Knottins are aminooxy residues that can be conjugated to molecules such as doxorubicin. The knottins produced in the present invention contain non-natural amino acids, and their formation is exemplified through the use of dimers derived from the aldehyde 4-formyl benzoic acid (4FB) and the oxime 4,9-Dioxa-1,2-dodecanediamine (1) to produce the compound (2).
CONJUGATED KNOTTIN MINI-PROTEINS CONTAINING NON-NATURAL AMINO ACIDS

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Patent Application No. 61/716,363 filed on October 19, 2012, which is hereby incorporated by reference in its entirety.

STATEMENT OF GOVERNMENTAL SUPPORT

This invention was made with Government support under contract R21 CA 143498 awarded by the National Cancer Institute. The Government has certain rights in this invention.

REFERENCE TO SEQUENCE LISTING, COMPUTER PROGRAM, OR COMPACT DISK

The instant application contains a Sequence Listing which has been submitted as an ASCII text file and is hereby incorporated by reference in its entirety. This text file was created on October 17, 2013, named 3815_114_l_Seq_list, and is 6517 bytes in size.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to the field of knottin mini-proteins (also known as cysteine-knot peptides), and to the field of chemoselective site-specific oxime conjugation chemistry, in particular incorporating a non-natural amino acid containing an aminooxy side chain, exemplified for use in knottin mini-proteins.

Related Art

The presently exemplified peptides contain engineered (i.e. artificially created) loops having a high binding affinity for cell surface adhesion receptors (e.g. integrins) which can mediate binding to the extracellular matrix (ECM). Altered ECM interactions play an important role in tumorigenesis. 1 Mediated by various receptors, these interactions are often
found to enhance tumor proliferation and aggressiveness. Integrins, a family of adhesion receptors, bind to components of ECM providing the anchorage that is necessary for cell division, migration, and invasion. Several integrins, including αβ3, αβ5, and α5β1 are overexpressed in certain types of cancer and tumor vasculature, and therefore inhibitors of these integrins have generated clinical interest.

Many integrin receptors bind to an Arg-Gly-Asp (RGD) peptide motif, and the residues around it determine specificity and affinity. Using a RGD motif, different examples of peptides, peptidomimetics, and proteins have been developed for potential cancer therapy, but peptide scaffolds have been less explored for such application.

Previously, we developed nanomolar-affinity αβ3, αβ5, and α5β1 integrin binding peptides by evolving a solvent exposed loop of cystine knot peptides, also known as knottins, using yeast surface display. The presently exemplified peptides may bind all three of the above integrins, or αβ3 only, or αβ3/αβ5 integrins.

Knottins have a disulfide-bonded framework and triple-stranded beta-sheet fold that often provides remarkable stability in harsh conditions, rendering them as promising candidates as pharmacophoric scaffolds for diagnostic and therapeutic applications. Additionally, knottins are attractive for protein engineering, because the disulfide-constrained loops tolerate sequence diversity.

Previously, low molecular weight scaffolds, including porphyrins, calixarenes, and carbohydrates have been shown to achieve orders of magnitude increase in binding strength through dimerization. However, larger scaffolds such as peptides that target integrins, have demonstrated only a several fold increase in binding strength with rarely improved therapeutic efficacy. Thus, there remains a need in the art for the development of peptides that bind integrins with significantly improved binding affinity.

Patents and Publications

Cochran et al. "Engineered Integrin Binding Peptides," US 2009/0257952, published 10/15/09, discloses the present engineered integrin-binding knottins, namely EETI 2.5F and 2.5D and AgRP 7C.

peptide with an aminooxy group. Chemoseletive oxime chemistry was used to provide an easy, one-step synthesis of [18F]FDG-RGG and [18F]FDG-cyclo(RGD<sup>DYK</sup>) as probes for positron emission tomography of U87MG tumor cells expressing α<sub>v</sub>β<sub>3</sub> integrins. The aminooxy group was part of the C terminal end of the peptide and coupled to a labeled fluoro-2-deoxyglucose molecule.

Lemieux, et al., "Chemoselective ligation reactions with proteins, oligosaccharides and cells," TIBTECH, December 1998 (Vol. 16), pp. 506-512, discloses that the reaction of aldehydes or ketones with aminooxy group can form oxime bonds used in the synthesis of multiple peptides. The aminooxy group can be used as a chemoselective coupling partner to ligate proteins. No specific examples of protein ligation using this group are given.


Schaffer et al., "Assembly of high-affinity insulin receptor agonists and antagonists from peptide building blocks," Proc. Nat. Acad. Sci. 100(8):4435-4439 (2003) discloses chemically linked dimers of peptides (S371, S446) that act as insulin receptor agonists. In one approach, the two peptides were prepared recombinantly with glycine/serine linkers; in another approach, they were chemoselectively ligated. A serine was attached to an amino group and subsequently oxidized to an aldehyde function. Triethylene or tetaethylene glycol was functionalized with an oxyamino function at each end and used to chemoselectively ligate two aldehydes by formation of stable oxime bonds.


**BRIEF SUMMARY OF THE INVENTION**

The following brief summary is not intended to include all features and aspects of the present invention, nor does it imply that the invention must include all features and aspects discussed in this summary.

In certain aspects, the present invention concerns engineered knottin proteins (e.g. EETI-II or AgRP) comprising a non-natural amino acid such as an aminooxy (AO) residue
that serves to provide a covalent bond to a linker molecule for creating multimeric (e.g. dimeric) peptides. The knottins are preferably engineered to contain a binding sequence for specifically recognizes a target, such as an RGD sequence to bind to integrins flanked by appropriate residues that facilitate binding. The linker molecule is covalently bound to two or more engineered knottins. In certain aspects, the present invention comprises the use of a non-natural amino acid introduced into the knottin for conjugation of an engineered integrin binding knottin to another molecule, such as a drug. The exemplified peptide dimers are shown to have increased binding strength to integrin receptor targets. At least one aminooxy (AO) residue is in a scaffold portion of a knottin polypeptide chain, and the knottin further contains a binding loop. The binding loop is composed of an amino acid sequence containing a binding motif, e.g. an RGD motif specific to bind to at least one of $\alpha_\nu\beta_3$ integrin, $\alpha_\nu\beta_5$ integrin and $\alpha_\nu\beta_\iota$ integrin.

In certain aspects of the present invention, the aminooxy (AO) residue has a side chain that is 2-amino-3-(2-(aminooxy)acetamido)propanoic acid.

In certain aspects of the present invention, the knottin proteins are dimerized through chemical conjugation and a linker molecule. The AO residue contains a side-chain with an aldehyde group, for attachment to the linker molecule. Functional groups binding to aldehydes are incorporated into the linker molecules.

In certain aspects of the present invention, the linker molecule is N,N’-((butane-1,4-diylbis(oxy))bis(propane-3,1-diyl))bis(4-formylbenzamide) (Fig. IB). The length of the linker molecule is selected to give approximately a 13 angstrom distance between the two knottin subunits within the dimer. This distance helps ensure unhindered interaction of both knottin subunits within the dimer to separate integrin receptors. Other distances may be used.

In certain aspects, the present invention relates to a knottin protein comprising an aminooxy residue conjugated to a small molecule. The small molecule contains a ketone or aldehyde group, or has a linker that contains a ketone or aldehyde group, that reacts with the AO residue for knottin conjugation. In certain aspects of the present invention, the small molecule is a therapeutic anticancer drug, such as doxorubicin, an anthracycline-based chemotherapeutic agent.
BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a drawing showing a chemical structures for 4-formyl benzoic acid (4FB) and 4,9-dioxa-1,12-dodecanediamine (1), which reacts to yield the dialdehyde linker 2.

Figure 1B is a schematic representation of oxime ligation of 2 and 3 to yield the dimeric knottin 4.

Figure 2A are flow cytometry histograms showing integrin (ανβ3, ανβ5, ας, and βι) expression on U87MG cells, a recognized cancer cell model (human glioblastoma-astrocytoma, epithelial-like cell line), as measured using integrin-specific antibodies. Since the α5 subunit can only pair with the βι subunit, the α5 histogram represents the amount of c^lintegrin complex expressed on the cell surface.

Figure 2B is a graph showing a competition assay of EETI-based integrin binding proteins 2.5F dimer and 2.5F monomer to U87MG cells, as measured by flow cytometry. Alexa488-labeled EETI 2.5F was used as a competitor. Monomeric EETI 2.5F with an introduced aminooxy residue is designated as 2.5F_AO. EETI-based peptides containing a scrambled sequence that does not bind integrin (FNRDG monomer and FNRDG dimer) are shown as negative controls.

Figure 2C is a graph showing a competition assay of AgRP-based integrin binding proteins: dimeric 7C and monomeric 7C to U87MG cells, as measured by flow cytometry. Alexa488-labeled AgRP 7C was used as a competitor. Monomeric AgRP 7C with aminooxy residue is designated as Monomeric 7C_AO. EETI-based peptides containing a scrambled sequence that does not bind integrin (monomeric FNRDG and dimeric FNRDG) are shown as negative controls.

