthesized by use of a peptide synthesizer or through the use of solid-phase methods known in the art.

[0100] Furthermore, if desired, nonclassical amino acids or chemical amino acid analogs can be introduced as a substitution or addition into the polypeptide sequence. Non-classical amino acids include, but are not limited to, the D-isomers of the common amino acids, 2,4-diaminobutyric acid, α -amino isobutyric acid, 4-aminobutyric acid, Abu, 2-amino butyric acid, γ -Abu, ϵ -Ahx, 6-amino hexanoic acid, Aib, 2-amino isobutyric acid, 3-amino propionic acid, ornithine, norleucine, norvaline, hydroxyproline, sarcosine, citrulline, homocitrulline, cysteic acid, t-butylglycine, t-butylalanine, phenylglycine, cyclohexylalanine, β -alanine, fluoro-amino acids, designer amino acids such as β -methyl amino acids, Ca-methyl amino acids, Na-methyl amino acids, and amino acid analogs in general. Furthermore, the amino acid can be D (dextrorotary) or L (levo rotary).

[0101] The disintegrin variant of the invention can be recovered and purified from chemical synthesis and recombinant cell cultures by standard methods which include, but are not limited to, ammonium sulfate or ethanol precipitation, acid extraction, anion or cation exchange chromatography, phosphocellulose chromatography, hydrophobic interaction chromatography, affinity chromatography, hydroxylapatite chromatography and lectin chromatography. In one embodiment, high performance liquid chromatography ("HPLC") is employed for purification. Well known techniques for refolding protein may be employed to regenerate active conformation when the polypeptide is denatured during isolation and/or purification.

[0102] A disintegrin variant of the invention can be modified with or covalently coupled to one or more of a variety of hydrophilic polymers to increase solubility and circulation half-life of the peptide. Suitable nonproteinaceous hydrophilic polymers for coupling to a peptide include, but are not limited to, polyalkylethers as exemplified by polyethylene glycol and polypropylene glycol, polylactic acid, polyglycolic acid, polyoxyalkenes, polyvinylalcohol, polyvinylpyrrolidone, cellulose and cellulose derivatives, dextran, and dextran derivatives. Generally, such hydrophilic polymers have an average molecular weight ranging from about 500 to about 100,000 daltons, from about 2,000 to about 40,000 daltons, or from about 5,000 to about

20,000 daltons. The peptide can be derivatized with or coupled to such polymers using any of the methods set forth in Zallipsky, S. (1995) *Bioconjugate Chem.*, 6:150-165; Monfardini, C., et al. (1995) *Bioconjugate Chem.* 6:62-69; U.S. Pat. Nos. 4,640,835; 4,496,689; 4,301,144; 4,670,417; 4,791,192; 4,179,337, or WO 95/34326.

[0103] Pharmaceutical Compositions

[0104] Another general aspect of the invention relates to a pharmaceutical composition comprising a disintegrin variant of the invention and a pharmaceutically acceptable carrier. Depending on the need, the pharmaceutical compositions can be formulated into preparations in solid, semi-solid, liquid, or gaseous forms, such as tablets, capsules, powders, granules, ointments, solutions, suppositories, injections, inhalants and aerosols. The following methods and excipients are merely exemplary and are in no way limiting.

[0105] In some embodiments, a disintegrin variant of the invention is provided in formulation with pharmaceutically acceptable carriers, excipients, and diluents, of which a wide variety are known in the art. These pharmaceutical carriers, excipients, and diluents include those listed in the USP pharmaceutical excipients listing. USP and NF Excipients, Listed by Categories, p. 2404-2406, USP 24 NF 19, United States Pharmacopeial Convention Inc., Rockville, Md. (ISBN 1-889788-03-1). Pharmaceutically acceptable excipients, such as vehicles, adjuvants, carriers, or diluents, are readily available to the public. Moreover, pharmaceutically acceptable auxiliary substances, such as pH adjusting and buffering agents, tonicity adjusting agents, stabilizers, wetting agents and the like, are readily available to the public.

[0106] Suitable carriers include, but are not limited to, water, dextrose, trehalose, histidine, glycerol, saline, ethanol, and combinations thereof. The carrier can contain additional agents such as wetting or emulsifying agents, pH buffering agents, or adjuvants which enhance the effectiveness of the formulation. Topical carriers include liquid petroleum, isopropyl palmitate, polyethylene glycol, ethanol (95%), polyoxyethylene monolaurate (5%) in water, or sodium lauryl sulfate (5%) in water. Other materials such as anti-oxidants, humectants, viscosity stabilizers, and similar agents can be added as necessary. Percutaneous penetration enhancers such as Azone can also be included.

[0107] Actual methods of preparing such dosage forms are known, or will be apparent, to those skilled in the art. The composition or formulation to be administered will, in any event, contain a quantity of the agent adequate to achieve the desired state in the subject being treated.

[0108] In certain embodiments, disintegrin variant of the invention can be formulated into preparations for injection by dissolving, suspending or emulsifying them in an aqueous or nonaqueous solvent, such as vegetable or other similar oils, synthetic aliphatic acid glycerides,

esters of higher aliphatic acids or propylene glycol; and if desired, with conventional additives such as solubilizers, isotonic agents, suspending agents, emulsifying agents, stabilizers, and preservatives. Other formulations for oral or parenteral delivery can also be used, as conventional in the art.

[0109] In pharmaceutical dosage forms, the pharmaceutical compositions of the invention can be administered in the form of their pharmaceutically acceptable salts, or they can also be used alone or in appropriate association, as well as in combination, with other pharmaceutically active compounds. The subject compositions are formulated in accordance to the mode of potential administration. In a preferred embodiment, the pharmaceutical composition is formulated for parental administration, such as in a liquid form for injection.

[0110] Methods of Treatment

[0111] The invention also relates to uses of the disintegrin variants in treating and/or preventing a disease associated with one or more integrins selected from the group consisting of $\alpha 5\beta 1$, $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$ and $\alpha v\beta 8$ in a subject in need thereof. Such diseases include, but are not limited to, osteoporosis, bone tumor or cancer growth and symptoms related thereto, angiogenesis-related tumor growth and metastasis, tumor metastasis in bone, malignancy-induced hypercalcemia, angiogenesis-related eye diseases, Paget's disease, rheumatic arthritis, and osteoarthritis. The method comprises administering to the subject in need of the treatment a pharmaceutical composition comprising a therapeutically effective amount of a disintegrin variant of the invention and a pharmaceutically acceptable carrier.

[0112] In one embodiment of the invention, a disintegrin variant of the invention is used for treatment and/or prevention of an angiogenesis-related eye disease, which includes, but is not limited to, age-related macular degeneration, diabetic retinopathy, corneal neovascularizing diseases, ischaemia-induced neovascularizing retinopathy, high myopia, and retinopathy of prematurity.

[0113] In another embodiment of the invention, a disintegrin variant of the invention is used for treatment and/or prevention of angiogenesis-related disease, including, but not limited to, cancer, eye-related disease, such as macular degeneration, edema.

[0114] In another embodiment, the invented disintegrin variant binds to αv -integrins present in the cornea ($\alpha v\beta 5$, $\alpha v\beta 6$, and $\alpha v\beta 8$), mediates transforming growth factor β (TGF β) activation, resulting in treatment of related diseases. These diseases include eye disease, arthritis and cancer. In a further aspect, the invented polypeptide is an anti-angiogenic drugs for relieving the arthritic pain and preventing bone joint destruction caused by these pathological and destructive blood vessels. The invented polypeptides can also prove to be useful when combined with

conventional chemotherapy or radiation therapy, as part of a “multiple warhead” approach to attack cancer via different strategies simultaneously.

[0115] In still another embodiment of the invention, a disintegrin variant of the invention is used for treatment and/or prevention of osteoporosis. The osteoporosis is associated with a pathological condition chosen from post-menopausal estrogen deficiency, secondary osteoporosis, rheumatoid arthritis, ovariectomy, Paget's disease, bone cancer, bone tumor, osteoarthritis, increased osteoclast formation, and increased osteoclast activity. Furthermore, the osteoporosis includes, but is not limited to, an ovariectomy-induced osteoporosis or bone loss and post-menopausal osteoporosis or bone loss.

[0116] Yet another embodiment of the invention is a method of using the disintegrin variant for treatment and/or prevention of physiological changes in a mammal including a human induced by ovariectomy or post-menopausal osteoporosis. The method includes administering to the mammal in need thereof a therapeutically effective amount of an isolated polypeptide, or a pharmaceutically acceptable salt thereof, which has integrin $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$ or $\alpha 5\beta 1$ receptor-antagonist activity and substantially reduced integrin $\alpha IIb\beta 3$ receptor-blocking activity as compared to a wild-type disintegrin, and thereby resulting in treatment and/or prevention of the ovariectomy-induced physiological change in the mammal.

[0117] In other aspect, the invention provides a method for inhibiting platelet aggregation, comprising administering an effective amount of a disintegrin variant of the invention or a pharmaceutical composition of the invention to a subject in need of such treatment.

[0118] A disintegrin variant of the invention can be administered to a subject in need of treatment by systemic injection, such as by intravenous injection; or by injection or application to the relevant site, such as by direct injection, or direct application to the site when the site is exposed in surgery; or by topical application, such as if the disorder is on the skin, for example.

