PEPTIDES AND COMPOUNDS THAT BIND TO A RECEPTOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to Application No. 60/498,740 filed on August 28, 2003.

FIELD OF THE INVENTION

The present invention provides peptides and compounds that bind to and activate the thrombopoietin receptor (c-mpl or TPO-R) or otherwise act as a TPO agonist. The invention has application in the fields of biochemistry and medicinal chemistry and particularly provides TPO agonists for use in the treatment of human disease.

BACKGROUND OF THE INVENTION

Megakaryocytes are bone marrow-derived cells, which are responsible for producing circulating blood platelets. Although comprising <0.25% of the bone marrow cells in most species, they have >10 times the volume of typical marrow cells. See Kuter, et. al., Proc. Natl. Acad. Sci. USA 91:11104-11108 (1994). Megakaryocytes undergo a process known as endomitosis whereby they replicate their nuclei but fail to undergo cell division and thereby give rise to polyploid cells. In response to a decreased platelet count, the endomitotic rate increases, higher ploidy megakaryocytes are formed, and the number of megakaryocytes may increase up to 3-fold. See Harker, J. Clin. Invest., 47:458-465 (1968). In contrast, in response to an elevated platelet count, the endomitotic rate decreases, lower ploidy megakaryocytes are formed, and the number of megakaryocytes may decrease by 50%.

The exact physiological feedback mechanism by which the mass of circulating platelets regulates the endomitotic rate and number of bone marrow megakaryocytes is not known. The circulating thrombopoietic factor involved in mediating this feedback loop is now thought to be thrombopoietin (TPO). More specifically, TPO has been shown to be the main humoral regulator in situations involving thrombocytopenia. See, e.g., Metcalf,

Nature, 369:519-520 (1994). TPO has been shown in several studies to increase platelet counts, increase platelet size, and increase isotope incorporation into platelets of recipient animals. Specifically, TPO is thought to affect megakaryocytopoiesis in several ways: (1) it produces increases in megakaryocyte size and number; (2) it produces an increase in DNA content, in the form of polyploidy, in megakaryocytes; (3) it increases megakaryocyte endomitosis; (4) it produces increased maturation of megakaryocytes; and (5) it produces an increase in the percentage of precursor cells, in the form of small acetylcholinesterase-positive cells, in the bone marrow.

Because platelets (thrombocytes) are necessary for blood clotting and when their numbers are very low a patient is at serious risk of death from catastrophic hemorrhage, TPO has potential useful application in both the diagnosis and the treatment of various hematological disorders, for example, diseases primarily due to platelet defects. Ongoing clinical trials with TPO have indicated that TPO can be administered safely to patients. In addition, recent studies have provided a basis for the projection of efficacy of TPO therapy in the treatment of thrombocytopenia, and particularly thrombocytopenia resulting from chemotherapy, radiation therapy, or bone marrow transplantation as treatment for cancer or lymphoma. See, e.g., McDonald, Am. J. Ped. Hematology/Oncology, 14:8-21 (1992).

The gene encoding TPO has been cloned and characterized. See Kuter, et al., Proc. Natl. Acad. Sci. USA, 91:11104-11108 (1994); Barley, et al., Cell 77:1117-1124 (1994); Kaushansky et al., Nature 369:568-571 (1994); Wendling, et al., Nature, 369:571-574 (1994); and Sauvage et al., Nature 369:533-538 (1994). Thrombopoietin is a glycoprotein with at least two forms, with apparent molecular masses of 25 kDa and 31 kDa, with a common N-terminal amino acid sequence. See, Bartley, et al., Cell, 77:1117-1124 (1994). Thrombopoietin appears to have two distinct regions separated by a potential Arg-Arg cleavage site. The amino-terminal region is highly conserved in man and mouse, and has some homology with erythropoietin and interferon-a and interferon-b. The carboxy-terminal region shows wide species divergence.

The DNA sequences and encoded peptide sequences for human TPO-R (also known as c-mpl) have been described. See Vigon, et al., Proc. Natl. Acad. Sci. USA, 89:5640-5644 (1992). TPO-R is a member of the hematopoietin growth factor receptor

family, a family characterized by a common structural design of the extracellular domain, including four conserved C residues in the N-terminal portion and a WSXWS motif (SEQ ID NO:1) close to the transmembrane region. See Bazan, Proc. Natl. Acad. Sci. USA, 87:6934-6938 (1990). Evidence that this receptor plays a functional role in hematopoiesis includes observations that its expression is restricted to spleen, bone marrow, or fetal liver in mice (see Souyri, et al., Cell 63:1137-1147 (1990)) and to megakaryocytes, platelets, and CD34+ cells in humans (see Methia, et al., Blood 82:1395-1401 (1993)). Furthermore, exposure of CD34+ cells to synthetic oligonucleotides antisense to mpl RNA significantly inhibits the appearance of megakaryocyte colonies without affecting erythroid or myeloid colony formation. Some workers postulate that the receptor functions as a homodimer, similar to the situation with the receptors for G-CSF and erythropoietin.

The availability of cloned genes for TPO-R facilitates the search for agonists of this important receptor. The availability of the recombinant receptor protein allows the study of receptor-ligand interaction in a variety of random and semi-random peptide diversity generation systems. These systems include the "peptides on plasmids" system described in U.S. Pat. Nos. 5,270,170 and 5,338,665; the "peptides on phage" system described in U.S. patent application Ser. No. 07/718,577, filed Jun. 20, 1991, U.S. patent application Ser. No. 07/541,108, filed Jun. 20, 1990, and in Cwirla, et al., Proc. Natl. Acad. Sci. USA, 87:6378-6382 (1990); the "polysome" system described in U.S. patent application Ser. No. 08/300,262, filed Sep. 2, 1994, which is a continuation-in-part application based on U.S. patent application Ser. No. 08/144,775, filed Oct. 29, 1993 and PCT WO 95/11992; the "encoded synthetic library" system described in U.S. patent application Ser. No. 08/146,886, filed Nov. 12, 1993, Ser. No. 07/946,239, filed Sep. 16, 1992, and Ser. No. 07/762,522, filed Sep. 18, 1991; and the "very large scale immobilized polymer synthesis" system described in U.S. Pat. No. 5,143,854; PCT Patent Publication No. 90/15070, published Dec. 13, 1990; U.S. patent application Ser. No. 07/624,120, filed Dec. 6, 1990; Fodor, et al., Science, 251:767-773 (2/1991); Dower, et al., Ann. Rep. Med. Chem., 26:271-180 (1991); and U.S. patent application Ser. No. 07/805,727, filed Dec. 6, 1991; each of the foregoing patent applications and publications is incorporated herein by reference.

The slow recovery of platelet levels in patients suffering from thrombocytopenia is a serious problem, and has lent urgency to the search for a blood growth factor agonist able to accelerate platelet regeneration. The present invention provides such an agonist.

SUMMARY OF THE INVENTION

This invention is directed, in part, to the novel and unexpected discovery that a defined low molecular weight peptide and peptide mimetic has strong binding properties to the TPO-R and can activate the TPO-R. Accordingly, the peptides and peptide mimetics can be useful for therapeutic purposes in treating conditions mediated by TPO (e.g., thrombocytopenia resulting from chemotherapy, radiation therapy, or bone marrow transfusions) as well as for diagnostic purposes in studying the mechanism of hematopoiesis and for the in vitro expansion of megakaroycytes and committed progenitor cells.

Peptides and peptide mimetics suitable for therapeutic and/or diagnostic purposes have an IC_{50} of about 2 mM or less, as determined by the binding affinity assay set forth in Example 3 below wherein a lower IC_{50} correlates to a stronger binding affinity to TPO-R. For pharmaceutical purposes, the peptides and peptidomimetics (or peptidemimetics) preferably have an IC_{50} of no more than about 100 μM, more preferably, no more than 500 nM. In a preferred embodiment, the molecular weight of the peptide or peptide mimetic is from about 250 to about 8,000 daltons. If the peptides of this invention are oligomerized, dimerized and/or derivatized with a hydrophilic polymer as described herein, the molecular weights of such peptides will be substantially greater and can range anywhere from about 500 to about 120,000 daltons, more preferable from about 8,000 to about 80,000 daltons.

When used for diagnostic purposes, the peptides and peptide mimetics of the present invention preferably are labeled with a detectable label and, accordingly, the peptides and peptide mimetics without such a label serve as intermediates in the preparation of labeled peptides and peptide mimetics.

A peptide meeting the defined criteria for molecular weight and binding affinity for TPO-R comprise 9 or more amino acids wherein the amino acids are naturally occurring or synthetic (non-naturally occurring) amino acids.

Accordingly, preferred peptides and peptide mimetics comprise a compound having:

(1) a molecular weight of less than about 5000 daltons, and

(2) a binding affinity to TPO-R as expressed by an IC_{50} of no more than about 100 μM,

wherein from zero to all of the --C(O)NH-- linkages of the peptide have been replaced by a linkage selected from the group consisting of a $-CH_2OC(O)NR$-- linkage; a phosphonate linkage; a -- $CH_2S(O)_2NR$-- linkage; a --CH_2NR-- linkage; and a --$C(O)NR^6$ -- linkage; and a --NHC(O)NH-- linkage where R is hydrogen or lower alkyl and R^6 is lower alkyl,

further wherein the N-terminus of said peptide or peptide mimetic is selected from the group consisting of a $-NRR^1$ group; a --NRC(O)R group; a --NRC(O)OR group; a --$NRS(O)_2R$ group; a --NHC(O)NHR group; a succinimide group; a benzyloxycarbonyl-NH-- group; and a benzyloxycarbonyl-NH-- group having from 1 to 3 substituents on the phenyl ring selected from the group consisting of lower alkyl, lower alkoxy, chloro, and bromo, where R and R^1 are independently selected from the group consisting of hydrogen and lower alkyl,

and still further wherein the C-terminus of said peptide or peptide mimetic has the formula --$C(O)R^2$ where R^2 is selected from the group consisting of hydroxy, lower alkoxy, and $-NR^3R^4$ where R^3 and R^4 are independently selected from the group consisting of hydrogen and lower alkyl and where the nitrogen atom of the $-NR^3R4$ group can optionally be the amine group of the N-terminus of the peptide so as to form a cyclic peptide,

and physiologically acceptable salts thereof.

In a related embodiment, the invention is directed to a labeled peptide or peptide mimetic comprising a peptide or peptide mimetic described as above having covalently attached thereto a label capable of detection.