Figure 3A is a graph measuring comparative inhibition of adhesion of U87MG cells treated with dimeric and monomeric 2.5F to fibronectin, a component of ECM. Fibronectin coated plates were incubated with U87MG cells with the indicated concentrations of peptides. Adherent cells remaining after several wash steps were quantified with crystal violet staining by absorbance at 600nm. EETI-based peptides containing a scrambled sequence that does not bind integrin (monomeric FNRDG and dimeric FNRDG) are shown as negative controls. Values were normalized to negative control containing no competing peptides.
Figure 3B is a panel of microscope images of the U87MG cells on culture plates after 24 h treatment with 500 nM of the indicated knottins.

Figure 4A is a bar graph showing time dependent cytotoxicity of U87MG cells after treatment with the indicated knottin mini-proteins. Cytotoxicity was monitored by incubating U87MG cells on culture plates with 500 nM of each knottin in 4% FBS media at 37°C and 5% CO₂ and measuring cell viability at 24, 48, and 72 h after the treatment using the AlamarBlue indicator dye.

Figure 4B is a bar graph showing dose dependent cytotoxicity of U87MG cells assessed by treating with different concentrations of knottins for 72 h and measuring cell viability using the AlamarBlue indicator dye.

Figure 5 is a drawing showing the general scheme for the conjugation of doxorubicin to the engineered knottin via an oxime bond.

Figure 6 is a graph showing a competition assay of EETI-based integrin binding proteins dimeric 2.5F and monomeric 2.5F to U87MG cells compared to Cilengitide, as measured by flow cytometry. Alexa488-labeled EETI 2.5F was used as a competitor.

Figure 7 is a graph measuring comparative inhibition of adhesion of U87MG cells treated with dimeric and monomeric 2.5F or Cilgenitide to fibronectin, a component of ECM. Fibronectin coated plates were incubated with U87MG cells with the indicated concentrations of peptides. Adherent cells remaining after several wash steps were quantified with crystal violet staining by absorbance at 600nm. Values were normalized to negative control containing no competing peptides.

Figure 8 is a bar graph showing dose dependent cytotoxicity of U87MG cells assessed by treating with different concentrations of dimeric or monomeric 2.5F or Cilgenitide for 72 h and measuring cell viability using the AlamarBlue indicator dye.

Figure 9 is a drawing showing the chemical structure for 4-formyl benzoic acid (4FB) as shown in Figure 1A, which was reacted with a different starting material to generate a longer cross-linker.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Definitions

The term "scaffold portion" or "molecular scaffold" means a polypeptide or portions thereof having a sequence that is used in combination with a binding loop portion and also having a specific three-dimensional structure, which presents the binding loop portion for optimal target binding. Typically a scaffold portion will be held in place by disulfide linkages between cysteine residues and will be based on a knottin sequence. The binding loop portion is held in place at terminal ends by the molecular scaffold portion. The term "molecular scaffold" has an art-recognized meaning (in other contexts), which is also intended here. For example, a review by Skerra, "Engineered protein scaffolds for molecular recognition," J. Mol. Recognit. 2000;13:167-187 describes the following scaffolds: single domains of antibodies of the immunoglobulin superfamily, protease inhibitors, helix-bundle proteins, disulfide-knotted peptides and lipocalins. Guidance is given for the selection of an appropriate molecular scaffold.

The term "binding loop portion" means a polypeptide having an amino acid sequence of about 9-13 residues. It contains a sequence that is constructed to bind to a target, thereby referred to an engineered loop. It is exogenous to the scaffold portion, which is derived from a knottin. It will further contain a sequence that is engineered to bind to a target, with high affinity, and that the not a knottin native target. For example, a binding loop portion can be created through experimental methods such as directed molecular evolution to bind to a specific ligand. That is, for example, the sequence contains an RGD sequence or the like, flanked by residues that dictate high affinity and specificity. It should be noted that these engineered loops are identified and optimized through combinatorial library screening, or simply grafted entirely from natural binding sequences present within known proteins. The term "specifically recognizes a target" refers to the presence of the binding loop portion having high affinity for binding to another molecule, such as binding to integrins, as described below. The present recognition involves binding at nanomolar concentrations, as exemplified below.

The term "knottin mini-protein", "knottin peptide", or "knottin protein" is used as accepted in the art and refers to a member of a family of small proteins, typically 25-50 amino acids in length, that bind to various molecular targets, including proteins, sugars and lipids. Their three-dimensional structure is minimally defined by a particular arrangement of
three disulfide bonds. This characteristic topology forms a molecular knot in which one disulfide bond passes through a macrocycle formed by the other two intrachain disulfide bridges. Although their secondary structure content is generally low, knottins share a small triple-stranded antiparallel β-sheet, which is stabilized by the disulfide bond framework.

Specific examples of knottins include the trypsin inhibitor EETI-II from *Ecballium elaterium* seeds, the neuronal N-type Ca\(^{2+}\) channel blocker ω-conotoxin from the venom of the predatory cone snail Conus geographus, the Agouti-related protein (See Millhauser et al., "Loops and Links: Structural Insights into the Remarkable Function of the Agouti-Related Protein," *Ann. N.Y. Acad. Sci.*, June 1, 2003; 994(1): 27 - 35), the omega agatoxin family, etc.

As will be understood from the description below, the knottins referred to herein are modified to contain a non-natural amino acid and an engineered binding loop, e.g. an integrin-binding loop containing the sequence RGD.

The term "amino acid" includes both naturally occurring and synthetic amino acids and includes both the D and L form of the acids. More specifically, amino acids contain up to ten carbon atoms. They may contain an additional carboxyl group, and heteroatoms such as nitrogen and sulfur. Preferably the amino acids are α and β-amino acids. The term α-amino acid refers to amino acids in which the amino group is attached to the carbon directly attached to the carboxyl group, which is the α-carbon. The term β-amino acid refers to amino acids in which the amino group is attached to a carbon one removed from the carboxyl group, which is the β-carbon. The amino acids described here are referred to in standard IUPAC single letter nomenclature, with "X" means in the present sequence listing, AO.

The non-natural amino acid "AO" is defined in the exemplified sequences as:

![Amino Acid Structure](image-url)
The term "aminooxy" is defined below as R’-0-NH2.

The term "EETI" means Protein Data Bank Entry (PDB) 2ETI. Its entry in the Knottin database is EETI-II. It has the sequence of SEQ ID NO: 1:

GC PRILMR CKQSDCLAGCVCGPNGFCG (SEQ ID NO: 1)

The term "AgRP" means PDB entry 1HYK. Its entry in the Knottin database is SwissProt AGRP_HUMAN, where the full-length sequence of 129 amino acids may be found. It comprises the sequence beginning at amino acid 87. An additional G is added to this construct. It also includes a C105A mutation described in Jackson, et al. 2002 Biochemistry, 41, 7565.

GCVRLHESCLGOQVPCCDPCATCYC RFFNAF CYCR—KLGTAMNPCSRT (SEQ ID NO: 10)

The dashed portion shows a fragment omitted in the "mini" version, below. The bold and underlined portion, from loop 4, is replaced by the engineered binding loop, having RGD sequences described below.

The term includes a "mini" AgRP, in reference to a truncated AgRP that means PDB entry 1MRO. It is also SwissProt AGRP_HUMAN. It has the sequence, similar to that given above,

GCVRLHESCLGOQVPCCDPAATCYC RFFNAF CYCR (SEQ ID NO: 6)

where the italicized "A" represents an amino acid substitution which eliminates a free cysteine. The bold and underlined portion, from loop 4, is replaced by the below described he RGD sequences in binding portions.

The term "cystine" refers to a Cys residue in which the sulfur group is linked to another amino acid though a disulfide linkage; the term "cysteine" refers to the -SH ("half cystine") form of the residue. Binding loop portions may be adjacent to cystines, i.e. there are no other intervening cystines in the primary sequence in the binding loop.

The term "non-natural amino acid" means an amino acid other than the 20 proteinogenic alpha-amino acids which in nature are the building blocks of all proteins within humans and other eukaryotes, and which are also directly encoded by the universal genetic
code. Such non-natural amino acids may be obtained commercially, and may be in a protected or unprotected form. See, for examples, the non-natural amino acid products available from HBCChem, Inc. described at http\(colon\slash slash\)hbcchem-inc.com/unnatural_AA.html.

