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**Beta-sheet mimetics and use thereof as protease inhibitors**

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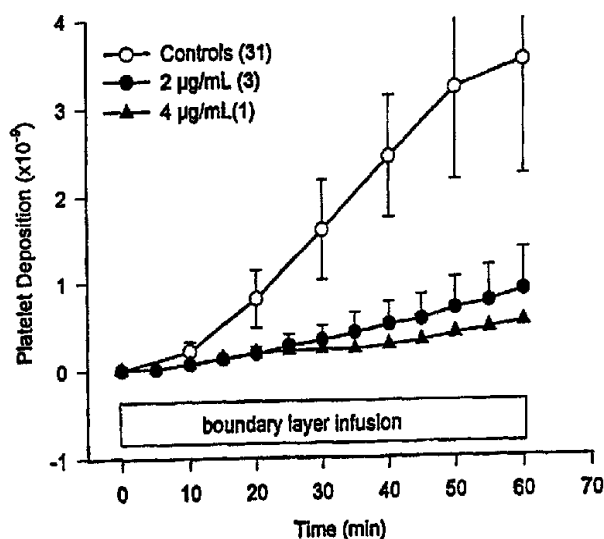


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(54) Title:  $\beta$ -SHEET MIMETICS AND USE THEREOF AS PROTEASE INHIBITORS



(57) Abstract

There are disclosed  $\beta$ -sheet mimetics and methods relating to the same for imparting or stabilizing the  $\beta$ -sheet structure of a peptide, protein or molecule. In one aspect, the  $\beta$ -sheet mimetics are covalently attached at the end or within the length of the peptide or protein. The  $\beta$ -sheet mimetics have utility as protease inhibitors generally, including activity as serine protease inhibitors such as thrombin, elastase and Factor X.

Description

β-SHEET MIMETICS AND USE THEREOF  
AS PROTEASE INHIBITORS

5

Cross-Reference to Prior Application

This application is a continuation-in-part of U.S. Patent Application No. 08/549,006, filed October 27, 1995; which is a continuation-in-part of U.S. Patent Application No. 08/410,518, filed March 24, 1995.

10

Technical Field

This invention relates generally to β-sheet mimetics and, more specifically, to β-sheet mimetics for use as protease inhibitors.

15

Background of the Invention

The β-sheet conformation (also referred to as a β-strand conformation) is a secondary structure present in many polypeptides. The β-sheet conformation is nearly fully extended, with axial distances between adjacent amino acids of approximately 3.5 Å. The β-sheet is stabilized by hydrogen bonds between NH and CO groups in different polypeptides strands. Additionally, the dipoles of the peptide bonds alternate along the strands which imparts intrinsic stability to the β-sheet. The adjacent strands in the β-sheet can run in the same direction (i.e., a parallel β-sheet) or in opposite directions (i.e., an antiparallel β-sheet). Although the two forms differ slightly in dihedral angles, both are sterically favorable. The extended conformation of the β-sheet conformation results in the amino acid side chains protruding on alternating faces of the β-sheet.

20  
25  
30

The importance of  $\beta$ -sheets in peptides and proteins is well established (e.g., Richardson, *Nature* 268:495-499, 1977; Halverson et al., *J. Am. Chem. Soc.* 113:6701-6704, 1991; Zhang, *J. Biol. Chem.* 266:15591-15596, 1991; Madden et al., *Nature* 353:321-325, 1991). The  $\beta$ -sheet is important in a number of biological recognition events, including the interaction between proteases and proteolytic substrates. Protease activity has been implicated in many disease states.

10 Cathepsin B is a lysosomal cysteine protease normally involved in proenzyme processing and protein turnover. Elevated levels of activity have been implicated in tumor metastasis (Sloane, B.F. et al., "Cathepsin B and its endogenous inhibitors: the role in  
15 tumor malignancy," *Cancer Metastasis Rev.* 9:333-352, 1990), rheumatoid arthritis (Werb, Z. "Proteinases and matrix degradation," in *Textbook of Rheumatology*, Keller, W.N.; Harris, W.D.; Ruddy, S.; Sledge, C.S., Eds., 1989, W.B. Saunders Co., Philadelphia, PA, pp. 300-321), and  
20 muscular dystrophy (Katunuma N. & Kominami E., "Abnormal expression of lysosomal cysteine proteinases in muscle wasting diseases," *Rev. Physiol. Biochem. Pharmacol.* 108:1-20, 1987).

Calpains are cytosolic or membrane bound  $\text{Ca}^{++}$ -  
25 activated proteases which are responsible for degradation of cytoskeletal proteins in response to changing calcium levels within the cell. They contribute to tissue degradation in arthritis and muscular dystrophy (see Wang K.K. & Yuen P.W., "Calpain inhibition: an overview of its  
30 therapeutic potential," *Trends Pharmacol. Sci.* 15:412-419, 1994).

Interleukin Converting Enzyme (ICE) cleaves pro-IL-1 beta to IL-1 beta, a key mediator of inflammation, and therefore inhibitors of ICE may prove useful in the

treatment of arthritis (see, e.g., Miller B.E. et al., "Inhibition of mature IL-1 beta production in murine macrophages and a murine model of inflammation by WIN 67694, an inhibitor of IL-1 beta converting enzyme," *J. Immunol.* 154:1331-1338, 1995). ICE or ICE-like proteases may also function in apoptosis (programmed cell death) and therefore play roles in cancer, AIDS, Alzheimer's disease, and other diseases in which dysregulated apoptosis is involved (see Barr, P.J.; Tomei, L.D., "Apoptosis and its Role in Human Disease," *Biotechnol.* 12:487-493, 1994).

HIV protease plays a key role in the life cycle of HIV, the AIDS virus. In the final steps of viral maturation it cleaves polyprotein precursors to the functional enzymes and structural proteins of the virion core. HIV protease inhibitors were quickly identified as an excellent therapeutic target for AIDS (see Huff, J.R., "HIV protease: a novel chemotherapeutic target for AIDS," *J. Med. Chem.* 34:2305-2314) and have already proven useful in its treatment as evidenced by the recent FDA approval of zidovudine, Crixivan, and zalcitabine.

Angiotensin converting enzyme (ACE) is part of the renin-angiotensin system which plays a central role in the regulation of blood pressure. ACE cleaves angiotensin I to the octapeptide angiotensin II, a potent pressor agent due to its vasoconstrictor activity. Inhibition of ACE has proved therapeutically useful in the treatment of hypertension (Williams, G.H., "Converting-enzyme inhibitors in the treatment of hypertension," *N. Engl. J. Med.* 319:1517-1525, 1989).

Collagenases cleave collagen, the major constituent of the extracellular matrix (e.g., connective tissue, skin, blood vessels). Elevated collagenase activity contributes to arthritis (Krone S.M. et al., "Mechanisms of matrix degradation in rheumatoid

arthritis," *Ann. N.Y. Acad. Sci.* 580:340-354, 1990.), tumor metastasis (Flug M. & Kopf-Maier P., "The basement membrane and its involvement in carcinoma cell invasion," *Acta Anat. Basel* 152:69-84, 1995), and other diseases  
5 involving the degradation of connective tissue.

Trypsin-like serine proteases form a large and highly selective family of enzymes involved in hemostasis/coagulation (Davie, E.W. and K. Fujikawa, "Basic mechanisms in blood coagulation," *Ann. Rev.* 799-  
10 829, 1975) and complement activation (Muller-Eberhard, H.J., "Complement," *Ann. Rev. Biochem.* 44:697-724, 1975). Sequencing of these proteases has shown the presence of a homologous trypsin-like core with amino acid insertions that modify specificity and which are generally  
15 responsible for interactions with other macromolecular components (Magnusson et al., "Proteolysis and Physiological Regulation," *Miami Winter Symposia* 11:203-239, 1976).

Thrombin, a trypsin-like serine protease, acts  
20 to provide limited preolysis, both in the generation of fibrin from fibrinogen and the activation of the platelet receptor, and thus plays a critical role in thrombosis and hemostasis (Mann, K.G., "The assembly of blood clotting complexes on membranes," *Trends Biochem. Sci.* 12:229-233,  
25 1987). Thrombin exhibits remarkable specificity in the removal of fibrinopeptides A and B of fibrinogen through the selective cleavage of only two Arg-Gly bonds of the one-hundred and eighty-one Arg- or Lys-Xaa sequences in fibrinogen (Blomback, H., *Blood Clotting Enzymology*,  
30 Seeger, W.H. (ed.), Academic Press, New York, 1967, pp. 143-215).

Many significant disease states are related to abnormal hemostasis, including acute coronary syndromes. Aspirin and heparin are widely used in the treatment of

patients with acute coronary syndromes. However, these agents have several intrinsic limitations. For example, thrombosis complicating the rupture of atherosclerotic plaque tends to be a thrombin-mediated, platelet-dependent process that is relatively resistant to inhibition by aspirin and heparin (Fuster et al., "The pathogenesis of coronary artery disease and the acute coronary syndromes," *N. Engl. J. Med.* 326:242-50, 1992).

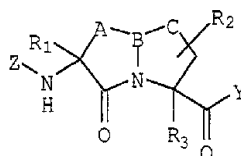
Thrombin inhibitors prevent thrombus formation at sites of vascular injury *in vivo*. Furthermore, since thrombin is also a potent growth factor which initiates smooth muscle cell proliferation at sites of mechanical injury in the coronary artery, inhibitors block this proliferative smooth muscle cell response and reduce restenosis. Thrombin inhibitors would also induce the inflammatory response in vascular wall cells (Harker et al., *Am. J. Cardiol* 75:12B-16B, 1995).

In view of the important biological role played by the  $\beta$ -sheet, there is a need in the art for compounds which can stabilize the intrinsic  $\beta$ -sheet structure of a naturally occurring or synthetic peptide, protein or molecule. There is also a need in the art for making stable  $\beta$ -sheet structures, as well as the use of such stabilized structures to effect or modify biological recognition events which involve  $\beta$ -sheet structures. The present invention fulfills these needs and provides further related advantages.

#### Summary of the Invention

Briefly stated, the present invention is directed to  $\beta$ -sheet mimetics and, more specifically, to  $\beta$ -sheet mimetics which stabilize the  $\beta$ -strand structure of a natural or synthetic peptide, protein or molecule.

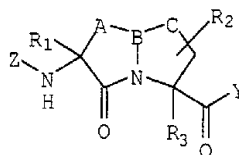
In one aspect of this invention,  $\beta$ -sheet mimetics are disclosed including a bicyclic ring system, wherein the  $\beta$ -sheet mimetic has the general structure (I):



(I)

and pharmaceutically acceptable salts thereof, wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof; A is selected from  $-\text{C}(=\text{O})-$ ,  $-(\text{CH}_2)_{1-4}-$ ,  $-\text{C}(=\text{O})(\text{CH}_2)_{1-3}-$ ,  $-(\text{CH}_2)_{1-2}\text{O}-$  and  $-(\text{CH}_2)_{1-2}\text{S}-$ ; B is selected from N and CH; C is selected from  $-\text{C}(=\text{O})-$ ,  $-(\text{CH}_2)_{1-3}-$ ,  $-\text{O}-$ ,  $-\text{S}-$ ,  $-\text{O}-(\text{CH}_2)_{1-2}-$  and  $-\text{S}(\text{CH}_2)_{1-2}-$ ; Y and Z represent the remainder of the molecule; and any two adjacent CH groups of the bicyclic ring may form a double bond; with the provisos that (i)  $R_1$  is an amino acid side chain moiety or derivative thereof other than hydrogen, (ii) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-\text{CH}_2\text{CH}_2-$  and B is CH, then C is not  $-\text{CH}_2-$ , (iii) when  $R_1$  is methyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-\text{CH}_2\text{O}-$  and B is CH, then C is not  $-\text{CH}_2-$ , and (iv) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-\text{CH}_2-$  and B is CH, then C is not  $-\text{S}-$ .

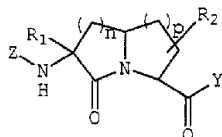
In one embodiment of structure (I) above,  $\beta$ -sheet mimetics are disclosed having the following structure (II):



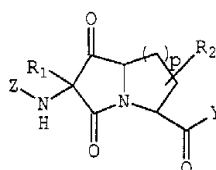
(II)

wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino  
 5 acid side chain moieties and derivatives thereof; A is  
 selected from  $-C(=O)-$ ,  $-(CH_2)_{1-4}-$  and  $-C(=O)(CH_2)_{1-3}-$ ; B is  
 selected from N and CH; C is selected from  $-C(=O)-$  and  
 $-(CH_2)_{1-3}-$ ; Y and Z represent the remainder of the molecule  
 10 no double bonds between adjacent CH groups of the bicyclic  
 ring system).

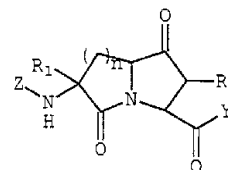
In an embodiment of structure (II) where B is CH  
 and  $R_3$  is hydrogen,  $\beta$ -sheet mimetics are disclosed having  
 the following structures (III), (IV) and (V):



(III)



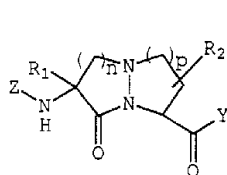
(IV)



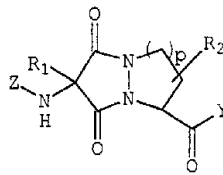
(V)

wherein  $R_1$  and  $R_2$  are independently selected from amino  
 acid side chain moieties and derivatives thereof; n is an  
 20 integer from 1 to 4; p is an integer from 1 to 3; and Y  
 and Z represent the remainder of the molecule.

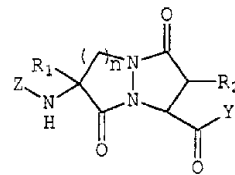
In an embodiment of structure (II) where B is N  
 and  $R_3$  is hydrogen,  $\beta$ -sheet mimetics are disclosed having  
 the following structures (VI), (VII) and (VIII):



(VI)



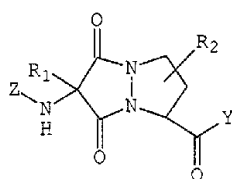
(VII)



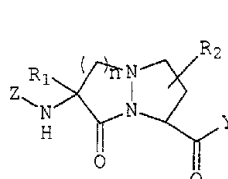
(VIII)

wherein  $R_1$  and  $R_2$  are independently selected from amino acid side chain moieties and derivatives thereof;  $n$  is an integer from 1 to 4;  $p$  is an integer from 1 to 3; and  $Y$  and  $Z$  represent the remainder of the molecule.

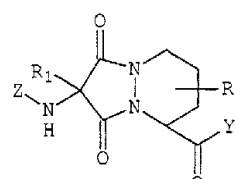
In preferred embodiments of this aspect of the invention,  $\beta$ -sheet mimetics are disclosed having the following structures (IX), (X) and (XI):



(IX)



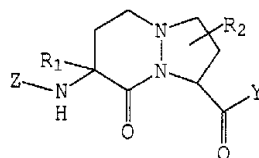
(X)



(XI)

wherein  $R_1$  and  $R_2$  are independently selected from amino acid side chain moieties and derivatives thereof;  $n$  is an integer from 1 to 4; and  $Y$  and  $Z$  represent the remainder of the molecule.

In a further preferred embodiment of this aspect of the invention, a  $\beta$ -sheet mimetic is disclosed of structure (X) above wherein  $n$  is 2, and having the following structure (Xa):

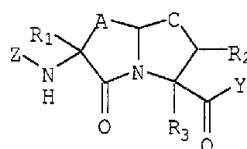


(Xa)

wherein  $R_1$  and  $R_2$  are independently selected from amino  
 5 acid side chain moieties and derivatives thereof; and Y  
 and Z represent the remainder of the molecule.

In another embodiment of structure (I) above,  
 $\beta$ -sheet mimetics are disclosed having the following  
 structure (XII):

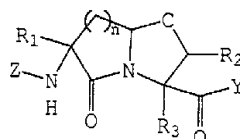
10



(XII)

wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino  
 15 acid side chain moieties and derivatives thereof; A is  
 selected from  $-(CH_2)_{1-4}-$ ,  $-(CH_2)_{1-2}O-$  and  $-(CH_2)_{1-2}S-$ , C is  
 selected from  $-(CH_2)_{1-3}-$ ,  $-O-$ ,  $-S-$ ,  $-O(CH_2)_{1-2}-$  and  
 $-S(CH_2)_{1-2}-$ ; Y and Z represent the remainder of the molecule  
 and the bicyclic ring system is saturated.