In one embodiment, the core peptide comprises a sequence of amino acids: (SEQ ID NO:2)

$X_9\ X_8\ G\ X_1\ X_2\ X_3\ X_4\ X_5\ X_6\ X_7$

where X_9 is A, C, E, G, I, L , M, P, R, Q, S, T, or V; and X_8 is A, C, D, E, K, L, Q, R, S, T, or V; and X_6 is a b-(2-naphthyl)alanine (referred to herein as "2-Nal") residue. More preferably, X_9 is A or I; and X_8 is D, E, or K. Further X_1 is C, L, M, P, Q, V; X_2 is F, K, L, N, Q, R, S, T or V; X_3 is C, F, I, L, M, R, S, V or W; X_4 is any of the 20 genetically coded L-amino acids; X_5 is A, D, E, G, K, M, Q, R, S, T, V or Y; and X_7 is C, G, I, K, L, M, N, R or V.

A particularly preferred peptide includes the amino acid sequence (SEQ ID NO:3): I E G P T L R Q (2-Nal) L A A R A.

In another embodiment, the peptide compounds of the present invention are preferably dimerized or oligomerized to increase the affinity and/or activity of the compounds. An example of a preferred dimerized peptide compound includes, but is not limited to, the following:

I E G P T L R Q (2-Nal) L A A R A-X_{10}
\
$K(NH_2)$
/
I E G P T L R Q (2-Nal) L A A R A-X_{10}

Where X_{10} is a sarcosine or β-alanine residue (SEQ ID NO:4). The above structure can also be represented by the following structure: (H-IEGPTLRQ(2-Nal)LAARX$_{10}$)$_2$K-NH_2.

In yet a further embodiment, preferred peptides for use in this invention include peptides that are covalently attached to one or more of a variety of hydrophilic polymers. Suitable hydrophilic polymers 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, etc., as described in U.S. Patent No. 5,869,451, the entire content of which is hereby incorporated by reference.

The compounds described herein are useful for the prevention and treatment of diseases mediated by TPO, and particularly for treating hematological disorders, including but not limited to, thrombocytopenia resulting from chemotherapy, radiation therapy, or

bone marrow transfusions. Thus, the present invention also provides a method for treating wherein a patient having a disorder that is susceptible to treatment with a TPO agonist receives, or is administered, a therapeutically effective dose or amount of a compound of the present invention.

The invention also provides for pharmaceutical compositions comprising one or more of the compounds described herein and a physiologically acceptable carrier. These pharmaceutical compositions can be in a variety of forms including oral dosage forms, as well as inhalable powders and solutions and injectable and infusible solutions.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 shows and compares the activity of different compounds.

Fig. 2 shows and compares the activity of different compounds.

Fig. 3 shows and compares the in vivo change in platelet counts in rat demonstrating the relative potency of PEGylated compounds.

Figs 4 and 5 show and compare the number and volume of circulating platelets in a dose dependent manner, respectively.

DESCRIPTION OF SPECIFIC EMBODIMENTS

I. Definitions And General Parameters

The following definitions are set forth to illustrate and define the meaning and scope of the various terms used to describe the invention herein.

"Agonist" refers to a biologically active ligand which binds to its complementary biologically active receptor and activates the latter either to cause a biological response in the receptor or to enhance preexisting biological activity of the receptor.

"Pharmaceutically acceptable salts" refer to the non-toxic alkali metal, alkaline earth metal, and ammonium salts commonly used in the pharmaceutical industry including the sodium, potassium, lithium, calcium, magnesium, barium, ammonium, and protamine zinc salts, which are prepared by methods well known in the art. The term also includes non-toxic acid addition salts, which are generally prepared by reacting the compounds of this

invention with a suitable organic or inorganic acid. Representative salts include the hydrochloride, hydrobromide, sulfate, bisulfate, acetate, oxalate, valerate, oleate, laurate, borate, benzoate, lactate, phosphate, tosylate, citrate, maleate, fumarate, succinate, tartrate, napsylate, and the like.

"Pharmaceutically acceptable acid addition salt" refers to those salts which retain the biological effectiveness and properties of the free bases and which are not biologically or otherwise undesirable, formed with inorganic acids such as hydrochloric acid, hydrobromic acid, sulfuric acid, nitric acid, phosphoric acid and the like, and organic acids such as acetic acid, propionic acid, glycolic acid, pyruvic acid, oxalic acid, malic acid, malonic acid, succinic acid, maleic acid, fumaric acid, tartaric acid, citric acid, benzoic acid, cinnamic acid, mandelic acid, menthanesulfonic acid, ethanesulfonic acid, p-toluenesulfonic acid, salicylic acid and the like. For a description of pharmaceutically acceptable acid addition salts as prodrugs, see Bundgaard, H., supra.

"Pharmaceutically acceptable ester" refers to those esters which retain, upon hydrolysis of the ester bond, the biological effectiveness and properties of the carboxylic acid or alcohol and are not biologically or otherwise undesirable. For a description of pharmaceutically acceptable esters as prodrugs, see Bundgaard, H., ed., Design of Prodrugs, Elsevier Science Publishers, Amsterdam (1985). These esters are typically formed from the corresponding carboxylic acid and an alcohol. Generally, ester formation can be accomplished via conventional synthetic techniques. (See, e.g., March, Advanced Organic Chemistry, 4th Ed., John Wiley & Sons, New York (1992), 393-396 and references cited therein, and Mark, et al., Encyclopedia of Chemical Technology, John Wiley & Sons, New York (1980).) The alcohol component of the ester will generally comprise (i) a C_2 -C_{12} aliphatic alcohol that can or can not contain one or more double bonds and can or can not contain branched carbons or (ii) a C_7 -C_{12} aromatic or heteroaromatic alcohols. This invention also contemplates the use of those compositions which are both esters as described herein and at the same time are the pharmaceutically acceptable acid addition salts thereof.

"Pharmaceutically acceptable amide" refers to those amides which retain, upon hydrolysis of the amide bond, the biological effectiveness and properties of the carboxylic

acid or amine and are not biologically or otherwise undesirable. For a description of pharmaceutically acceptable amides as prodrugs, see Bundgaard, H., ed., Design of Prodrugs, Elsevier Science Publishers, Amsterdam (1985). These amides are typically formed from the corresponding carboxylic acid and an amine. Generally, amide formation can be accomplished via conventional synthetic techniques. (See, e.g., March, Advanced Organic Chemistry, 4th Ed., John Wiley & Sons, New York (1992), p. 393 and Mark, et al. Encyclopedia of Chemical Technology, John Wiley & Sons, New York (1980).) This invention also contemplates the use of those compositions which are both amides as described herein and at the same time are the pharmaceutically acceptable acid addition salts thereof.

"Pharmaceutically or therapeutically acceptable carrier" refers to a carrier medium which does not interfere with the effectiveness of the biological activity of the active ingredients and which is not toxic to the host or patient.

"Stereoisomer" refers to a chemical compound having the same molecular weight, chemical composition, and constitution as another, but with the atoms grouped differently. That is, certain identical chemical moieties are at different orientations in space and, therefore, when pure, has the ability to rotate the plane of polarized light. However, some pure stereoisomers may have an optical rotation that is so slight that it is undetectable with present instrumentation. The compounds of the instant invention may have one or more asymmetrical carbon atoms and therefore include various stereoisomers. All stereoisomers are included within the scope of the invention.

"Therapeutically- or pharmaceutically-effective amount" as applied to the compositions of the instant invention refers to the amount of composition sufficient to induce a desired biological result. That result can be alleviation of the signs, symptoms, or causes of a disease, or any other desired alteration of a biological system. In the present invention, the result will typically involve a decrease in the immunological and/or inflammatory responses to infection or tissue injury.

Amino acid residues in peptides are abbreviated as follows: Phenylalanine is Phe or F; Leucine is Leu or L; Isoleucine is Ile or I; Methionine is Met or M; Valine is Val or V;

Serine is Ser or S; Proline is Pro or P; Threonine is Thr or T; Alanine is Ala or A; Tyrosine is Tyr or Y; Histidine is His or H; Glutamine is Gln or Q; Asparagine is Asn or N; Lysine is Lys or K; Aspartic Acid is Asp or D; Glutamic Acid is Glu or E; Cysteine is Cys or C; Tryptophan is Trp or W; Arginine is Arg or R; and Glycine is Gly or G. Additionally, t-Buo is tert-bulyloxy, Bzl is benzyl, CHA is cyclohexylamine, Ac is acetyl, Me is methyl, Pen is penicillamine, Aib is aminoisobutyric acid, Nva is norvaline, Abu is aminobutyric acid, Thi is thienylalanine, OBn is O-benzyl, and hyp is hydroxyproline.

In addition to peptides consisting only of naturally-occurring amino acids, peptidomimetics or peptide analogs are also provided. Peptide analogs are commonly used in the pharmaceutical industry as non-peptide drugs with properties analogous to those of the template peptide. These types of non-peptide compound are termed " peptidemimetics" or "peptide mimetics" or "peptidomimetics" (Luthman, et al., A Textbook of Drug Design and Development, 14:386-406, 2nd Ed., Harwood Academic Publishers (1996); Joachim Grante, Angew. Chem. Int. Ed. Engl., 33:1699-1720 (1994); Fauchere, J., Adv. Drug Res., 15:29 (1986); Veber and Freidinger TINS, p. 392 (1985); and Evans, et al., J. Med. Chem. 30:1229 (1987), which are incorporated herein by reference). Peptide mimetics that are structurally similar to therapeutically useful peptides may be used to produce an equivalent or enhanced therapeutic or prophylactic effect. Generally, peptidomimetics are structurally similar to a paradigm polypeptide (i.e., a polypeptide that has a biological or pharmacological activity), such as naturally-occurring receptor-binding polypeptide, but have one or more peptide linkages optionally replaced by an alternative linkage such as --CH_2NH--, --CH_2S --, etc. by methods known in the art and further described in the following references: Spatola, A. F. in Chemistry and Biochemistry of Amino Acids, Peptides, and Proteins, B. Weinstein, eds., Marcel Dekker, New York, p. 267 (1983); Spatola, A. F., Vega Data (March 1983), Vol. 1, Issue 3, Peptide Backbone Modifications (general review); Morley, Trends Pharm. Sci. pp. 463-468 (1980), (general review); Hudson, et al., Int. J. Pept. Prot. Res., 14:177-185 (1979); Spatola, et al., Life Sci., 38:1243-1249 (1986); Hann, J. Chem. Soc. Perkin Trans. I, 307-314 (1982); Almquist, et al., J. Med. Chem., 23:1392-1398, (1980); Jennings-White, et al., Tetrahedron Lett. 23:2533 (1982); Szelke, et al., European Appln. EP 45665 (1982); Holladay, et al.,

Tetrahedron Lett., 24:4401-4404 (1983); and Hruby, Life Sci., 31:189-199 (1982); each of which is incorporated herein by reference. A particularly preferred non-peptide linkage is –CH_2NH--. Such peptide mimetics may have significant advantages over polypeptide embodiments, including, for example: more economical production, greater chemical stability, enhanced pharmacological properties (half-life, absorption, potency, efficacy, etc.), altered specificity (e.g., a broad-spectrum of biological activities), reduced antigenicity, and others. Labeling of peptidomimetics usually involves covalent attachment of one or more labels, directly or through a spacer (e.g., an amide group), to non-interfering position(s) on the peptidomimetic that are predicted by quantitative structure-activity data and/or molecular modeling. Such non-interfering positions generally are positions that do not form direct contacts with the macromolecules(s) (e.g., immunoglobulin superfamily molecules) to which the peptidomimetic binds to produce the therapeutic effect. Derivitization (e.g., labeling) of peptidomimetics should not substantially interfere with the desired biological or pharmacological activity of the peptidomimetic. Generally, peptidomimetics of receptor-binding peptides bind to the receptor with high affinity and possess detectable biological activity (i.e., are agonistic or antagonistic to one or more receptor-mediated phenotypic changes).