The term "substantial identity" in the context of a peptide indicates that a peptide comprises a sequence with at least 70% sequence identity to a reference sequence, preferably 80%, more preferably 85%, most preferably at least 90% or at least 95% sequence identity to the reference sequence over a specified comparison window, which in this case is either the entire peptide, a molecular scaffold portion, or a binding loop portion (-9-11 residues). Preferably, optimal alignment is conducted using the homology alignment algorithm of Needleman and Wunsch (1970) J. Mol. Biol., 48:443 453. An indication that two peptide sequences are substantially identical is that one peptide is immunologically reactive with antibodies raised against the second peptide. Another indication for present purposes, that a sequence is substantially identical to a specific sequence explicitly exemplified is that the sequence in question will have an integrin binding affinity at least as high as the reference sequence. Thus, a peptide is substantially identical to a second peptide, for example, where the two peptides differ only by a conservative substitution. "Conservative substitutions" are well known, and exemplified, e.g., by the PAM 250 scoring matrix. Peptides that are "substantially similar" share sequences as noted above except that residue positions that are not identical may differ by conservative amino acid changes. As used herein, "sequence identity" or "identity" in the context of two nucleic acid or polypeptide sequences makes reference to the residues in the two sequences that are the same when aligned for maximum correspondence over a specified comparison window. When percentage of sequence identity is used in reference to proteins it is recognized that residue positions which are not identical often differ by conservative amino acid substitutions, where amino acid residues are substituted for other amino acid residues with similar chemical properties (e.g., charge or hydrophobicity) and therefore do not change the functional properties of the molecule. When sequences differ in conservative substitutions, the percent sequence identity may be adjusted upwards to correct for the conservative nature of the substitution. Sequences that differ by such conservative substitutions are said to have "sequence similarity" or "similarity." Means for making this adjustment are well known to those of skill in the art. Typically this involves scoring a conservative substitution as a partial rather than a full mismatch, thereby increasing
the percentage sequence identity. Thus, for example, where an identical amino acid is given a score of 1 and a non-conservative substitution is given a score of zero, a conservative substitution is given a score between zero and 1. The scoring of conservative substitutions is calculated, e.g., as implemented in the NIH Multiple alignment workshop (http colon:slash slash helixweb.nih.gov/multi-align/). Three-dimensional tools may also be used for sequence comparison.

As used herein, "percentage of sequence identity" means the value determined by comparing two optimally aligned sequences over a comparison window, wherein the portion of the polynucleotide sequence in the comparison window may comprise additions or deletions (i.e., gaps) as compared to the reference sequence (which does not comprise additions or deletions) for optimal alignment of the two sequences. The percentage is calculated by determining the number of positions at which the identical nucleic acid base or amino acid residue occurs in both sequences to yield the number of matched positions, dividing the number of matched positions by the total number of positions in the window of comparison, and multiplying the result by 100 to yield the percentage of sequence identity.

The term "lower alkyl" means a straight or branched chain hydrocarbon having from one to twelve carbon atoms, optionally substituted with substituents selected from the group consisting of lower alkyl, lower alkoxy, lower alkylsulfanyl, lower alkylsulfonyl, lower alkylsulfenyl, oxo, mercapto, amino optionally substituted by alkyl, carboxy, carbamoyl optionally substituted by alkyl, aminosulfonyl optionally substituted by alkyl, nitro, or lower perfluoroalkyl, multiple degrees of substitution being allowed. Examples of "alkyl" as used herein include, but are not limited to, n-butyl, n-pentyl, isobutyl, and isopropyl, and the like.

The term "alkylene" means a straight or branched chain divalent hydrocarbon radical having from one to ten carbon atoms, optionally substituted with substituents selected from the group which includes lower alkyl, lower alkoxy, lower alkylsulfanyl, lower alkylsulfonyl, lower alkylsulfenyl, oxo, hydroxy, mercapto, amino optionally substituted by alkyl, carboxy, carbamoyl optionally substituted by alkyl, aminosulfonyl optionally substituted by alkyl, nitro, cyano, halogen and lower perfluoroalkyl, multiple degrees of substitution being allowed. Examples of "alkylene" as used herein include, but are not limited to, methylene, ethylene, n-propylene, n-butylene, and the like.
As used herein, the term "alkyl" refers to a straight or branched chain hydrocarbon having from one to twelve carbon atoms, optionally substituted with substituents selected from the group consisting of lower alkyl, lower alkoxy, lower alkylsulfanyl, lower alkylsulfonyl, lower halogen, lower alkylsilyl, oxo, mercapto, amino optionally substituted by alkyl, carboxy, carbamoyl optionally substituted by alkyl, aminosulfonyl optionally substituted by alkyl, nitro, or lower perfluoroalkyl, multiple degrees of substitution being allowed. Examples of "alkyl" as used herein include, but are not limited to, n-butyl, n-pentyl, isobutyl, and isopropyl, and the like.

As used herein, the term "alkoxy" means the group R_aO—, where R_a is alkyl as defined above and the term "C_1-C_2 alkoxy" means the group R_aO—, where R_a is C_1-C_2 alkyl as defined above.

"Haloalkyl" refers to a straight or branched chain hydrocarbon containing at least 1 and at most 4, carbon atoms substituted with at least one halogen, halogen being as defined herein. Examples of branched or straight chained "C_1-C_4 haloalkyl" groups useful in the present invention include, but are not limited to, methyl, ethyl, propyl, isopropyl, isobutyl and n-butyl substituted independently with one or more halogens, e.g., fluoro, chloro, bromo and iodo.

As used herein, the term "haloalkoxy" means the group R_aO—, where R_a is haloalkyl as defined above and the term "C_1-C_2 haloalkoxy" means the group R_aO—, where R_a is C_2 haloalkyl as defined above.

The term "aryl" refers to an optionally substituted benzene ring or to an optionally substituted benzene ring system fused to one or more optionally substituted benzene rings to form, for example, anthracene, phenanthrene, or naphthalene ring systems. Exemplary optional substituents include lower alkyl, lower alkoxy, lower alkylsulfanyl, lower alkylsulfonyl, lower alkylsilyl, oxo, hydroxy, mercapto, amino optionally substituted by alkyl, carboxy, tetrazolyl, carbamoyl optionally substituted by alkyl, aminosulfonyl optionally substituted by alkyl, acyl, aroyl, heteroaryl, acyloxy, aroyloxy, heteroaryloxy, alkoxycarbonyl, nitro, cyano, halogen, lower perfluoroalkyl, heteroaryl, or aryl, multiple degrees of substitution being allowed. Examples of "aryl" groups include, but are not limited to, phenyl, 2-naphthyl, 1-naphthyl, biphenyl, as well as substituted derivatives thereof. As used herein, the term "aralkyl" refers to an aryl or heteroaryl group, as defined herein including both unsubstituted
and substituted versions thereof, attached through a lower alkylene linker, wherein lower alkylene is as defined herein. As used herein, the term "heteroaralkyl" is included within the scope of the term "aralkyl". The term heteroaralkyl is defined as a heteroaryl group, as defined herein, attached through a lower alkylene linker, lower alkylene is as defined herein. Examples of "aralkyl", including "heteroaralkyl", include, but are not limited to, benzyl, phenylpropyl, 2-pyridinylmethyl, 4-pyridinylmethyl, 3-isoxazolylmethyl, 5-methyl-3-isoxazolylmethyl, and 2-imidazoyly ethyl.

As used herein the term "aralkoxy" means the group $R_a R_b O —$, where $R_a$ is alkylene and $R_b$ is aryl, both as defined above.

As used herein, the term "alkylsulfanyl" means the group $R_a S —$, where $R_a$ is alkyl as defined above.

As used herein, the term "alkylsulfenyl" means the group $R_a S(0) —$, where $R_a$ is alkyl as defined above.

As used herein, the term "alkylsulfonyl" means the group $R_a S O_2 —$, where $R_a$ is alkyl as defined above.

As used herein, the term "oxo" means the group $=0$

As used herein, the term "mercapto" means the group $—SH$.

As used herein, the term "carboxy" means the group $—COOH$.


**General Overview**

The present invention relates to compositions and methods for providing a simple and efficient way to increase the binding strength of small engineered peptides such as knottin mini-proteins. A non-natural amino acid residue, containing an aminooxy (AO) side-chain, was incorporated into the native peptide backbone of two different classes of knottin scaffolds, *Ecballium elaterium* trypsin inhibitor (EETI) and the Agouti-related protein (AgRP).
As described above, knottin mini-proteins have a characteristic disulfide-bonded structure, which is illustrated in Gelly et al., "The KNOTTIN website and database: a new information system dedicated to the knottin scaffold," \textit{Nucleic Acids Research}, 2004, Vol. 32, Database issue D156-D159. A triple-stranded β-sheet is present in many knottnins. The spacing between Cys residues is important, as is the molecular topology and conformation of the RGD-containing integrin binding loop. These attributes are critical for high affinity integrin binding. The RGD mimic loop is inserted between knottin Cys residues, but the length of the loop must be adjusted for optimal integrin binding depending on the three-dimensional spacing between those Cys residues. For example, if the flanking Cys residues are linked to each other directly, the optimal loop may be shorter than if the flanking Cys residues are linked to Cys residues separated in primary sequence. Otherwise, particular amino acid substitutions can be introduced that constrain a longer RGD-containing loop into an optimal conformation for high affinity integrin binding.

Engineered integrin-binding variants of EETI and AgRP were site-selectively dimerized through a linker molecule, such as a polyether linker modified to contain two aldehyde groups (N,N’-((butane-1,4-diylbis(oxy))bis(propene-3,1-diyl))bis(4-formylbenzamide)). The conjugation chemistry is based on the chemoselective reaction of AO groups with aldehydes to form oxime groups. The present invention also relates to oxime-based conjugation of knottin mini-proteins to small molecules, such as drugs or imaging labels. The linker may be any suitable polymeric chain, including polyether, alkyl chain, polypeptide, β-peptide, or polypeptoid.