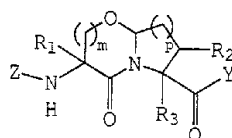
20 In an embodiment of structure (XII) where A is  
 $-(CH_2)_{1-4}-$ ,  $\beta$ -sheet mimetics are disclosed having the  
 following structure (XIII):



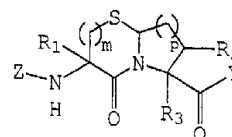
(XIII)

5 wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof;  $n$  is an integer from 1 to 4;  $C$  is selected from  $-(CH_2)_{1-3}-$ ,  $-O-$ ,  $-S-$ ,  $-O(CH_2)_{1-2}-$  and  $-S(CH_2)_{1-2}-$ ; and  $Y$  and  $Z$  represent the remainder of the molecule.

10 In an embodiment of structure (XII) where  $A$  is  $-(CH_2)_{1-2}O-$  or  $-(CH_2)_{1-2}S-$ ,  $\beta$ -sheet mimetics are disclosed having the following structures (XIV) and (XV):



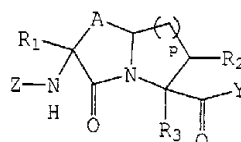
(XIV)



(XV)

15 wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof;  $m$  is an integer from 1 to 2;  $p$  is an integer from 1 to 3; and  $Y$  and  $Z$  represent the remainder of the molecule.

20 In an embodiment of structure (XII) where  $C$  is  $-(CH_2)_{1-3}-$ ,  $\beta$ -sheet mimetics are disclosed having the following structure (XVI):

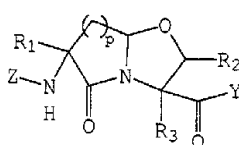


(XVI)

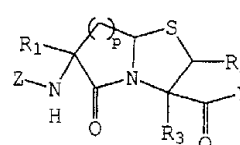
wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from an amino acid side chain moiety and derivatives thereof;  $p$  is an integer from 1 to 3;  $A$  is selected from  $-(CH_2)_{1-4}-$ ,  $-(CH_2)_{1-2}O-$  and  $-(CH_2)_{1-2}S-$ ; and  $Y$  and  $Z$  represent the remainder of the molecule.

In an embodiment of structure (XII) where  $C$  is  $-O-$  or  $-S-$ ,  $\beta$ -sheet mimetics are disclosed having the following structures (XVII) and (XVIII):

10



(XVII)

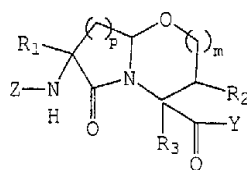


(XVIII)

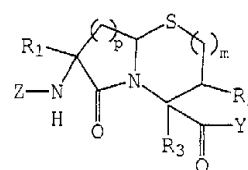
15 wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof;  $p$  is an integer from 1 to 3; and  $Y$  and  $Z$  represent the remainder of the molecule.

In an embodiment of structure (XII) where  $C$  is  $-O(CH_2)_{1-2}-$  or  $-S(CH_2)_{1-2}-$ ,  $\beta$ -sheet mimetics are disclosed having the following structures (XIX) and (XX):

25



(XIX)



(XX)

wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof;  $p$  is an

integer from 1 to 3; m is an integer from 1 to 2; and Y and Z represent the remainder of the molecule.

In a further aspect of the present invention,  $\beta$ -sheet modified peptides or proteins are disclosed wherein a  $\beta$ -sheet mimetic of this invention is covalently attached to at least one amino acid of a naturally occurring or synthetic peptide or protein. In this embodiment, Y and/or Z in the above structures (I) through (XX) represent one or more amino acids of the peptide or protein. In a related embodiment, a method for imparting and/or stabilizing a  $\beta$ -sheet structure of a natural or synthetic peptide or protein is disclosed. This method includes covalently attaching one or more  $\beta$ -sheet mimetics of this invention within, or to the end of, a peptide or protein.

In yet a further embodiment, methods are disclosed for inhibiting a protease in a warm-blooded animal by administering to the animal an effective amount of a compound of this invention. Proteases include serine proteases, such as thrombin, elastase and Factor X, as well as aspartic, cysteine and metallo proteases.

Other aspects of this invention will become apparent upon reference to the following detailed description.

#### 25 Brief Description of the Drawings

Figure 1 is a plot showing the effect of various concentrations of structure (20b) on platelet deposition in a vascular graft.

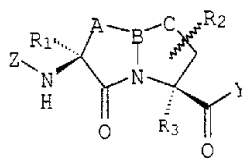
Figure 2 is a plot showing the effect of various concentrations of structure (39) on platelet deposition in a vascular graft.

Figure 3 is a plot showing the effect of various concentrations of structure (29b) on platelet deposition in a vascular graft.

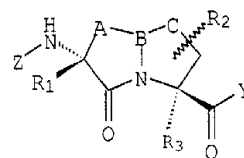
#### 5 Detailed Description of the Invention

As mentioned above, the  $\beta$ -sheet is an important structural component for many biological recognition events. The  $\beta$ -sheet mimetics of this invention serve to impart and/or stabilize the  $\beta$ -sheet structure of a natural or synthetic peptide, protein or molecule, particularly with regard to conformational stability. In addition, the  $\beta$ -sheet mimetics of this invention are more resistant to proteolytic breakdown, thus rendering a peptide, protein or molecule containing the same more resistant to degradation.

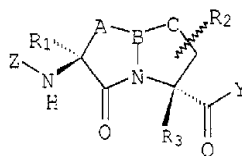
The  $\beta$ -sheet mimetics of this invention are generally represented by structure (I) above, as well as the more specific embodiments represented by structures (II) through (XX), and have stereochemistries represented by structures (I') through (I''') below:



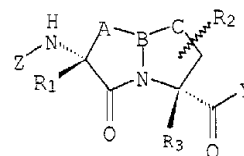
(I')



(I'')



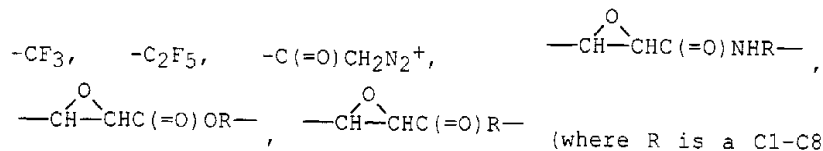
(I''')



(I'''')

wherein  $R_1$ ,  $R_2$ ,  $R_3$ , A, B, C, Y and Z are as defined above. In other words, all stereoconformations of structure (I), as well as the more specific embodiments represented by structures (II) through (XX), are included within the scope of this invention. For example, the  $\beta$ -sheet mimetics of this invention may be constructed to mimic the three-dimensional conformation of a  $\beta$ -sheet comprised of naturally occurring L-amino acids, as well as the structure of a  $\beta$ -sheet comprised of one or more D-amino acids. In a preferred embodiment, the  $\beta$ -sheet mimetic has the stereoconformation of structure (I') or (I'').

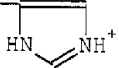
As used in the context of this invention, the term "remainder of the molecule" (as represented by Y and Z in structures (I) through (XX) above) may be any chemical moiety. For example, when the  $\beta$ -sheet mimetic is located within the length of a peptide or protein, Y and Z may represent amino acids of the peptide or protein. Alternatively, if two or more  $\beta$ -sheet mimetics are linked, the Y moiety of a first  $\beta$ -sheet mimetic may represent a second  $\beta$ -sheet mimetic while, conversely, the Z moiety of the second  $\beta$ -sheet mimetic represents the first  $\beta$ -sheet mimetic. When the  $\beta$ -sheet mimetic is located at the end of a peptide or protein, or when the  $\beta$ -sheet mimetic is not associated with a peptide or protein, Y and/or Z may represent a suitable terminating moiety. Representative terminating moieties for the Z moiety include, but are not limited to, -H, -OH, -R, -C(=O)R and -SO<sub>2</sub>R (where R is a C1-C8 alkyl or aryl moiety), or may be a suitable protecting group for protein synthesis, such as BOC, FMOC or CBZ (i.e., tert-butyloxycarbonyl, 9-fluorenylmethoxycarbonyl, and benzyloxycarbonyl, respectively). Similarly, representative terminating moieties for the Y moiety include, but are not limited to, -H, -OH, -R, -NHOH, -NHNHR, -C(=O)OR, -C(=O)NHR, -CH<sub>2</sub>Cl,

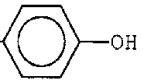
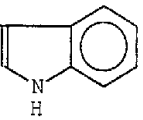


As used herein, the term "an amino acid side chain moiety" represents any amino acid side chain moiety present in naturally occurring proteins, including (but not limited to) the naturally occurring amino acid side chain moieties identified in Table 1 below. Other naturally occurring side chain moieties of this invention include (but are not limited to) the side chain moieties of 3,5-dibromotyrosine, 3,5-diiodotyrosine, hydroxylysine, naphthylalanine, thienylalanine,  $\gamma$ -carboxyglutamate, phosphotyrosine, phosphoserine and glycosylated amino acids such as glycosylated serine, asparagine and threonine.

20

Table 1

| <u>Amino Acid Side Chain Moiety</u>                                                                        | <u>Amino Acid</u> |
|------------------------------------------------------------------------------------------------------------|-------------------|
| -H                                                                                                         | Glycine           |
| -CH <sub>3</sub>                                                                                           | Alanine           |
| -CH(CH <sub>3</sub> ) <sub>2</sub>                                                                         | Valine            |
| -CH <sub>2</sub> CH(CH <sub>3</sub> ) <sub>2</sub>                                                         | Leucine           |
| -CH(CH <sub>3</sub> )CH <sub>2</sub> CH <sub>3</sub>                                                       | Isoleucine        |
| -(CH <sub>2</sub> ) <sub>4</sub> NH <sub>3</sub> <sup>+</sup>                                              | Lysine            |
| -(CH <sub>2</sub> ) <sub>3</sub> NHC(NH <sub>2</sub> )NH <sub>2</sub> <sup>+</sup>                         | Arginine          |
| ---CH <sub>2</sub> ---  | Histidine         |

| <u>Amino Acid Side Chain Moiety</u>                                                              | <u>Amino Acid</u> |
|--------------------------------------------------------------------------------------------------|-------------------|
| $-\text{CH}_2\text{COO}^-$                                                                       | Aspartic acid     |
| $-\text{CH}_2\text{CH}_2\text{COO}^-$                                                            | Glutamic acid     |
| $-\text{CH}_2\text{CONH}_2$                                                                      | Asparagine        |
| $-\text{CH}_2\text{CH}_2\text{CONH}_2$                                                           | Glutamine         |
| $-\text{CH}_2$  | Phenylalanine     |
| $-\text{CH}_2$  | Tyrosine          |
| $-\text{CH}_2$  | Tryptophan        |
| $-\text{CH}_2\text{SH}$                                                                          | Cysteine          |
| $-\text{CH}_2\text{CH}_2\text{SCH}_3$                                                            | Methionine        |
| $-\text{CH}_2\text{OH}$                                                                          | Serine            |
| $-\text{CH}(\text{OH})\text{CH}_3$                                                               | Threonine         |

In addition to naturally occurring amino acid side chain moieties, the amino acid side chain moieties of the present invention also include various derivatives thereof. As used herein, a "derivative" of an amino acid side chain moiety includes all modifications and/or variations to naturally occurring amino acid side chain moieties. For example, the amino acid side chain moieties of alanine, valine, leucine, isoleucine and phenylalanine may generally be classified as lower chain alkyl, aryl or aralkyl moieties. Derivatives of amino acid side chain moieties include other straight chain or branched, cyclic or noncyclic, substituted or unsubstituted, saturated or unsaturated lower chain alkyl, aryl or aralkyl moieties.

As used herein, "lower chain alkyl moieties" contain from 1-12 carbon atoms, "lower chain aryl

moieties" contain from 6-12 carbon atoms, and "lower chain aralkyl moieties" contain from 7-12 carbon atoms. Thus, in one embodiment, the amino acid side chain derivative is selected from a C<sub>1-12</sub> alkyl, a C<sub>6-12</sub> aryl and a C<sub>7-12</sub> aralkyl, and in a more preferred embodiment, from a C<sub>1-7</sub> alkyl, a C<sub>6-10</sub> aryl and a C<sub>7-11</sub> aralkyl.

Amino acid side chain derivatives of this invention further include substituted derivatives of lower chain alkyl, aryl and aralkyl moieties, wherein the substituent is selected from (but are not limited to) one or more of the following chemical moieties: -OH, -OR, -COOH, -COOR, -CONH<sub>2</sub>, -NH<sub>2</sub>, -NHR, -NRR, -SH, -SR, -SO<sub>2</sub>R, -SO<sub>2</sub>H, -SOR and halogen (including F, Cl, Br and I), wherein each occurrence of R is independently selected from a lower chain alkyl, aryl or aralkyl moiety. Moreover, cyclic lower chain alkyl, aryl and aralkyl moieties of this invention include naphthalene, as well as heterocyclic compounds such as thiophene, pyrrole, furan, imidazole, oxazole, thiazole, pyrazole, 3-pyrroline, pyrrolidine, pyridine, pyrimidine, purine, quinoline, isoquinoline and carbazole. Amino acid side chain derivatives further include heteroalkyl derivatives of the alkyl portion of the lower chain alkyl and aralkyl moieties, including (but not limited to) alkyl and aralkyl phosphonates and silanes.

Bicyclic lactams are known in the art. See, e.g., Columbo, L. et al., *Tet. Lett.* 36(4):625-628, 1995; Baldwin, J.E. et al., *Heterocycles* 34(5):903-906, 1992; and Slomczynska, U. et al., *J. Org. Chem.* 61:1198-1204, 1996. However, the bicyclic lactams of the invention are not disclosed in these references.

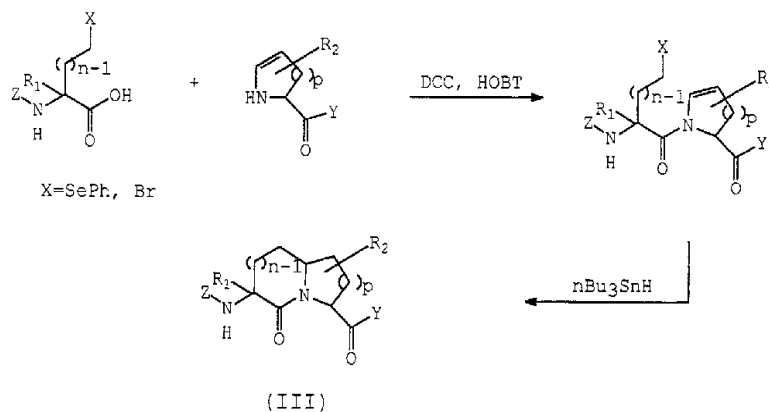
As mentioned above, the  $\beta$ -sheet mimetics of this invention serve to impart and/or stabilize the  $\beta$ -sheet structure of a protein, peptide or molecule. The  $\beta$ -sheet

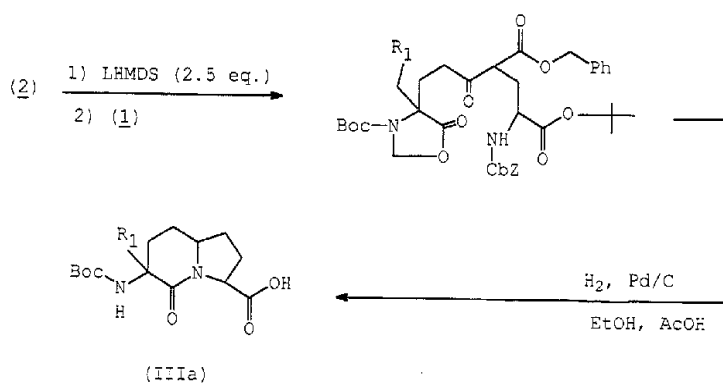
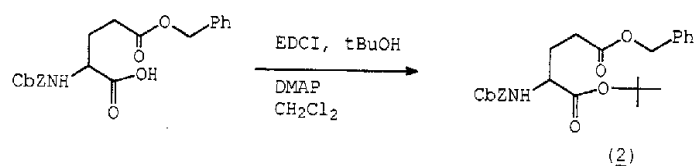
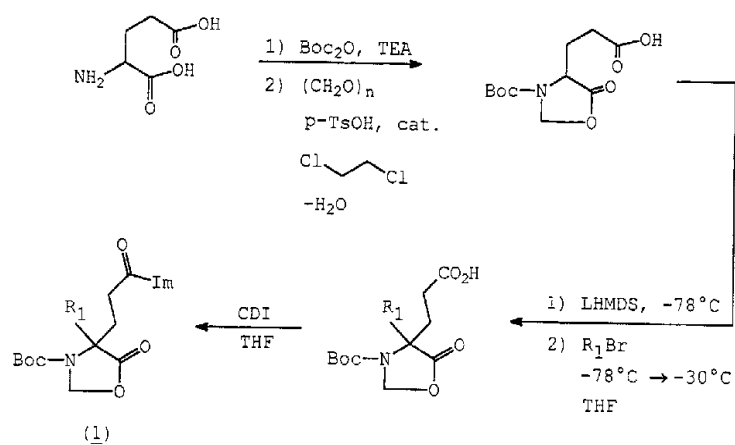
mimetic may be positioned at either the C-terminus or N-terminus of the protein, peptide or molecule, or it may be located within the protein, peptide or molecule itself. In addition, more than one  $\beta$ -sheet mimetic of the present invention may be incorporated in a protein, peptide or molecule.