[0119] A disintegrin variant of the invention can be used as monotherapy. Alternatively, the disintegrin variant of the invention can be used in combination with standard regimens to treat integrin associated diseases. For example, the peptides of the invention can be used in a combinational therapy with a therapeutically effective amount of one or more other pharmaceutical agents. Preferably, another pharmaceutical agent is selected from the group consisting of an anti-cancer agent, an anti-inflammatory agent, an immune-modulating agent and an anti-osteoporosis agent. Preferably, an anti-cancer agent is selected from the group consisting of an anti-angiogenic agent, a cytotoxic agent and an anti-neoplastic agent. The other pharmaceutical agent(s) can be administered prior to, together with, or after administration of the peptides of the invention.

[0120] In some embodiments, a disintegrin variant of the invention is particularly effective against cancers which are associated with a highly expressed osteopontin. In preferred embodiments, the polypeptides of the invention can inhibit osteopontin-induced tumor invasion.

[0121] Administration of disintegrin variants can be achieved in various ways, including oral, buccal, nasal, rectal, parenteral, intraperitoneal, intradermal, transdermal, subcutaneous, intravenous, intra-arterial, intracardiac, intraventricular, intracranial, intratracheal, and intrathecal administration, etc., or otherwise by implantation or inhalation.

[0122] The following examples of the invention are to further illustrate the nature of the invention. It should be understood that the following examples do not limit the invention and that the scope of the invention is to be determined by the appended claims.

Examples

Example 1: Construction of Expression Vectors Expressing Wild-type Rho and Rho Mutants (Disintegrin Variants)

[0123] The DNA encoding Rho was composed of codons preferentially used in *Pichia pastoris*. Rho DNA was amplified by the polymerase chain reaction (PCR) with the sense primer 5'-GAATTCGAATTCCATCATCATCATCAT CATGGTAAGGAATGTGACTGTTCT-3' (SEQ ID NO: 183) that had Eco R1 recognition site and encodes six histidine residues for facilitating purification. The antisense primer has the sequence of 5'-CCGCGGCCGCGGTCAGTGGTATCTTGGACAGTCAGC-3' (SEQ ID NO: 180) or 5'-CCGCGGCCGCGGTTAGTGGTATCTTGGACAGTCAGC-3' (SEQ ID NO: 184) with Sac II recognition and a TCA (or TTA) stop codon. The PCR product was purified and then ligated into the Eco R1 and Sac II sites of the yeast recombination vector, pPICZα A. The recombinant plasmid was used to transform a DH5α strain, and colonies were selected on agar plates with low salt LB (1% tryptone, 0.5% yeast extract, 0.5% NaCl, 1.5% agar at pH 7.0) and 25 µg/ml antibiotic Zeocin.

[0124] The various DNA constructs encoding the mutants of Rho were synthesized and amplified by the PCR using an overlapping oligonucleotide strategy with primers containing Eco RI and Sac II restriction sites. For illustration purpose, Table 2 lists the consensus sequences of some disintegrin variants, and the primers used to construct these variants according to embodiments of the invention, wherein the primer sequences are presented from the 5' to 3' (left to the right).

[0125] Expression vectors encoding other variants encompassed by the invention have been or can be constructed in similar manner in view of the present disclosure. Various primers used for synthesizing or confirming disintegrin variants are listed in SEQ ID NOs: 180-305.

Example 2 Expression and Purification of Rho Mutants

[0126] The protein expression of rhodostomin mutants and variants in *Pichia pastoris* was performed according to the protocols of the *Pichia* EasyComp™ Kit with minor modifications. Briefly, a total of 10 µg plasmids containing DNA encoding rhodostomin or the variants of disintegrin were purified and digested with *Sac* I to linearize the plasmids. *Pichia* strain X33 was transformed with the linearized constructs by a heat shock method, using a *Pichia* EasyComp™ kit from Invitrogen®. The transformant integrated at the 5'AOX1 locus by a single crossover. PCR was used to analyze *Pichia* integrants to determine if the Rho gene had been integrated into the *Pichia* genome, and cells were lysed by Lyticase (Sigma). Colonies were selected on agar plates containing YPD (1% yeast extract, 2% peptone, 2% glucose, and 2% agar) and 100 µg/ml Zeocin. A number of clones with multiple copies of disintegrin insertions were selected to pick the clone for the highest variants of disintegrin protein expression.

[0127] Recombinant Rho mutants were produced as follows: selected colonies were grown in the YPD medium (1% yeast extract, 2% peptone, and 2% dextrose) containing 100 µg/ml Zeocin at 30° C. After 48 hours, cells were collected by centrifugation and grown in 1 liter of minimal methanol medium (containing 1.34% yeast nitrogen base with ammonium sulfate without amino acids and 4×10^{-5} % biotin). A total of 1% methanol was added once every 24 hours to induce Rho or variant expression for 2 days. The supernatant was collected by centrifugation and dialyzed twice against 5 liter buffer A (5 mM EDTA, 8M urea and 10 mM Na-phosphate buffer, pH 7.7). The final solution was loaded into a nickel-chelating column and eluted with a gradient of 200 mM imidazole. The recombinant rhodostomin and the variants of disintegrin were further purified by HPLC (reverse phase C18 HPLC). The purified recombinant variants of the disintegrin had a purity of greater than 95% as judged by tricine-SDS-PAGE.

[0128] Table 2. Illustration of Primers Used to Construct Rho and Rho Variants

Rho/Variant		Primer Sequence	SEQ ID NO
RGDM	Sense	AGAGGTGACATG	(SEQ ID NO. 181)
GRGDM	Antisense	CATGTCACCTCTACCGATTCTAC	(SEQ ID NO. 182)
Rho-1	Sense	GAATTCGAATTCCATCATCATCATCA TCATGGTAAGGAATGTGACTGTTCT	(SEQ ID NO. 183)
Rho-2	Antisense	CCGCGGCCGCGGTTAGTGGTATCTTG GACAGTCAGC	(SEQ ID NO. 184)
LRGDM	Antisense	CATGTCACCTCTCAAGATTCTAC	(SEQ ID NO. 185)
RRGDM	Antisense	CATGTCACCTCTTCTGATTCTAC	(SEQ ID NO. 186)
VRGDM	Antisense	CATGTCACCTCTAACGATTCTAC	(SEQ ID NO. 187)
HRGDM	Antisense	CATGTCACCTCTATGGATTCTAC	(SEQ ID NO. 188)
WRGDM	Antisense	CATGTCACCTCTCCAGATTCTAC	(SEQ ID NO. 189)
FRGDM	Antisense	CATGTCACCTCTAAAGATTCTAC	(SEQ ID NO. 190)
P48A-1	Sense	TGTAGAATCGCTAGAGGTGACATG	(SEQ ID NO. 191)
P48A-2	Antisense	CATGTCACCTCTAGCGATTCTACA	(SEQ ID NO. 192)
SRGDM	Antisense	CATGTCACCTCTAGAGATTCTAC	(SEQ ID NO. 193)
MRGDM	Antisense	CATGTCACCTCTCATGATTCTAC	(SEQ ID NO. 194)
TRGDM	Antisense	CATGTCACCTCTAGTGATTCTAC	(SEQ ID NO. 195)
NRGDM	Antisense	CATGTCACCTCTGTTGATTCTAC	(SEQ ID NO. 196)
QRGDM	Antisense	CATGTCACCTCTTTGGATTCTAC	(SEQ ID NO. 197)
YRGDM	Antisense	CATGTCACCTCTGTAGATTCTAC	(SEQ ID NO. 198)
IRGDM	Antisense	CATGTCACCTCTAATGATTCTAC	(SEQ ID NO. 199)
KRGDM	Antisense	CATGTCACCTCTCTTGATTCTAC	(SEQ ID NO. 200)
ERGDM	Antisense	CATGTCACCTCTTTCGATTCTAC	(SEQ ID NO. 201)
DRGDM	Antisense	CATGTCACCTCTATCGATTCTAC	(SEQ ID NO. 202)
RAD	Sense	GTAGAATCCCAAGAGCTGACATGCC	(SEQ ID NO. 203)
RRD	Sense	GTAGAATCCCAAGAAAGAGACATGCC	(SEQ ID NO. 204)
RND	Sense	GTAGAATCCCAAGAAACGACATGCC	(SEQ ID NO. 205)
RDD	Sense	GTAGAATCCCAAGAGATGACATGCC	(SEQ ID NO. 206)
RED	Sense	GTAGAATCCCAAGAGAAGACATGCC	(SEQ ID NO. 207)
RQD	Sense	GTAGAATCCCAAGACAAGACATGCC	(SEQ ID NO. 208)
RKD	Sense	GTAGAATCCCAAGAAAGGACATGCC	(SEQ ID NO. 209)
RMD	Sense	GTAGAATCCCAAGAATGGACATGCC	(SEQ ID NO. 210)
RFD	Sense	GTAGAATCCCAAGATTTGACATGCC	(SEQ ID NO. 211)

Example 3 Rho Mutants Selectively Inhibited Cell Attachment Mediated by Different α v Integrins and α 5 β 1 Integrin

[0129] The inhibitory activities of Rho mutants and variants were evaluated by cell adhesion inhibition assays as described previously (Zhang, *et al.*, 1998 *J Biol Chem* 73:7345-7350). The adhesions of CHO- α IIB β 3 cells to fibrinogen, CHO- α v β 3 cells to fibrinogen, K562 cells to fibronectin, HT-29 cells to vitronectin, and HT-29 cells to fibronectin were used to determine the inhibitory activities of tested protein to integrins α IIB β 3, α v β 3, α 5 β 1, α v β 5, and α v β 6. Briefly, 96-well Immulon-2 microtiter plates (Costar, Corning, NY) were coated with 100 μ L of phosphate-buffered saline (PBS: 10 mM phosphate buffer, 0.15M NaCl, pH 7.4) containing substrates at a concentration of 50-500 nM, and incubated overnight at 4 °C. The substrates and their coating concentrations were fibrinogen (Fg) 200 μ g/ml, vitronectin (Vn) 50 μ g/ml, and fibronectin (Fn) 25 μ g/ml. Non-specific protein binding sites were blocked by incubating each well with 200 μ L of heat-denatured 1% bovine serum albumin (BSA) (Calbiochem) at room temperature for 1.5 h. The heat-denatured BSA was discarded and each well was washed twice with 200 μ L of PBS.