Systematic substitution of one or more amino acids of a consensus sequence with a D-amino acid of the same type (e.g., D-lysine in place of L-lysine) may be used to generate more stable peptides. In addition, constrained peptides comprising a consensus sequence or a substantially identical consensus sequence variation may be generated by methods known in the art (Rizo, et al., Ann. Rev. Biochem., 61:387 (1992), incorporated herein by reference); for example, by adding internal cysteine residues capable of forming intramolecular disulfide bridges which cyclize the peptide.

Synthetic or non-naturally occurring amino acids refer to amino acids which do not naturally occur in vivo but which, nevertheless, can be incorporated into the peptide structures described herein. Preferred synthetic amino acids are the D-α-amino acids of naturally occurring L-α-amino acid as well as non-naturally occurring D- and L-α-amino acids represented by the formula H_2NCHR^5COOH where R^5 is 1) a lower alkyl group, 2) a cycloalkyl group of from 3 to 7 carbon atoms, 3) a heterocycle of from 3 to 7 carbon atoms

and 1 to 2 heteroatoms selected from the group consisting of oxygen, sulfur, and nitrogen, 4) an aromatic residue of from 6 to 10 carbon atoms optionally having from 1 to 3 substituents on the aromatic nucleus selected from the group consisting of hydroxyl, lower alkoxy, amino, and carboxyl, 5) -alkylene-Y where alkylene is an alkylene group of from 1 to 7 carbon atoms and Y is selected from the group consisting of (a) hydroxy, (b) amino, (c) cycloalkyl and cycloalkenyl of from 3 to 7 carbon atoms, (d) aryl of from 6 to 10 carbon atoms optionally having from 1 to 3 substituents on the aromatic nucleus selected from the group consisting of hydroxyl, lower alkoxy, amino and carboxyl, (e) heterocyclic of from 3 to 7 carbon atoms and 1 to 2 heteroatoms selected from the group consisting of oxygen, sulfur, and nitrogen, (f) --C(O)R^2 where R^2 is selected from the group consisting of hydrogen, hydroxy, lower alkyl, lower alkoxy, and –NR^3 R^4 where R3 and R^4 are independently selected from the group consisting of hydrogen and lower alkyl, (g) --S(O)n R^6 where n is an integer from 1 to 2 and R^6 is lower alkyl and with the proviso that R^5 does not define a side chain of a naturally occurring amino acid.

Other preferred synthetic amino acids include amino acids wherein the amino group is separated from the carboxyl group by more than one carbon atom such as β-alanine, gamma-aminobutyric acid, and the like.

Particularly preferred synthetic amino acids include the D-amino acids of naturally occurring L-amino acids and in particular L-(2-naphthyl)-alanine (2-Nal).

"Detectable label" refers to materials, which when covalently attached to the peptides and peptide mimetics of this invention, permit detection of the peptide and peptide mimetics in vivo in the patient to whom the peptide or peptide mimetic has been administered. Suitable detectable labels are well known in the art and include, by way of example, radioisotopes, fluorescent labels (e.g., fluorescein), and the like. The particular detectable label employed is not critical and is selected relative to the amount of label to be employed as well as the toxicity of the label at the amount of label employed. Selection of the label relative to such factors is well within the skill of the art.

Covalent attachment of the detectable label to the peptide or peptide mimetic is accomplished by conventional methods well known in the art. For example, when the 125

I radioisotope is employed as the detectable label, covalent attachment of 125 I to the peptide or the peptide mimetic can be achieved by incorporating the amino acid tyrosine into the peptide or peptide mimetic and then iodimating the peptide (see, e.g., Weaner, et al., Synthesis and Applications of Isotopically Labelled Compounds, pp. 137-140 (1994)). If tyrosine is not present in the peptide or peptide mimetic, incorporation of tyrosine to the N or C terminus of the peptide or peptide mimetic can be achieved by well known chemistry. Likewise, 32 P can be incorporated onto the peptide or peptide mimetic as a phosphate moiety through, for example, a hydroxyl group on the peptide or peptide mimetic using conventional chemistry.

II. Overview

The present invention provides compounds that bind to and activate the TPO-R or otherwise behave as a TPO agonist. These compounds include "lead" peptide compounds and "derivative" compounds constructed so as to have the same or similar molecular structure or shape as the lead compounds but that differ from the lead compounds either with respect to susceptibility to hydrolysis or proteolysis and/or with respect to other biological properties, such as increased affinity for the receptor. The present invention also provides compositions comprising an effective amount of a TPO agonist, and more particularly a compound, that is useful for treating hematological disorders, and particularly, thrombocytopenia associated with chemotherapy, radiation therapy, or bone marrow transfusions.

III. Identification Of TPO-Agonists

Peptides having a binding affinity to TPO-R can be readily identified by random peptide diversity generating systems coupled with an affinity enrichment process.

Specifically, random peptide diversity generating systems include the "peptides on plasmids" system described in U.S. Pat. Nos. 5,270,170 and 5,338,665; the "peptides on phage" system described in U.S. patent application Ser. No. 07/718,577, filed Jun. 20, 1991 which is a continuation in part application of U.S. patent application Ser. No. 07/541,108, filed Jun. 20, 1990, and in Cwirla, et al., Proc. Natl. Acad. Sci. USA, 87:6378-6382 (1990); the "polysome system" described in U.S. patent application Ser. No.

08/300,262, filed Sep. 2, 1994, which is a continuation-in-part application based on U.S. patent application Ser. No. 08/144,775, filed Oct. 29, 1993 and PCT WO 95/11992; the "encoded synthetic library (ESL)" system described in U.S. patent application Ser. No. 08/146,886, filed Nov. 12, 1993 which is a continuation in part application of U.S. patent application Ser. No. 07/946,239, filed Sep. 16, 1992, which is a continuation in part application of U.S. patent application Ser. No. 07/762,522, filed Sep. 18, 1991; and the "very large scale immobilized polymer synthesis" system described in U.S. Pat. No. 5,143,854; PCT Patent Publication No. 90/15070, published Dec. 13, 1990; U.S. patent application Ser. No. 07/624,120, filed Dec. 6, 1990; Fodor, et al., Science, 251:767-773 (2/1991); Dower, et al., Ann. Rep. Med. Chem., 26:271-180 (1991); and U.S. patent application Ser. No. 805,727, filed Dec. 6, 1991.

Using the procedures described above, random peptides were generally designed to have a defined number of amino acid residues in length (e.g., 12). To generate the collection of oligonucleotides encoding the random peptides, the codon motif (NNK)x, where N is nucleotide A, C, G, or T (equimolar; depending on the methodology employed, other nucleotides can be employed), K is G or T (equimolar), and x is an integer corresponding to the number of amino acids in the peptide (e.g., 12) was used to specify any one of the 32 possible codons resulting from the NNK motif: 1 for each of 12 amino acids, 2 for each of 5 amino acids, 3 for each of 3 amino acids, and only one of the three stop codons. Thus, the NNK motif encodes all of the amino acids, encodes only one stop codon, and reduces codon bias.

In the systems employed, the random peptides were presented either on the surface of a phage particle, as part of a fusion protein comprising either the pIII or the pVIII coat protein of a phage fd derivative (peptides on phage) or as a fusion protein with the LacI peptide fusion protein bound to a plasmid (peptides on plasmids).

The phage or plasmids, including the DNA encoding the peptides, were identified and isolated by an affinity enrichment process using immobilized TPO-R. The affinity enrichment process, sometimes called "panning," involves multiple rounds of incubating the phage, plasmids, or polysomes with the immobilized receptor, collecting the phage, plasmids, or polysomes that bind to the receptor (along with the accompanying DNA or

mRNA), and producing more of the phage or plasmids (along with the accompanying LacI-peptide fusion protein) collected. The extracellular domain (ECD) of the TPO-R typically was used during panning.

After several rounds of affinity enrichment, the phage or plasmids and accompanying peptides were examined by ELISA to determine if the peptides bind specifically to TPO-R. This assay was carried out similarly to the procedures used in the affinity enrichment process, except that after removing unbound phage, the wells were typically treated with rabbit anti-phage antibody, then with alkaline phosphatase (AP)-conjugated goat anti-rabbit antibody. The amount of alkaline phosphatase in each well was determined by standard methods. A similar ELISA procedure for use in the peptides on plasmids system is described in detail below.

By comparing test wells with control wells (no receptor), one can determine whether the fusion proteins bind to the receptor specifically. The phage pools found to bind to TPO-R were screened in a colony lift probing format using radiolabelled monovalent receptor. This probe can be produced using protein kinase A to phosphorylate a peptide sequence fused to the C-terminus of the soluble receptor. The "engineered" form of the TPO receptor is then expressed in host cells, typically CHO cells. Following PI-PLC harvest of the receptors, the receptor was tested for binding to TPO or TPO-R specific phage clones. The receptor is then labeled to high specific activity with 33 P for use as a monovalent probe to identify high affinity ligands using colony lifts.

Peptides found to bind specifically to the receptor were then synthesized as the free peptide (e.g., no phage) and tested in a blocking assay. The blocking assay was carried out in similar fashion to the ELISA, except that TPO or a reference peptide was added to the wells before the fusion protein (the control wells were of two types: (1) no receptor; and (2) no TPO or reference peptide). Fusion proteins for which the binding to the receptor was blocked by TPO or the reference peptide contain peptides in the random peptide portion that are preferred compounds of the invention.

TPO-R, as well as its extracellular domain, were produced in recombinant host cells. One useful form of TPO-R is constructed by expressing the protein as a soluble

protein in baculovirus transformed host cells using standard methods; another useful form is constructed with a signal peptide for protein secretion and for glycophospholipid membrane anchor attachment. This form of anchor attachment is called "PIG-tailing". See Caras, et al., Science, 243:1196-1198 (1989) and Lin, et al., Science, 249:677-679 (1990).