The  $\beta$ -sheet mimetics of this invention may be synthesized by a number of reaction schemes. For example, the various embodiments of structure (I) may be synthesized according to the following reaction schemes (1) through (17).

Reaction Scheme (1)

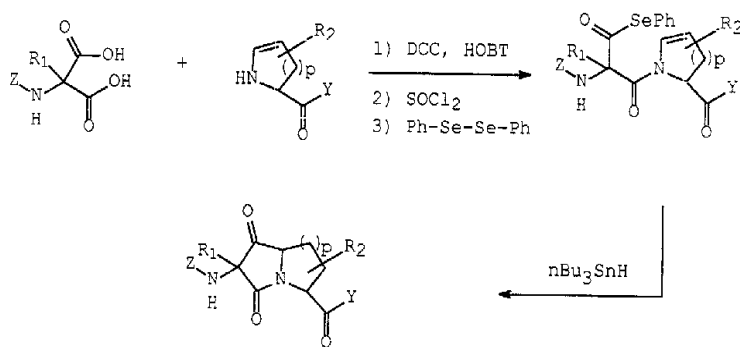
Structure (III) and representative compounds thereof having structure (IIIa) can be synthesized by the following reaction schemes:





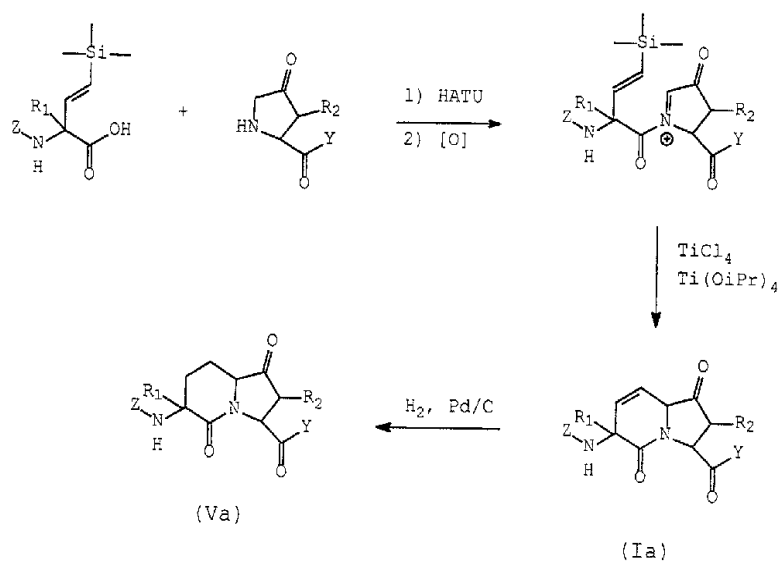
Reaction Scheme (2)

Structure (IV) can be synthesized by the following reaction scheme:

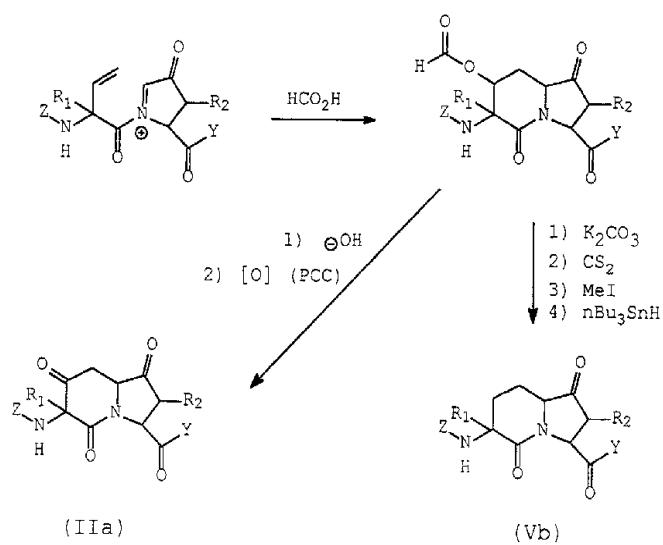


Reaction Scheme (3)

Representative compounds of structure (V) having structure (Va) can be synthesized by the following reaction scheme, where structure (Ia) in scheme (3) is a  
5 representative structure of the invention having a double bond in the bicyclic ring system:

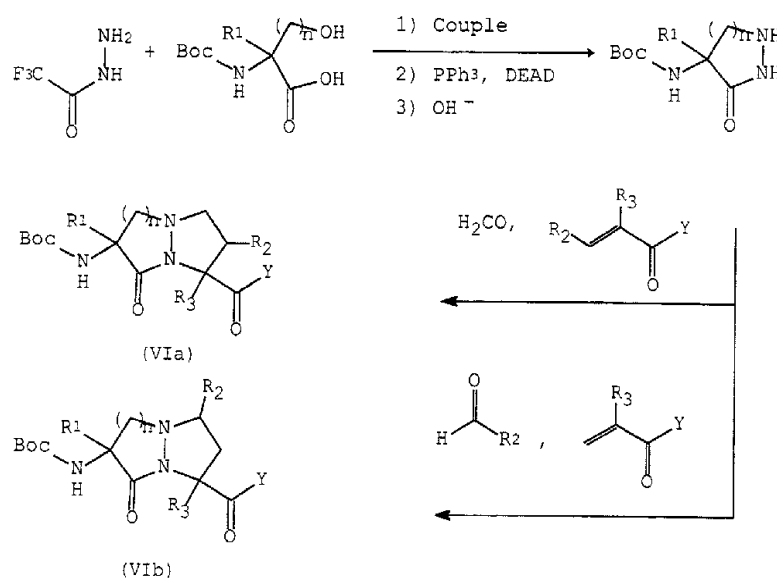


In addition, representative compounds of structure (V) having structure (Vb) may be synthesized by the following reaction scheme, and when A of structure (II) is  $-C(=O)(CH_2)_{1-3}-$ , a related compound (designated (IIa) below) can be synthesized by the following reaction scheme:



## Reaction Scheme (4)

Representative compounds of structure (VI) having structures (VIa) and (VIb) below, wherein  $R_3$  is hydrogen, can be synthesized by the following reaction scheme (see Holmes and Neel, *Tet. Lett.* 31:5567-70, 1990):

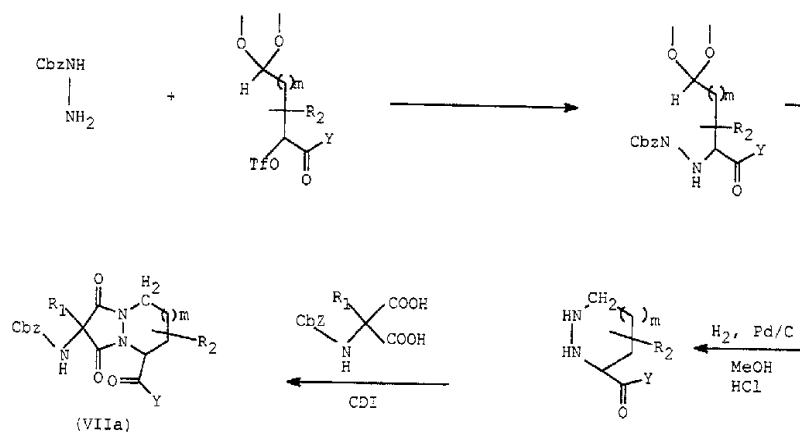


Representative compounds of structure (II) wherein  $R_3$  is an amino acid side chain moiety or derivative thereof may also be prepared according to the above scheme (4).

Reaction Scheme (5)

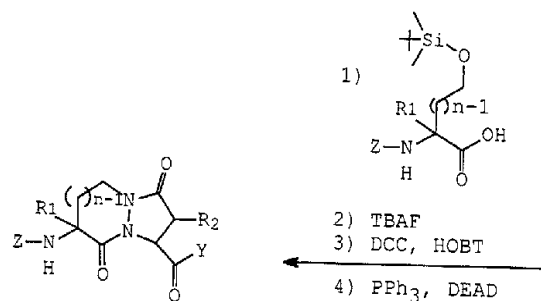
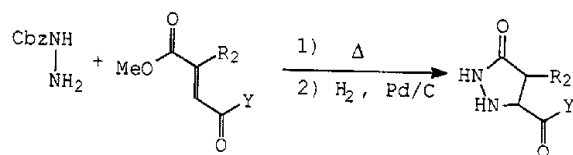
Representative compounds of structure (VII) having structure (VIIa) can be synthesized by the following reaction scheme:

5



Reaction Scheme (6)

Structure (VIII) can be synthesized by the following reaction scheme:

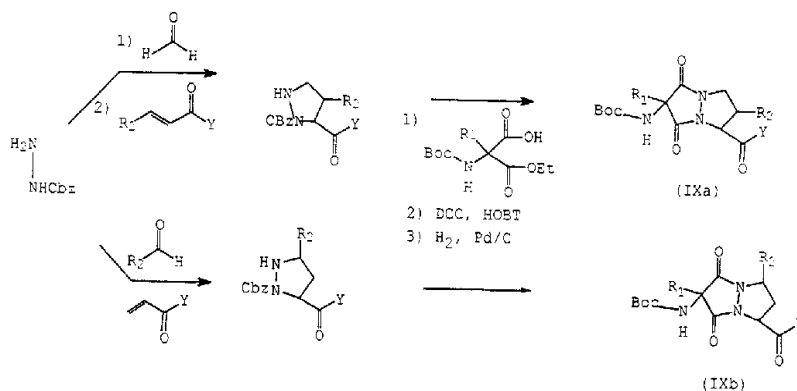


(VIII)

5

Reaction Scheme (7)

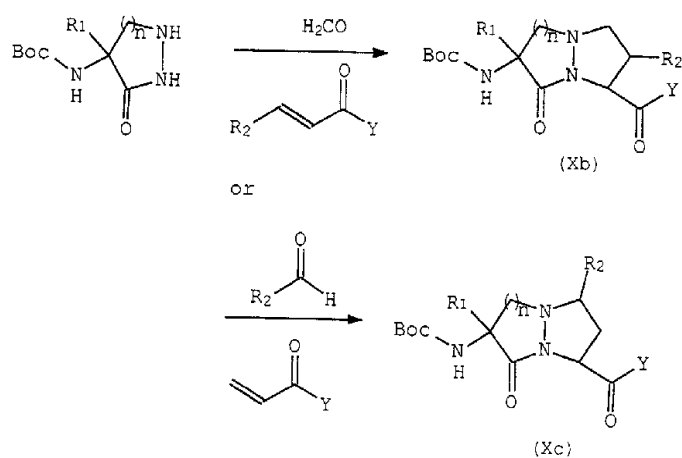
Representative compounds of structure (IX) having structures (IXa) and (IXb) shown below, can be synthesized by the following reaction scheme:



(IXb)

Reaction Scheme (8)

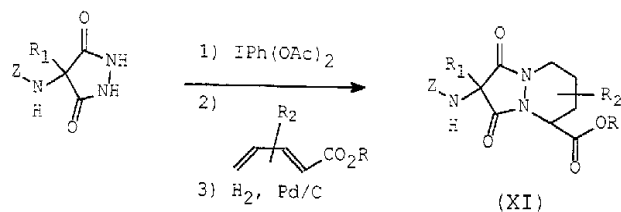
Representative compounds of structure (X) having  
 5 structures (Xb) and (Xc) can be synthesized by the  
 following reaction scheme (see Jungheim & Sigmund, *J. Org.*  
*Chem.* 52:4007-4013, 1987):



10

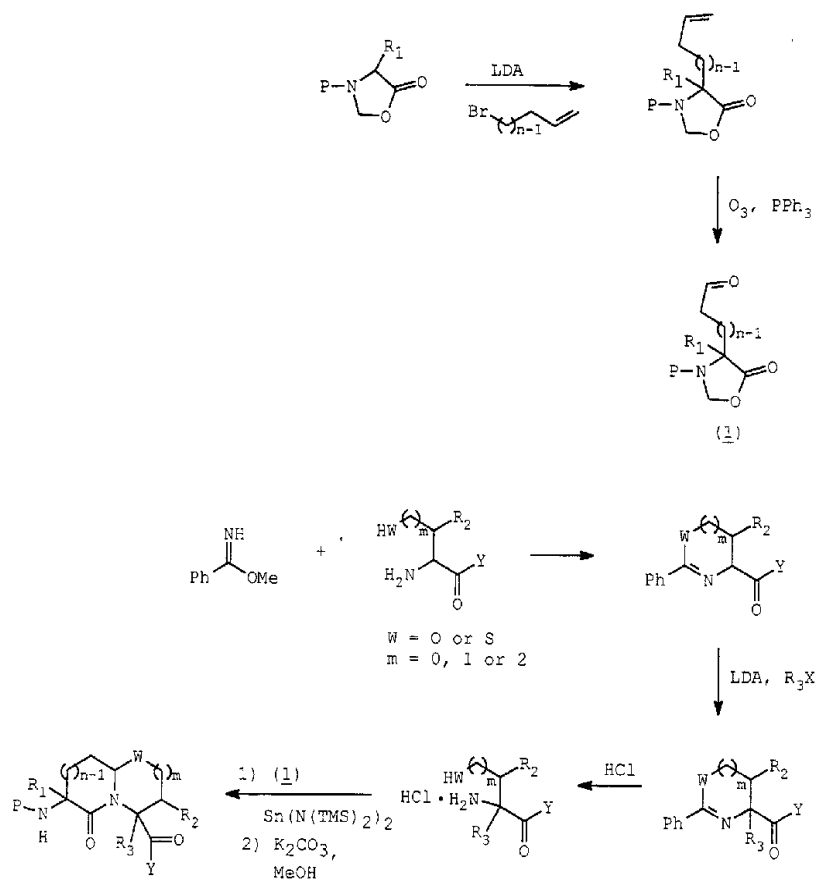
Reaction Scheme (9)

Structure (XI) may be synthesized by the  
 following reaction scheme (see Perkin, *J. Chem. Soc. Perk.*  
 15 *Trans.* 1:155-164, 1984):