[0130] CHO cells that expressed the integrins α v β 3 (CHO- α v β 3) and α IIB β 3 (CHO- α IIB β 3) were kindly provided by Dr. Y. Takada (Scripps Research Institute) and maintained in DMEM. Human erythroleukemia K562 and colorectal adenocarcinoma HT-29 cells were purchased from ATCC and cultured in Roswell Park Memorial Institute (RPMI)-1640 medium containing 5% FCS. Harvested K562 and HT-29 cells were washed in PBS buffer containing 1 mM EDTA and resuspended in Tyrode's buffer (150 mM NaCl, 5 mM KCl, and 10 mM Hepes) [pH 7.35] containing 1 mM MgSO₄, 2 mM CaCl₂, and 500 μ M MnCl₂. Cells (CHO, K562, and HT-29) were diluted to 3 $\times$ 10⁵ cells/mL, and 100 μ L of the cells were used for the assay. Rho and its mutants were added to the cultured cells and incubated at 37° C, 5% CO₂ for 15 minutes. Rho and its variants were used as inhibitors at the concentrations of 0.001-500 μ M. The treated cells were then added into the coated plate and reacted at 37° C, 5% CO₂ for 1 hour. The incubation solution was then discarded and non-adhered cells were removed by washing twice with 200 μ L PBS.

[0131] Bound cells were quantified by crystal violet staining. Briefly, the well was fixed with 100 μ L of 10% formalin for 10 minutes and dried. Fifty microliters of 0.05%

crystal violet were then added into the well at room temperature for 20 minutes. Each well was washed with 200 μ L of distilled water four times and dried. Colorization was carried out by adding 150 μ L of colorizing solution (50% alcohol and 0.1% acetic acid). The resulting absorbance was read at 600 nm and the readings were correlated with the number of adhering cells. Inhibition was defined as % inhibition = $100 - [\text{OD600 (Rho wild type or disintegrin-treated sample)} / \text{OD600 (untreated sample)}] \times 100$.

[0132] IC₅₀ was defined as the concentration (nM) of a disintegrin variant required for 50% inhibition of the cell adhesion mediated by a particular integrin. Therefore, lower IC₅₀ indicates greater specificity or potency of the disintegrin variant in inhibiting the cell adhesion activity of the respective integrin, thus higher binding activity (or selectivity) of the disintegrin variant to the respective integrin. The IC₅₀ results are summarized in Tables 3 to 14 below.

[0133] A series of Rho mutants involved in the RGD loop region (R⁵⁰XD, ⁴⁸XRGD (SEQ ID NO: 341), XRGD⁵²XP (SEQ ID NO: 342), XRGDM⁵³X (SEQ ID NO: 343), ⁴⁶X⁴⁷XPRGD (SEQ ID NO: 344), and ARGD⁵¹X⁵²X (SEQ ID NO: 340)), the linker region, and C-terminal region were recombinantly expressed and purified to homogeneity. The cell adhesion and platelet aggregation assays were used to determine their integrin-binding affinity. It was found that variants of rhodostomin or disintegrins with one or more modifications in these regions have different selective binding affinity to α V β 3, α V β 5, α V β 6, α 5 β 1 and α I**b** β 3 (Tables 3-14).

[0134] For example, it was found that Rho variants with certain mutations in the RXD motif, in which the “Gly50 (G)” residue was replaced by Leu (L), Val (V), Ile (I), Glu (E), Asp (D), Gln (Q), Phe (F), Trp (W), His (H), Lys (K), or Arg (R), had their highest effects on integrins in the following order: α I**b** β 3 (~1686-fold) > α 5 β 1 (~586-fold) > α v β 5 (~348-fold) > α v β 6 (~179-fold) > α v β 3 (~26-fold), showing their binding selectivity to α V β 3 (Table 3). Rho variants with the mutation in the XRGD (SEQ ID NO: 341) motif, in which the P48 residue was replaced by other amino acids, had their highest effects on integrins in the following order: α 5 β 1 (~71-fold) > α I**b** β 3 (~41-fold) > α v β 3 (~5-fold) (Table 4). Rho variants with the mutation in the XRGDXP (SEQ ID NO: 342) motif, in which the M52 residue was replaced by other amino acids, had their highest effects on integrins in the following order: α I**b** β 3 (~209-fold) > α 5 β 1 (~122-fold) >

α V β 3 (~14-fold) (Table 5). Rho variants with the mutation in the XRGDMX (SEQ ID NO: 343) motif, in which the P⁵³ residue was replaced by other amino acids, had their highest effects on integrins in the following order: α IIb β 3 (~258-fold) > α 5 β 1 (~45-fold) > α V β 3 (~40-fold) (Table 6). Rho variants with the mutation in the XXPRGD (SEQ ID NO: 344) motif, in which the R46 and I47 residues were replaced by other amino acids, had their highest effects on integrins in the following

order: $\alpha\text{IIb}\beta 3$ (~73-fold) > $\alpha 5\beta 1$ (~19-fold) > $\alpha\text{V}\beta 3$ (~10-fold) (Table 7). These results showed that the mutations in the RGD loop exhibited significant effect on the inhibitory activity in integrins $\alpha\text{IIb}\beta 3$ and $\alpha 5\beta 1$, but not $\alpha\text{V}\beta 3$ integrin.

[0135] Mutants of rhodostomin or disintegrins with one or more modifications in addition to the RGD motif, e.g., in the linker region or the C-terminus, exhibited the capability to selectively binding to $\alpha\text{V}\beta 3$, $\alpha\text{V}\beta 5$, $\alpha\text{V}\beta 6$, $\alpha 5\beta 1$ or $\alpha\text{IIb}\beta 3$ (Table 8-14). For example, Rho variants with the mutation in the linker region in which the SRAGKIC (SEQ ID NO: 332) was replaced by KKKRTIC (SEQ ID NO: 306), KKARTIC (SEQ ID NO: 313), MKKGTIC (SEQ ID NO: 307), IEEGTIC (SEQ ID NO: 308), LKEGTIC (SEQ ID NO: 310), AKKRTIC (SEQ ID NO: 311), KAKRTIC (SEQ ID NO: 312), KGAGKIC (SEQ ID NO: 309), KKKATIC (SEQ ID NO: 314), KKKRAIC (SEQ ID NO: 315), KAKRAIC (SEQ ID NO: 316), and SKAGTIC (SEQ ID NO: 317) amino acids, had their highest effects on integrins in the following order: $\alpha\text{IIb}\beta 3$ (~2-fold) > $\alpha 5\beta 1$ (~5-fold) > $\alpha\text{V}\beta 3$ (~14-fold) (Table 8). These results showed that the mutations in the linker region of Rho exhibited significant effect on the inhibitory activity in integrin $\alpha\text{V}\beta 3$.

[0136] Rho variants with the mutation in the C-terminal region, in which the PRYH (SEQ ID NO: 334) was replaced by PGLYG (SEQ ID NO: 324), PRNRFH (SEQ ID NO: 321), PRNRFHA (SEQ ID NO: 322), PRWNDL (SEQ ID NO: 319), PRNGLYG (SEQ ID NO: 323), and PRNPWNG (SEQ ID NO: 320) amino acids, had their highest effects on integrins in the following order: $\alpha\text{IIb}\beta 3$ (~13-fold) > $\alpha\text{V}\beta 5$ (~8-fold) = $\alpha\text{V}\beta 6$ (~8-fold) > $\alpha\text{V}\beta 3$ (~4-fold) > $\alpha 5\beta 1$ (~2-fold) (Table 9). These results showed that the mutations on the C-terminal region of Rho exhibited significant effect on the inhibitory activity in integrins $\alpha\text{IIb}\beta 3$, $\alpha\text{V}\beta 5$, and $\alpha\text{V}\beta 6$.

[0137] Rho variants with the mutation in the C-terminal region, in which PRYH (SEQ ID NO: 334) was replaced by PGLYG (SEQ ID NO: 324), PPLYG (SEQ ID NO: 327), PRLYG (SEQ ID NO: 328), PGLY (SEQ ID NO: 325), PYLYG (SEQ ID NO: 352) and PELYG (SEQ ID NO: 337) amino acids, had their highest effects on integrins in the following order: $\alpha\text{IIb}\beta 3$ (~6493-fold) > $\alpha 5\beta 1$ (~40-fold) > $\alpha\text{V}\beta 5$ (~8-fold) > $\alpha\text{V}\beta 6$ (~6-fold) > $\alpha\text{V}\beta 3$ (~1-fold), showing its significant effect on integrins $\alpha\text{IIb}\beta 3$ and $\alpha 5\beta 1$ (Table 10).