Using the PIG-tailing system, one can cleave the receptor from the surface of the cells expressing the receptor (e.g., transformed CHO cells selected for high level expression of receptor with a cell sorter) with phospholipase C. The cleaved receptor still comprises a carboxy terminal sequence of amino acids, called the "HPAP tail", from the signal protein for membrane attachment and can be immobilized without further purification. The recombinant receptor protein can be immobilized by coating the wells of microtiter plates with an anti-HPAP tail antibody (Ab 179 or MAb 179), blocking non-specific binding with bovine serum albumin (BSA) in PBS, and then binding cleaved recombinant receptor to the antibody. Using this procedure, one should perform the immobilization reaction in varying concentrations of receptor to determine the optimum amount for a given preparation, because different preparations of recombinant protein often contain different amounts of the desired protein. In addition, one should ensure that the immobilizing antibody is completely blocked (with TPO or some other blocking compound) during the affinity enrichment process. Otherwise, unblocked antibody can bind undesired phage during the affinity enrichment procedure. One can use peptides that bind to the immobilizing antibody to block unbound sites that remain after receptor immobilization to avoid this problem or one can simply immobilize the receptor directly to the wells of microtiter plates, without the aid of an immobilizing antibody. See U.S. patent application Ser. No. 07/947,339, filed Sep. 18, 1992, incorporated herein by reference.

When using random peptide generation systems that allow for multivalent ligand-receptor interaction, one must recognize that the density of the immobilized receptor is an important factor in determining the affinity of the ligands that can bind to the immobilized receptor. At higher receptor densities (e.g., each anti-receptor antibody-coated well treated with 0.25 to 0.5 mg of receptor), multivalent binding is more likely to occur than at lower receptor densities (e.g., each anti-receptor antibody-coated well treated with 0.5 to 1 ng of the receptor). If multivalent binding is occurring, then one will be more likely to isolate

ligands with relatively lower affinity, unless one uses high densities of immobilized receptor to identify lead compounds and uses lower receptor densities to isolate higher affinity derivative compounds.

To discriminate among higher affinity peptides, a monovalent receptor probe frequently is used. This probe can be produced using protein kinase A to phosphorylate a peptide sequence fused to the C-terminus of the soluble receptor. The "engineered" form of the TPO receptor is then expressed in host cells, typically CHO cells. Following PI-PLC harvest of the receptors, the receptor was tested for binding to TPO or TPO-R specific phage clones. The receptor is then labeled to high specific activity with 33 P for use as a monovalent probe to identify high affinity ligands using colony lifts.

Preferred screening methods to facilitate identification of peptides which bind TPO-R involve first identifying lead peptides which bind to the extracellular domain of the receptor and then making other peptides which resemble the lead peptides. Specifically, using a pIII or pVIII-based peptides on phage system, a random library can be screened to discover a phage that presents a peptide that binds to TPO-R. The phage DNAs are sequenced to determine the sequences of the peptides displayed on the surface of the phages.

Clones capable of specific binding to the TPO-R were identified from a random linear 10-mer pVIII library and a random cyclic 10-mer and 12-mer pVIII libraries. The sequences of these peptides serve as the basis for the construction of other peptide libraries designed to contain a high frequency of derivatives of the initially identified peptides. These libraries can be synthesized so as to favor the production of peptides that differ from the binding peptide in only a few residues. This approach involves the synthesis of an oligonucleotide with the binding peptide coding sequence, except that rather than using pure preparations of each of the four nucleoside triphosphates in the synthesis, one uses mixtures of the four nucleoside triphosphates (i.e., 55% of the "correct" nucleotide, and 15% each of the other three nucleotides is one preferred mixture for this purpose and 70% of the "correct" nucleotide and 10% of each of the other three nucleotides is another preferred mixture for this purpose) so as to generate derivatives of the binding peptide coding sequence.

A variety of strategies were used to derivatize the lead peptides by making "mutagenesis on a theme" libraries. These included a pVIII phagemid mutagenesis library based on the consensus sequence mutagenized at 70:10:10:10 frequency and extended on each terminus with random residues to produce clones.

The "peptides on plasmids" techniques was also used for peptide screening and mutagenesis studies and is described in greater detail in U.S. Pat. No. 5,338,665, which is incorporated herein by reference for all purposes. According to this approach, random peptides are fused at the C-terminus of LacI through expression from a plasmid vector carrying the fusion gene. Linkage of the LacI-peptide fusion to its encoding DNA occurs via the lacO sequences on the plasmid, forming a stable peptide-LacI-plasmid complex that can be screened by affinity purification (panning) on an immobilized receptor. The plasmids thus isolated can then be reintroduced into E. coli by electroporation to amplify the selected population for additional rounds of screening, or for the examination of individual clones.

In addition, random peptide screening and mutagenesis studies can be performed using a modified C-terminal Lac-I display system in which display valency was reduced ("headpiece dimer" display system). The libraries were screened and the resulting DNA inserts can be cloned as a pool into a maltose binding protein (MBP) vector allowing their expression as a C-terminal fusion protein. Crude cell lysates from randomly picked individual MBP fusion clones can then be assayed for TPO-R binding in an ELISA format, as discussed above.

Peptide mutagenesis studies can also be conducted using the polysome display system, as described in U.S. patent application Ser. No. 08/300,262, filed Sep. 2, 1994, which is a continuation-in-part application based on U.S. patent application Ser. No. 08/144,775, filed Oct. 29, 1993 and PCT WO 95/11992, each of which is incorporated herein by references for all purposes.

It was found that the core peptide can comprises a sequence of amino acids: (SEQ ID NO:2) X_9 X_8 G X_1 X_2 X_3 X_4 X_5 X_6 X_7, where X_6 may be β-(1-napthy)alanine and where X_9 is A, C, E, G, I, L , M, P, R, Q, S, T, or V; and X_8 is A, C, D, E, K, L, Q, R, S, T,

or V. More preferably, X_9 is A or I; and X_8 is D, E, or K. Further X_1 is C, L, M, P, Q, V; X_2 is F, K, L, N, Q, R, S, T or V; X_3 is C, F, I, L, M, R, S, V or W; X_4 is any of the 20 genetically coded L-amino acids; X_5 is A, D, E, G, K, M, Q, R, S, T, V or Y; and X_7 is C, G, I, K, L, M, N, R or V.

However, as described further below, it has been surprisingly found that by replacing X_6 with β-(2-napthy)alanine, the compound provides enhanced properties over the compound containing β-(1-napthy)alanine. Accordingly, a particularly preferred peptide includes the amino acid sequence (SEQ ID NO:3): I E G P T L R Q (2-Nal) L A A R A.

In another embodiment, the peptide compounds of the present invention are preferably dimerized or oligomerized to increase the affinity and/or activity of the compounds. An example of a preferred dimerized peptide compound includes, but is not limited to, the following:

I E G P T L R Q (2-Nal) L A A R A-X_{10}
\
$K(NH_2)$
/
I E G P T L R Q (2-Nal) L A A R A-X_{10}

Where X_{10} is a sarcosine or β-alanine residue (SEQ ID NO:4). It should be noted that one X_{10} residue can be sarcosine and the other residue can be β-alanine. The above structure can also be represented by the following: (H-IEGPTLRQ(2-Nal)LAARX_{10})$_2$K-NH2.

Peptides and peptidomimetics having an IC_{50} of greater than about 100 mM lack sufficient binding to permit use in either the diagnostic or therapeutic aspects of this invention. Preferably, for diagnostic purposes, the peptides and peptidomimetics have an IC_{50} of about 2 mM or less and, for pharmaceutical purposes, the peptides and peptidomimetics have an IC_{50} of about 100 μM or less.

Fig. 1 compares the activity of three different batches of un-PEGylated IEGPTLRQ(2-Nal)LAAR with un-PEGylated IEGPTLRQ(1-Nal)LAAR using standard

relative luminescent units assay techniques. The assay employs murine cells engineered to stably express the human TPO receptor and a luciferase reporter construct driven by the fos promoter. As shown from Fig. 1, the activity is similar for each compound.

Fig. 2 compares the activity of several different PEGylated peptides (pegylation of the compounds of the present invention is described in more detail below). Both of the PEGylated IEGPTLRQ(1-Nal)LAAR compounds show high activity with essentially the same level of activity as the un-PEGylated peptide. The remaining lines illustrate the activity of different PEGylated batches of dimerized IEGPTLRQ(2-Nal)LAAR. As shown by Fig. 2, in this model, the latter have less activity relative to the PEGylated IEGPTLRQ(1-Nal)LAAR compounds.

Fig. 3 demonstrates the relative potency of a PEGylated peptide containing β-(1-napthyl)alanine) and the PEGylated peptide containing β-(2-naphthyl)alanine. Through a rat model, Fig. 3 shows the in-vivo change in platelet counts after administration of dimerized PEGylated β-(2-naphthyl)alanine and β-(1-napthyl)alanine. As shown by Fig. 3, the highest dose of the PEGylated β-(2-naphthyl)alanine material has the same activity as the lowest dose of the PEGylated β-(1-napthyl)alanine. A less potent compound may provide a less drastic stimulus to the target cell, which could reduce the risk of side effects caused by overstimulation of the target cell, such as exacerbated thrombocytopenia following subsequent cycle of chemotherapy.

Figs. 4 and 5 show the results of a head-to-head dose response study of a PEGylated peptide containing β-(1-napthyl)alanine) and the PEGylated peptide containing β-(2-naphthyl)alanine in normal mice. Fig. 4 shows increases in platelet levels and Fig. 5 shows Mean Platelet Volume six (6) days following treatment. The dose range was from 10 to 3000ug/kg. Both compounds increased the number of circulating platelets in a dose-dependent manner with increases relative to the control group observed at doses as low as 30ug/kg for both compounds. At the maximal response, these compounds elevated platelet counts to levels that were up to 4-fold greater than control values. The dose-response curves for these compounds were very similar indicating that in this model there was essentially no difference between the two test articles based on these endpoints.