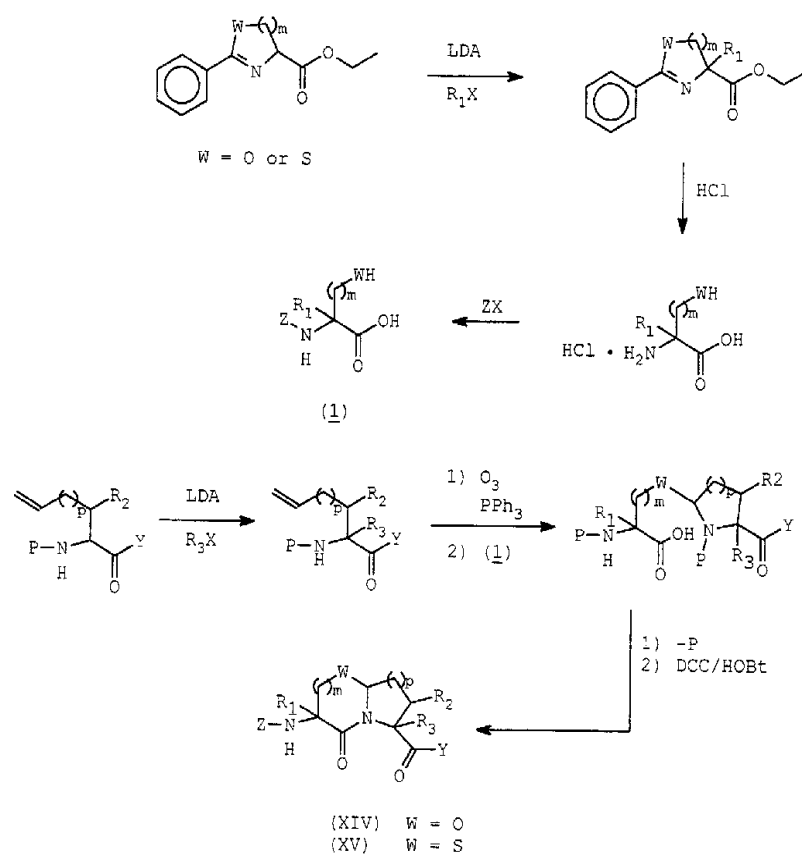
## Reaction Scheme (10)

Structure (XIII) may be synthesized by the following reaction scheme:



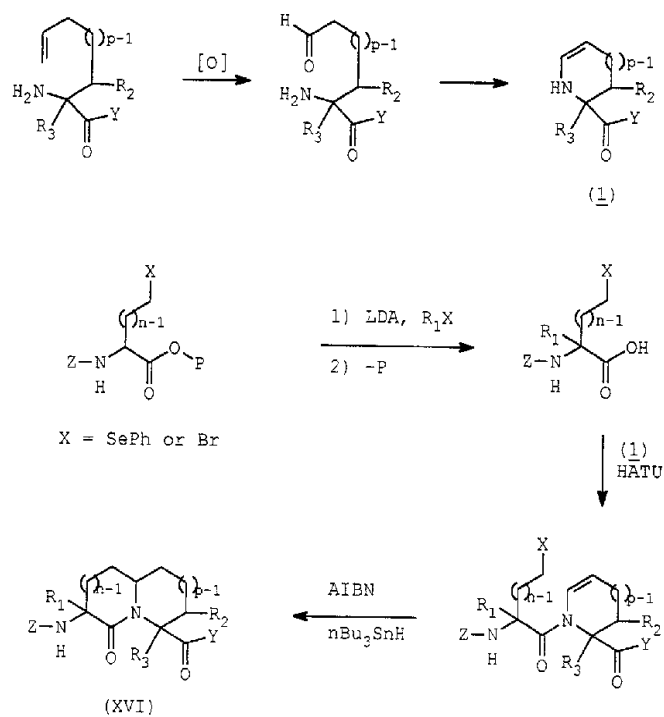
## Reaction Scheme (11)

Structures (XIV) and (XV) may be synthesized by the following reaction scheme:



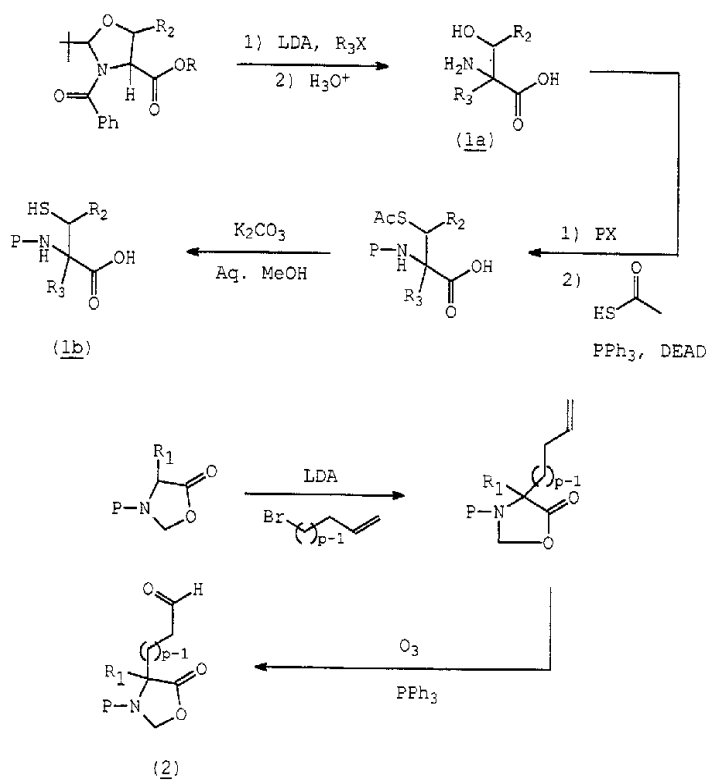
## Reaction Scheme (12)

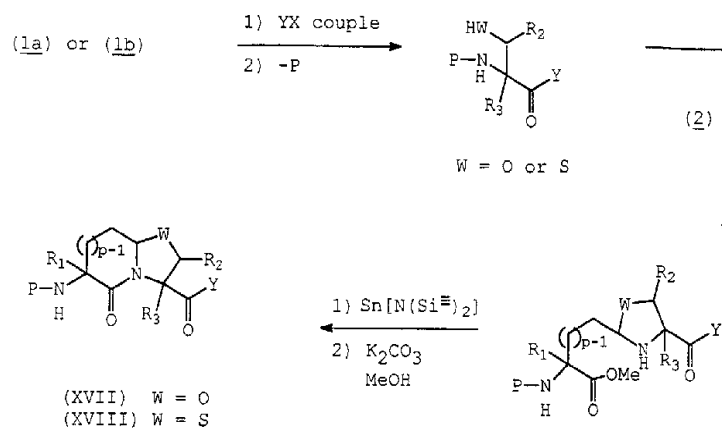
Structure (XVI) may be synthesized by the following reaction scheme:



Reaction Scheme (13)

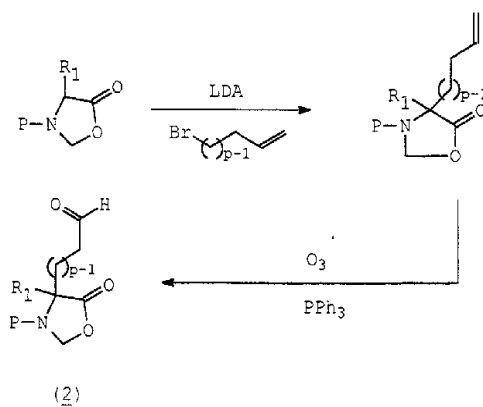
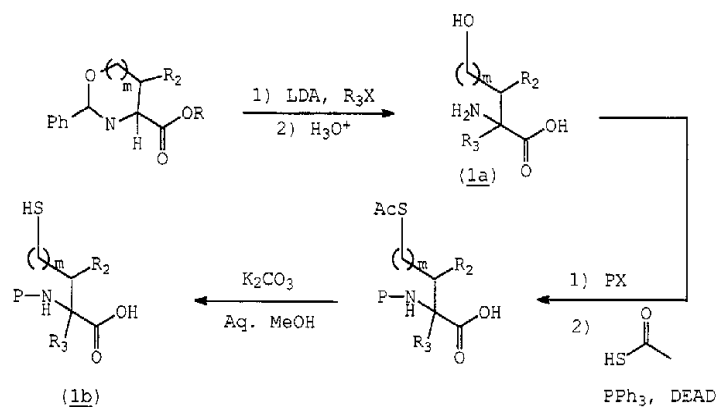
Structures (XVII) and (XVIII) may be synthesized by the following reaction scheme:

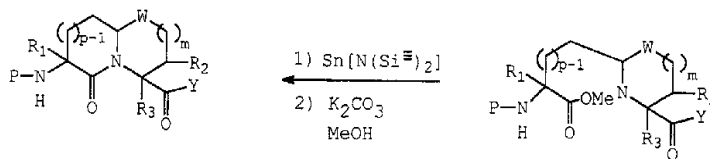




Reaction Scheme (14)

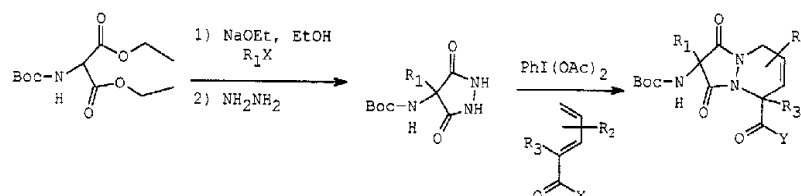
Structures (XIX) and (XX) may be synthesized by the following reaction scheme:





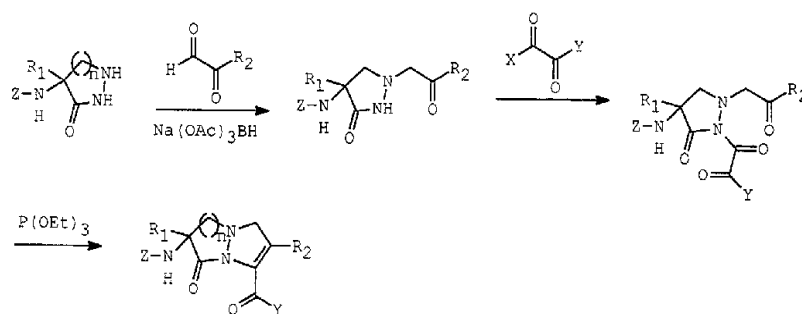
Reaction Schemes (15), (16) and (17) illustrate  
20 synthetic methodology for preparing representative  
compounds of structure (I) wherein the bicyclic ring  
system is formed in part by a  $-C=C-$  group.

## Reaction Scheme (15)



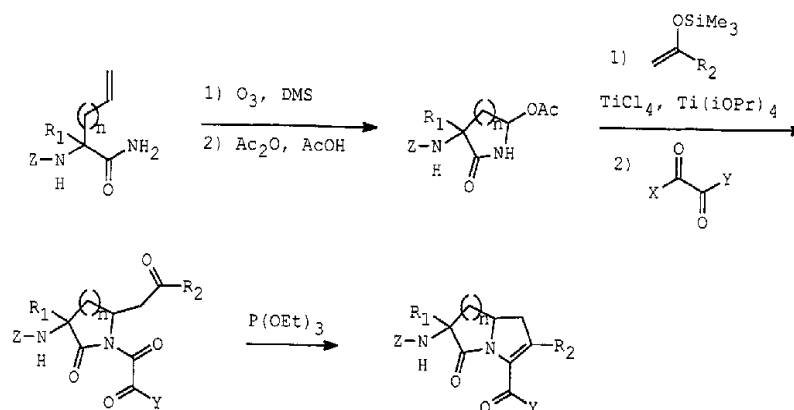
5

## Reaction Scheme (16)

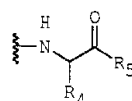


10

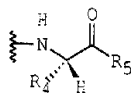
## Reaction Scheme (17)



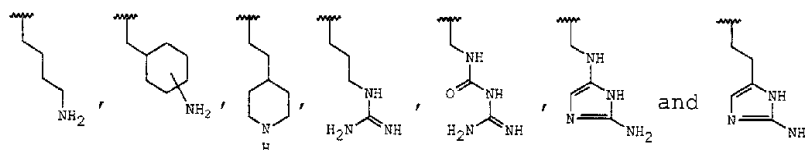
In  $\beta$ -sheet mimetics of the invention, preferred  
 5 Y groups have the structure:



where a preferred stereochemistry is:

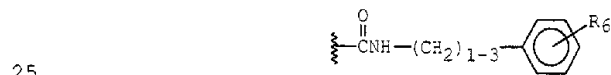


Preferred  $R_4$  groups are organoamine moieties having from about 2 to about 10 carbon atoms and at least one nitrogen atom. Suitable organoamine moieties have the chemical formula  $C_{2-10}H_{4-20}N_{1-6}O_{0-2}$ ; and preferably have the chemical formula  $C_{3-7}H_{7-14}N_{1-4}O_{0-1}$ . Exemplary organoamine moieties of the invention are:

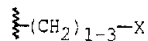


In the above structure,  $R_5$  is selected from (a) alkyl of 1 to about 12 carbon atoms, optionally substituted with 1-4 of halide,  $C_{1-5}$ alkoxy and nitro, (b)  $-C(=O)NH-C_{1-5}$ alkyl, wherein the alkyl group is optionally substituted with halide or  $C_{1-5}$ alkoxy, (c)  $-C(=O)NH-C_{1-10}$ aryl where the aryl group may be optionally substituted with up to five groups independently selected from nitro, halide,  $-NH-(C=O)C_{1-5}$ alkyl,  $-NH-(C=O)C_{6-10}$ aryl,  $C_{1-5}$ alkyl and  $C_{1-5}$ alkoxy, and (d) monocyclic and bicyclic heteroaryl of 4 to about 11 ring atoms, where the ring atoms are selected from carbon and the heteroatoms oxygen, nitrogen and sulfur, and where the heteroaryl ring may be optionally substituted with up to about 4 of halide,  $C_{1-5}$ alkyl,  $C_{1-5}$ alkoxy,  $-C(=O)NHC_{1-5}$ alkyl,  $-C(=O)NHC_{6-10}$ aryl, amino,  $-C(=O)OC_{1-5}$ alkyl and  $-C(=O)OC_{6-10}$ aryl.

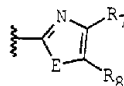
Preferred  $R_5$  groups are:



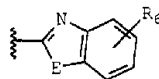
wherein  $R_6$  is hydrogen, nitro, halide,  $NH-C(=O)-C_{1-5}$ alkyl,  $NH-C(=O)-C_{6-10}$ aryl,  $C_{1-5}$ alkyl and  $C_{1-5}$ alkoxy;



wherein X is halide;



wherein E is -O-, -NH- or -S- and R<sub>7</sub> and R<sub>8</sub> are  
 5 independently selected from hydrogen, C<sub>1-5</sub>alkyl,  
 -C(=O)OC<sub>1-5</sub>alkyl, -C(=O)OC<sub>6-10</sub>aryl, -C(=O)NHC<sub>1-5</sub>alkyl and  
 -C(=O)NHC<sub>6-10</sub>aryl; and



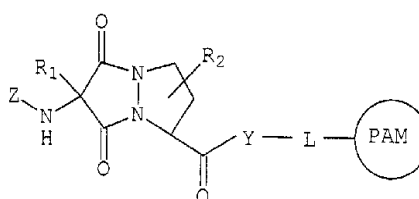
wherein E and R<sub>6</sub> are as defined previously.

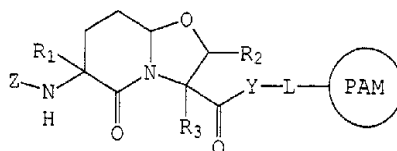
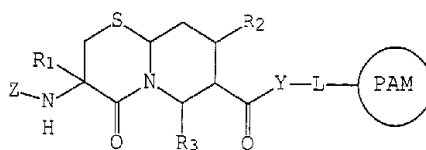
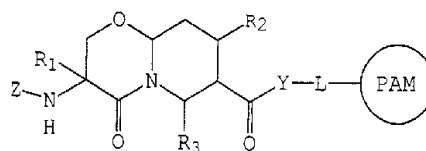
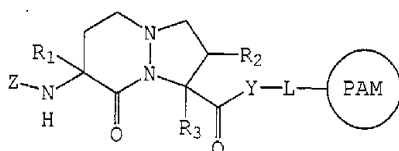
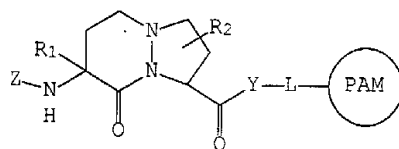
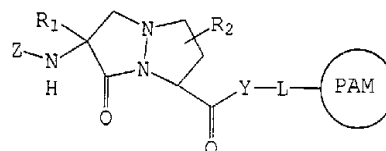
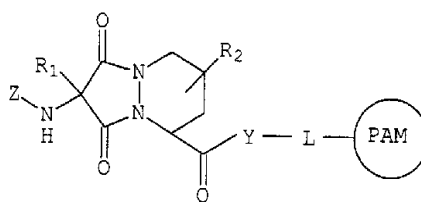
10 The  $\beta$ -sheet mimetics of the present invention  
 may be used in standard peptide synthesis protocols,  
 including automated solid phase peptide synthesis.  
 Peptide synthesis is a stepwise process where a peptide is  
 formed by elongation of the peptide chain through the  
 15 stepwise addition of single amino acids. Amino acids are  
 linked to the peptide chain through the formation of a  
 peptide (amide) bond. The peptide link is formed by  
 coupling the amino group of the peptide to the carboxylic  
 acid group of the amino acid. The peptide is thus  
 20 synthesized from the carboxyl terminus to the amino  
 terminus. The individual steps of amino acid addition are  
 repeated until a peptide (or protein) of desired length  
 and amino acid sequence is synthesized.