[0138] Disintegrin (Rho) variants specific to integrins $\alpha v\beta 3$ and $\alpha 5\beta 1$ were successfully obtained by modifying the RGD loop region, the linker region, and C-terminal region of Rho. For example, the mutant ³⁹KKART-⁴⁶ARGRGDNP -⁶⁶DLYG (SEQ ID NO: 147) exhibited an excellent inhibitory activity to integrins $\alpha v\beta 3$ and $\alpha 5\beta 1$ but not to $\alpha IIb\beta 3$, $\alpha v\beta 5$, and $\alpha v\beta 6$ (Table 11). The mutations in the RGD loop and linker region increased its activity in inhibiting integrins $\alpha v\beta 3$ and $\alpha 5\beta 1$ and significantly decreased its activity in

inhibiting integrin $\alpha\text{IIb}\beta 3$. The mutations in the C-terminal region decreased its activity in inhibiting integrins $\alpha\text{v}\beta 5$, and $\alpha\text{v}\beta 6$.

[0139] Disintegrin (Rho) variants specific to integrins $\alpha\text{v}\beta 3$, $\alpha\text{v}\beta 5$, and $\alpha 5\beta 1$ were successfully obtained by modifying the RGD loop region, the linker region, and C-terminal region of Rho. For example, the mutant ³⁹KKART-⁴⁶ARGRGDDL-⁶⁶GLYG (SEQ ID NO: 339) exhibited an excellent inhibitory activity to $\alpha\text{v}\beta 3$, $\alpha\text{v}\beta 5$, and $\alpha 5\beta 1$ but not to $\alpha\text{IIb}\beta 3$ and $\alpha\text{v}\beta 6$ (Table 12). The mutations of SRAGKIC (SEQ ID NO: 332) into KKARTIC (SEQ ID NO: 313) in the linker region increased its activity in inhibiting RGD-binding integrins. The mutations of R46A, I47R, P48A, M52D, and P53L in the RGD loop decreased its activity in inhibiting integrins $\alpha\text{IIb}\beta 3$ and $\alpha\text{v}\beta 6$. The mutations of PRYH (SEQ ID NO: 334) into PGLYG (SEQ ID NO: 324) in the C-terminal region decreased its activity in inhibiting integrin $\alpha\text{IIb}\beta 3$.

[0140] Disintegrin (Rho) variants specific to integrins $\alpha\text{v}\beta x$ and $\alpha 5\beta 1$ were successfully obtained by modifying the RGD loop region, the linker region, and C-terminal region of Rho. For example, the mutant ³⁹KKART-⁴⁶ARGRGDNP-⁶⁶RYH (SEQ ID NO: 123) exhibit an excellent inhibitory to integrins $\alpha\text{v}\beta 3$ and $\alpha 5\beta 1$ but not to $\alpha\text{IIb}\beta 3$, $\alpha\text{v}\beta 5$, and $\alpha\text{v}\beta 6$ (Table 13). The mutations in the RGD loop and linker region increased its activity in inhibiting integrins $\alpha\text{v}\beta 3$ and $\alpha 5\beta 1$ and significantly decreased its activity in inhibiting integrin $\alpha\text{IIb}\beta 3$. The mutations on the C-terminal region decreased its activity in inhibiting integrins $\alpha\text{v}\beta 5$, and $\alpha\text{v}\beta 6$.

Example 4. Inhibition of Platelet Aggregation by Rho Mutants

[0141] Disintegrin (Rho) variants were also tested for their ability to inhibit platelet aggregation that is mediated by $\alpha\text{IIb}\beta 3$. Venous blood (9 parts) samples from healthy donors who had not received any medication for at least two weeks were collected in 3.8 % sodium citrate (1 part). Blood samples were centrifuged at 150 x g for 10 min to obtain platelet-rich plasma (PRP) and allowed to stand for 5 min, and PRP was collected. The platelet-poor plasma (PPP) was prepared from the remaining blood by centrifuging at 2000x g for 25 min. The PPP platelet count was measured on a hematology analyzer and diluted to 250,000 platelets/ μl . A solution of 190 μl of PRP and 10 μl of either Rho or PBS buffer were incubated for 5 min in a Hema Tracer 601 aggregometer at 37°C. Ten microliters of 200 μM adenosine diphosphate (ADP) were further added to monitor the

response of platelet aggregation by light transmission. The results on inhibition of platelet aggregation are also summarized in Tables 3 to 14 below.

[0142] Table 3: Integin Selectivity and Inhibition of Platelet Aggregation by the RXD Disintegrin Variants

Consensus Sequence		IC ₅₀ (nM)			Platelet Aggregation (nM)
		[Interaction towards targets]			
		α5β1	αVβ3	αIIbβ3	
49R□D (Rho wild type) (SEQ ID NO: 1)		216.0	11.4	17.8	77.5
1.	R□D (SEQ ID NO: 7)	14425.3	74.6	299.1	176.5
2.	R□D (SEQ ID NO: 8)	104452.5	2275.0	6122.3	1236.0
3.	R□D (SEQ ID NO: 9)	3296.0	63.9	2554.3	523.8
4.	R□D (SEQ ID NO: 10)	3043.3	32.4	1998.8	480.3
5.	R□D (SEQ ID NO: 11)	2604.3	119.9	4895.0	669.6
6.	R□D (SEQ ID NO: 12)	4915.6	188.7	185.4	414.4
7.	R□D (SEQ ID NO: 13)	3325.3	274.6	5486.6	652.6
8.	R□D (SEQ ID NO: 14)	1231.7	247.5	2001.6	508.3
9.	R□D (SEQ ID NO: 15)	1104.8	291.0	2425.8	476.5
10.	R□D (SEQ ID NO: 16)	6254.5	78.1	142.2	189.9
11.	R□D (SEQ ID NO: 17)	5420.6	54.1	1154.3	281.7
12.	R□D (SEQ ID NO: 18)	43192.0	88.0	647.1	186.7
13.	R□D (SEQ ID NO: 19)	77335.0	132.3	2920.6	539.4
14.	R□D (SEQ ID NO: 20)	131702.0	123.5	10688.3	1216.5
15.	R□D (SEQ ID NO: 21)	86954.5	89.9	35411.3	2162.3
16.	R□D (SEQ ID NO: 22)	6489.0	131.6	2109.0	465.7
17.	R□D (SEQ ID NO: 23)	150186.5	387.8	33915.7	1527.3
18.	R□D (SEQ ID NO: 24)	111949.0	404.2	4372.3	401.7

Table 4: Integrin Selectivity and Inhibition of Platelet Aggregation by the XRGD Disintegrin Variants

Consensus Sequence		IC ₅₀ (nM) [Interaction towards targets]			Platelet Aggregation (nM)
		$\alpha v\beta 3$	$\alpha 5\beta 1$	$\alpha IIb\beta 3$	
⁴⁸ P ¹ RGD (Rho wild type) (SEQ ID NO: 1)		13.0	256.8	21.0	83.2
1.	D ¹ RGD (SEQ ID NO: 26)	15.3	4188.3	860.2	631.3
2.	E ¹ RGD (SEQ ID NO: 27)	12.9	522.2	677.2	528.1
3.	G ¹ RGD (SEQ ID NO: 25)	19.6	92.2	68.4	370.2
4.	A ¹ RGD (SEQ ID NO: 32)	15.8	59.0	31.6	110.3
5.	T ¹ RGD (SEQ ID NO: 34)	20.4	139.4	38.6	214.6
6.	S ¹ RGD (SEQ ID NO: 33)	12.9	251.3	28.5	115.1
7.	Y ¹ RGD (SEQ ID NO: 41)	11.4	310.6	20.4	68.9
8.	W ¹ RGD (SEQ ID NO: 42)	41.0	248.2	39.8	142.0
9.	F ¹ RGD (SEQ ID NO: 40)	14.9	282.1	36.1	124.0
10.	L ¹ RGD (SEQ ID NO: 29)	11.3	283.4	22.1	168.0
11.	I ¹ RGD (SEQ ID NO: 30)	17.6	281.7	47.9	183.9
12.	V ¹ RGD (SEQ ID NO: 28)	19.5	194.7	47.6	136.9
13.	M ¹ RGD (SEQ ID NO: 31)	11.3	222.7	26.4	137.4
14.	Q ¹ RGD (SEQ ID NO: 36)	8.8	190.9	60.9	128.9

15.	☐ NRGD (SEQ ID NO: 35)	8.0	264.6	28.5	274.4
16.	☐ KRGD (SEQ ID NO: 38)	24.1	246.6	22.3	157.0
17.	☐ RRGD (SEQ ID NO: 37)	15.5	214.4	30.0	179.4
18.	☐ HRGD (SEQ ID NO: 39)	11.6	194.8	24.4	115.2

[0143] Table 5: Integrin Selectivity and Inhibition of Platelet Aggregation by the ARGDXP Disintegrin Variants