IV. Preparation of Peptides and Peptide Mimetics

A. Solid Phase Synthesis

The peptides of the invention can be prepared by classical methods known in the art, for example, by using standard solid phase techniques. The standard methods include exclusive solid phase synthesis, partial solid phase synthesis methods, fragment condensation, classical solution synthesis, and even by recombinant DNA technology. See, e.g., Merrifield, J. Am. Chem. Soc., 85:2149 (1963), incorporated herein by reference. On solid phase, the synthesis is typically commenced from the C-terminal end of the peptide using an alpha-amino protected resin. A suitable starting material can be prepared, for instance, by attaching the required alpha-amino acid to a chloromethylated resin, a hydroxymethyl resin, or a benzhydrylamine resin. One such chloromethylated resin is sold under the tradename BIO-BEADS SX-1 by Bio Rad Laboratories, Richmond, CA, and the preparation of the hydroxymethyl resin is described by Bodonszky, et al., Chem. Ind. (London), 38:1597 (1966). The benzhydrylamine (BHA) resin has been described by Pietta and Marshall, Chem. Commn., 650 (1970) and is commercially available from Beckman Instruments, Inc., Palo Alto, Calif., in the hydrochloride form.

Thus, the compounds of the invention can be prepared by coupling an alpha-amino protected amino acid to the chloromethylated resin with the aid of, for example, cesium bicarbonate catalyst, according to the method described by Gisin, Helv. Chim. Acta., 56:1467 (1973). After the initial coupling, the alpha-amino protecting group is removed by a choice of reagents including trifluoroacetic acid (TFA) or hydrochloric acid (HCl) solutions in organic solvents at room temperature.

The alpha-amino protecting groups are those known to be useful in the art of stepwise synthesis of peptides. Included are acyl type protecting groups (e.g., formyl, trifluoroacetyl, acetyl), aromatic urethane type protecting groups (e.g. benzyloxycarboyl (Cbz) and substituted Cbz), aliphatic urethane protecting groups (e.g., t-butyloxycarbonyl (Boc), isopropyloxycarbonyl, cyclohexyloxycarbonyl) and alkyl type protecting groups (e.g., benzyl, triphenylmethyl). Boc and Fmoc are preferred protecting groups. The side chain protecting group remains intact during coupling and is not split off during the

deprotection of the amino-terminus protecting group or during coupling. The side chain protecting group must be removable upon the completion of the synthesis of the final peptide and under reaction conditions that will not alter the target peptide.

The side chain protecting groups for Tyr include tetrahydropyranyl, tert-butyl, trityl, benzyl, Cbz, Z--Br--Cbz, and 2,5-dichlorobenzyl. The side chain protecting groups for Asp include benzyl, 2,6-dichlorobenzyl, methyl, ethyl, and cyclohexyl. The side chain protecting groups for Thr and Ser include acetyl, benzoyl, trityl, tetrahydropyranyl, benzyl, 2,6-dichlorobenzyl, and Cbz. The side chain protecting group for Thr and Ser is benzyl. The side chain protecting groups for Arg include nitro, Tosyl (Tos), Cbz, adamantyloxycarbonyl mesitoylsulfonyl (Mts), or Boc. The side chain protecting groups for Lys include Cbz, 2-chlorobenzyloxycarbonyl (2-Cl--Cbz), 2-bromobenzyloxycarbonyl (2-BrCbz), Tos, or Boc.

After removal of the alpha-amino protecting group, the remaining protected amino acids are coupled stepwise in the desired order. An excess of each protected amino acid is generally used with an appropriate carboxyl group activator such as dicyclohexylcarbodiimide (DCC) in solution, for example, in methylene chloride (CH_2Cl_2), dimethyl formamide (DMF) mixtures.

After the desired amino acid sequence has been completed, the desired peptide is decoupled from the resin support by treatment with a reagent such as trifluoroacetic acid or hydrogen fluoride (HF), which not only cleaves the peptide from the resin, but also cleaves all remaining side chain protecting groups. When the chloromethylated resin is used, hydrogen fluoride treatment results in the formation of the free peptide acids. When the benzhydrylamine resin is used, hydrogen fluoride treatment results directly in the free peptide amide. Alternatively, when the chloromethylated resin is employed, the side chain protected peptide can be decoupled by treatment of the peptide resin with ammonia to give the desired side chain protected amide or with an alkylamine to give a side chain protected alkylamide or dialkylamide. Side chain protection is then removed in the usual fashion by treatment with hydrogen fluoride to give the free amides, alkylamides, or dialkylamides.

These solid phase peptide synthesis procedures are well known in the art and further described by John Morrow Stewart and Janis Dillaha Young, Solid Phase Peptide Syntheses (2nd Ed., Pierce Chemical Company, 1984).

Using the "encoded synthetic library" or "very large scale immobilized polymer synthesis" system described in U.S. patent application Ser. No. 07/492,462, filed Mar. 7, 1990; Ser. No. 07/624,120, filed Dec. 6, 1990; and Ser. No. 07/805,727, filed Dec. 6, 1991; one can not only determine the minimum size of a peptide with such activity, one can also make all of the peptides that form the group of peptides that differ from the preferred motif (or the minimum size of that motif) in one, two, or more residues. This collection of peptides can then be screened for ability to bind to TPO-R. This immobilized polymer synthesis system or other peptide synthesis methods can also be used to synthesize truncation analogs and deletion analogs and combinations of truncation and deletion analogs of all of the peptide compounds of the invention.

B. Synthetic Amino Acids

These procedures can also be used to synthesize peptides in which amino acids other than the 20 naturally occurring, genetically encoded amino acids are substituted at one, two, or more positions of any of the compounds of the invention. For instance, naphthylalanine can be substituted for tryptophan, facilitating synthesis. Other synthetic amino acids that can be substituted into the peptides of the present invention include L-hydroxypropyl, L-3, 4-dihydroxyphenylalanyl, d amino acids such as L-d-hydroxylysyl and D-d-methylalanyl, L-α-methylalanyl, β amino acids, and isoquinolyl. D amino acids and non-naturally occurring synthetic amino acids can also be incorporated into the peptides of the present invention (see, e.g., Roberts, et al., Unusual Amino/Acids in Peptide Synthesis, 5(6):341-449 (1983)).

One can replace the naturally occurring side chains of the 20 genetically encoded amino acids (or D amino acids) with other side chains, for instance with groups such as alkyl, lower alkyl, cyclic 4-, 5-, 6-, to 7-membered alkyl, amide, amide lower alkyl, amide di(lower alkyl), lower alkoxy, hydroxy, carboxy and the lower ester derivatives thereof, and with 4-, 5-, 6-, to 7-membered hetereocyclic. In particular, proline analogs in which

the ring size of the proline residue is changed from 5 members to 4, 6, or 7 members can be employed. Cyclic groups can be saturated or unsaturated, and if unsaturated, can be aromatic or non-aromatic. Heterocyclic groups preferably contain one or more nitrogen, oxygen, and/or sulphur heteroatoms. Examples of such groups include the furazanyl, furyl, imidazolidinyl, imidazolyl, imidazolinyl, isothiazolyl, isoxazolyl, morpholinyl (e.g. morpholino), oxazolyl, piperazinyl (e.g. 1-piperazinyl), piperidyl (e.g. 1-piperidyl, piperidino), pyranyl, pyrazinyl, pyrazolidinyl, pyrazolinyl, pyrazolyl, pyridazinyl, pyridyl, pyrimidinyl, pyrrolidinyl (e.g. 1-pyrrolidinyl), pyrrolinyl, pyrrolyl, thiadiazolyl, thiazolyl, thienyl, thiomorpholinyl (e.g. thiomorpholino), and triazolyl. These heterocyclic groups can be substituted or unsubstituted. Where a group is substituted, the substituent can be alkyl, alkoxy, halogen, oxygen, or substituted or unsubstituted phenyl.

One can also readily modify the peptides of the instant invention by phosphorylation (see, e.g., W. Bannwarth, et al., Biorganic and Medicinal Chemistry Letters, 6(17):2141-2146 (1996)), and other methods for making peptide derivatives of the compounds of the present invention are described in Hruby, et al., Biochem. J., 268(2):249-262 (1990). Thus, the peptide compounds of the invention also serve as a basis to prepare peptide mimetics with similar biological activity.

C. Terminal Modifications

Those of skill in the art recognize that a variety of techniques are available for constructing peptide mimetics with the same or similar desired biological activity as the corresponding peptide compound but with more favorable activity than the peptide with respect to solubility, stability, and susceptibility to hydrolysis and proteolysis. See, for example, Morgan, et al., Ann. Rep. Med. Chem., 24:243-252 (1989). The following describes methods for preparing peptide mimetics modified at the N-terminal amino group, the C-terminal carboxyl group, and/or changing one or more of the amido linkages in the peptide to a non-amido linkage. It being understood that two or more such modifications can be coupled in one peptide mimetic structure (e.g., modification at the C-terminal carboxyl group and inclusion of a $-CH_2$ -carbamate linkage between two amino acids in the peptide).

1. N-terminal Modifications

The peptides typically are synthesized as the free acid but, as noted above, could be readily prepared as the amide or ester. One can also modify the amino and/or carboxy terminus of the peptide compounds of the invention to produce other compounds of the invention. Amino terminus modifications include methylation, acetylation, adding a benzyloxycarbonyl group, or blocking the amino terminus with any blocking group containing a carboxylate functionality defined by RCOO--, where R is selected from the group consisting of naphthyl, acridinyl, steroidyl, and similar groups. Carboxy terminus modifications include replacing the free acid with a carboxamide group or forming a cyclic lactam at the carboxy terminus to introduce structural constraints.

Amino terminus modifications are as recited above and include alkylating, acetylating, adding a carbobenzoyl group, forming a succinimide group, etc. (See, e.g., Murray, et al., Burger's Medicinal Chemistry and Drug Discovery, 5th ed., Vol. 1, Manfred E. Wolf, ed., John Wiley and Sons, Inc. (1995).) Specifically, the N-terminal amino group can then be reacted as follows:

(a) to form an amide group of the formula RC(O)NH-- where R is as defined above by reaction with an acid halide or symmetric anhydride. Typically, the reaction can be conducted by contacting about equimolar or excess amounts (e.g., about 5 equivalents) of an acid halide to the peptide in an inert diluent (e.g., dichloromethane) preferably containing an excess (e.g., about 10 equivalents) of a tertiary amine, such as diisopropylethylamine, to scavenge the acid generated during reaction. Reaction conditions are otherwise conventional (e.g., room temperature for 30 minutes). Alkylation of the terminal amino to provide for a lower alkyl N-substitution followed by reaction with an acid halide as described above will provide for N-alkyl amide group of the formula RC(O)NR--;

(b) to form a succinimide group by reaction with succinic anhydride. As before, an approximately equimolar amount or an excess of succinic anhydride (e.g., about 5 equivalents) can be employed and the amino group is converted to the succinimide by methods well known in the art including the use of an excess (e.g., ten equivalents) of a

tertiary amine such as diisopropylethylamine in a suitable inert solvent (e.g., dichloromethane). See, for example, Wollenberg, et al., U.S. Pat. No. 4,612,132 which is incorporated herein by reference in its entirety. It is understood that the succinic group can be substituted with, for example, alkyl or --SR substituents which are prepared in a conventional manner to provide for substituted succinimide at the N-terminus of the peptide. Such alkyl substituents are prepared by reaction of a lower olefin with maleic anhydride in the manner described by Wollenberg, et al., supra and --SR substituents are prepared by reaction of RSH with maleic anhydride where R is as defined above;