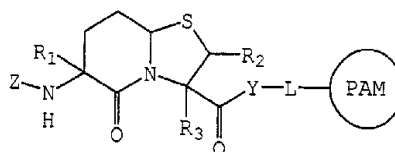
To accomplish peptide (or protein or molecule)  
 25 synthesis as described above, the amino group of the amino  
 acid to be added to the peptide should not interfere with  
 peptide bond formation between the amino acid and the  
 peptide (i.e., the coupling of the amino acid's carboxyl  
 group to the amino group of the peptide). To prevent such

interference, the amino groups of the amino acids used in peptide synthesis are protected with suitable protecting groups. Typical amino protecting groups include, for example, BOC and FMOC groups. Accordingly, in one embodiment of the present invention, the  $\beta$ -sheet mimetics of the present invention bear a free carboxylic acid group and a protected amino group, and are thus suitable for incorporation into a peptide by standard synthetic techniques.

The  $\beta$ -sheet mimetics of this invention have broad utility in naturally occurring or synthetic peptides, proteins and molecules. For example, the  $\beta$ -sheet mimetics disclosed herein have activity as inhibitors of the large family of trypsin-like serine proteases, including those preferring arginine or lysine as a P' substituent. These enzymes are involved in blood coagulation, and include (but are not limited to) Factor VIIa, Factor IXa, Factor Xa, thrombin, kallikrein, urokinase (which is also involved in cancer metastasis) and plasmin. Thus, the ability to selectively inhibit these enzymes has wide utility in therapeutic applications involving cardiovascular disease and oncology. To this end, the following  $\beta$ -sheet mimetics can be synthesized on solid support (e.g., PAM resin):







In the above  $\beta$ -sheet mimetics, L is an optional linker.

5           The  $\beta$ -sheet mimetics may then be cleaved from the solid support by, for example, aminolysis, and screened as competitive substrates against appropriate agents, such as the chromogenic substrate BAPNA (benzyoylarginine paranitroanalide) (see Eichler and Houghten, *Biochemistry* 32:11035-11041, 1993) (incorporated herein by reference). Alternatively, by employing a suitable linker moiety, such screening may be performed while the  $\beta$ -sheet mimetics are still attached to the solid support.

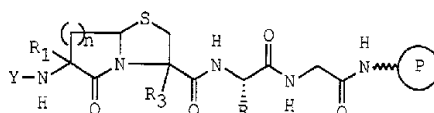
15           Once a substrate is selected by the above kinetic analysis, the  $\beta$ -sheet mimetic may be converted into a protease inhibitor by modifications to the C-terminal - that is, by modification to the Y moiety. For example, the terminal Y moiety may be replaced with  
20   -CH<sub>2</sub>Cl, -CF<sub>3</sub>, -H, or -C(O)NHR. Appropriate R moieties may be selected using a library of substrates, or using a library of inhibitors generated using a modification of the procedure of Wasserman and Ho (*J. Org. Chem.* 59:4364-4366, 1994) (incorporated herein by reference).

25           Libraries of compounds containing  $\beta$ -strand templates may be constructed to determine the optimal sequence for substrate recognition or binding. Representative strategies to use such libraries are discussed below.

30           A representative  $\beta$ -sheet mimetic substrate library may be constructed as follows. It should be

understood that the following is exemplary of methodology that may be used to prepare a  $\beta$ -sheet mimetic substrate library, and that other libraries may be prepared in an analogous manner.

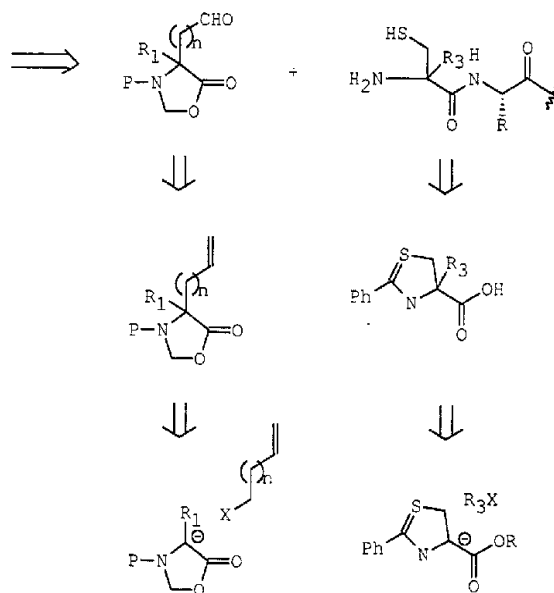
5 In a first step, a library of the following type:



10  $R_1$ ,  $R_3$ ,  $R$  = amino acid side chain moieties or derivatives thereof;  $Y = H$ ,  $Ac$ ,  $SO_2R$ ; and the circled "P" represents a solid support.

may be constructed on a solid support (PEGA resin, Meldal, *M. Tetrahedron Lett.* 33:3077-80, 1992; controlled pore  
15 glass, Singh et al., *J. Med. Chem.* 38:217-19, 1995). The solid support may then be placed in a dialysis bag (Bednarski et al., *J. Am. Chem. Soc.* 109:1283-5, 1987) with the enzyme (e.g., a protease) in an appropriate buffer. The bag is then placed in a beaker with bulk  
20 buffer. The enzymatic reaction is monitored as a function of time by HPLC and materials cleaved from the polymer are analyzed by MS/MS. This strategy provides information concerning the best substrates for a particular enzyme/protease.

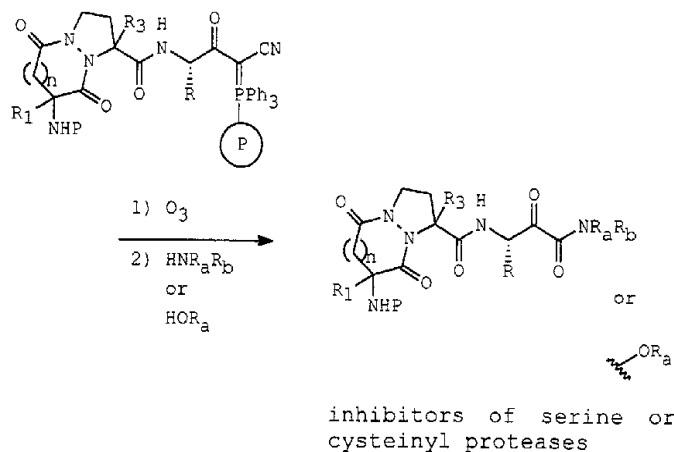
25 The synthesis of the above  $\beta$ -sheet mimetic is illustrated by the retrosynthetic procedure shown next:



The complexity of the library generated by this technique is  $(R_1)(R_3)(R)(Y)$ . Assuming  $R_1$ ,  $R_3$  and  $R$  are selected from naturally occurring amino acid side chain moieties,  $n$  is constant, and  $Y$  is H, Ac or  $-SO_2R$  as defined above, a library having on the order of 24,000 members  $[(20)(20)(20)(3)]$  is generated.

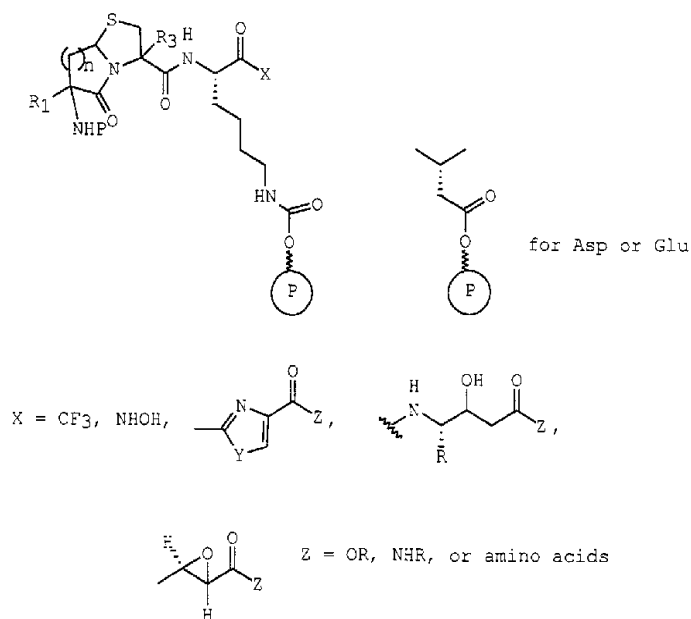
After screening the library against a protease, the library may then recovered and screened with a second protease, and so on.

In addition, a library of inhibitors can be constructed and screened in a standard chromogenic assay. For example, the library may be constructed as follows, where the following example is merely representative of the inhibitor libraries that may be prepared in an analogous manner to the specific example provided below.

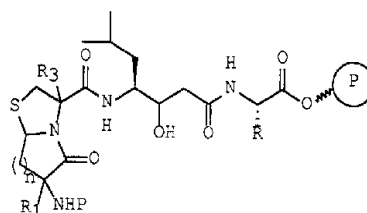


5 (See Wasserman et al., *J. Org. Chem.* 59:4364-6, 1994.)

A further alternative strategy is to link the library through the sidechain R group as shown below.

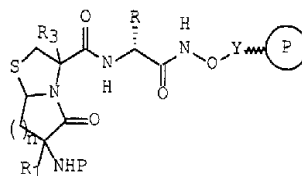


A library of aspartic protease inhibitors may be constructed having the following exemplary structure, and then cleaved from the resin and screened:



5

Similarly, for metalloproteases, a library having the exemplary structure shown below may be constructed and then cleaved from the resin to provide a library of hydroxamic acids:



The activity of the  $\beta$ -sheet mimetics of this invention may be further illustrated by reference to Table 2 which lists biologically active peptides. In particular, the peptides of Table 2 are known to have biological activity as substrates or inhibitors.

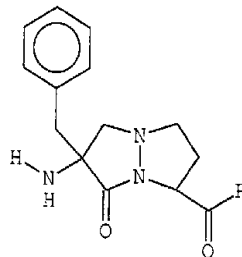
15

Table 2  
Biologically Active Protease Inhibitors

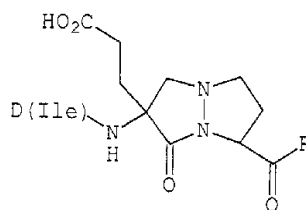
- (a) (D)FPR (Thrombin)  
Enzyme 40:144-48, 1988
- (b) (D)IEGR (Factor X)  
Handbook of Synthetic Substrates for the  
Coagulation and Fibrinolytic Systems, H.C.  
Hemker, pp. 1-175, 1983, Martinus Nijhoff  
Publishers, The Hague.

In view of the above biologically active  
peptides,  $\beta$ -sheet mimetics of this invention may be  
substituted for one or more amino acids thereof. For  
example, the following  $\beta$ -sheet modified peptides may be  
synthesized:

(a')



(b')

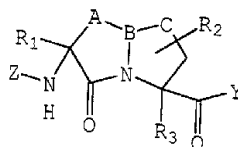


More generally, the  $\beta$ -sheet mimetics of this  
invention can be synthesized to mimic any number of

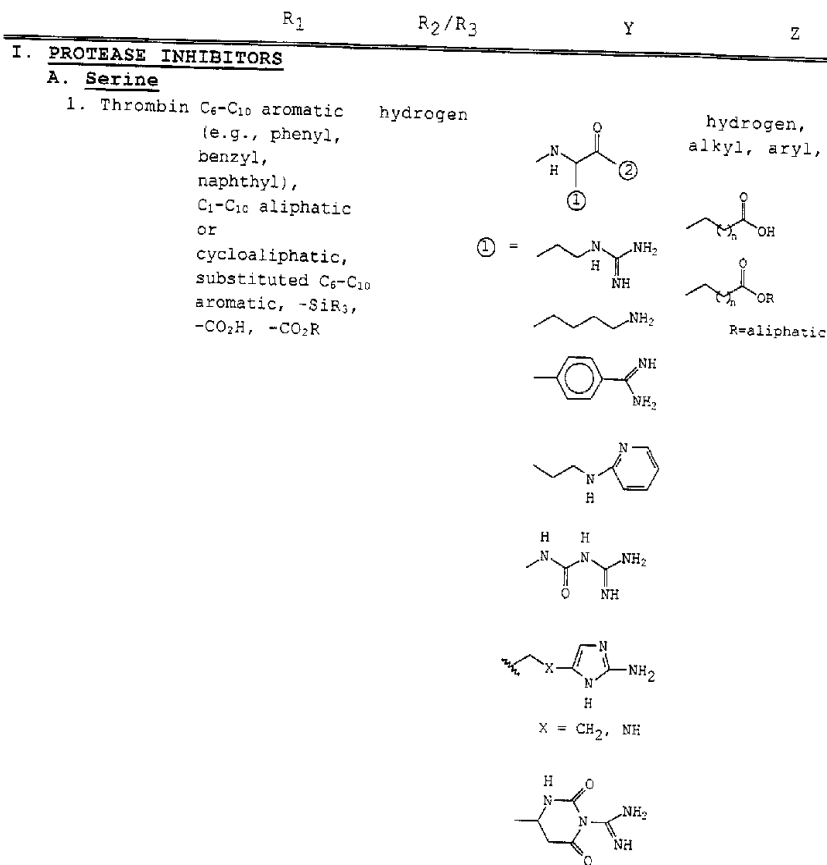
biologically active peptides by appropriate choice of the  $R_1$ ,  $R_2$ ,  $R_3$ , Y and Z moieties (as well as the A, B and C moieties of structure (I) itself). This is further illustrated by Table 3 which discloses various modifications which may be made to the  $\beta$ -sheet mimetics of structure (I) to yield biologically active compounds. In Table 3,  $R_2$  and  $R_3$  are independently chosen from among the atoms or groups shown under the " $R_2/R_3$ " column.