Consensus Sequence		IC ₅₀ (nM) [Interaction towards targets]			Platelet Aggregation (nM)
		$\alpha v\beta 3$	$\alpha 5\beta 1$	$\alpha IIb\beta 3$	
1.	⁴⁸ PARGDMP (wild type) (SEQ ID NO: 1)	13.0	256.8	21.0	83.2
2.	AARGDMP (SEQ ID NO: 32)	15.8	59.0	31.6	110.3
3.	AARGDDP (SEQ ID NO: 44)	45.3	5044.5	850.9	752.7
4.	AARGDEP (SEQ ID NO: 45)	156.3	2436.0	1063.0	518.8
5.	AARGDLP (SEQ ID NO: 46)	19.6	517.4	72.5	100.5
6.	AARGDVP (SEQ ID NO: 47)	21.5	368.2	36.2	145.7
7.	AARGDIP (SEQ ID NO: 48)	34.5	139.7	112.5	200.0
8.	AARGDKP (SEQ ID NO: 49)	18.8	199.7	70.5	106.9
9.	AARGDAP (SEQ ID NO: 50)	11.1	199.1	247.4	149.4
10.	AARGDSP (SEQ ID NO: 51)	36.9	138.8	71.6	146.2
11.	AARGDTP (SEQ ID NO: 52)	26.9	178.7	51.4	167.7
12.	AARGDNP (SEQ ID NO: 53)	18.3	44.1	262.7	213.6
13.	AARGDQP (SEQ ID NO: 54)	18.5	88.1	68.1	171.9
14.	AARGDWP (SEQ ID NO: 55)	29.6	52.0	12.4	129.8
15.	AARGDYP (SEQ ID NO: 56)	38.5	45.2	44.7	76.2

16.	ARGDFP (SEQ ID NO: 57)	17.5	51.1	16.6	99.4
17.	ARGDHP (SEQ ID NO: 58)	55.0	91.9	39.1	97.8
18.	ARGDRP (SEQ ID NO: 59)	3.0	49.1	51.2	77.1
19.	ARGDGP (SEQ ID NO: 60)	224.7	840.5	2643.3	359.6
20.	ARGDPP (SEQ ID NO: 61)	40940.0	62460.0	64665.0	49410.0

[0144] Table 6: Integrin Selectivity and Inhibition of Platelet Aggregation by the ARGDMX Disintegrin Variants

Consensus Sequence		IC ₅₀ (nM)			Platelet Aggregation (nM)
		[Interaction towards targets]			
		αvβ3	α5β1	αIIbβ3	
48PARGDMP (Rho wild type) (SEQ ID NO: 1)		13.0	256.8	21.0	83.2
1.	ARGDMP (SEQ ID NO: 32)	15.8	59.0	135.2	110.3
2.	ARGDMN (SEQ ID NO: 62)	97.2	4496.6	557.6	240.4
3.	ARGDMQ (SEQ ID NO: 63)	93.0	6212.3	2317.3	171.5
4.	ARGDMD (SEQ ID NO: 64)	144.6	11416.3	1198.3	196.1
5.	ARGDME (SEQ ID NO: 65)	196.0	5619.7	2792.0	200.8
6.	ARGDMH (SEQ ID NO: 66)	118.7	3329.3	3297.8	216.7
7.	ARGDMR (SEQ ID NO: 67)	213.8	9787.8	1142.4	86.5
8.	ARGDMK (SEQ ID NO: 68)	398.9	16794.7	1909.7	84.1
9.	ARGDMG (SEQ ID NO: 69)	83.5	4607.8	7057.7	224.5
10.	ARGDML (SEQ ID NO: 70)	57.4	785.6	1328.3	165.5
11.	ARGDMW (SEQ ID NO: 71)	18.6	1386.7	1002.0	130.2
12.	ARGDMF (SEQ ID NO: 72)	16.8	755.8	1280.0	187.5
13.	ARGDMY (SEQ ID NO: 73)	10.7	505.7	2212.7	160.1
14.	ARGDMM (SEQ ID NO: 74)	20.9	687.0	340.7	103.1

15.	ARGDMA (SEQ ID NO: 75)	11.3	1090.7	1237.3	138.6
16.	ARGDMI (SEQ ID NO: 76)	10.0	673.2	688.6	129.5
17.	ARGDMV (SEQ ID NO: 77)	12.9	139.1	181.6	139.3
18.	ARGDMT (SEQ ID NO: 78)	16.1	218.4	562.7	115.8

[0145] Table 7: Integrin Selectivity and Inhibition of Platelet Aggregation by the XXPRGD Disintegrin Variants

Consensus Sequence		IC ₅₀ (nM)			Platelet Aggregation (nM)
		[Interaction towards targets]			
		αvβ3	α5β1	αIIbβ3	
46RIPRGD (Rho wild type) (SEQ ID NO: 1)		13.0	256.8	21.7	83.2
1.	RR (SEQ ID NO: 79)	3.5	69.5	22.0	122.3
2.	RM (SEQ ID NO: 80)	8.3	393.3	31.5	198.4
3.	RV (SEQ ID NO: 81)	11.9	256.8	36.9	180.6
4.	RA (SEQ ID NO: 82)	15.5	383.0	94.1	178.4
5.	RQ (SEQ ID NO: 83)	15.9	768.1	63.6	200.3
6.	RE (SEQ ID NO: 84)	13.6	1292.3	51.1	189.7
7.	RF (SEQ ID NO: 85)	4.9	351.5	17.0	159.4
8.	RP (SEQ ID NO: 86)	18.8	460.7	89.3	397.7
9.	KR (SEQ ID NO: 87)	5.1	38.1	14.3	170.0
10.	KK (SEQ ID NO: 88)	14.2	76.6	36.7	235.5
11.	KM (SEQ ID NO: 89)	9.1	481.1	34.8	205.8
12.	KI (SEQ ID NO: 90)	12.1	449.8	70.3	152.7
13.					
14.	FI (SEQ ID NO: 91)	6.3	458.6	35.5	239.3
15.	QI	7.3	823.8	51.2	467.0

	(SEQ ID NO: 92)				
16.	AI (SEQ ID NO: 93)	62.1	1293.3	188.7	587.2
17.	EI (SEQ ID NO: 94)	18.7	913.4	477.1	1468.0

[0146] Table 8: Integrin Selectivity and Inhibition of Platelet Aggregation by the Disintegrin Variants with Mutant RGD Loop, Mutant Linker and/or Mutant C-Terminus

	Consensus Sequence			IC ₅₀ (nM)			
				[Interaction towards targets]			
				Platelet Aggregation	αIIbβ3	αVβ3	α5β1
	³⁹ SRAGK- ⁴⁶ RIPRGDMP- ⁶⁷ YH (Rho wild type) (SEQ ID NO: 1)			64.2	33.8	18.8	223.4
1.	KKKRT	RIPRGDMP	YH	104.5	25.6	1.3	76.1
	(SEQ ID NO: 127)						
2.	SRAGK	RIARGDNP	YH	125.4	256.0	22.6	40.0
	(SEQ ID NO: 128)						
3.	KKKRT	RIARGDNP	YH	88.2	133.4	5.9	10.0
	(SEQ ID NO: 129)						
4.	SRAGK	RIARGDNP	NGLYG	195.0	146.1	23.0	53.0
	(SEQ ID NO: 347)						
5.	KKKRT	RIARGDNP	NGLYG	160.2	31.7	3.7	11.5
	(SEQ ID NO: 131)						
6.	SRAGK	RRAARGDNP	NGLYG	199.8	85.0	9.6	10.9
	(SEQ ID NO: 130)						
7.	KKKRT	RRAARGDNP	NGLYG	147.6	31.4	3.6	2.7
	(SEQ ID NO: 132)						
8.	SRAGK	RRAARGDNP	NGLYG	233.7	98.7	2.5	2.2
	(SEQ ID NO: 130)						
9.	KKKRT	RRAARGDNP	NGLYG	153.5	44.3	3.2	1.6
	(SEQ ID NO: 132)						
10.	KKKRT	RIARGDNP	NGLYG	160.2	31.7	3.7	11.5
	(SEQ ID NO: 131)						
11.	AKKRT	RIARGDNP	NGLYG	132.2	27.6	6.9	64.0
	(SEQ ID NO: 138)						
12.	KAKRT	RIARGDNP	NGLYG	190.2	65.5	16.0	47.6
	(SEQ ID NO: 139)						
13.	KKART	RIARGDNP	NGLYG	157.5	34.2	3.5	15.5
	(SEQ ID NO: 140)						
14.	KKKAT	RIARGDNP	NGLYG	140.9	26.7	6.9	21.0
	(SEQ ID NO: 141)						
15.	KKKRA	RIARGDNP	NGLYG	192.2	78.4	19.2	58.2

	(SEQ ID NO: 142)						
16.	KAKRA	RIARGDNP	NGLYG	156.6	25.0	1.9	68.4
	(SEQ ID NO: 143)						
17.	SKAGT	RIARGDNP	NGLYG	174.6	124.4	23.7	71.3
	(SEQ ID NO: 144)						
18.	IEEGT	RIARGDNP	NGLYG	206.1	401.0	15.7	50.6
	(SEQ ID NO: 135)						
19.	KGAGK	RIARGDNP	NGLYG	176.0	43.8	9.8	116.1
	(SEQ ID NO: 136)						
20.	LKEGT	RIARGDNP	NGLYG	187.9	80.6	8.2	118.2
	(SEQ ID NO: 137)						
21.	MKKGT	RIARGDNP	NGLYG	178.5	151.8	4.0	113.4
	(SEQ ID NO: 134)						

[0147] Table 9: Integrin Selectivity and Inhibition of Platelet Aggregation by the Disintegrin Variants with Mutant C-Terminus