(c) to form a benzyloxycarbonyl-NH-- or a substituted benzyloxycarbonyl-NH-- group by reaction with approximately an equivalent amount or an excess of CBZ--Cl (i.e., benzyloxycarbonyl chloride) or a substituted CBZ--Cl in a suitable inert diluent (e.g., dichloromethane) preferably containing a tertiary amine to scavenge the acid generated during the reaction;

(d) to form a sulfonamide group by reaction with an equivalent amount or an excess (e.g., 5 equivalents) of R--$S(O)_2$ Cl in a suitable inert diluent (dichloromethane) to convert the terminal amine into a sulfonamide where R is as defined above. Preferably, the inert diluent contains excess tertiary amine (e.g., ten equivalents) such as diisopropylethylamine, to scavenge the acid generated during reaction. Reaction conditions are otherwise conventional (e.g., room temperature for 30 minutes);

(e) to form a carbamate group by reaction with an equivalent amount or an excess (e.g., 5 equivalents) of R--OC(O)Cl or R--$OC(O)OC_6H_4$ -p-NO_2 in a suitable inert diluent (e.g., dichloromethane) to convert the terminal amine into a carbamate where R is as defined above. Preferably, the inert diluent contains an excess (e.g., about 10 equivalents) of a tertiary amine, such as diisopropylethylamine, to scavenge any acid generated during reaction. Reaction conditions are otherwise conventional (e.g., room temperature for 30 minutes); and

(f) to form a urea group by reaction with an equivalent amount or an excess (e.g., 5

equivalents) of R—N=C=O in a suitable inert diluent (e.g., dichloromethane) to convert the terminal amine into a urea (i.e., RNHC(O)NH--) group where R is as defined above. Preferably, the inert diluent contains an excess (e.g., about 10 equivalents) of a tertiary amine, such as diisopropylethylamine. Reaction conditions are otherwise conventional (e.g., room temperature for about 30 minutes).

2. C-Terminal Modifications

In preparing peptide mimetics wherein the C-terminal carboxyl group is replaced by an ester (i.e., --C(O)OR where R is as defined above), the resins used to prepare the peptide acids are employed, and the side chain protected peptide is cleaved with base and the appropriate alcohol, e.g., methanol. Side chain protecting groups are then removed in the usual fashion by treatment with hydrogen fluoride to obtain the desired ester.

In preparing peptide mimetics wherein the C-terminal carboxyl group is replaced by the amide --C(O)NR^3 R^4, a benzhydrylamine resin is used as the solid support for peptide synthesis. Upon completion of the synthesis, hydrogen fluoride treatment to release the peptide from the support results directly in the free peptide amide (i.e., the C-terminus is --C(O)NH_2). Alternatively, use of the chloromethylated resin during peptide synthesis coupled with reaction with ammonia to cleave the side chain protected peptide from the support yields the free peptide amide and reaction with an alkylamine or a dialkylamine yields a side chain protected alkylamide or dialkylamide (i.e., the C-terminus is --C(O)NRR^1 where R and R^1 are as defined above). Side chain protection is then removed in the usual fashion by treatment with hydrogen fluoride to give the free amides, alkylamides, or dialkylamides.

One can also cyclize the peptides of the invention, or incorporate a desamino or descarboxy residue at the terminii of the peptide, so that there is no terminal amino or carboxyl group, to decrease susceptibility to proteases or to restrict the conformation of the peptide. C-terminal functional groups of the compounds of the present invention include amide, amide lower alkyl, amide di(lower alkyl), lower alkoxy, hydroxy, and carboxy, and the lower ester derivatives thereof, and the pharmaceutically acceptable salts thereof.

In addition to the foregoing N-terminal and C-terminal modifications, the peptide compounds of the invention, including peptidomimetics, can advantageously be modified with or covalently coupled to one or more of a variety of hydrophilic polymers. It has been found that when the peptide compounds are derivatized with a hydrophilic polymer, their solubility and circulation half-lives are increased and their immunogenicity is masked. Quite surprisingly, the foregoing can be accomplished with little, if any, diminishment in their binding activity. Nonproteinaceous polymers suitable for use in accordance with the present invention 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, etc. Generally, such hydrophilic polymers have an average molecular weight ranging from about 500 to about 100,000 daltons, more preferably from about 2,000 to about 40,000 daltons and, even more preferably, from about 5,000 to about 20,000 daltons. In preferred embodiments, such hydrophilic polymers have an average molecular weights of about 5,000 daltons, 10,000 daltons and 20,000 daltons.

The peptide compounds of the invention can be derivatized with or coupled to such polymers using any of the methods set forth in Zallipsky, S., Bioconjugate Chem., 6:150-165 (1995); Monfardini, C, et al., Bioconjugate Chem., 6:62-69 (1995); U.S. Pat. No. 4,640,835; U.S. Pat. No. 4,496,689; U.S. Pat. No. 4,301,144; U.S. Pat. No. 4,670,417; U.S. Pat. No. 4,791,192; U.S. Pat. No. 4,179,337 or WO 95/34326, all of which are incorporated by reference in their entirety herein.

In a presently preferred embodiment, the peptide compounds of the present invention are derivatized with polyethylene glycol (PEG). PEG is a linear, water-soluble polymer of ethylene oxide repeating units with two terminal hydroxyl groups. PEGs are classified by their molecular weights which typically range from about 500 daltons to about 40,000 daltons. In a presently preferred embodiment, the PEGs employed have molecular weights ranging from 5,000 daltons to about 20,000 daltons. PEGs coupled to the peptide compounds of the present invention can be either branched or unbranched. (See, e.g., Monfardini, C., et al., Bioconjugate Chem., 6:62-69 (1995)). PEGs are commercially available from Shearwater Polymers, Inc. (Huntsville, Ala.), Sigma

Chemical Co. and other companies. Such PEGs include, but are not limited to, monomethoxypolyethylene glycol (MePEG-OH), monomethoxypolyethylene glycol-succinate (MePEG-S), monomethoxypolyethylene glycol-succinimidyl succinate (MePEG-S-NHS), monomethoxypolyethylene glycol-amine (MePEG-NH_2), monomethoxypolyethylene glycol-tresylate (MePEG-TRES), and monomethoxypolyethylene glycol-imidazolyl-carbonyl (MePEG-IM).

Briefly, in one exemplar embodiment, the hydrophilic polymer which is employed, e.g., PEG, is preferably capped at one end by an unreactive group such as a methoxy or ethoxy group. Thereafter, the polymer is activated at the other end by reaction with a suitable activating agent, such as cyanuric halides (e.g., cyanuric chloride, bromide or fluoride), diimadozle, an anhydride reagent (e.g., a dihalosuccinic anhydride, such as dibromosuccinic anhydride), acyl azide, p-diazoiumbenzyl ether, 3-(p-diazoniumphenoxy)-2-hydroxypropylether) and the like. The activated polymer is then reacted with a peptide compound of the present invention to produce a peptide compound derivatized with a polymer. Alternatively, a functional group in the peptide compounds of the invention can be activated for reaction with the polymer, or the two groups can be joined in a concerted coupling reaction using known coupling methods. It will be readily appreciated that the peptide compounds of the invention can be derivatized with PEG using a myriad of other reaction schemes known to and used by those of skill in the art.

In addition to derivatizing the peptide compounds of this invention with a hydrophilic polymer (e.g., PEG), other small peptides, e.g., other peptides or ligands that bind to a receptor, can also be derivatized with such hydrophilic polymers with little, if any, loss in biological activity (e.g., binding activity, agonist activity, antagonist activity, etc.). It has been found that when these small peptides are derivatized with a hydrophlilic polymer, their solubility and circulation half-lives are increased and their immunogenicity is decreased. Again, quite surprisingly, the foregoing can be accomplished with little, if any, loss in biological activity. In fat, in preferred embodiments, the derivatized peptides have an activity that is 0.1 to 0.01-fold that of the unmodified peptides. In more preferred embodiments, the derivatized peptides have an activity that is 0.1 to 1-fold that of the

unmodified peptides. In even more preferred embodiments, the derivatized peptides have an activity that is greater than the unmodified peptides.

Peptides suitable for use in this embodiment generally include those peptides, i.e., ligands, that bind to a receptor, such as the TPO, EPO, IL-1, G-CSF and IL-5 receptors; the hematopoietic growth factor receptors; the cytokine receptors; the G-protein-linked receptors; the cell surface receptors, etc. Such peptides typically comprise about 150 amino acid residues or less and, more preferably, about 100 amino acid residues or less (e.g., .about.10-12 kDa). Hydrophilic polymers suitable for use in the present invention 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, etc. Generally, such hydrophilic polymers have an average molecular weight ranging from about 500 to about 100,000 daltons, more preferably from about 2,000 to about 40,000 daltons and, even more preferably, from about 5,000 to about 20,000 daltons. In preferred embodiments, such hydrophilic polymers have an average molecular weights of about 5,000 daltons, 10,000 daltons and 20,000 daltons. The peptide compounds of this invention can be derivatized with using the methods described above and in the cited references.

D. Backbone Modifications

Other methods for making peptide derivatives of the compounds of the present invention are described in Hruby, et al., Biochem J., 268(2):249-262 (1990), incorporated herein by reference. Thus, the peptide compounds of the invention also serve as structural models for non-peptidic compounds with similar biological activity. Those of skill in the art recognize that a variety of techniques are available for constructing compounds with the same or similar desired biological activity as the lead peptide compound but with more favorable activity than the lead with respect to solubility, stability, and susceptibility to hydrolysis and proteolysis. See Morgan, et al., Ann. Rep. Med. Chem., 24:243-252 (1989), incorporated herein by reference. These techniques include replacing the peptide backbone with a backbone composed of phosphonates, amidates, carbamates, sulfonamides, secondary amines, and N-methylamino acids.

Suitable reagents include, for example, amino acid analogues wherein the carboxyl group of the amino acid has been replaced with a moiety suitable for forming one of the above linkages.

Similarly, replacement of an amido linkage in the peptide with a phosphonate linkage can be achieved in the manner set forth in U.S. patent application Ser. Nos. 07/943,805, 08/081,577, and 08/119,700, the disclosures of which are incorporated herein by reference in their entirety.

Replacement of an amido linkage in the peptide with a urea linkage can be achieved in the manner set forth in U.S. patent application Ser. No. 08/147,805 which application is incorporated herein by reference in its entirety.