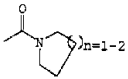
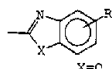
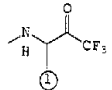
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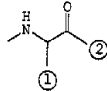
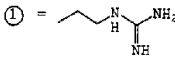
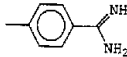
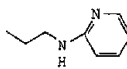
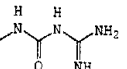
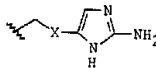
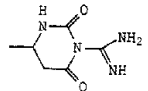
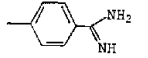
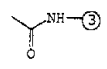
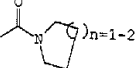
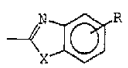
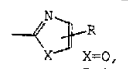
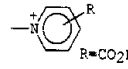
Table 3  
Modifications to Structure (I) to Yield  
Biological Active Compounds

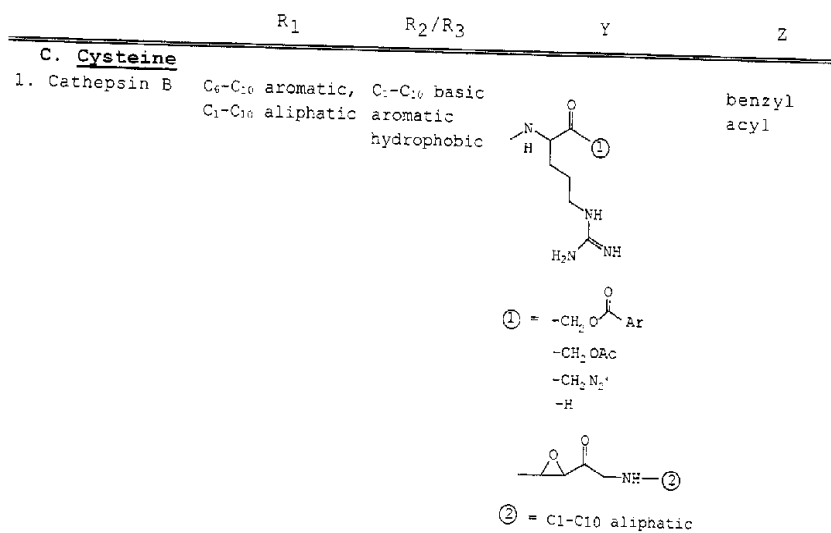
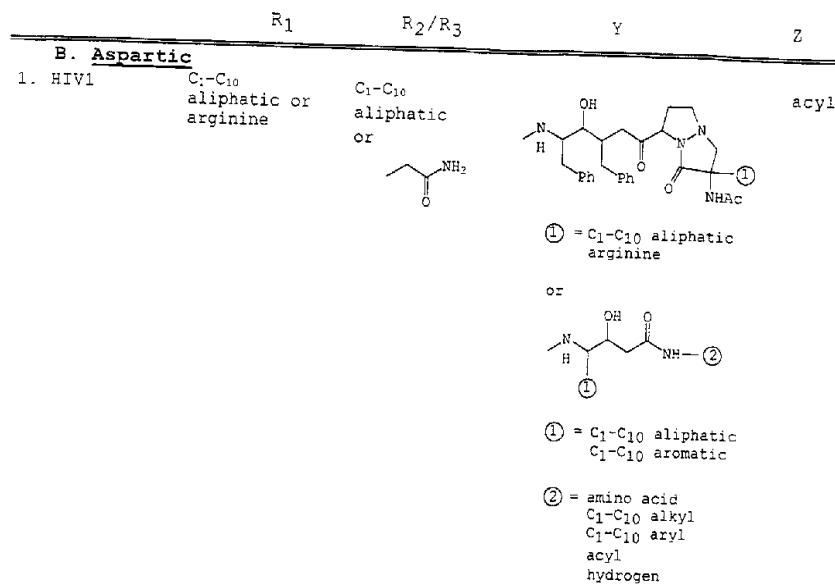


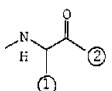
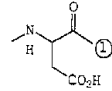
15



|             | R <sub>1</sub>                               | R <sub>2</sub> /R <sub>3</sub>                               | Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Z    |
|-------------|----------------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
|             |                                              |                                                              | $\textcircled{2} = \text{CH}_2\text{Cl}$<br>$\text{CF}_3$<br> cycloaliphatic<br><br><br>$\text{X}=\text{O}, \text{S}, \text{NH}$<br>$\text{R}=\text{CO}_2\text{H}, \text{CO}_2\text{R},$<br>$\text{SO}_2\text{R}, \text{COCF}_3$<br><br>$\text{X}=\text{O}, \text{S}, \text{NH}$<br>$\text{R}=\text{CO}_2\text{H}, \text{SO}_2\text{R},$<br>$\text{CO}_2\text{R}$<br><br>$\text{R}=\text{CO}_2\text{H}, \text{CO}_2$<br>$\text{SO}_2\text{R}, \text{COCF}_3$ |      |
| 2. Elastase | C <sub>1</sub> -C <sub>10</sub><br>aliphatic | hydrogen or C <sub>1</sub> -<br>C <sub>10</sub> heterocyclic | <br>$\textcircled{1} = -\text{CH}_3$<br>$-\text{CH}(\text{CH}_3)_2$<br>or<br> aromatic<br>or<br>aliphatic                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | acyl |

|             | R <sub>1</sub>                                                                                                                                          | R <sub>2</sub> /R <sub>3</sub> | Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Z                        |
|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| 3. Factor X | C <sub>1</sub> -C <sub>10</sub><br>aliphatic<br>carboxylic<br><br>aromatic<br>carboxylate<br><br>C <sub>1</sub> -C <sub>10</sub> acidic<br>heterocyclic | hydrogen                       | <br><br><br><br><br><br><br><p>X = CH<sub>2</sub>, NH</p><br><br><br><p>② = -CH<sub>2</sub>Cl<br/>-CF<sub>3</sub></p><br><br><br><br><p>X=O, S, NH<br/>R=CO<sub>2</sub>H, CO<sub>2</sub>R,<br/>SO<sub>2</sub>R, COCF<sub>3</sub></p><br><br><p>X=O, S, NH<br/>R=CO<sub>2</sub>H, SO<sub>2</sub>R,<br/>CO<sub>2</sub>R</p><br><br><p>R=CO<sub>2</sub>H, CO<sub>2</sub><br/>SO<sub>2</sub>R, COCF<sub>3</sub></p><br><p>③ = aliphatic<br/>cycloaliphatic<br/>peptide</p> | D(Ile)<br>Acyl<br>Dansyl |

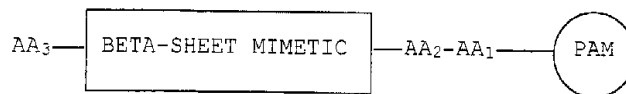


|            | R <sub>1</sub>                                                                                         | R <sub>2</sub> /R <sub>3</sub>               | Y                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Z                                                          |
|------------|--------------------------------------------------------------------------------------------------------|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| 2. Calpain | C <sub>6</sub> -C <sub>10</sub> aromatic,<br>C <sub>1</sub> -C <sub>10</sub> aliphatic,<br>hydrophobic | C <sub>1</sub> -C <sub>10</sub><br>aliphatic |  <p>① = C<sub>1</sub>-C<sub>10</sub> aromatic,<br/>hydrophobic<br/>           ② = -CH<sub>2</sub>F<br/>           -CH<sub>2</sub>N<sub>2</sub><br/>           -CH<sub>2</sub>OAc<br/>           -H</p>                                                                                                                                                                     | benzyl<br>acyl                                             |
| 3. ACE     | C <sub>1</sub> -C <sub>10</sub> aliphatic                                                              | hydrogen                                     |  <p>① = -H<br/>           -CH<sub>2</sub>F<br/>           -CH<sub>2</sub>N<sub>2</sub><sup>+</sup><br/>           -CH<sub>2</sub>C(=O)Ar<br/>           -CH<sub>2</sub>OAc</p>  <p>② = C<sub>1</sub>-C<sub>10</sub> aliphatic<br/>           C<sub>1</sub>-C<sub>10</sub> aromatic</p> | dihydro-<br>cinnamic,<br>aromatic,<br>aliphatic,<br>acetyl |

|                   | R <sub>1</sub>                               | R <sub>2</sub> /R <sub>3</sub>                     | Y   | Z                                                                                                                                                                                    |
|-------------------|----------------------------------------------|----------------------------------------------------|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| D. <u>Metallo</u> |                                              |                                                    |     |                                                                                                                                                                                      |
| 1. ACE            | C <sub>1</sub> -C <sub>10</sub><br>aliphatic | indoyl C <sub>1</sub> -C <sub>10</sub><br>aromatic | -OH |  <p>① = C<sub>1</sub>-C<sub>10</sub> alkyl<br/>           C<sub>1</sub>-C<sub>10</sub> aryl</p> |

|                | R <sub>1</sub>                              | R <sub>2</sub> /R <sub>3</sub>                                                                                                       | Y                                                                                                | Z                                                                                                                                                                                                                                                     |
|----------------|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2. Collagenase | C <sub>1</sub> -C <sub>10</sub> alkyl       | C <sub>1</sub> -C <sub>10</sub><br>aromatic, C <sub>1</sub> -<br>C <sub>10</sub> aliphatic,<br>C <sub>1</sub> -C <sub>10</sub> basic | <br>① = alkyl | hydroxyl<br><br>① = hydrogen<br>C <sub>1</sub> -C <sub>10</sub> alkyl                                                                                              |
|                | or                                          |                                                                                                                                      |                                                                                                  |                                                                                                                                                                    |
|                | C <sub>6</sub> -C <sub>10</sub><br>aromatic | C <sub>1</sub> -C <sub>10</sub> alkyl<br><br>C <sub>1</sub> -C <sub>10</sub><br>aliphatic                                            | -NHOH                                                                                            | hydroxyl<br><br>① = hydrogen<br>C <sub>1</sub> -C <sub>10</sub> alkyl, or<br> |

When the  $\beta$ -sheet mimetics of this invention are substituted for one or more amino acids of a biologically active peptide, the structure of the resulting  $\beta$ -sheet modified peptide (prior to cleavage from the solid support, such as PAM) may be represented by the following diagram, where AA<sub>1</sub> through AA<sub>3</sub> represent the same or different amino acids:



10

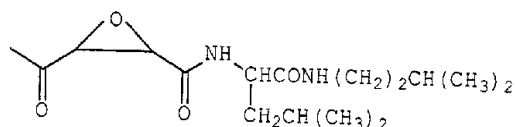
The precise  $\beta$ -sheet mimetic may be chosen by any of a variety of techniques, including computer modeling, randomization techniques and/or by utilizing natural

substrate selection assays. The  $\beta$ -sheet mimetic may also be generated by synthesizing a library of  $\beta$ -sheet mimetics, and screening such library members to identify active members as disclosed above.

5       Once the optimized  $\beta$ -sheet mimetic is chosen, modification may then be made to the various amino acids attached thereto. A series of  $\beta$ -sheet modified peptides having a variety of amino acid substitutions are then cleaved from the solid support and assayed to identify a  
10 preferred substrate. It should be understood that the generation of such substrates may involve the synthesis and screening of a number of  $\beta$ -sheet modified peptides, wherein each  $\beta$ -sheet modified peptide has a variety of amino acid substitutions in combination with a variety of  
15 different  $\beta$ -sheet mimetics. In addition, it should also be recognized that, following cleavage of the  $\beta$ -sheet modified peptide from the solid support, the Z moiety is AA<sub>3</sub> and the Y moiety is AA<sub>2</sub> and AA<sub>1</sub> in the above diagram. (While this diagram is presented for illustration,  
20 additional or fewer amino acids may be linked to the  $\beta$ -sheet mimetic - that is, AA<sub>3</sub> may be absent or additional amino acids may be joined thereto; and AA<sub>2</sub> and/or AA<sub>1</sub> may be omitted or additional amino acids may be joined thereto).

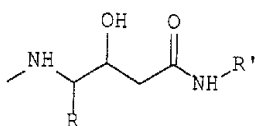
25       Once a preferred substrate is identified by the procedures disclosed above, the substrate may be readily converted to an inhibitor by known techniques. For example, the C-terminal amino acid (in this case AA<sub>1</sub>) may be modified by addition of a number of moieties known to  
30 impart inhibitor activity to a substrate, including (but not limited to) -CF<sub>3</sub> (a known reversible serine protease inhibitor), -CH<sub>2</sub>Cl (a known irreversible serine protease inhibitor), -CH<sub>2</sub>N<sub>2</sub><sup>+</sup> and -CH<sub>2</sub>S(CH<sub>3</sub>)<sub>2</sub><sup>+</sup> (known cysteinyl

protease inhibitors), -NHOH (a known metalloprotease inhibitor),



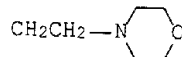
5

(a known cysteinyl protease inhibitor), and



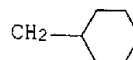
$R' = \text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$

or



$R = \text{CH}_2\text{CH}(\text{CH}_3)_2$

or



10 (a known aspartyl protease inhibitor).

While the utility of the  $\beta$ -sheet mimetics of this invention have been disclosed with regard to certain embodiments, it will be understood that a wide variety and type of compounds can be made which includes the  $\beta$ -sheet mimetics of the present invention. For example, a  $\beta$ -sheet mimetic of this invention may be substituted for two or more amino acids of a peptide or protein. In addition to improving and/or modifying the  $\beta$ -sheet structure of a peptide or protein, especially with regard to conformational stability, the  $\beta$ -sheet mimetics of this invention also serve to inhibit proteolytic breakdown. This results in the added advantage of peptides or proteins which are less prone to proteolytic breakdown due to incorporation of the  $\beta$ -sheet mimetics of this invention.

In another aspect, the present invention encompasses pharmaceutical compositions prepared for storage or administration which comprise a therapeutically effective amount of a  $\beta$ -sheet mimetic or compound of the present invention in a pharmaceutically acceptable carrier. Anticoagulant therapy is indicated for the treatment and prevention of a variety of thrombotic conditions, particularly coronary artery and cerebrovascular disease. Those experienced in this field are readily aware of the circumstances requiring anticoagulant therapy.

The "therapeutically effective amount" of a compound of the present invention will depend on the route of administration, the type of warm-blooded animal being treated, and the physical characteristics of the specific animal under consideration. These factors and their relationship to determining this amount are well known to skilled practitioners in the medical arts. This amount and the method of administration can be tailored to achieve optimal efficacy but will depend on such factors as weight, diet, concurrent medication and other factors which as noted those skilled in the medical arts will recognize.

The "therapeutically effective amount" of the compound of the present invention can range broadly depending upon the desired effects and the therapeutic indication. Typically, dosages will be between about 0.01 mg/kg and 100 mg/kg body weight, preferably between about 0.01 and 10 mg/kg, body weight.

"Pharmaceutically acceptable carriers" for therapeutic use are well known in the pharmaceutical art, and are described, for example, in *Remington's Pharmaceutical Sciences*, Mack Publishing Co. (A.R. Gennaro edit. 1985). For example, sterile saline and

phosphate-buffered saline at physiological pH may be used. Preservatives, stabilizers, dyes and even flavoring agents may be provided in the pharmaceutical composition. For example, sodium benzoate, sorbic acid and esters of p-hydroxybenzoic acid may be added as preservatives. In addition, antioxidants and suspending agents may be used.

Thrombin inhibition is useful not only in the anticoagulant therapy of individuals having thrombotic conditions, but is useful whenever inhibition of blood coagulation is required such as to prevent coagulation of stored whole blood and to prevent coagulation in other biological samples for testing or storage. Thus, the thrombin inhibitors can be added to or contacted with any medium containing or suspected of containing thrombin and in which it is desired that blood coagulation be inhibited (e.g., when contacting the mammal's blood with material selected from the group consisting of vascular grafts, stems, orthopedic prosthesis, cardiac prosthesis, and extracorporeal circulation systems).

The thrombin inhibitors can be co-administered with suitable anti-coagulation agents or thrombolytic agents such as plasminogen activators or streptokinase to achieve synergistic effects in the treatment of various vascular pathologies. For example, thrombin inhibitors enhance the efficiency of tissue plasminogen activator-mediated thrombolytic reperfusion. Thrombin inhibitors may be administered first following thrombus formation, and tissue plasminogen activator or other plasminogen activator is administered thereafter. They may also be combined with heparin, aspirin, or warfarin.

The thrombin inhibitors of the invention can be administered in such oral forms as tablets, capsules (each of which includes sustained release or timed release formulations), pills, powders, granules, elixers,

tinctures, suspensions, syrups, and emulsions. Likewise, they may be administered in intravenous (bolus or infusion), intraperitoneal, subcutaneous, or intramuscular form, all using forms well known to those of ordinary skill in the pharmaceutical arts. An effective but non-toxic amount of the compound desired can be employed as an anti-aggregation agent or treating ocular build up of fibrin. The compounds may be administered intraocularly or topically as well as orally or parenterally.

The thrombin inhibitors can be administered in the form of a depot injection or implant preparation which may be formulated in such a manner as to permit a sustained release of the active ingredient. The active ingredient can be compressed into pellets or small cylinders and implanted subcutaneously or intramuscularly as depot injections or implants. Implants may employ inert materials such as biodegradable polymers or synthetic silicones, for example, Silastic, silicone rubber or other polymers manufactured by the Dow-Corning Corporation.

The thrombin inhibitors can also be administered in the form of liposome delivery systems, such as small unilamellar vesicles, large unilamellar vesicles and multilamellar vesicles. Liposomes can be formed from a variety of phospholipids, such as cholesterol, stearylamine or phosphatidylcholines.

The thrombin inhibitors may also be delivered by the use of monoclonal antibodies as individual carriers to which the compound molecules are coupled. The thrombin inhibitors may also be coupled with soluble polymers as targetable drug carriers. Such polymers can include polyvinylpyrrolidone, pyran copolymer, polyhydroxy-propyl-methacrylamide-phenol, polyhydroxyethyl-aspartarnide-phenol, or

polyethyleneoxide-polylysine substituted with palmitoyl residues. Furthermore, the thrombin inhibitors may be coupled to a class of biodegradable polymers useful in achieving controlled release of a drug, for example, poly(lactic acid), poly(glycolic acid), copolymers of poly(lactic acid) and poly(glycolic acid), poly(epsilon-caprolactone), poly(hydroxy butyric acid), poly(orthoesters), polyacetals, poly(dihydropyrans), polycyanoacrylates and cross linked or amphipathic block copolymers of hydrogels.