	Consensus Sequence	IC ₅₀ (nM)					
		[Interaction towards targets]					
		$\alpha v \beta 3$	$\alpha v \beta 5$	$\alpha v \beta 6$	$\alpha 5 \beta 1$	$\alpha IIb \beta 3$	Platelet Aggregation
	PRGDMP- ⁶⁵ P ^{RYH} (Rho wild type) (SEQ ID NO: 1)	13.0	94.4	176.2	256.8	52.2	83.2
1.	PRGDMP- ⁶⁵ P ^{RWNDL} (SEQ ID NO: 102)	9.8	88.5	133.7	365.9	53.7	100.9
2.	PRGDMP- ⁶⁵ P ^{RNRFH} (SEQ ID NO: 103)	15.0	162.9	140.8	590.8	81.8	107.9
3.	PRGDMP- ⁶⁵ P ^{RNRFHA} (SEQ ID NO: 104)	26.6	712.3	192.7	309.7	290.9	154.7
4.	PRGDMP- ⁶⁵ P ^{RNPWNG} (SEQ ID NO: 105)	40.7	681.1	160.2	260.0	235.2	121.9
5.	PRGDMP- ⁶⁵ P ^{RNGLYG} (SEQ ID NO: 106)	26.7	258.3	282.5	238.1	186.0	96.6
6.	PRGDMP- ⁶⁵ P ^{GLYG} (SEQ ID NO: 107)	30.1	274.8	1062.6	157.0	710.6	204.7

[0148] Table 10: Integrin Selectivity and Inhibition of Platelet Aggregation by the Disintegrin Variants

	Consensus Sequence	IC ₅₀ (nM)					
		[Interaction towards targets]					
		$\alpha v \beta 3$	$\alpha v \beta 5$	$\alpha v \beta 6$	$\alpha 5 \beta 1$	$\alpha IIb \beta 3$	Platelet Aggregation
	³⁹ SRAGK ⁴⁶ RIPR ^{GDMP} - ⁶⁵ P ^{RYH} (Rho wild type) (SEQ ID NO: 1)	13.0	94.4	176.2	256.8	52.2	83.2
1.	³⁹ KKART ⁴⁶ ARGRGDNP- ⁶⁵ P ^{GLYG} (SEQ ID NO: 124)	12.0	445.3	1081.8	27.8	133335.0	35253.2
2.	³⁹ KKART ⁴⁶ ARGRGDNP-	7.1	410.2	245.6	35.8	>95011.0	23790.5

	⁶⁵ P[P]LYG (SEQ ID NO: 160)						
3.	³⁹ KKART- ⁴⁶ ARGRGDNP- ⁶⁵ P[R]LYG (SEQ ID NO: 149)	6.8	363.5	417.0	6.5	43085.5	5208.5
4.	³⁹ KKART- ⁴⁶ ARGRGDNP- ⁶⁵ P[Y]LYG (SEQ ID NO: 120)	9.5	413.8	989.9	21.6	>136245.0	30285.5
5.	³⁹ KKART- ⁴⁶ ARGRGDNP- ⁶⁵ P[E]LYG (SEQ ID NO: 121)	13.6	720.2	986.8	15.3	>338956.0	46147.5

[0149] Table 11. Disintegrin Variants Specific to Integrins $\alpha v\beta 3$ and $\alpha 5\beta 1$

Consensus Sequence		IC ₅₀ (nM) [Interaction towards targets]					
		$\alpha v\beta 3$	$\alpha v\beta 5$	$\alpha v\beta 6$	$\alpha 5\beta 1$	$\alpha IIb\beta 3$	Platelet Aggregation
	³⁹ SRAGK- ⁴⁶ RIPRGDMP - ⁶⁶ RYH (Rho wild-type) (SEQ ID NO: 1)	13.0	94.4	176.2	256.8	52.2	83.2
1.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ GLYG (SEQ ID NO: 124)	12.0	445.3	1081.8	27.8	133335.0	35253.2
2.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ YLYG (SEQ ID NO: 120)	11.0	413.8	1072.7	7.5	136245.0	30285.5
3.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ ELYG (SEQ ID NO: 121)	13.6	720.2	979.4	16.9	643101.0	46147.5
4.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ DLYG (SEQ ID NO: 147)	6.6	833.7	1996.2	15.4	450958.0	84719.0

[0150] Table 12: Disintegrin Variants Specific to Integrins $\alpha v\beta 3$, $\alpha v\beta 5$, and $\alpha 5\beta 1$

Consensus Sequence		IC ₅₀ (nM)					
		[Interaction towards targets]					
		$\alpha v\beta 3$	$\alpha v\beta 5$	$\alpha v\beta 6$	$\alpha 5\beta 1$	$\alpha IIb\beta 3$	Platelet Aggregation
	³⁹ SRAGK- ⁴⁶ RIPRGDMP - ⁶⁶ RYH (Rho wild-type) (SEQ ID NO: 1)	13.0	94.4	176.2	256.8	52.2	83.2
1.	³⁹ SRAGK- ⁴⁶ RIARGDMP - ⁶⁶ RYH (SEQ ID NO: 43)	15.8	70.6	217.4	59.0	126.2	110.3
2.	³⁹ SRAGK- ⁴⁶ RIARGDDP - ⁶⁶ RYH (SEQ ID NO: 44)	45.3	6886.0	14980.5	5044.5	5117.2	752.7
3.	³⁹ SRAGK- ⁴⁶ RIARGDDL - ⁶⁶ RYH (SEQ ID NO: 338)	41.3	226.6	15734.5	526.7	1518.1	454.6
4.	³⁹ KKART- ⁴⁶ ARGRGDDL - ⁶⁶ GLYG (SEQ ID NO: 339)	42.5	242.5	17323.3	562.3	44232.2	47329.0

[0151] Table 13: Disintegrin Variants Specific to Integrins $\alpha v\beta x$ and $\alpha 5\beta 1$

Consensus Sequence		IC ₅₀ (nM)					
		[Interaction towards targets]					
		$\alpha v\beta 3$	$\alpha v\beta 5$	$\alpha v\beta 6$	$\alpha 5\beta 1$	$\alpha IIb\beta 3$	Platelet Aggregation
	³⁹ SRAGK- ⁴⁶ RIPRGDMP - ⁶⁶ RYH (Rho wild-type) (SEQ ID NO: 1)	13.0	94.4	176.2	256.8	52.2	83.2
1.	³⁹ SRAGK- ⁴⁶ RIARLDDL - ⁶⁶ RYH (SEQ ID NO: 125)	42.0	941.4	20683.3	14539.0	23171.0	10380.0
2.	³⁹ SRAGK- ⁴⁶ DDPRGDMP - ⁶⁶ RYH (SEQ ID NO: 126)	25.1	500.0	1251.5	8653.0	>44540.0	18922.3
3.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ RYH (KG, AR-NP) (SEQ ID NO: 123)	5.0	445.7	317.0	28.8	37925.0	4478.3
4.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ GLYG (KG-P) (SEQ ID NO: 124)	12.0	445.3	1081.8	27.8	133335.0	35253.2
5.	³⁹ KKART- ⁴⁶ ARGRGDNP - ⁶⁶ RWNDL (KG-WN) (SEQ ID NO: 171)	1.8	43.7	108	25.6	27985	4533

[0152] Table 14: Integrin Selectivity and Inhibition of Platelet Aggregation by Varying One or More of the Linker, RGD Loop and the C-Terminus

Consensus Sequence of Disintegrin Variant		IC ₅₀ (nM) [Interaction towards targets]			
		$\alpha 5\beta 1$	$\alpha V\beta 3$	$\alpha IIb\beta 3$	Platelet Aggregation
1.	----- ⁴⁸ ARGD ⁶⁵ PR (SEQ ID NO: 115)	3636.5	479.6	1588.3	107.1
2.	----- ⁴⁸ ARGD ⁶⁵ PRNGL (SEQ ID NO: 348)	5161.0	146.0	1086.3	69.9
3.	----- ⁴⁸ ARGD ⁶⁵ PRNGLYG (SEQ ID NO: 119)	9529.3	1191.8	245.2	83.4
4.	----- ⁴⁸ ARGD ⁶⁵ PRNPWNG (SEQ ID NO: 118)	2679.0	1259.0	184.7	132.7
5.	³⁹ KKKRT- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 131)	11.5± 1.3	3.7± 0.9	31.7± 4.7	160.2± 16.9
6.	³⁹ MKKGT- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 349)	113.4± 2.3	4.0± 0.8	151.8± 23.7	178.5± 10.3
7.	³⁹ IEEGT- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 135)	50.6± 5.0	15.7± 2.2	401.0± 77.9	206.1± 17.9
8.	³⁹ SRAGK- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 347)	53.0± 7.8	23.0± 7.1	146.1± 30.9	195.0± 45.7
9.	³⁹ KGAGK- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 136)	116.1± 19.9	9.8± 1.8	43.8± 3.5	176.0± 35.9
10.	³⁹ LKEGT- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 137)	118.2± 6.2	8.2± 0.5	80.6± 2.5	187.9± 25.7
11.	³⁹ AKKR ⁴³ T- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 138)	64.0± 3.9	6.9± 1.0	27.6± 6.5	132.2± 27.1
12.	^K ⁴⁰ AKR ⁴³ T- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 139)	47.6± 9.5	16.0± 2.4	65.5± 3.5	190.2± 16.5
13.	^{KK} ⁴¹ AR ⁴³ T- ⁴⁸ ARGDN ⁵³ P- ⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 140)	15.5± 3.2	3.5± 0.4	34.2± 5.3	157.5± 10.