E. Disulfide Bond Formation

The compounds of the present invention may exist in a cyclized form with an intramolecular disulfide bond between the thiol groups of the cysteines, if present. Alternatively, an intermolecular disulfide bond between the thiol groups of the cysteines can be produced to yield a dimeric (or higher oligomeric) compound. One or more of the cysteine residues may also be substituted with a homocysteine.

V. Utility

The compounds of the invention are useful in vitro as unique tools for understanding the biological role of TPO, including the evaluation of the many factors thought to influence, and be influenced by, the production of TPO and the receptor binding process. The present compounds are also useful in the development of other compounds that bind to and activate the TPO-R, because the present compounds provide important information on the relationship between structure and activity that should facilitate such development.

The compounds are also useful as competitive binders in assays to screen for new TPO receptor agonists. In such assay embodiments, the compounds of the invention can be used without modification or can be modified in a variety of ways; for example, by labeling, such as covalently or non-covalently joining a moiety which directly or indirectly provides a detectable signal. In any of these assays, the materials thereto can be labeled

either directly or indirectly. Possibilities for direct labeling include label groups such as: radiolabels such as ^{125}I, enzymes (U.S. Pat. No. 3,645,090) such as peroxidase and alkaline phosphatase, and fluorescent labels (U.S. Pat. No. 3,940,475) capable of monitoring the change in fluorescence intensity, wavelength shift, or fluorescence polarization. Possibilities for indirect labeling include biotinylation of one constituent followed by binding to avidin coupled to one of the above label groups. The compounds may also include spacers or linkers in cases where the compounds are to be attached to a solid support.

Moreover, based on their ability to bind to the TPO receptor, the peptides of the present invention can be used as reagents for detecting TPO receptors on living cells, fixed cells, in biological fluids, in tissue homogenates, in purified, natural biological materials, etc. For example, by labelling such peptides, one can identify cells having TPO-R on their surfaces. In addition, based on their ability to bind the TPO receptor, the peptides of the present invention can be used in in situ staining, FACS (fluorescence-activated cell sorting), Western blotting, ELISA, etc. In addition, based on their ability to bind to the TPO receptor, the peptides of the present invention can be used in receptor purification, or in purifying cells expressing TPO receptors on the cell surface (or inside permeabilized cells).

The compounds of the present invention can also be utilized as commercial reagents for various medical research and diagnostic uses. Such uses include but are not limited to: (1) use as a calibration standard for quantitating the activities of candidate TPO agonists in a variety of functional assays; (2) use to maintain the proliferation and growth of TPO-dependent cell lines; (3) use in structural analysis of the TPO-receptor through co-crystallization; (4) use to investigate the mechanism of TPO signal transduction/receptor activation; and (5) other research and diagnostic applications wherein the TPO-receptor is preferably activated or such activation is conveniently calibrated against a known quantity of a TPO agonist, and the like.

The compounds of the present invention can be used for the in vitro expansion of megakaryocytes and their committed progenitors, both in conjunction with additional cytokines or on their own. See, e.g., DiGiusto, et al., PCT Publication No. 95/05843, which

is incorporated herein by reference. Chemotherapy and radiation therapies cause thrombocytopenia by killing the rapidly dividing, more mature population of megakaryocytes. However, these therapeutic treatments can also reduce the number and viability of the immature, less mitotically active megakaryocyte precursor cells. Thus, amelioration of the thrombocytopenia by TPO or the compounds of the present invention can be hastened by infusing patients post chemotherapy or radiation therapy with a population of his or her own cells enriched for megakaryocytes and immature precursors by in vitro culture.

The compounds of the invention can also be administered to warm blooded animals, including humans, to activate the TPO-R in vivo. Thus, the present invention encompasses methods for therapeutic treatment of TPO related disorders that comprise administering a compound of the invention in amounts sufficient to mimic the effect of TPO on TPO-R in vivo. For example, the peptides and compounds of the invention can be administered to treat a variety of hematological disorders, including but not limited to platelet disorders and thrombocytopenia, particularly when associated with bone marrow transfusions, radiation therapy, and chemotherapy.

In some embodiments of the invention, TPO antagonists are preferably first administered to patients undergoing chemotherapy or radiation therapy, followed by administration of the TPO agonists of the invention.

The activity of the compounds of the present invention can be evaluated either in vitro or in vivo in one of the numerous models described in McDonald, Am. J. of Pediatric Hematology/Oncology, 14:8-21 (1992), which is incorporated herein by reference.

According to one embodiment, the compositions of the present invention are useful for treating thrombocytopenia associated with bone marrow transfusions, radiation therapy, or chemotherapy. The compounds typically will be administered prophylactically prior to chemotherapy, radiation therapy, or bone marrow transplant or after such exposure.

Accordingly, the present invention also provides pharmaceutical compositions comprising, as an active ingredient, at least one of the peptides or peptide mimetics of the invention in association with a pharmaceutical carrier or diluent. The compounds of this

invention can be administered by oral, pulmonary, parental (intramuscular, intraperitoneal, intravenous (IV) or subcutaneous injection), inhalation (via a fine powder formulation), transdermal, nasal, vaginal, rectal, or sublingual routes of administration and can be formulated in dosage forms appropriate for each route of administration. See, e.g., Bernstein, et al., PCT Patent Publication No. WO 93/25221; Pitt, et al., PCT Patent Publication No. WO 94/17784; and Pitt, et al., European Patent Application 613,683, each of which is incorporated herein by reference.

Solid dosage forms for oral administration include capsules, tablets, pills, powders, and granules. In such solid dosage forms, the active compound is admixed with at least one inert pharmaceutically acceptable carrier such as sucrose, lactose, or starch. Such dosage forms can also comprise, as is normal practice, additional substances other than inert diluents, e.g., lubricating agents such as magnesium stearate. In the case of capsules, tablets, and pills, the dosage forms may also comprise buffering agents. Tablets and pills can additionally be prepared with enteric coatings.

Liquid dosage forms for oral administration include pharmaceutically acceptable emulsions, solutions, suspensions, syrups, with the elixirs containing inert diluents commonly used in the art, such as water. Besides such inert diluents, compositions can also include adjuvants, such as wetting agents, emulsifying and suspending agents, and sweetening, flavoring, and perfuming agents.

Preparations according to this invention for parental administration include sterile aqueous or non-aqueous solutions, suspensions, or emulsions. Examples of non-aqueous solvents or vehicles are propylene glycol, polyethylene glycol, vegetable oils, such as olive oil and corn oil, gelatin, and injectable organic esters such as ethyl oleate. Such dosage forms may also contain adjuvants such as preserving, wetting, emulsifying, and dispersing agents. They may be sterilized by, for example, filtration through a bacteria retaining filter, by incorporating sterilizing agents into the compositions, by irradiating the compositions, or by heating the compositions. They can also be manufactured using sterile water, or some other sterile injectable medium, immediately before use.

Compositions for rectal or vaginal administration are preferably suppositories which may contain, in addition to the active substance, excipients such as cocoa butter or a suppository wax. Compositions for nasal or sublingual administration are also prepared with standard excipients well known in the art.

The compositions containing the compounds can be administered for prophylactic and/or therapeutic treatments. In therapeutic applications, compositions are administered to a patient already suffering from a disease, as described above, in an amount sufficient to cure or at least partially arrest the symptoms of the disease and its complications. An amount adequate to accomplish this is defined as "therapeutically effective dose". Amounts effective for this use will depend on the severity of the disease and the weight and general state of the patient.

The compositions of the invention can also be microencapsulated by, for example, the method of Tice and Bibi (in Treatise on Controlled Drug Delivery, ed. A. Kydonieus, Marcel Dekker, New York (1992), pp. 315-339).

In prophylactic applications, compositions containing the compounds of the invention are administered to a patient susceptible to or otherwise at risk of a particular disease. Such an amount is defined to be a "prophylactically effective dose". In this use, the precise amounts again depend on the patient's state of health and weight.

The quantities of the TPO agonist necessary for effective therapy will depend upon many different factors, including means of administration, target site, physiological state of the patient, and other medicants administered. Thus, treatment dosages should be titrated to optimize safety and efficacy. Typically, dosages used in vitro may provide useful guidance in the amounts useful for in situ administration of these reagents. Animal testing of effective doses for treatment of particular disorders will provide further predictive indication of human dosage. Various considerations are described, e.g., in Gilman, et al. (eds), Goodman and Gilman's: The Pharmacological Basis of Therapeutics, 8th ed., Pergamon Press (1990); and Remington's Pharmaceutical Sciences, 7th Ed., Mack Publishing Co., Easton, Pa. (1985); each of which is hereby incorporated by reference.

The peptides and peptide mimetics of this invention are effective in treating TPO mediated conditions when administered at a dosage range of from about 0.001 mg to about 10 mg/kg of body weight per day. The specific dose employed is regulated by the particular condition being treated, the route of administration as well as by the judgement of the attending clinician depending upon factors such as the severity of the condition, the age and general condition of the patient, and the like.

Although only preferred embodiments of the invention are specifically described above, it will be appreciated that modifications and variations of the invention are possible without departing from the spirit and intended scope of the invention.

EXAMPLE 1

Solid Phase Peptide Synthesis

Various peptides of the invention were synthesized using the Merrifield solid phase synthesis techniques (see Steward and Young, Solid Phase Peptide Synthesis, 2d. edition, Pierce Chemical, Rockford, Ill. (1984) and Merrifield, J. Am. Chem. Soc., 85:2149 (1963)) or an Applied Biosystems Inc. Model 431A or 433A peptide synthesizer. The peptides were assembled using standard protocols of the Applied Biosystems Inc. Synth Assist.TM. 1.0.0 or Synth Assist.TM. 2.0.2. Each coupling was performed for 2.times.30 min. with HBTU (2-(1H-benzatriazol-1-yl)-1,1,3,3-tetramethyluronium hexafluorophosphate) and HOBt (1-hydroxybenzotriazole).

The resin used was HMP resin (p-hydroxymethyl phenoxymethyl)polystyrene resin or PAL (Milligen/Biosearch), which is a cross-linked polystyrene resin with 5-(4'-Fmoc-aminomethyl-3,5'-dimethyoxyphenoxy)valeric acid as a linker. Use of PAL resin results in a carboxyl terminal amide functionality upon cleavage of the peptide from the resin. Upon cleavage, the HMP resin produces a carboxylic acid moiety at the C-terminus of the final product. Most reagents, resins, and protected amino acids (free or on the resin) were purchased from Millipore or Applied Biosystems Inc.