**Knottin mini-protein structures**

The present knottin mini-proteins comprise a molecular scaffold portion. They are generally held in a rigid three dimensional conformation by disulfide bonds formed between two cystine residues. Loop portions exist between the cystines.

Characteristics of a desirable scaffold for protein design and engineering include: 1) high stability \textit{in vitro} and \textit{in vivo}, 2) the ability to replace amino acid regions of the scaffold with other sequences without disrupting the overall fold, 3) the ability to create multifunctional or bispecific targeting by engineering separate regions of the molecule, and 4) a small size to allow for chemical synthesis and incorporation of non-natural amino acids if desired. Scaffolds derived from human proteins are favored for therapeutic applications to
reduce toxicity or immunogenicity concerns, but are not always a strict requirement. Other scaffolds that have been used for protein design include fibronectin (Koide et al., 1998), lipocalin (Beste et al., 1999), cytotoxic T lymphocyte-associated antigen 4 (CTLA-4) (Hufton et al., 2000), and tandemimstat (McConnell and Hoess, 1995; Li et al., 2003). While these scaffolds have proved to be useful frameworks for protein engineering, molecular scaffolds such as knottins have distinct advantages over other molecular scaffolds.

**Chemoselective Chemistry**

Chemical strategies frequently used for protein or peptide conjugation rely on amine- or thiol-based reactivity endogenous to the 20 genetically encoded amino acids. However, it is often difficult to produce homogeneous and site-selective conjugation products using these approaches. Multiple reactive amines (Lysine and N-terminal amino groups) are present in proteins and peptides, and redox active cysteines can have unpredictable and undesirable effects on protein folding and stability.

The present invention exploits the chemoselective formation of an oxime bond between an aldehyde and an aminooxy functional group, neither of which are found in genetically-encoded amino acids. An oxime is formed by condensation of an aminooxy group with either an aldehyde or a ketone, as shown in Figure 1. The basic scheme for oxime conjugation is as follows:

\[
\begin{align*}
R_1 & \quad \text{aldehyde} \\
R_2 & \quad \text{aminooxy group} \\
R_3 & \quad \text{any other group}
\end{align*}
\]

The above chemistry is exploited in the present invention by providing a knottin with an amino acid having a non-natural side chain. The side chain will have one of the shown groups, so that another moiety (such as a small molecule, monomer peptide, or linker) can be
conjugated by means of the side chain. In the examples shown in Figure A and IB, the peptide is engineered to contain a side chain with aminooxy group, and a linker is prepared to have ends with aldehydes, specifically benzamides.

In particular, the aminooxy residue exemplified in the present invention is 2-amino-3-(2-(aminooxy)acetamido)propanoic acid, which has the following structure and is denoted here as residue "AO" in various sequences described:

As shown above, this residue is incorporated into the knottin polypeptide chain using standard methods for Fmoc-based solid phase peptide synthesis.

As can be seen above, the amino acid side chain may be represented as -CH$_2$-NH-C(=O)-CH$_2$-O-NH$_2$. The required aminooxy group is bolded and underlined. Various modifications may be employed in the CH$_2$-NH-C(=0)-CH$_2$ portion of the side chain, and may be represented using the general formula R'-'0'-NH$_2$, where R' is lower alkyl, alkylene, aryl, alkoxy, haloalkyl, haloalkoxy, aralkoxy, alkylsulfanyl, alkylsulfenyl, or alkylsulfonyl.

The present knottin peptides will generally have about 25-50 amino acid residues and so may be prepared by solid phase peptide synthesis or equivalent methods. See, e.g. Collins "Water Soluble Solid Phase Peptide Synthesis," US 2012/0041173, published 2/16/2012.

Methods of synthesis that allow for the incorporation of non-natural amino acids may be employed, such as described in Shen et al., "Umpolung reactivity in amide and peptide synthesis," Nature 465;1027-1032 (24 June 2010).

Using solid phase peptide synthesis (SPPS), a non-natural amino acid with either an aminooxy or an aldehyde group can be incorporated at different knottin sequence positions to allow for a variety of linking sites. Knottin dimers produced through oxime-based chemistry.
can contain linkers of varying lengths to alter or optimize biological properties. Non-naturals may also be included into the present peptides by mutagenesis, as described, e.g. in Hohsaka et al, "Incorporation of non-natural amino acids into proteins," Curr. Opinion in Chemical Biology, 6:809-815 (2002).

The present non-natural amino acids will contain a side chain that may be coupled to a linker; as such, they may contain a side chain that is aminooxy, aldehyde, ketone, alkyne, alkene, aryl halide diene or azide. Guidance for use of such amino acids may be found in US Patent 6,858,396 to Dix, entitled "Positively charged non-natural amino acids, methods of making and using thereof in peptides", issued Feb. 22, 2005; Mao et al. US Patent 8,048,988, issued Nov. 1, 2011, entitled "Compositions containing, methods Involving, and uses of non-natural amino acids and peptides." In other embodiments, the present peptides may contain side chains that are aminooxy, aldehyde, ketone, alkyne, azide, alkene, aryl halide, or diene. In other embodiments, the present peptides may contain side chains that are aminooxy, aldehyde, or ketone.

The side chain used will be selected to be easily reacted with a specific reactive group contained in a linker. The linker will have functional groups on its ends that react with the side chain of each non-natural amino acid used.

Furthermore, knottins containing non-natural amino acids according to the present invention can be conjugated to a therapeutic molecule for drug delivery. Such small molecules can have an aldehyde or ketone group, or a linker that contains an aldehyde or ketone group, to react with the aminooxy group present within the knottin.

Knottins prepared as dimers

Aminooxy residues were incorporated into two different classes of knottins for oxime-based dimerization: Ecballium elaterium trypsin inhibitor (EETI) and a truncated form of the Agouti-related protein (AgRP). Knottin variants contain an aminooxy residue along with an RGD integrin binding sequence.

EETI was modified as follows:

\[ \text{GC } PRILMR [CKQDSDC*LAGCV[CGPNGFC**]}G. \quad (\text{SEQ ID NO: 1}) \]
The bold and underlined portion is replaced with a binding portion. As illustrated below, an integrin-binding sequence(s) containing the RGD motif is used instead as this portion. Additional loops, identified here as loops 2 (*) and 3(**), are shown in brackets. These loops are part of the scaffold portion can also be varied without affecting binding efficiency, as is demonstrated below. As can be seen, they are delimited by C residues.

EETI 2.5F was evolved from EETI to have specificity for ανβ3, ανβ5, and α5β1 integrin with antibody-like affinity. In previous studies, a K15S mutation allowed site-specific attachment of molecular imaging probes to the knottin N-terminus.

EETI 2.5F: \textbf{GCPiR}_2^2 P_3^3 RGDN}_{7^7} P_8^8 P_9^9 LioTiiCKQDSDCLAGCVC\textbf{GPGFCG} (SEQ ID NO: 2)

Again, the bolded portion is the binding portion. The following sequences contain a non-natural AO instead of K at position just carboxy to the binding sequence, which is numbered as 1-11.

EETI 2.5F\_AO: GC\textbf{P}R\textbf{P}GDNPPPLTXQDSDCLAGC\textbf{VGFCG} (SEQ ID NO: 3)

Another variant was constructed, based on EETI 2.5D, which binds ανβ3 and ανβ5 integrin:

EETI 2.5D: \textbf{GCPQGRGDWAPTSCKQDSDCRAGC\textbf{VGFCG}} (SEQ ID NO: 4)

EETI 2.5D\_AO: \textbf{GCPQGRGDWAPTSCKQDSDCRAGC\textbf{VGFCG}} (SEQ ID NO: 5)

Again, the binding portions are the binding portions. AgRP 7C is a 38-amino acid knottin peptide evolved from a truncated cystine-knot domain of AgRP to have antibody-like affinity for ανβ3 integrin. This referenced paper discloses a truncated form of the Agouti-related protein (AgRP), a 4-kDa knottin peptide with four disulfide bonds and four solvent-exposed loops, used as a scaffold to engineer peptides that bound to ανβ3 integrins with high affinity and specificity.

Truncated AgRP: \textbf{GCVRLHE\textbf{SCLI}GQQVP\textbf{C}DPAATCYCRFFNAFCYCR} (SEQ ID NO: 6). The bolded portion is replaced by the binding portions.

AgRP 7C: \textbf{GCVRLHE\textbf{SCLI}GQQVP\textbf{C}DPAATCYCYGRGDNDLRCYCR} (SEQ ID NO: 7)
AgRP 7C_AO: GCVRLHESCLGQQVPCCDPAATCYCYGRGDNDLRCYCX (SEQ ID NO: 8)

The present peptides can be produced by recombinant DNA methods or by solid phase peptide synthesis, which has been demonstrated for both classes of knottins described here. These peptides can be conjugated through their N-termini to other molecules containing amine-reactive groups, such as fluorescent dyes, radioisotopes, or small molecule drugs. Still further, these peptides may be synthesized with non-natural amino acids that allow for additional crosslinking functionality, such as alkyne or azide groups used in Huisgen cycloaddition ("click") chemistry. Crosslinked polystyrene resin containing Rink amide linkers, such as TentaGel S RAM Fmoc resin, (Advanced ChemTech) may be used to give a C-terminal amide upon cleavage. Peptides are cleaved from the resin and side-chains are deprotected with 8% trifluoroacetic acid, 2% triisopropylsilane, 5% dithiothreitol, and the final product is recovered by ether precipitation. Modified amino acids such as B-alanine are used as the N-terminal amino acid to prevent thiazolidone formation and release of fluorescein during peptide deprotection (Hermanson, 1996). Peptides are purified by reverse phase HPLC using an acetonitrile gradient in 0.1 % trifluoroacetic acid and a C4 or C18 column (Vydac) and verified using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF) or electrospray ionization-mass spectrometry (ESTMS).