Consensus Sequence of Disintegrin Variant		IC ₅₀ (nM) [Interaction towards targets]			
		$\alpha 5\beta 1$	$\alpha V\beta 3$	$\alpha IIb\beta 3$	Platelet Aggregation
14.	KKK ⁴² A ⁴³ T ⁻⁴⁸ ARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 141)	21.0± 2.2	6.9± 1.3	26.7± 4.7	140.9± 10.6
15.	KKKR ⁴³ A ⁻⁴⁸ ARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 142)	58.2± 6.7	19.2± 1.2	78.4± 11.5	192.2± 6.9
16.	³⁹ KAKRA ⁴³ ⁻⁴⁸ ARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 143)	68.4	1.9	25.0± 4.4	156.6± 28.2
17.	³⁹ SKAGT ⁴³ ⁻⁴⁸ ARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 144)	71.3	23.7	124.4± 0.9	174.6± 23.7
18.	³⁹ SRAGKICR ⁻⁴⁷ RARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 130)	2.2	2.5	98.7± 9.1	233.7± 22.3
19.	³⁹ KKKRTICR ⁻⁴⁷ RARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 132)	1.6	3.2	44.3± 10.1	153.5± 5.4
20.	⁹ KKKRT ⁻⁴⁶ ARARGDN ⁵³ P ⁻⁶⁷ NGLY ⁷¹ G (SEQ ID NO: 169)	2.7	3.6	31.4	147.6
21.	³⁹ KKKR ⁴³ T ⁻⁴⁸ PRGDM ⁵³ P ⁻⁶⁷ Y ⁶⁸ H (SEQ ID NO: 127)	76.1± 22.3 (3)	1.3± 0.2 (2)	25.6± 7.0(3)	104.5± 23.0
22.	³⁹ SRAG ⁴³ K ⁻⁴⁸ ARGDN ⁵³ P ⁻⁶⁷ Y ⁶⁸ H (SEQ ID NO: 128)	40.0± 5.8 (2)	22.6± 3.7 (2)	256.0± 8.5(2)	125.4± 25.4
23.	³⁹ KKKR ⁴³ T ⁻⁴⁸ ARGDN ⁵³ P ⁻⁶⁷ Y ⁶⁸ H (SEQ ID NO: 166)	10.0± 2.4 (3)	5.9± 1.0 (3)	133.4± 15.1(3)	88.2± 17.2

Example 5. Inhibition of Cell Migration by Disintegrin Variant and Wild Type of Rhodostomin

[0153] Transwell filters were equilibrated in serum containing DMEM for 2 h before use. DMEM containing 10% FBS was added to the lower compartments of the migration filters. In a volume of 100 ml serum-free DMEM, 2×10^4 A375 human melanoma cells were plated per transwell filter. Cells were allowed to migrate for 6 h at 37 °C in 5% CO₂, and were subsequently fixed by immersion of the filters in methanol for 15 min at room temperature. Rhodostomin, AR-NP (see Table 13 for consensus sequence), or PBS buffer were added into upper chamber. Filters were washed once with water, and were stained in 0.2% crystal violet in a 20% methanol/water solution for 10 min. Cells were removed from the upper surface of the membrane with a cotton swab. Cells that had migrated to the underside of the membrane were counted at 200x magnification from five random fields per membrane.

[0154] The inhibitory activity of Rho, AR-NP, or PBS buffer in this study as shown in Figure 2. Briefly, AR-NP markedly inhibited the migration of A375 human melanoma cells.

Example 6: Inhibition of Angiogenesis by Disintegrin Variants in Matrigel Angiogenesis Assay

[0155] The matrigel containing VEGF (100 ng/ml) and heparin (24–26 U/ml) is subcutaneously injected into B6 mice. After 5 days the gels are recovered, weighed and processed for hemoglobin quantification or histology as previously described. Hemoglobin content is measured with a Drabkin reagent kit 525 (Sigma). For histological analyses, the matrigel pellets are fixed in 4% paraformaldehyde and embedded in paraffin; four micron sections are stained with hematoxylin-eosin by standard procedures.

[0156] An aliquot (300 µl) of MATRIGEL™ (Becton Dickinson Lab.) containing VEGF (150 ng) and heparin (30 IU) was injected subcutaneously into the dorsal region of 6–8 week-old C57BL/6 mice. The MATRIGEL™ formed a plug rapidly. AR-NP (1mg/kg) or ARLDDL (SEQ ID NO: 351) (1mg/kg) (see Table 13 for consensus sequence) was administered once intravenously 24 hr later. After 5 days, plugs were taken and photographed (upper panel). Neovessels were quantified by measuring the hemoglobin of the plugs as an indication of blood vessel formation with the Drabkin method and Drabkin reagent kit 525

(Sigma) (B&C). The analysis showed that AR-NP was more effective than ARLDDL (SEQ ID NO: 351) when the drug was injected only once during 5 days angiogenesis period. See Figure 3.

Example 7: Inhibition of Angiogenesis by Hyperoxia/Normoxia-Driven Model of Retinopathy of Prematurity (ROP)

[0157] One-week-old C57BL/6j mice or ICR mice and their mothers are exposed to $75\% \pm 2\%$ oxygen for 5 days (hyperoxia) and then returned to normoxic conditions for another 5 day (hyperoxic period, P7 to P12) for inducing relative hypoxic conditions, and were then housed in room air for a further 7 days (hypoxic-induced angiogenic period, P12 to P19). AR-NP (1 pg) was administered via intravitreal route on Day 12 and the mice were sacrificed on Day-19. Unexposed control animals are kept in room air. The animals are maintained at a constant temperature of $21 \pm 1^\circ\text{C}$ and on a 12-hour light-dark cycle. Oxygen concentration is measured with an oximeter. At the end of the oxygen exposure (day 12) and 5 days after return to normoxic conditions (day 17), the pups are killed, and retinal angiogenesis is evaluated by neovessels and endothelial cells.

[0158] The results of this study were shown in Figure 4. The analysis showed that AR-NP significantly reduced angiogenesis in a mouse model of retinopathy.

Example 8: Inhibition of Angiogenesis by Disintegrin Variants in Mice Aortic Ring Assays

[0159] . The thoracic aortas of mice 8-12 weeks of age are dissected out and cut into rings approximately 0.5 mm in width. The aortic rings are mounted in 200 ml matrigel covered with DMEM supplemented with 2.5% FCS and 30 ng/ml VEGF with or without the appropriate inhibitors or control agents. The experiment was conducted in CO₂ incubator at 37°C. After 7 d in culture, the aortic rings are fixed with 4% formaldehyde and stained them with crystal violet. The number of sprouts grown from each ring by using inverted microscope was counted.

[0160] Mouse aortic rings were incubated with VEGF and 0.1 μM AR-NP in matrigel containing 100 mg/ml of fibronectin. The culture medium was changed every 3 days. Graphs showed the microvessel sprouting after 7 days culture. Note that AR-NP significantly reduced the vessel sprouting (see Fig. 5).

Example 9: Inhibition of Colony Formation by Disintegrin Variants on Breast Cancer Cells

[0161] The representative images in Figure 6 showed the results of colony formation assay. 4-T1 breast cancer cells were plated in 6-well dishes with a top layer of 0.35% agar

and a bottom layer of 0.7% agar in medium. 0.3 mL of medium is supplemented every 3 days. After 18 days, the number of cell clusters per dish is identified by crystal violet staining and counted. The analysis showed that both ARLDDL (SEQ ID NO: 351) (0.1 μ M & 1 μ M) and AR-NP (0.1 μ M & 1 μ M) inhibited colony formation of 4-T1 breast cancer cells.

Example 10: Inhibition of Osteoclastogenesis by Disintegrin Variants

[0162] Six- to eight-week-old SD rats are obtained from the Animal Center of National Laboratory and are kept under controlled conditions including a $22 \pm 1^\circ\text{C}$ room temperature and a 12-h light–dark cycle. Animals are fed with Purina Laboratory Rodent Diet and distilled water ad libitum. Bone marrow cells are prepared by removing from femurs and tibiae and flushing the bone marrow cavity with DMEM (Invitrogen, Carlsbad, California) which is supplemented with 20 mM HEPES and 10% heat-inactivated FBS, 2 mM glutamine, penicillin (100 U/ml) and streptomycin (100 g/ml). The non-adherent cells (hematopoietic cells) are collected after 24 hr and used as osteoclast precursors. Cells are seeded at 1×10^6 cells/well in 24-well plates in the presence of human recombinant soluble RANKL (50 ng/ml) and M-CSF (20 ng/ml). The culture medium is replaced every 3 days. Osteoclast formation is measured on Day-8 by TRAP staining. In brief, adherent cells are fixed with 10% formaldehyde in PBS for 3 min and then stained with Naphthol AS-MX phosphate and tartrate solution for 1 hr at 37°C . Osteoclast-like cells in each well are scored by counting the number of TRAP-positive and multinucleated cells containing more than three nuclei.

[0163] The protein drugs were added on D1–D7. IC₅₀ of osteoclastogenesis for $\alpha 5\beta 1$ and $\alpha \nu \beta 3$ dual integrin AR-NP is 3.61 nM. As shown in Figure 7, AR-NP protein or ARLDDL protein (SEQ ID NO: 351) inhibited RANKL-induced osteoclastogenesis in comparison with untreated control.