The Fmoc group was used for amino protection during the coupling procedure. Primary amine protection on amino acids was achieved with Fmoc and side chain

protection groups were t-butyl for serine, tyrosine, glutamic acid, and threonine; trityl for glutamine; Pmc (2,2,5,7,8-pentamethylchroman-6-sulfonyl) for arginine; N-t-butyloxycarbonyl for tryptophan; N-trityl for histidine and S-trityl for cysteine.

Removal of the peptides from the resin and simultaneous deprotection of the side chain functions were achieved by treatment with reagent K or slight modifications of it. Alternatively, in the synthesis of those peptides, with an amidated carboxyl terminus, the fully assembled peptide was cleaved with a mixture of 90% trifluoroacetic acid, 5% ethanedithiol, and 5% water, initially at 4.degree. C., and gradually increasing to room temperature. The deprotected peptides were precipitated with diethyl ether. In all cases, purification was by preparative, reverse-phase, high performance liquid chromatography on a C18 bonded silica gel column with a gradient of acetonitrile/water in 0.1% trifluoroacetic acid. The homogeneous peptides were characterized by Fast Atom Bombardment mass spectrometry or electrospray mass spectrometry and amino acid analysis when applicable.

In a preferred embodiment, the peptides of this invention are dimerized using standard synthetic procedures known to and used by those of skill in the art. Following these synthetic schemes, those of skill in the art can readily prepare dimer peptide compounds in accordance with the present invention. In addition, it will be readily apparent to those of skill in the art that the dimeric subunits can readily be linked using known methodologies and linkers.

EXAMPLE 2

Pegylation of the Peptides

A polypeptide of the present invention was dissolved in 100 mM bicine pH 8.0 at a concentration of 10 mg/ml, added to a 1.25 fold molar excess of powdered PEG2 (commercially available from Shearwater Polymers, Inc. (Huntsville, Ala.)) and stirred at room temperature until the reaction was complete, typically 1-2 hours. The reaction was monitored by reverse phase HPLC using a 40-65% acetonitrile gradient with a YMC ODS AQ column. When the reaction was complete, the solution was added to a second 1.25 molar excess of powdered PEG2 and the process was repeated 4 times using a total of 5

moles of PEG2 for each mole of polypeptide. The solution was diluted 2 fold with PBS to reduce the viscosity and loaded onto a superdex 200 column (Pharmacia), previously equilibrated and eluted with PBS. Fractions from the size exclusion column were analyzed by reverse phase HPLC. Fractions containing di-PEG-polypeptide which eluted prior to any mono-PEG-polypeptide were pooled and stored at 5 degrees C or lyophilized.

What is claimed is:

1. A compound that binds to a thrombopoietin receptor, wherein said compound comprises (H-IEGPTLRQ(2-Nal)LAARX$_{10}$)$_2$K-NH2, wherein X$_{10}$ is selected from the group consisting of sarcosine or β-alanine.

2. The compound of claim 1, wherein said compound is covalently attached to a hydrophilic polymer.

3. The compound of claim 2, wherein said hydrophilic polymer has an average molecular weight of between about 500 to about 40,000 daltons.

4. The compound of claim 2, wherein said hydrophilic polymer has an average molecular weight of between about 5,000 to about 20,000 daltons.

5. The compound of claim 2, wherein said polymer is selected from the group consisting of polyethylene glycol, polypropylene glycol, polylactic acid and polyglycolic acid.

6. The compound of claim 5, wherein said compound is covalently attached to polyethylene glycol.

7. The compound of claim 1, wherein each of the dimeric subunits of said compound is covalently attached to a hydrophilic polymer.

8. A pharmaceutical composition comprising a compound of claim 1 in combination with a pharmaceutically acceptable carrier.

9. A method for treating a patient suffering from a disorder that is susceptible to treatment with a thrombopoietin agonist, comprising administering to the patient a therapeutically effective dose or amount of a compound of claim 1.

10. A physiologically active, substantially non-immunogenic water soluble polypeptide composition comprising a compound of claim 1 coupled with a coupling agent to at least one polymer having a molecular weight of between about 500 to about 20,000 daltons selected from the group consisting of polyethylene glycol and polypropylene glycol, wherein said polymer is unsubstituted or substituted by alkoxy or alkyl groups, said alkoxy or alkyl groups possessing less than 5 carbon atoms.

11. The polypeptide composition in accordance with claim 10, wherein said polymer has a molecular weight of about 750 to about 15,000 daltons.

12. The polypeptide composition in accordance with claim 10, wherein said polymer has a molecular weight of about 5,000 to about 10,000 daltons.

13. The polypeptide composition in accordance with claim 10, wherein said polymer is polyethylene glycol.

14. A substantially non-immunogenic water soluble polypeptide composition comprising a compound of claim 10 and a pharmaceutically acceptable carrier.

15. A method of activating a thrombopoietin receptor in a cell, comprising contacting said cell with an effective amount of a compound which comprises (H-IEGPTLRQ(2-Nal)LAARX$_{10}$)$_2$K-NH2, wherein X$_{10}$ is selected from the group consisting of sarcosine or β-alanine.

16. A method according to claim 15 wherein said cells comprise human megakaryocytes, platelets or CD34+ cells.

17. A method according to claim 15 wherein said cells comprise TPO-dependent cells.

18. A method of treating thrombocytopenia in a subject, comprising: (a) obtaining a

population of said subject's cells comprising megakaryocyte precursor cells;

(b) treating said cells according to the method of claim 15; and

(c) administering said treated cells to said subject, to increase the number of megakaryocytes present in said subject compared to that which would occur without such treatment.

19. A method according to claim 18 wherein said thrombocytopenia is due to chemotherapy.

20. A method according to claim 19 where said population of cells is obtained prior to said chemotherapy.

21. A method according to claim 18 wherein said thrombocytopenia is due to radiation therapy.

22. A method according to claim 21 where said population of cells is obtained prior to said radiation therapy.

23. A method of treating a patient suffering from thrombocytopenia, comprising administering to said patient a therapeutically effective dose of a compound which comprises (H-IEGPTLRQ(2-Nal)LAARX$_{10}$)$_2$K-NH2, wherein X$_{10}$ is selected from the group consisting of sarcosine or β-alanine.

24. A method according to claim 23 wherein said thrombocytopenia is due to chemotherapy or radiation therapy.

25. A method according to claim 24 wherein a TPO antagonist is administered to said patient prior to said chemotherapy or radiation therapy.

26. A method according to claim 23 wherein said thrombocytopenia is due to bone marrow transfusion.

27. A method of prophylactically treating a patient at risk of thrombocytopenia, comprising administering to said patient a prophylactically effective amount of a compound which comprises (H-IEGPTLRQ(2-Nal)LAARX$_{10}$)$_2$K-NH2, wherein X$_{10}$ is selected from the group consisting of sarcosine or β-alanine.

28. A method according to claim 27 where said compound is administered prior to bone marrow transplantation, chemotherapy, or radiation therapy.

29. A compound that binds to thrombopoietin receptor, said compound having:

(1) a molecular weight of less than about 8000 daltons, and

(2) a binding affinity to thrombopoietin receptor as expressed by an IC$_{50}$ of no more than about 100 μM, wherein said compound comprises the following sequence of amino acids:

X$_9$ X$_8$ G X$_1$ X$_2$ X$_3$ X$_4$ X$_5$ X$_6$ X$_7$

where X$_9$ is A, C, E, G, I, L, M, P, R, Q, S, T, or V; X$_8$ is A, C, D, E, K, L, Q, R, S, T, or V, X$_1$ is C, L, M, P, Q, V; X$_2$ is F, K, L, N, Q, R, S, T or V; X$_3$ is C, F, I, L, M, R, S, V or W; X$_4$ is any of the 20 genetically coded L-amino acids; X$_5$ is A, D, E, G, K, M, Q, R, S, T, V or Y; X$_7$ is C, G, I, K, L, M, N, R or V, and X$_6$ is β-(2-naphthyl)alanine.

30. The compound of claim 29, wherein said sequence of amino acids is cyclized.

31. The compound of claim 29, wherein said sequence of amino acids is dimerized.

32. 1. A method of activating a thrombopoietin receptor in a cell, comprising contacting said cell with an effective amount of a peptide having a molecular weight of less than about 8000 daltons, said compound comprises the following sequence of amino acids:

X_9 X_8 G X_1 X_2 X_3 X_4 X_5 X_6 X_7

where X_9 is A, C, E, G, I, L, M, P, R, Q, S, T, or V; X_8 is A, C, D, E, K, L, Q, R, S, T, or V, X_1 is C, L, M, P, Q, V; X_2 is F, K, L, N, Q, R, S, T or V; X_3 is C, F, I, L, M, R, S, V or W; X_4 is any of the 20 genetically coded L-amino acids; X_5 is A, D, E, G, K, M, Q, R, S, T, V or Y; X_7 is C, G, I, K, L, M, N, R or V, and X_6 is β-(2-naphthyl)alanine.

33. The compound of claim 32, wherein said sequence of amino acids is cyclized.

34. The compound of claim 32, wherein said sequence of amino acids is dimerized.

35. A method of activating a thrombopoietin receptor in a cell, comprising contacting said cell with an effective amount of a compound covalently attached to a hydrophilic polymer, said compound comprises the amino acid sequence I E G P T L R Q (2-Nal) L A A R A.

36. The method of claim 35 wherein said hydrophilic polymer has an average molecular weight of between about 500 to about 40,000 daltons.

37. The method of claim 35 wherein said hydrophilic polymer has an average molecular weight of between about 5,000 to about 20,000 daltons.

38. The method claim 35 wherein said polymer is selected from the group consisting of polyethylene glycol, polypropylene glycol, polylactic acid and polyglycolic acid.

39. The method of claim 38 wherein said compound is covalently attached to polyethylene glycol.

40. A method according to claim 35 wherein said cells are in vivo.

41. A method according to claim 35 wherein said cells are in vitro.

42. A method according to claim 35 wherein said cells comprise human megakaryocytes, platelets or CD34+ cells.

43. A method according to claim 35 wherein said cells comprise TPO-dependent cells.

44. A method of treating thrombocytopenia in a subject, comprising:

(a) obtaining a population of said subject's cells comprising megakaryocyte precursor cells;

(b) treating said cells according to the method of claim 35; and

(c) administering said treated cells to said subject, to increase the number of megakaryocytes present in said subject compared to that which would occur without such treatment.

45. A method according to claim 44 wherein said thrombocytopenia is due to chemotherapy.

46. A method according to claim 45 where said population of cells is obtained prior to said chemotherapy.

47. A method according to claim 44 wherein said thrombocytopenia is due to radiation therapy.

48. A method according to claim 47 where said population of cells is obtained prior to said radiation therapy.

49. The compound of claim 29, wherein the compound comprises the following amino acid sequence: I E G P T L R Q (2-Nal) L A A R A.