The peptides specifically set forth herein may be modified in a number of ways. For example, the peptides may be further crosslinked internally, or may be crosslinked to each other, or the RGD-containing loops may be grafted onto other crosslinked molecular scaffolds. There are a number of commercially-available cross-linking reagents for preparing protein or peptide bioconjugates. Many of these crosslinkers allow dimeric homo- and heteroconjugation of biological molecules through free amine or sulfhydryl groups in protein side chains. More recently, other crosslinking methods involving coupling through carbohydrate groups with hydrazide moieties have been developed. These reagents have offered convenient, facile, crosslinking strategies for researchers with little or no chemistry experience in preparing bioconjugates.

Dimerization/multimerization and linkage

The present knottin monomers are linked to each other and/or to other molecules by means of the incorporation of a reactive residue within the chain of the monomer at a position
determined to be on the surface of the folded peptide. The reactive residue contains an
aminooxy group pendant to the peptide chain; the aminooxy group provides a basis for an
oxime linkage to another molecule, i.e. a "linking molecule," group containing an aldehyde
or ketone group. The linking molecule has two reactive aldehyde groups for the preparation
of a dimer of aminooxy-containing knottins; branched linking molecules may be used for
higher order knottin clusters, e.g. trimers, tetramers, pentamers, etc. The linker molecules is
chosen to provide a spacer between knottins to allow the engineered binding loop on each
knottin to interact with the cognate ligand, e.g. the ability of RGD in a binding loop to bind to
ανβ3 integrin on a tumor cell.

As discussed below, the selection of linker spacing and linker site provided here
allows "clustering" of knottin peptides and a surprising level of binding enhancement of the
multimer to the target. A linker as exemplified in Figure 1A has a diamine portion of 13
Angstroms and 17.3 Angstroms in the overall linker shown at compound 2, was used in the
present examples; linkers are generally chosen to contain flexible chains of about 20-100
atoms, and may comprise aliphatic and aromatic groups in a chain.

The AO group of the present knottins may also be used for conjugation to a variety of
small molecules, in particular anti-cancer drugs. As discussed below in connection with
Figure 5, an anthracycline antibiotic (doxorubicin) having a - C(=O)CH₂OH structure is
coupled to the knottin through the keto group. Other molecules, including the many known
analogs of doxorubicin may be coupled to the present knottins in this way.

EXAMPLES

EXAMPLE 1: Knottin Monomers

The aminooxy group was substituted for Lys15 in EETI2.5F and Arg38 in AgRP7C
since previous studies demonstrated flexibility of these positions. 1130 See SEQ ID NOs; 3, 5
and 8.

These knottin monomers were prepared by incorporating the aminooxy residue 2-
amino-3-(2-(aminooxy)acetamido)propanoic acid into the polypeptide using solid phase
peptide synthesis with an Fmoc-protected version.

EXAMPLE 2: Dimerization of knottin monomers
Because various lengths of diamine chains were readily available from vendors, the dialdehyde cross-linkers were prepared by conjugating two 4-formyl benzoic acid groups (4FB) to a diamine chain (Figure 1A, IB). 4,9-Dioxa-1,12-dodecanediamine (1) was chosen as the diamine chain to provide up to an approximately 13 Å distance between two covalently linked knottins since a shorter spacer length may hinder the dimeric interaction between the ligand and the receptor. 21,25 4FB was coupled to 1 with dicyclocarbodiimide and HOBt in CH₂C₁₂ at 0 °C for 2 h.

The compound 2 was purified with reverse phase HPLC (RP-HPLC) in 76% yield and conjugated to knottins containing an aminooxy residue (3) in phosphate buffer at 25 °C (Figure IB). After 1.5 h of incubation, the dimeric knottins (4) were purified with RP-HPLC in 96% yield (Table 1).

<table>
<thead>
<tr>
<th>Peptide</th>
<th>RP-HPLC&lt;sup&gt;a&lt;/sup&gt;</th>
<th>ESI-MS&lt;sup&gt;b&lt;/sup&gt;</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R&lt;sub&gt;t&lt;/sub&gt; (min)</td>
<td>[M + H]&lt;sup&gt;+&lt;/sup&gt;&lt;sub&gt;calc&lt;/sub&gt;</td>
<td>[M + H]&lt;sup&gt;+&lt;/sup&gt;&lt;sub&gt;exp&lt;/sub&gt;</td>
</tr>
<tr>
<td>Diaaldehyde linker</td>
<td>33.2</td>
<td>469.5</td>
<td>469.3</td>
</tr>
<tr>
<td>EETI 2.5F_AO</td>
<td>17.6</td>
<td>3365.6</td>
<td>3365.4</td>
</tr>
<tr>
<td>EETI 2.5F-Dimer</td>
<td>23.9</td>
<td>7162.7</td>
<td>7160.4</td>
</tr>
<tr>
<td>AgRP 7C_AO</td>
<td>18.5</td>
<td>4225.8</td>
<td>4226.3</td>
</tr>
<tr>
<td>AgRP 7C Dimer</td>
<td>22.3</td>
<td>8883.1</td>
<td>8883.0</td>
</tr>
<tr>
<td>FNRDG_AO</td>
<td>18.4</td>
<td>3178.3</td>
<td>3177.8</td>
</tr>
<tr>
<td>FNRDG-Dimer</td>
<td>23.9</td>
<td>6789.1</td>
<td>6788.0</td>
</tr>
</tbody>
</table>

<sup>a</sup>The gradient used for RP-HPLC is 10-60% solvent B (90% acetonitrile/10% water/0.1% trifluoroacetic acid) over 38 min. <sup>b</sup>Molecular masses were determined by electrospray ionization mass spectrometry (ESI-MS).

**EXAMPLE 3: Competition binding assay**

Competition binding assays were performed to measure the relative binding affinities of engineered knottins to U87MG cells expressing ανβ3, ανβ5, and αςβ1 integrins (Figure 2A, 2B, 2C). 2 x 10<sup>5</sup> U87MG cells were incubated at 4 °C for 10 h in integrin binding buffer.
(20 mM Tris pH 7.5, 1 mM MgCl₂, 1 mM MnCl₂, 2 mM CaCl₂, 100 mM NaCl, and 0.1% BSA) and varying concentrations of the peptides with 0.25 nM of Alexa488-labeled EETI 2.5F as a competitor for dimeric and monomeric EETI 2.5F, and 5 nM of Alexa488-labeled AgRP 7C as a competitor for dimeric and monomeric AgRP 7C. Half-maximal inhibitory concentration (IC₅₀) values were determined by nonlinear regression analysis using KaleidaGraph (Synergy Software), and are presented as the average of three separate experiments.

As shown by the IC₅₀ values, the apparent binding affinities of EETI2.5F and AgRP7C dimers increased by approximately 46- and 4-fold compared to the monomers, respectively (Table 2).

### Table 2: U87MG cell binding and adhesion data

<table>
<thead>
<tr>
<th>Ligand</th>
<th>Binding IC₅₀ (nM)</th>
<th>Adhesion EC₅₀ (nM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EETI 2.5F</td>
<td>1.64 ± 0.03</td>
<td>180 ± 14</td>
</tr>
<tr>
<td>EETI 2.5F_AO</td>
<td>1.57 ± 0.05</td>
<td>N.D.</td>
</tr>
<tr>
<td>EETI 2.5F Dimer</td>
<td>0.036 ± 0.002</td>
<td>8 ± 2</td>
</tr>
<tr>
<td>AgRP7C</td>
<td>13 ± 1</td>
<td>N.D.</td>
</tr>
<tr>
<td>AgRP 7C Dimer</td>
<td>3.2 ± 0.6</td>
<td>N.D.</td>
</tr>
<tr>
<td>FNRDG_AO</td>
<td>(---)</td>
<td>(---)</td>
</tr>
<tr>
<td>FNRDG Dimer</td>
<td>(---)</td>
<td>(---)</td>
</tr>
</tbody>
</table>

IC₅₀ values from competition binding assays (Figure 2) and EC₅₀ values cell adhesion assays (Figure 3) are summarized. (---) indicates very weak to no competition. N.D. = not determined

The scrambled EETI FNRDG monomer and dimer showed negligible binding, indicating that the binding observed is due to the specific interaction between the knottins and the integrins.
EXAMPLE 4: Inhibition of integrin-dependent cell adhesion.

Since the EETI 2.5F dimer showed remarkable improvement in integrin binding strength we analyzed its ability to block interaction between U87MG cells and fibronectin through a cell adhesion assay (Figure 3A). Fibronectin is known to interact with αβ3, αβ5, and α5β1 integrins, and our previous study showed that EETI 2.5F effectively blocks these interactions and detaches cells from fibronectin coated plates.