Example 11: Inhibition of Glioma Invasion by Disintegrin

[0164] Human glioma cells (U251) were cultured in upper chamber with matrigel containing 100 g/ml hyaluronan. Disintegrin variant was added in both upper and lower chambers. 24 hours later, the cells in the lower chamber were stained using crestal violet and counted. As shown in Figure 8, both ARLDDL (SEQ ID NO: 351) (0.1 μ M) and AR-NP (0.1 μ M) markedly inhibited glioma invasion.

Example 12: Effect of AR-NP on Blood Pressure and Heart Rate

[0165] Blood pressure and heart rate were recorded from tail using non-invasive method under isoflurane anesthesia in Wistar rat. AR-NP was administered from

tail vein after getting a stable measurement. Note that AR-NP at 5 mg/kg did not significantly affect blood pressure and heart rate (Figure 9). The usual dose of AR-NP for pharmacological effect is 1 mg/kg.

Example 13: Inhibition of A375 Melanoma Growth by AR-NP

[0166] A375 tumor cells (at 5×10^6) were injected subcutaneously in the flank of 4-5 week-old male SCID mice. One week after cell implantation, mice were injected with AR-NP (KKART-ARGRGDNP; SEQ ID NO: 350) (2 mg/kg, 5 days/week, i.p.). Tumor volume was measured every two days. Tumors were excised and weighed after 18 days of drug treatment. Scale bar: 1 cm. Note that AR-NP treatment markedly inhibited tumor growth (see Fig. 10).

Example 14: Inhibition of Tumor Growth by KG (AR-NP) in K-rasG12D transgenic mice

[0167] K-Ras^{G12D} transgenic mice was fed with 400 mg/L doxycycline to induce lung cancer. After 3.5 months, TG mice were intraperitoneally (IP) injected with 2mg/kg of AR-NP at two days interval for one month. Two weeks after fifteenth treatment, mice were sacrificed. Lungs were injected with India ink and fixated in Fekete's solution. The number of tumor nodules on lung were counted. **, P value < 0.001. As shown in Figure 11, the disintegrin variant (AR-NP) inhibited tumor growth in K-rasG12D transgenic mice.

Example 15: Inhibition of Brain Tumor Growth in U87-bearing Mice by KG

[0168] NOD-SCID mice were originally purchased and bred/maintained in a specific-pathogen-free vivarium with a well-controlled environment with a 12-h/12-h light/dark cycle and controlled humidity and temperature. 8-10 week-old mice weighing approximately 22-25 g were used. The mice were intraperitoneally anesthetized with a mixture of Dexdomitor/Zoletil (20 μ g/kg/2mg/kg), then placed in a stereotactic frame, and the skull was exposed by incision. U87-MG cells were harvested and adjusted to a density of 2.5×10^5 cells/ μ L in phosphate buffered saline (PBS) before intracranial injection. 2 μ L of U87-MG cells were injected into the striatum at the designated coordinates from the Bregma using a micro-infusion pump and 10-ml Hamilton syringe with a 30S-gage needle. The skull was then cleaned, the hole was sealed with bone wax, and the incision was sutured.

[0169] MRI was performed in a horizontal 7.0-T spectrometer with an active shielding gradient of 300 mT/m in 80 μ s. The outlines of the tumors were delineated based on the contrast provided by the T2WIs between the tumor and the brain tissues. The total tumor

volume (mm^3) was calculated by summing the tumor area across the slices covered by tumor using MR Vision software. Growth curves were plotted as the change in tumor volume at each time point. Starting from day 23 after tumor implantation, the mice were treated intravenously via tail vein with the disintegrin variant (AR-NP) only or a mixture at 5mg/kg once a day, five days a week. As shown by the results in Figure 12, the disintegrin variant (AR-NP) also inhibited tumor growth in U87-bearing mice.

[0170] While the invention has been described in detail, and with reference to specific embodiments thereof, it will be apparent to one of ordinary skill in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

What is claimed is:

1. A disintegrin variant of rhodostomin comprising the amino acid sequence of SEQ ID NO: 1, comprising a mutant RGD loop, wherein the amino acid sequence at positions 46 to 53 of SEQ ID NO: 1 is substituted with an amino acid sequence selected from the group consisting of SEQ ID NOs: 329, 330, 331, 353 and 354, and at least one selected from the group consisting of:
 - (a) a mutant linker, wherein the amino acid sequence at positions 39 to 45 of SEQ ID NO: 1 is substituted with an amino acid sequence selected from the group consisting of SEQ ID NO: 306 to SEQ ID NO: 317; and
 - (b) a mutant C-terminus, wherein the amino acid sequence at positions 65 to 68 of SEQ ID NO: 1 is substituted with an amino acid sequence selected from the group consisting of SEQ ID NOs: 319, 323, 324, 326, 327, 328, 337 and 352,wherein the disintegrin variant has an increased selectivity for at least one of $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha v\beta 8$ and $\alpha 5\beta 1$ integrins over $\alpha IIb\beta 3$ integrin as compared to wild-type rhodostomin having the amino acid sequence of SEQ ID NO: 1.
2. The disintegrin variant of claim 1, comprising the mutant RGD loop, the mutant linker and the mutant C-terminus.
3. The disintegrin variant of claim 1, comprising the amino acid sequence selected from the group consisting of SEQ ID NOs: 123, 124, 147, 149 and 171.
4. The disintegrin variant of any one of claims 1 to 3, wherein the disintegrin variant is pegylated or conjugated with albumin or Fc.
5. A polynucleotide encoding the disintegrin variant of any one of claims 1 to 4.
6. A recombinant host cell comprising a polynucleotide encoding the disintegrin

variant of any one of claims 1 to 4.

7. A pharmaceutical composition comprising the disintegrin variant of any one of claims 1 to 4 and a pharmaceutically acceptable carrier.
8. The pharmaceutical composition of claim 7, which is for treating a disease associated with at least one integrin selected from the group consisting of $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha v\beta 8$ and $\alpha 5\beta 1$ integrins in a subject in need thereof, wherein the disease is selected from the group consisting of osteoporosis, bone tumor or cancer growth and symptoms related thereto, angiogenesis-related tumor growth and metastasis, tumor metastasis in bone, malignancy-induced hypercalcemia, angiogenesis-related eye diseases, Paget's disease, rheumatic arthritis, and osteoarthritis.
9. The pharmaceutical composition of claim 8, wherein the integrin-associated disease is an angiogenesis-related eye disease selected from the group consisting of age-related macular degeneration, diabetic retinopathy, corneal neovascularizing diseases, ischaemia-induced neovascularizing retinopathy, high myopia, and retinopathy of prematurity.
10. The pharmaceutical composition of claim 8, wherein the integrin-associated disease is a cancer selected from the group consisting of metastatic melanoma, metastatic prostate cancer, metastatic breast cancer, colorectal carcinoma, liver cancer, ovarian cancer, cervical cancer, pancreatic cancer, non-small-cell lung cancer, and glioblastoma multiforme.
11. Use of a disintegrin variant of any one of claims 1 to 4 in the manufacture of a medicament for the treatment of a disease associated with at least one integrin selected from the group consisting of $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha v\beta 8$ and $\alpha 5\beta 1$ integrins in a subject in need thereof, wherein the disease is selected from the

group consisting of osteoporosis, bone tumor or cancer growth and symptoms related thereto, angiogenesis-related tumor growth and metastasis, tumor metastasis in bone, malignancy-induced hypercalcemia, angiogenesis-related eye diseases, Paget's disease, rheumatic arthritis, and osteoarthritis.

12. The disintegrin variant of claim 1, comprising a mutant RGD loop of SEQ ID NO: 331 and a mutant linker of SEQ ID NO: 313.
13. A disintegrin variant comprising the amino acid sequence selected from the group consisting of SEQ ID NOs: 120, 121, 123, 124, 129-132, 134-144, 147, 149, 160, 166, 169, 171, 339, 347, and 349.
14. A pharmaceutical composition comprising the disintegrin variant of claim 13 and a pharmaceutically acceptable carrier.
15. The pharmaceutical composition of claim 14, which is for treating a disease associated with at least one integrin selected from the group consisting of $\alpha v\beta 1$, $\alpha v\beta 3$, $\alpha v\beta 5$, $\alpha v\beta 6$, $\alpha v\beta 8$ and $\alpha 5\beta 1$ integrins in a subject in need thereof, wherein the disease is selected from the group consisting of osteoporosis, bone tumor or cancer growth and symptoms related thereto, angiogenesis-related tumor growth and metastasis, tumor metastasis in bone, malignancy-induced hypercalcemia, angiogenesis-related eye diseases, Paget's disease, rheumatic arthritis, and osteoarthritis.
16. The pharmaceutical composition of claim 14, wherein the integrin-associated disease is an angiogenesis-related eye disease selected from the group consisting of age-related macular degeneration, diabetic retinopathy, corneal neovascularizing diseases, ischaemia-induced neovascularizing retinopathy, high myopia, and retinopathy of prematurity.
17. The pharmaceutical composition of claim 14, wherein the integrin-associated

disease is a cancer selected from the group consisting of metastatic melanoma, metastatic prostate cancer, metastatic breast cancer, colorectal carcinoma, liver cancer, ovarian cancer, cervical cancer, pancreatic cancer, non-small-cell lung cancer, and glioblastoma multiforme.