The dose and method of administration can be tailored to achieve optimal efficacy but will depend on such factors as weight, diet, concurrent medication and other factors which those skilled in the medical arts will recognize. When administration is to be parenteral, such as intravenous on a daily basis, injectable pharmaceutical compositions can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection, or as emulsions.

Tablets suitable for oral administration of active compounds of the invention (e.g., structures (47), (20b), (37), (39), (29a), (35), (45), (51), (29b), (41) and (13b)), can be prepared as follows:

|    |                            | Amount-mg |       |       |
|----|----------------------------|-----------|-------|-------|
|    |                            | 25.0      | 50.0  | 100.0 |
|    | Active Compound            | 25.0      | 50.0  | 100.0 |
|    | Microcrystalline cellulose | 37.25     | 100.0 | 200.0 |
|    | Modified food corn starch  | 37.25     | 4.25  | 8.5   |
| 25 | Magnesium stearate         | 0.50      | 0.75  | 1.5   |

All of the active compound, cellulose, and a portion of the corn starch are mixed and granulated to 10% corn starch paste. The resulting granulation is sieved,

dried and blended with the remainder of the corn starch and the magnesium stearate. The resulting granulation is then compressed into tablets containing 25.0, 50.0, and 100.0 mg, respectively, of active ingredient per tablet.

5           An intravenous dosage form of the above-indicated active compounds may be prepared as follows:

|                           |              |
|---------------------------|--------------|
| Active Compound           | 0.5-10.0mg   |
| Sodium Citrate            | 5-50mg       |
| Citric Acid               | 1-15mg       |
| Sodium Chloride           | 1-8mg        |
| Water for Injection (USP) | q.s. to 1 ml |

Utilizing the above quantities, the active  
10 compound is dissolved at room temperature in a previously prepared solution of sodium chloride, citric acid, and sodium citrate in Water for Injection (USP, see page 1636 of United States Pharmacopoeia/National Formulary for 1995, published by United States Pharmacopoeia Convention, 15 Inc., Rockville, Maryland, copyright 1994).

Compounds of the present invention when made and selected as disclosed are useful as potent inhibitors of thrombin *in vitro* and *in vivo*. As such, these compounds are useful as *in vitro* diagnostic reagents to prevent the  
20 clotting of blood and as *in vivo* pharmaceutical agents to prevent thrombosis in mammals suspected of having a condition characterized by abnormal thrombosis.

The compounds of the present invention are useful as *in vitro* diagnostic reagents for inhibiting  
25 clotting in blood drawing tubes. The use of stoppered test tubes having a vacuum therein as a means to draw blood obtained by venipuncture into the tube is well known in the medical arts (Kasten, B.L., "Specimen Collection,"

*Laboratory Test Handbook*, 2nd Edition, Lexi-Comp Inc., Cleveland pp. 16-17, Edits. Jacobs, D.S. et al. 1990). Such vacuum tubes may be free of clot-inhibiting additives, in which case, they are useful for the isolation of mammalian serum from the blood they may alternatively contain clot-inhibiting additives (such as heparin salts, EDTA salts, citrate salts or oxalate salts), in which case, they are useful for the isolation of mammalian plasma from the blood. The compounds of the present invention are potent inhibitors of factor Xa or thrombin, and as such, can be incorporated into blood collection tubes to prevent clotting of the mammalian blood drawn into them.

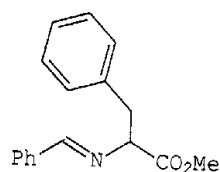
The compounds of the present invention are used alone, in combination of other compounds of the present invention, or in combination with other known inhibitors of clotting, in the blood collection tubes. The amount to be added to such tubes is that amount sufficient to inhibit the formation of a clot when mammalian blood is drawn into the tube. The addition of the compounds to such tubes may be accomplished by methods well known in the art, such as by introduction of a liquid composition thereof, as a solid composition thereof, or liquid composition which is lyophilized to a solid. The compounds of the present invention are added to blood collection tubes in such amounts that, when combined with 2 to 10 mL of mammalian blood, the concentration of such compounds will be sufficient to inhibit clot formation. Typically, the required concentration will be about 1 to 10,000 nM, with 10 to 1000 nM being preferred.

The following examples are offered by way of illustration, not limitation.

## EXAMPLES

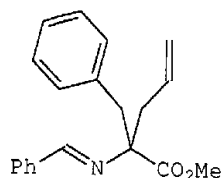
Example 1Synthesis of Representative  $\beta$ -Sheet Mimetic

5 This example illustrates the synthesis of a representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (1):

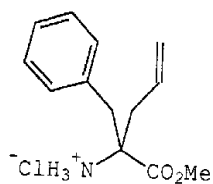
(1)

10 Phenylalanine benzaldimine, structure (1), was synthesized as follows. To a mixture of L-phenylalanine methyl ester hydrochloride (7.19 g, 33.3 mmol) and benzaldehyde (3.4 ml, 33.5 mmol) stirred in CH<sub>2</sub>Cl<sub>2</sub> (150  
15 ml) at room temperature was added triethylamine (7.0 ml, 50 mmol). Anhydrous magnesium sulfate (2 g) was added to the resulting solution and the mixture was stirred for 14 h then filtered through a 1 inch pad of Celite with CH<sub>2</sub>Cl<sub>2</sub>. The filtrate was concentrated under reduced  
20 pressure to ca. one half of its initial volume then diluted with an equal volume of hexanes. The mixture was extracted twice with saturated aqueous NaHCO<sub>3</sub>, H<sub>2</sub>O and brine then dried over anhydrous Na<sub>2</sub>SO<sub>4</sub> and filtered. Concentration of the filtrate under vacuum yielded 8.32 g  
25 (93% yield) of colorless oil. <sup>1</sup>H NMR analysis indicated nearly pure (>95%) phenylalanine benzaldimine. The crude product was used without further purification.

Synthesis of Structure (2):

(2)

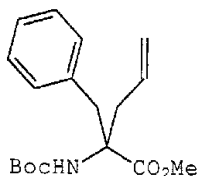
5  $\alpha$ -Allylphenylalanine benzaldimine, structure (2), was synthesized as follows. To a solution of diisopropylamine (4.3 ml, 33 mmol) stirred in THF (150 ml) at  $-78^{\circ}\text{C}$  was added dropwise a solution of *n*-butyllithium (13 ml of a 2.5 M hexane solution, 33 mmol). The resulting solution was stirred for 20 min. then a solution of phenylalanine benzaldimine (7.97 g, 29.8 mmol) in THF (30 ml) was slowly added. The resulting dark red-orange solution was stirred for 15 min. then allyl bromide (3.1 ml, 36 mmol) was added. The pale yellow solution was stirred for 30 min. at  $-78^{\circ}\text{C}$  then allowed to warm to room temperature and stirred an additional 1 h. Saturated aqueous ammonium chloride was added and the mixture was poured into ethyl acetate. The organic phase was separated and washed with water and brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded 8.54 g of a viscous yellow oil. Purification by column chromatography yielded 7.93 g (87%) of  $\alpha$ -allylphenylalanine benzaldimine as a viscous colorless oil.

Synthesis of Structure (3):

(3)

$\alpha$ -Allylphenylalanine hydrochloride, structure (3), was synthesized as follows. To a solution of  $\alpha$ -allylphenylalanine benzaldimine (5.94 g, 19.3 mmol) stirred in methanol (50 ml) was added 5% aqueous hydrochloric acid (10 ml). The solution was stirred at room temperature for 2 h then concentrated under vacuum to an orange-brown caramel. The crude product was dissolved in  $\text{CHCl}_3$  (10 ml) and the solution was heated to boiling. Hexanes (~150 ml) were added and the slightly cloudy mixture was allowed to cool. The liquid was decanted away from the crystallized solid then the solid was rinsed with hexanes and collected. Removal of residual solvents under vacuum yielded 3.56 g (72%) of pure  $\alpha$ -allylphenylalanine hydrochloride as a white crystalline solid.

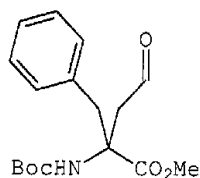
$^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  8.86 (3 H, br s), 7.32-7.26 (5H, m), 6.06 (1 H, dddd,  $J = 17.5, 10.5, 7.6, 7.3$  Hz), 5.33 (1H, d,  $J = 17.5$  Hz), 5.30 (1 H, d,  $J = 10.5$  Hz), 3.70 (3 H, s), 3.41 (1 H, d,  $J = 14.1$  Hz), 3.35 (1 H, d,  $J = 14.1$  Hz), 2.98 (1 H, dd,  $J = 14.5, 7.3$  Hz), 2.88 (1 H, dd,  $J = 14.5, 7.6$  Hz).

Synthesis of Structure (4):

(4)

- N-tert-butyloxycarbonyl-α-allylphenylalanine, structure (4) was synthesized as follows. To a solution of D,L α-allylphenylalanine hydrochloride (565 mg, 2.21 mmol) stirred in a mixture of THF (15 ml) and water (5 ml) was added di-tert-butyl dicarbonate followed by careful addition of solid sodium bicarbonate in small portions. The resulting two phase mixture was vigorously stirred at room temperature for 2 days then diluted with ethyl acetate. The organic phase was separated and washed with water and brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded a colorless oil that was purified by column chromatography (5 to 10% EtOAc in hexanes gradient elution) to yield 596 mg (86%) of N-tert-butyloxycarbonyl-α-allylphenylalanine.

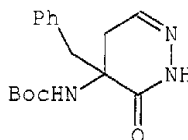
- TLC R<sub>f</sub> = 0.70 (silica, 20% EtOAc in hexanes);  
<sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.26-7.21 (3 H, m), 7.05 (2 H, d, J = 6.1 Hz), 5.64 (1 H, dddd, J = 14.8, 7.6, 7.2, 7.2 Hz), 5.33 (1 H, br s), 5.12-5.08 (2 H, m), 3.75 (3 H, s), 3.61 (1 H, d, J = 13.5 Hz), 3.21 (1 H, dd, J = 13.7, 7.2 Hz), 3.11 (1 H, d, J = 13.5 Hz), 2.59 (1 H, dd, J = 13.7, 7.6 Hz), 1.47 (9 H, s).

Synthesis of Structure (5):

(5)

An aldehyde of structure (5) was synthesized as follows. Ozone was bubbled through a solution of 2.10 g (6.57 mmol) of the structure (4) olefin stirred at  $-78^{\circ}\text{C}$  in a mixture of  $\text{CH}_2\text{Cl}_2$  (50 ml) and methanol (15 ml) until the solution was distinctly blue in color. The solution was stirred an additional 15 min. then dimethyl sulfide was slowly added. The resulting colorless solution was stirred at  $-78^{\circ}\text{C}$  for 10 min. then allowed to warm to room temperature and stirred for 6 h. The solution was concentrated under vacuum to 2.72 g of viscous pale yellow oil which was purified by column chromatography (10 to 20% EtOAc in hexanes gradient elution) to yield 1.63 g of pure aldehyde as a viscous colorless oil.

TLC  $R_f$  = 0.3 (silica, 20% EtOAc in hexanes);  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  9.69 (1 H, br s), 7.30-7.25 (3 H, m), 7.02 (2 H, m), 5.56 (1 H, br s), 3.87 (1 H, d,  $J$  = 17.7 Hz), 3.75 (3 H, s), 3.63 (1 H, d,  $J$  = 13.2 Hz), 3.08 (1 H, d,  $J$  = 17.7 Hz), 2.98 (1 H, d,  $J$  = 13.2 Hz), 1.46 (9 H, s).

Synthesis of Structure (6):

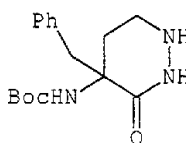
25

(6)

A hydrazone of structure (6) was synthesized as follows. To a solution of the aldehyde of structure (5) (1.62 g, 5.03 mmol) stirred in THF (50 ml) at room temperature was added hydrazine hydrate (0.32 ml, 6.5 mmol). The resulting solution was stirred at room temperature for 10 min. then heated to reflux for 3 days. The solution was allowed to cool to room temperature then concentrated under vacuum to 1.59 g (105% crude yield) of colorless foam. The crude hydrazone product, structure (6), was used without purification.

TLC  $R_f$  = 0.7 (50% EtOAc in hexanes);  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  8.55 (1 H, br s), 7.32-7.26 (3 H, m), 7.17 (1 H, br s), 7.09 (2H, m), 5.55 (1 H, br s), 3.45 (1 H, d,  $J$  = 17.7 Hz), 3.29 (1 H, d,  $J$  = 13.5 Hz), 2.90 (1 H, d,  $J$  = 13.5 Hz), 2.88 (1 H, dd,  $J$  = 17.7, 1.3 Hz), 1.46 (9 H, s); MS ( $\text{CI}^+$ ,  $\text{NH}_3$ )  $m/z$  304.1 ( $\text{M} + \text{H}^+$ ).

Synthesis of Structure (7):



(7)

20

A cyclic hydrazide of structure (7) was synthesized as follows. The crude hydrazone of structure (6) (55 mg, 0.18 mmol) and platinum oxide (5 mg, 0.02 mmol) were taken up in methanol and the flask was fitted with a three-way stopcock attached to a rubber balloon. The flask was flushed with hydrogen gas three times, the balloon was inflated with hydrogen, and the mixture was stirred vigorously under a hydrogen atmosphere for 17 hours. The mixture was filtered through Celite with ethyl acetate and the filtrate was concentrated under vacuum to a white foam. Purification of the white foam by flash

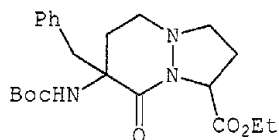
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chromatography yielded 44 mg of the pure cyclic hydrazide of structure (7) (80%).

$^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.34-7.28 (3 H, m), 7.21 (2 H, m), 6.95 (1 H, br s), 5.29 (1 H, br s), 3.91 (1 H, br s), 3.35 (1 H, d,  $J = 12.9$  Hz), 3.00 (1 H, ddd,  $J = 13.9, 5.3, 5.0$  Hz), 2.96 (1 H, d,  $J = 12.9$  Hz), 2.67 (1 H, br m), 2.38 (1 H, br m), 2.30 (1 H, ddd,  $J = 13.9, 5.4, 5.0$  Hz), 1.45 (9 H, s); MS ( $\text{CI}^+$ ,  $\text{NH}_3$ )  $m/z$  306.2 ( $M + \text{H}^+$ ).

10

Synthesis of Structure (8):

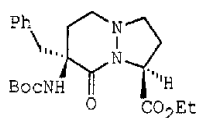


(8)

Structure (8) was synthesized as follows. To a solution of the cyclic hydrazide of structure (7) (4.07 g, 13.32 mmol) stirred in ethyl acrylate (200 ml) at 90°C was added formaldehyde (1.2 mL of a 37% aqueous solution). The mixture was heated to reflux for 15 h then allowed to cool to room temperature and concentrated under vacuum to a white foam. The products were separated by column chromatography (5% then 10% acetone/chloroform) to yield 0.851 g of the least polar diastereomer of the bicyclic ester, structure (8b), and a more polar diastereomer (8a). The impure fractions were subjected to a second chromatography to afford more pure structure (8b), 25% combined yield.

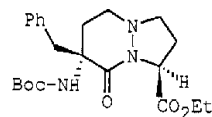
$^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.27-7.21 (3 H, m), 7.09 (2 H, d,  $J = 6.5$  Hz), 5.59 (1 H, br s), 4.52 (1 H, dd,  $J = 9.1, 3.4$  Hz), 4.21 (2 H, m), 3.40 (1 H, d,  $J = 12.5$  Hz), 3.32 (1 H, d,  $J = 12.5$  Hz), 3.10 (2 H, m), 2.79 (1 H, br m), 2.66 (1 H, br m), 2.79 (1 H, br m), 2.66 (1 H, br m), 2.54 (1 H, br m), 2.46 (1 H, m), 2.18 (1 H, m),

1.44 (9 H, s), 1.28 (3 H, t,  $J = 7.0$  Hz); MS (CI+,  $\text{NH}_3$ ) 418.4 ( $M + H^+$ ).