Varying concentrations of peptides were added to 4 x 10⁴ cells in 100 μl of IBB, incubated for 1 h at 37°C, 5% CO₂, and gently washed with Dulbecco’s PBS (DPBS, Invitrogen). Remaining adherent cells were incubated with 100 μl of 0.2% crystal violet and 10% ethanol for 10 min at room temperature, washed in DPBS and solubilized with 100 μl/well of a 50:50 mixture of 100mM sodium phosphate, pH 4.5 and ethanol for 10 min. The absorbance at 600 nm was measured using Synergy HT microplate reader (BioTek).

Both EETI 2.5F monomer and dimer were able to inhibit U87MG cell adhesion to fibronectin-coated plates in a dose-dependent manner. As shown by the IC₅₀ values, EETI 2.5F dimer was 100-fold more effective in preventing U87MG cell adhesion compared to the monomer, while the scrambled FNRDG monomer and dimer controls were not able to inhibit cell adhesion (Table 2). When incubated in the presence of 500 nM of EETI 2.5F monomer and dimer for 24 h in DMEM media with 4% FBS, U87MG cells exhibited a rounded morphology (Figure 3B).

EXAMPLE 5: Cytotoxicity of EETI 2.5F monomer and dimer with U87MG cells

To demonstrate the cytotoxicity of the EETI 2.5F monomer and dimer, U87MG cells were incubated in medium containing 4% FBS with 1 μM of the knottins on fibronectin coated plates, and the cell viability was determined after 24, 48, and 72 hours of treatment using AlamarBlue indicator reagent (Invitrogen).

Both EETI 2.5F monomer and dimer inhibited U87MG cell proliferation in time-dependent manner, with the dimer exhibiting significantly higher potency (Figure 4A). At a concentration of 500 nM, EETI 2.5F dimer induced 53 %, 68 %, and 69 % inhibition while EETI 2.5F monomer induced 37 %, 44 %, and 50 % inhibition after 24, 48, and 72 h of treatment, respectively. Dose-dependent inhibition of U87MG proliferation was also observed (Figure 4B). At concentrations of 1000 nM, 100 nM, and 10 nM after 72 hours of
treatment, EETI 2.5F dimer induced 70%, 52%, and 28% inhibition, while the EETI 2.5F monomer induced 60%, 30%, and 15% inhibition, respectively. The scrambled EETI FNRDG monomer and dimer did not induce significant inhibition, demonstrating that the cytotoxicity was mediated by binding to the integrins.

5 **EXAMPLE 6: Conjugation of Drugs for Targeted Delivery**

In this example, a knottin containing an aminooxy residue is added to a mixture containing a therapeutic molecule, such as doxorubicin. Mixed with PBS at 25°C, the ketone group on the therapeutic molecule doxorubicin interacts with the aminooxy group of the non-natural amino acid on the knottin peptide, producing the conjugate (Figure 5).

Conjugating a therapeutic small molecule to the knottin peptide provides an effective means for targeted drug delivery. Doxorubicin is used in cancer chemotherapy and interacts with DNA. Its ketone group can react with the aminooxy group of the knottin peptide monomer. Additionally, the knottins are able to traverse the vasculature, allowing delivery of the therapeutic agent to brain tumors.

EETI 2.5D and EETI 2.5F were conjugated with doxorubicin in this manner. The conjugate was purified using reverse phase HPLC with a 0.1% formic acid in acetonitrile gradient over 20 minutes. The conjugate elutes at 7.33 minutes (data not shown). The resulting purified conjugate was further verified using electrospray ionization-mass spectrosometry (ESTMS).

**Example 7: Exemplary peptide modifications**

The above-exemplified knottin sequences may be varied to produce other knottins for multimerization in that have substantial identity to those disclosed. The knottin sequences of the present invention, as described above, have (i) a scaffold portion, (ii) a binding loop portion, and (iii) an aminooxy (AO) residue or other non-natural amino acid. The non-natural amino acid is advantageously placed adjacent to a binding loop; however, in certain embodiments it may be placed at a terminus. The AO was placed at the C-terminus of AgRP.

The scaffold portion provides the structural framework and is made rigid by disulfide binds between the cystine residues underlined in the exemplary sequence by the engineered EETI-II, 2.5F_AO:
As to the binding loop (bolded in SEQ ID NO: 3), the RGD sequence should be invariant, as stated previously. The other positions may be substituted as taught in Cochran et al. US 20090257952, "Engineered Integrin Binding Peptides," published 10/15/2009. As stated there, the RGD-containing loop may be varied from the specific sequences disclosed. For example the loop sequence of EETI 2.5F, shown between P and C may be varied by 8 of the amino acids, but are invariant as to the RGD sequence. The other residues can be varied to a certain degree without affecting binding specificity and potency. For example, if three of the eleven residues were varied, one would have about 70% identity to 2.5F. For guidance in selecting which residues to vary, histograms in Figure 11 (of the previously cited 20090257952) presents information on likely residues for each position. For example, in position -3 (the first X), one would most likely use a proline residue, based on isolated mutants that had positive integrin binding. However, His or Leu are also possible choices, as shown by their higher incidence in mutants with good integrin binding properties.

In specific, the present engineered knottin peptides may be dimers that contain integrin binding portions, and the peptide comprising (i) a binding sequence specific to bind to at least one of αvβ5 integrin, αvβ3 integrin and α5β1 integrin, and (ii) a knottin protein scaffold, said binding sequence being comprised in said knottin protein scaffold and being an 11 amino acid engineered integrin binding loop, 11 amino acids long comprising the sequence RGD, wherein said RGD is in the sequence between residues 3 and 7 in an 11 residue binding loop; (iii), and said knottin protein scaffold, except for the engineered integrin binding loop, being substantially identical to one of: EETI-II, AgRP, mini-AGRP,
agatoxin or miniagatoxin, wherein, when the knottin protein scaffold is substantially identical to EETI-II, said integrin binding peptide has a sequence at least 90% identical having three or fewer amino acid substitutions to a peptide.

The present peptides contain at least one non-natural amino acid, in particular an amino acid residue with a side chain comprising an aminooxy, \(-\text{N-C}(=\text{O})-\text{CH}_2-\text{O-NH}_2\).

The present knottin may contain a binding loop portion between the 11 residues loop, said binding loop being within a scaffold portion, wherein said scaffold portion may have up to two amino acid substitutions so as to be at least 90% identical to SEQ ID NO: 3, SEQ NO: 5. Residue Pis in the binding loop above, (See SEQ NO: 2) can be selected from the group consisting of A, V, L, P, F, Y, S, H, D, and N; R is selected from the group consisting of G, V, L, P, R, E, and Q; P is selected from the group consisting of G, A, and P; N is selected from the group consisting of W and N; P is selected from the group consisting of A, P, and S; P is selected from the group consisting of P and R; \(L_{10}\) is selected from the group consisting of A, V, L, P, S, T, and E; and \(T_{11}\) is selected from the group consisting of G, A, W, S, T, K, and E.

**Variants of AgRp mini peptide**

\[\text{GCVRLHESLGQQVPCDDAPATC} \text{CYiG}_2 \text{RGDN}_6 \text{D}_7 \text{L}_8 \text{R}_9 \text{CYCX} \] (SEQ ID NO: 8) may be made, for example as follows, with respect to the binding loop (bolded above): \(\gamma_1\) may be F, W or H

\(G_2\) may be A, S or V

\(N_6\) may be D, Y

\(D_7\) may be N or Y

\(L_8\) may be I, V, or F, and

\(R_9\) may be K or N. The aminooxy (AO) residue is as illustrated above. In this embodiment, the AO non-natural amino acid is positioned at the carboxy terminus of the peptide.
As to the scaffold portion of the peptide (un-bolded) two to three amino acids may be substituted. This is shown for the following examples:

GCVRLHE S-y_CLGQQVPPCDDPAATCYCYiG 2RGDN6D7L8R9CYCX (SEQ ID NO: 9),
GCVRHESCLGQQVPPCDDPA A-CTCYCYiG 2RGDN6D7L8R9CYCX (SEQ ID NO: 11),
GCVRHESCLGQQVPPC E-PAAPACYiG 2RGDN6D7L8R9CYCX (SEQ ID NO: 12),
and so forth.

Variations of EETI-II

As further examples, one may vary the location of the non-natural amino acid. EETI-II 2.5F_AO has the AO (shown as "X") in place of the lysine at position 15:

GCPRPRGDNPPLTCXQDSDCLAGCVCGPNGFCG (SEQ ID NO: 3). In other words, As before, the binding loop is bolded. EETI 2.5F_AO may be shown by residue number as follows:


EETI 2.5F_AO-2 is GCPRPRGDNPPLTCQDSDCLAGCVCGPNGFCGX (SEQ ID NO: 13). This exemplified addition of the AO (shown as "X") to the carboxyl terminal end, i.e. following residue 33.

Using the above numbering, one may see that the AO residue or other non-natural amino acid may be used, for example in place of any one of residues A015-G23, residues G27-F31, or other loops. Another variant was constructed, based on EETI 2.5D, which binds αβ3 and αβ5 integrin:

EETI 2.5D GCPQGRGDWAPTSCKQDSDCRAGCVCGPNGFCG (SEQ ID NO: 4)
EETI 2.5D_AO GCPQGRGDWAPTSXQDSDCRAGCVCGPNGFCG (SEQ ID NO: 5), X = AO.

EETI 2.5D_AO has the same numbering as the EETI2.5F_AO, although the sequence is different; the AO residue is at position 15, as in EETI 2.5F-AO. Variations in sequences may be made as described in connection with sequence EETI 2.5F.
Example 8: Comparison of EETI 2.5F knottin monomer and dimer to Cilengitide

As is known, Cilengitide is a molecule designed and synthesized at the Technical University Munich in collaboration with Merck KGaA in Darmstadt. It is based on the cyclic peptide cyclo(-RGDFV-), which is selective for αv integrins, which are important in angiogenesis (forming new blood vessels). Hence, it is under investigation for the treatment of glioblastoma by inhibiting angiogenesis. The European Medicines Agency has granted cilengitide orphan drug status.

Relative U87MG binding affinity, and inhibition of U87MG cell adhesion and proliferation was measured for the EETI 2.5F dimer, EETI 2.5F monomer, and Cilengitide as described in Examples 3, 4, and 5. The relative binding affinity (IC₅₀) of Cilengitide to U87MG cells (using 0.25 nM of Alexa488-labeled EETI 2.5F as the competitor) was 4.1 ± 2 nM compared to 1.64 ± 0.03 nM for the EETI 2.5F monomer and 0.036 ± 0.002 nM for the EETI 2.5F dimer (Figure 6). Unlike the EETI 2.5F dimer and EETI 2.5F monomer, Cilengitide does not inhibit U87MG cell adhesion to fibronectin at the highest concentration tested (Figure 7). Remarkably, the EETI 2.5F dimer is 100-fold more potent at inhibiting cell proliferation compared to Cilengitide (Figure 8).

Example 9: Pharmaceutical compositions

The present engineered knottins may be used for imaging or for therapeutic purposes, as demonstrated above. The present peptides may also be formulated as pharmaceutical compositions for use in vivo in humans. Suitable formulations may be derived by reference to US 7,262,165, entitled "Aqueous preparation containing oligopeptides and etherified cyclodextrin," issued August 28, 2007. Briefly, as described there, the knottin to be used will be soluble in water or a suitable buffer such as physiological saline. Based on this solubility, a concentration of knottin peptide in the solution of the pharmaceutical composition may be determined. For example, if the peptide has a saturation solubility in physiological saline solution of about 19 mg/ml and it can therefore, for therapeutic use, be safely administered parenterally in a concentration of 15 mg/ml dissolved in physiological saline solution. If, for example, a dose of 1500 mg is necessary for therapy with the peptide, a volume to be
administered of 100 ml arises. Volumes in this order of magnitude can no longer simply be injected and must be infused, which is disadvantageous. Pharmaceutically acceptable ingredients may be added to increase solubility or tolerance for injection. The present peptides may also be formulated in enteric form (see e.g. US 5350741). Other formulations which may be employed are in Remington: The Science and Practice of Pharmacy, 19th Edition (1995) and/or Handbook of pharmaceutical granulation technology, chapter 7, "Drugs and the pharmaceutical sciences", vol. 81, 1997. In further embodiments of the present compositions, carriers are selected from hydrophilic binders, water-soluble diluents, surfactants, detergents, lubricants, disintegrants, antioxidants, non water-soluble diluents and/or other fillers known to the skilled person. In a particular embodiment the one or more carriers comprises at least a hydrophilic binder and a water-soluble diluent. Lyophilized formulations may be prepared as described in US 7,265,092, "Pharmaceutical compositions," issued September 4, 2007, to Li. as described there, various excipients and anti-aggregants may be used.

Parenteral administration is generally characterized by injection, either subcutaneously, intramuscularly, intraperitoneal, intravenously, and in the case of the present invention via intra-tumor injection. Injectable solutions can be prepared in conventional forms, either as liquid solutions or suspensions, solid (e.g., dried or lyophilized) forms suitable for reconstitution into solution or suspension in liquid prior to injection, or as emulsions. Generally, suitable excipients include, for example, water, saline, dextrose, glycerol, ethanol or the like. In addition, minor amounts of non-toxic auxiliary substances can be employed, such as wetting or emulsifying agents, pH buffering agents, solubility enhancers, tonicifiers and the like including, for example, sodium acetate, sorbitan monolaurate, triethanolamine olate, cyclodextrins, etc. Dosage forms for intravenous (IV) administration generally comprise an active peptide agent incorporated into a sterile solution of simple chemicals such as sugars, amino acids or electrolytes, which can be easily carried by the circulatory system and assimilated. Such solutions are typically prepared with saline or buffer. The pH of such IV fluids may vary, and will typically be from 3.5 to 8.0, as known in the art.

**Example 10: Cell inhibition of proliferation with dimer knottins**

Dimers of the present knottins with AO groups incorporated at different positions were prepared and conjugated with different linkages. There were tested for activity against carcinoma lines. Results are shown below in Table 3. As identified there, Dimer 1 is EETI
2.5F where the AO group was incorporated in place of Lys15, conjugated through the 17.3 Angstrom linker shown in Figure IB; Dimer 2 is EETI 2.5F, where the AO group was incorporated in place of Lys15, conjugated though the 68.5 Angstrom linker shown in Figure 9. Dimer 3 is EETI 2.5F, where the AO group was incorporated at the C-terminus following residue 33, conjugated through a 17.3 Angstrom linker shown in Figure IB; Dimer 4 is EETI 2.5F, where the AO group was incorporated at the C-terminus following residue 33, conjugated through the 68.5 Angstrom linker shown in Figure 9. It was observed that the position of the AO residue had a strong effect on binding activity. Peptide dimers with AO at position at 15 exhibited stronger binding than peptides with AO at the C-terminus. Also, it was observed that the length of the linkage had only a minor effect on binding. Binding, of course, it correlated with the activity in proliferation and apoptosis.

Table 3

<table>
<thead>
<tr>
<th>Cell line: MDA231 (Human breast adenocarcinoma)</th>
<th>Proliferation</th>
<th>Apoptosis (Caspase-3)</th>
</tr>
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<tbody>
<tr>
<td>Cilengitide</td>
<td>Weak inhibition</td>
<td>Moderate induction</td>
</tr>
<tr>
<td>2.5F Monomer</td>
<td>Weak inhibition</td>
<td>Moderate induction</td>
</tr>
<tr>
<td>2.5F Dimer1</td>
<td>Strong inhibition</td>
<td>Strong induction</td>
</tr>
<tr>
<td>2.5F Dimer2</td>
<td>Strong inhibition</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Dimer3</td>
<td>Moderate inhibition</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Dimer4</td>
<td>Moderate inhibition</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cell line: SKOV 3 (Ovarian adenocarcinoma)</th>
<th>Proliferation</th>
<th>Apoptosis (Caspase-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cilengitide</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Monomer</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Dimer1</td>
<td>Strong inhibition</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Dimer2</td>
<td>Strong inhibition</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Dimer3</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2.5F Dimer4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The results above indicate that EETI 2.5F Dimers 1 and 2 more strongly inhibited tumor cell proliferation compared to Dimers 3 and 4, demonstrating that the location of the AO group
within the knottin mattered (position 15 versus C-terminus), but the crosslinker length did not
(17.3 versus 68.5 angstroms). All dimers, however, were more potent at inhibiting tumor cell proliferation compared to EETI 2.5F monomer and Cilengitide.

**Example 11: Additional linkages**

As described above, the present dimers are constructed of two engineered knottin peptides (e.g. EET-II and AgRP), where the peptides contain a binding loop, and, in the scaffold portion, at least one non-natural amino residue. The non-natural amino residue has a side chain that can bond to a linkage molecule. By example, the non-natural amino acid contains an aminooxy functional group. The linker molecule contains functional groups in their terminal portions. Each linker molecule can bond to two different engineered peptides. For example, the linker molecules are terminated with aldehyde groups. Alternative, the linker molecules can carry more than two functional groups, to form multimers of 3, 4, 5, or more, engineered knottins.

**Figure 9** illustrates linkage molecules having terminal aldehyde groups (4-formylbenzamide) and an alkoxy chain linking the aldehyde-bearing groups. In the compound in **Figure 9**, 0,0'-Bis(2-aminoethyl)octadecaethylene glycol was reacted with 4-Formyl benzoic acid (4FB) (similarly to the method of Example 2) to generate the crosslinker: N,N'-(3,6,9,12,15,18,21,24, 27,30,33,36,39,42,45,48,51,54,57-nonadecaoxanonapentacontane-1,59-diyl)bis(4-formylbenzamide). As can be appreciated, the various ethylene glycol monomers can be varied; instead of 18, one could use 2, as in **Figure 1**, or any number in between. One could use more than 18, e.g. as between 18 and 40 ethylene glycol monomers.

**CONCLUSION**

The above specific description is meant to exemplify and illustrate the invention and should not be seen as limiting the scope of the invention, which is defined by the literal and equivalent scope of the appended claims. Any patents or publications mentioned in this specification, including the below cited references are indicative of levels of those skilled in the art to which the patent pertains and are intended to convey details of the invention which may not be explicitly set out but which would be understood by workers in the field. Such patents or publications are hereby incorporated by reference to the same extent as if each was
specifically and individually incorporated by reference, as needed for the purpose of
describing and enabling the methods and materials.

REFERENCES


CLAIMS

What is claimed is:

1. A knottin peptide comprising a scaffold portion having a sequence essentially identical to a sequence of EETI-II or AgRP; an exogenous binding loop portion having a sequence which specifically recognizes a target; and a non-natural amino acid comprised in the scaffold portion.

2. The knottin peptide of claim 1 wherein the non-natural amino acid contains a side chain that is either aminooxy, aldehyde, ketone, alkyne, alkene, aryl halide, diene or azide.

3. The knottin peptide of claim 1 or claim 2 further comprising a linker molecule and wherein said knottin peptide is part of a dimer wherein monomers knottin peptides are linked by the linker molecule.

4. The knottin peptide of claim 3 wherein monomers have a sequence at least 90% or at least 95% identical to a peptide of SEQ ID NO: 3 (EETI 2.5F_AO); SEQ NO: 13 (2.5F-AO-2); SEQ ID NO: 5 (EETI 2.5D_AO); or SEQ ID NO: 8 (AgRP 7C_AO).

5. The knottin peptide of claim 1 wherein the scaffold portion from EETI-II; and the non-natural amino acid has an aminooxy residue; and said aminooxy residues is at a position that is between residues 15 and 23, or else at a position between residues 27-31, inclusive.

6. The knottin peptide of claim 1 wherein the knottin peptide comprises a scaffold portion from AgRP and the non-natural amino acid has an aminooxy residue is between residues 35 and 38, inclusive.

7. The knottin peptide of claim 1 wherein the non-natural amino acid is a single residue that has a side chain aminooxy residue is 2-amino-3-(2-(aminooxy)acetamido)propanoic acid.

8. The knottin peptide of claim 1 wherein the binding loop portion contains the sequence RGD and is between two adjacent cystines in the peptide.

9. A composition comprising knottin peptides of any one of claims 4-8 bound to each other by a linker molecule.
10. The composition of claim 9 wherein the linker molecule is conjugated to an aminooxy residue incorporated within each knottin peptide.

11. The dimer of claim 10 formed with a linker molecule which is a polyethylene, alkyl chain, polypeptide, β-peptide, or peptoid.

12. A knottin peptide comprising an aminooxy residue, said residue is conjugated to a small molecule, or is conjugated to a molecular linker.

13. The knottin peptide of claim 12 having a sequence at least 90% identical to a peptide listed as SEQ ID NO: 3, SEQ ID NO: 5, or SEQ ID NO: 8.

14. The knottin peptide of claim 12 wherein the small molecule is doxorubicin.

15. A method of interfering with adhesion between a tumor cell and an extracellular matrix, comprising delivering to said tumor cell a peptide having at least two knottin peptides, both knottin peptides comprising an engineered binding loop containing an RGD sequence, said knottin peptides being linked through a non-natural amino acid residue contained thereon and a linker molecule bonded the non-natural amino acid residues.

16. The method of claim 15 wherein at least one knottin peptide is an EETI-II peptide in which a loop comprising the amino acid sequence PRILMR is replaced with an integrin-binding loop.

17. The method of claim 15 wherein both knottin peptides are identical.

18. The method of claim 15 wherein at least one knottin peptide is an AgRP peptide in which a loop comprising the amino acid sequence RFFNAF is replaced with an integrin binding loop.

19. The method of any one of claims 15-18 wherein both knottin peptides are identical.

20. The method of one of claim 19 wherein the non-natural amino acid is one bearing an aminooxy functional group.

21. The method of any one of claims 15 through 18 wherein the non-natural amino acid is one bearing an aminooxy functional group.

22. The method of claim 21 wherein the linker comprises terminal aldehyde.

23. The method of claim 21 wherein the aldehyde group is attached to an aryl ring.
24. The method of claim 21 wherein the linker is a polyethylene glycol chain containing two terminal aldehyde groups each attached to separate aryl rings.

25. A pharmaceutical composition of a knottin peptide comprising a scaffold portion, a binding loop portion, and an aminooxy residue adjacent to the binding loop portion.

26. The pharmaceutical composition of claim 25 wherein the knottin peptide is comprised in a multimeric form in which multiple knottin peptides are linked to each other through a linker bonded to an aminooxy residue in each knottin peptide.
**FIG. 1A**

4-Formyl benzoic acid (4FB)

4,9-Dioxa-1,12-dodecanediamine (1)

\[ \text{N,N'}-((\text{butane-1,4-diyl})\text{bis(oxy)})\text{bis(propane-3,1-diyl})\text{bis}(4\text{-formylbenzamide}) \] (2)

**FIG. 1B**

\[ \text{(2)} \]

\[ \text{(3)} \]

\[ \text{(4)} \]

**Figure 1A, 1B**
Figure 2A
Figure 2B
Figure 2C
Figure 3A
Figure 4A
FIG. 4B

Figure 4B
Figure 5
Figure 6
Figure 7
Figure 8
4-Formyl benzoic acid (4FB) + O,O’-Bis(2-aminoethyl)octadecaethylene glycol

N,N’-(3,6,9,12,15,18,21,24,27,30,33,36,39,42,45,48,51,54,57-nonadecaoxanonapentacontane-1,59-diyl)bis(4-formylbenzamide)

Figure 9
A. CLASSIFICATION OF SUBJECT MATTER
C07K 19/00(2006.01)i, A61K 38/16(2006.01)i, A61P 35/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
C07K 19/00; C12P 21/04; C07K 14/00; C07K 20/00; A61K 38/16; A61P 35/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KrPO internal) & Keywords: cystine-knot peptide, kinttin peptide, scaffold, EETI-II, AgRP, binding loop, non-natural amino acid, aminooxy residue

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>A</td>
<td>US 2009-0257952 Al (COCHRAN, JENNIFER R. et al.) 15 Oct ober 2009 See abstract ; c laims 1, 3-4 , 7-8 and 13-15 .</td>
<td>1-8 , 12-26</td>
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<tr>
<td>A</td>
<td>wo 2012-064658 Al (THE BOARD OF TRUSTEES OF THE LELAND STANFORD JUNIOR UNIVERSITY) 18 May 2012 See abstract ; page 5 , lines 7-8 ; claims 1-2 , 4 and 24 .</td>
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<td>A</td>
<td>US 2011-0136740 Al (COCHRAN, JENNIFER R. et al.) 9 June 2011 See abstract ; claims 1 and 8-11 .</td>
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<td>A</td>
<td>KIMURA, RICHARD H. et al. , ’Engineered cyste ine knot pept ides that bind q VW β 3 , q VW β 5 , and q 5β I inte rgr ins with low-nanomo m Lar aff ini ty’ , Prot eins , 31 March 2009 , Vol. 77 , No. 2 , pp. 359-369 . See the whole document .</td>
<td>1-8 , 12-26</td>
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<td>A</td>
<td>KIMURA, RICHARD H. et al. , ’Engineered Knot tin Pept ides : A New Class of Agent s for Imaging Int egr in Expression in Living Subj ect s’ Cancer Reserach , 15 March 2009 , Vol. 69 . No. 6 , pp. 2435-2442. See the whole document .</td>
<td>1-8 , 12-26</td>
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</table>

Further documents are listed in the continuation of Box C. See patent family annex.

Date of the actual completion of the international search
27 January 2014 (27.01.2014)

Date of mailing of the international search report
28 January 2014 (28.01.2014)

Authorized officer
HEO, Joo Hyung

Telephone No. +82-42-811-8150

Form PCT/ISA/210 (second sheet) (July 2009)
<table>
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<th>Category</th>
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<th>Relevant to claim No.</th>
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<tr>
<td>A</td>
<td>CAIBERRY, PATRICK et al., &quot;Fluor ide-18 radi o labeling of pept ides bearing an aminooxy functional group to a prosthet ic ligand via an oxime bond”, Bioorganic &amp; Medicinal Chemistry Letters, 5 October 2011, Vol. 21, No. 23, pp. 6992-6995. See the whole document.</td>
<td>1-8, 12-26</td>
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<td>A</td>
<td>NCBI, GenBank access ion no. 1MR0_A (10 October 2012) See the whole document.</td>
<td>1-8, 12-26</td>
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</table>
This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. [X] Claims Nos. : 10-11
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
   Claims 10-11 are unclear since they are referring to the multiple dependent claims which do not comply with PCT Rule 6.4(a).

3. [X] Claims Nos. : 9
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- [ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- [ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- [ ] No protest accompanied the payment of additional search fees.
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<th>Patent family member(s)</th>
<th>Publication date</th>
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<tr>
<td></td>
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<td>WO 2008-045252 A3</td>
<td>07/08/2008</td>
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<td>18/05/2012</td>
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Form PCT/ISA/210 (patent family annex) (July 2009)