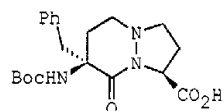
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(8b)



(8a)

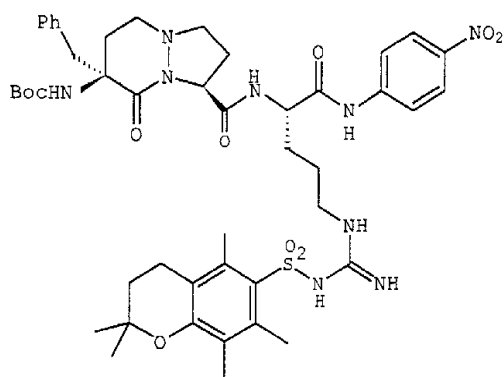
Synthesis of Structure (9b):



10

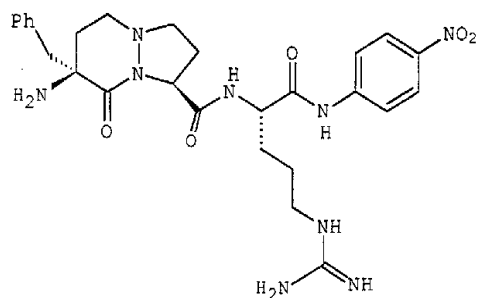
(9b)

Structure (9b) was synthesized as follows. To a solution of the least polar ethyl ester (i.e., structure (8b)) (31 mg, 0.074 mmol) stirred in THF (1 ml) was added aqueous lithium hydroxide (1 M, 0.15 ml). The resulting mixture was stirred at room temperature for 2 h then the reaction was quenched with 5% aqueous citric acid. The mixture was extracted with ethyl acetate (2 x) then the combined extracts were washed with water and brine. The organic layer was dried over anhydrous sodium sulfate, filtered and concentrated under vacuum to a colorless glass. The crude acid, structure (9b), was used in subsequent experiments without further purification.

Synthesis of Structure (10b):

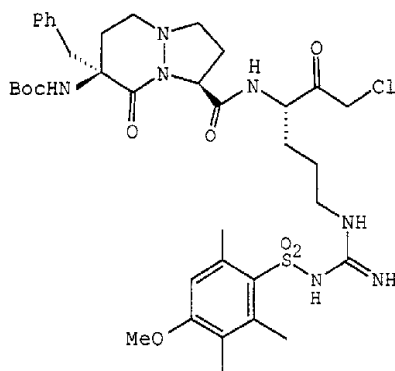
(10b)

5           Structure (10b) was synthesized as follows. The  
crude acid of structure (9b) (30 mg, 0.074 mmol),  
HArg(PMC)pNA (41 mg, 0.074 mmol), and HOBt (15 mg, 0.098  
mmol) were dissolved in THF (1 ml) then  
diisopropylethylamine (0.026 ml, 0.15 mmol) was added  
10 followed by EDC (16 mg, 0.084 mmol). The resulting  
mixture was stirred at room temperature for 4 h then  
diluted with ethyl acetate and extracted with 5% aqueous  
citric acid, saturated aqueous sodium bicarbonate, water  
and brine. The organic layer was dried over anhydrous  
15 sodium sulfate, filtered and concentrated under vacuum to  
54 mg of pale yellow glass. The products were separated  
by column chromatography to yield 33 mg (50%) of a mixture  
of diastereomers of the coupled (i.e., protected) product,  
structure (10b). MS (CI<sup>+</sup>, NH<sub>3</sub>) m/z 566.6 (M + H<sup>+</sup>).

Synthesis of Structure (11b):

(11b)

5           A  $\beta$ -sheet mimetic of structure (11b) was synthesized as follows. A solution of 0.25 ml of H<sub>2</sub>O, 0.125 ml of 1,2-ethanedithiol and 360 mg of phenol in 5 ml of TFA was prepared and the protected product of structure (10b) (33 mg, 0.035 mmol) was dissolved in 2 ml of this  
10 solution. The resulting solution was stirred at room temperature for 3 h then concentrated under reduced pressure. Ether was added to the concentrate and the resulting precipitate was collected by centrifugation. The precipitate was triturated with ether and centrifuged  
15 two more times then dried in a vacuum desiccator for 14 h. The crude product (14 mg) was purified by HPLC chromatography to yield the  $\beta$ -sheet mimetic of structure (11b). MS (CI<sup>+</sup>, NH<sub>3</sub>) m/z 954.8 (M + Na<sup>+</sup>).

Synthesis of Structure (12b):

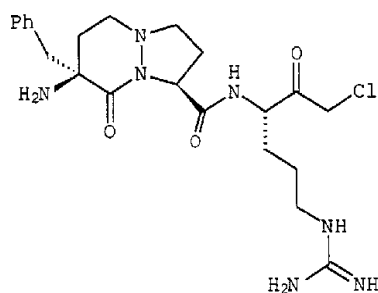
(12b)

5                    Structure (12b) was synthesized as follows. To  
a solution of the crude acid of structure (9b) (24 mg,  
0.062 mmol) and N-methylmorpholine (0.008 ml), stirred in  
THF (1 ml) at -50°C was added isobutyl chloroformate. The  
resulting cloudy mixture was stirred for 10 min. then  
10 0.016 ml (0.14 mmol) of N-methylmorpholine was added  
followed by a solution of HArg(Mtr)CH<sub>2</sub>Cl (50 mg, 0.068  
mmol) in THF (0.5 ml). The mixture was kept at -50°C for  
20 min. then was allowed to warm to room temperature  
during 1 h. The mixture was diluted with ethyl acetate  
15 and extracted with 5% aqueous citric acid, saturated  
aqueous sodium bicarbonate and brine. The organic layer  
was dried over anhydrous sodium sulfate, filtered and  
concentrated under vacuum to yield 49 mg of colorless  
glass, structure (12). Separation by column  
20 chromatography yielded 12 mg of a less polar diastereomer  
and 16 mg of a more polar diastereomer.

<sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.93 (1 H, br s), 7.39-  
7.31 (3 H, m), 7.16 (2 H, d, J = 6.9 Hz), 6.52 (1 H, s),  
6.30 (1 H, br s), 5.27 (1 H, s), 4.74 (1 H, dd, J = 9.1,  
25 6.9 Hz), 4.42 (1 H, br d, J = 6.8 Hz), 4.33 (1 H, d, J =

6.8 Hz), 3.82 (3 H, s), 3.28 (1 H, d,  $J = 13.3$  Hz), 3.26-3.12 (4 H, m), 2.98 (1 H, d,  $J = 13.3$  Hz), 2.69 (3 H, s), 2.60 (3 H, s), 2.59-2.33 (4 H, m), 2.25-2.10 (3 H, m), 2.11 (3 H, s), 1.77 (1 H, br m), 1.70-1.55 (3 H, br m),  
5 1.32 (9 H, s).

Synthesis of Structure (13b):



(13b)

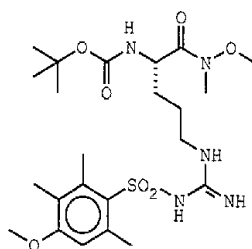
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A  $\beta$ -sheet mimetic of structure (13b) was synthesized as follows. The more polar diastereomer of structure (12b) (16 mg, 0.021 mmol) was dissolved in 95% TFA/H<sub>2</sub>O (1 ml) and the resulting solution was stirred at  
15 room temperature for 6 h then concentrated under vacuum to 11 mg of crude material. The crude product was triturated with ether and the precipitate was washed twice with ether then dried under high vacuum for 14 h. <sup>1</sup>H NMR analysis indicated a 1:1 mixture of fully deprotected product and  
20 product containing the Mtr protecting group. The mixture was dissolved in 95% TFA/H<sub>2</sub>O and stirred for 2 days and the product was recovered as above. Purification of the product by HPLC yielded 5 mg of the pure compound of structure (13b). MS (EI+)  $m/z$  477.9 ( $M^+$ ).

25

Example 2Synthesis of Representative  $\beta$ -Sheet Mimetic

This example illustrates the synthesis of a  
5 further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (14):

(14)

10

N,O-Dimethyl hydroxamate, structure (14), was synthesized as follows. To a mixture of Boc-N<sup>g</sup>-4-methoxy-2,3,6-trimethylbenzenesulfonyl-L-arginine (8.26 g, 14.38 mmol), N,O-dimethylhydroxylamine hydrochloride  
15 (2.78 g, 28.5 mmol) and 1-hydroxybenzotriazole hydrate (2.45 g, 16.0 mmol) stirred in THF (150 ml) at ambient temperature was added N,N-diisopropylethylamine (7.5 ml, 43 mmol) followed by solid EDC (3.01 g, 15.7 mmol). The resulting solution was stirred for 16h then diluted with  
20 ethyl acetate (200 ml) and extracted sequentially with 5% aqueous citric acid, saturated aqueous sodium bicarbonate, water and brine. The organic solution was dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded 7.412 g of white foam.

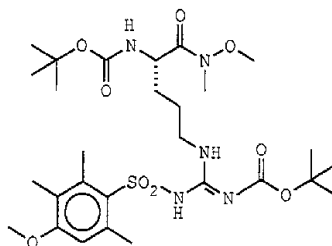
25

<sup>1</sup>H NMR (500MHz, CDCl<sub>3</sub>):  $\delta$  6.52 (1 H, s), 6.17 (1 H, br s), 5.49 (1 H, d, J=8.8Hz), 4.64 (1 H, br t), 3.82 (3H, s), 3.72 (3H, s), 3.36 (1 H, br m), 3.18 (3H, s), 3.17 (1 H, br m), 2.69 (3H, s), 2.61 (3H, s), 2.12 (3H,

2), 1.85-1.55 (5 H, m), 1.41 (9 H, s); MS (FB+): m/z 530.5 (M+H<sup>+</sup>).

Synthesis of Structure (15):

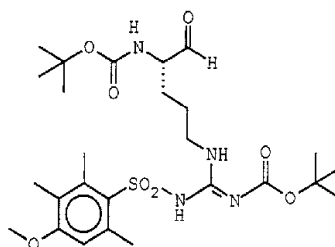
5



(15)

Structure (15) was synthesized as follows. To a solution of the arginine amide (7.412 g, 13.99 mmol) stirred in dichloromethane (150 ml) at room temperature was added N,N-diisopropylethylamine (2.9 ml, 17 mmol) followed by di-tert-butylidicarbonate (3.5 ml, 15.4 mmol) and N,N-dimethylaminopyridine (0.175 g, 1.43 mmol). The resulting solution was stirred for 1.5h then poured into water. The aqueous layer was separated and extracted with two 100ml portions of dichloromethane. The combine extracts were shaken with brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded a white foam that was purified by flash chromatography to yield 8.372 g of white foam.

<sup>1</sup>H NMR (500MHz, CDCl<sub>3</sub>): δ 9.79 (1 H, s), 8.30 (1 H, t, J=4.96), 6.54 (1 H, s), 5.18 (1 H, d, J=9.16 Hz), 4.64 (1 H, m), 3.83 (3 H, s), 3.74 (3 H, s), 3.28 (2 H, dd, J=12.6, 6.9 Hz), 3.18 (3 H, s), 2.70 (3 H, s), 2.62 (3 H, s), 2.14 (3 H, s), 1.73-1.50 (5 H, m), 1.48 (9H, s), 1.42 (9 H, s); MS (FB+): m/z 630.6 (M+H<sup>+</sup>).

Synthesis of Structure (16):

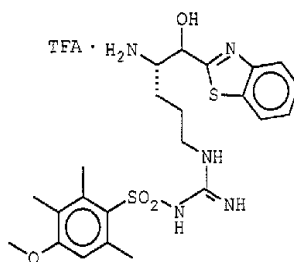
(16)

5 The arginal, structure (16), was synthesized as follows. To a solution of the arginine amide structure (15) stirred in toluene at  $-78^{\circ}\text{C}$  under a dry argon atmosphere was added a solution of diisobutylaluminum  
10 hydride in toluene (1.0 M, 7.3ml) dropwise over a period of 15 minutes. The resulting solution was stirred for 30 minutes then a second portion of diisobutylaluminum hydride (3.5ml) was added and stirring was continued for 15 minutes. Methanol (3ml) was added dropwise and the  
15 solution was stirred at  $-78^{\circ}\text{C}$  for 10 minutes then allowed to warm to room temperature. The mixture was diluted with ethyl acetate (100ml) and stirred vigorously with 50 ml of saturated aqueous potassium sodium tartrate for 2.5h. The aqueous phase was separated and extracted with ethyl  
20 acetate (2 x 100ml). The extracts were combined with the original organic solution and shaken with brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded a white foam that was separated by flash chromatography to yield 1.617g of the  
25 aldehyde as a white foam.

$^1\text{H}$  NMR (500MHz,  $\text{CDCl}_3$ ):  $\delta$  9.82 (1 H, s), 9.47 (1 H, s), 8.35 (1 H, br t), 6.55 (1 H, s), 5.07 (1 H, d,  $J=6.9$  Hz), 4.18 (1 H, br m), 3.84 (3 H, s), 3.25 (2 H, m),

2.70 (3 H, s), 2.62 (3 H, s), 2.14 (3 H, s), 1.89 (1 H, m), 1.63- 1.55 (4 H, m), 1.49 (9H, s), 1.44 (9 H, s); MS (FB+): m/z 571.6 (M+H<sup>+</sup>).

5                    Synthesis of Structure (17):



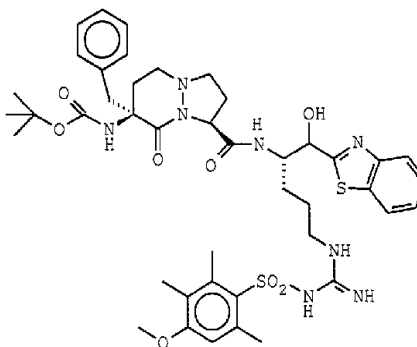
(17)

Hydroxybenzothiazole, structure (17), was  
10 synthesized as follows. To a solution of benzothiazole  
(1.55 ml, 14 mmol) stirred in anhydrous diethyl ether  
(60 ml) at -78°C under a dry argon atmosphere was added a  
solution of *n*-butyllithium (2.5 M in hexane, 5.6 ml,  
14 mmol) dropwise over a period of 10 minutes. The  
15 resulting orange solution was stirred for 45 minutes then  
a solution of the arginal structure (16) (1.609 g,  
2.819 mmol) in diethyl ether (5ml) was slowly added. The  
solution was stirred for 1.5 h then saturated aqueous  
ammonium chloride solution was added and the mixture was  
20 allowed to warm to room temperature. The mixture was  
extracted with ethyl acetate (3 x 100 ml) and the combined  
extracts were extracted with water and brine then dried  
over anhydrous sodium sulfate and filtered. Concentration  
of the filtrate under vacuum yielded a yellow oil that was  
25 purified by flash chromatography (30% then 40% ethyl  
acetate/hexanes eluent) to yield 1.22 g of the  
hydroxybenzothiazoles (ca. 2:1 mixture of diastereomers)  
as a white foam.

The mixture of hydroxybenzothiazoles (1.003 g, 1.414 mmol) was stirred in  $\text{CH}_2\text{Cl}_2$  (12 ml) at room temperature and trifluoroacetic acid (3 ml) was added. The resulting solution was stirred for 1.5h then concentrated under reduced pressure to yield 1.22 g of the benzothiazolylarginol trifluoroacetic acid salt as a yellow foam.

MS (EI+):  $m/z$  506.2 ( $M + H^+$ ).

10 Synthesis of Structure (18b):



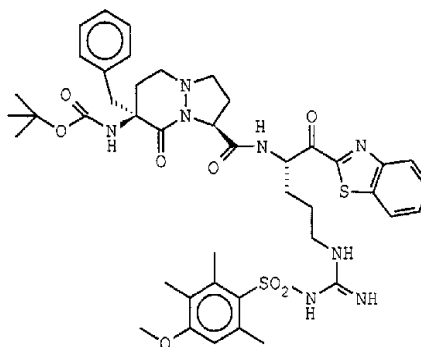
(18b)

The bicyclic compound, structure (18b) was synthesized as follows. The bicyclic acid of structure (9b) from Example 1 (151 mg, 0.387 mmol) and HOBt hydrate (71 mg, 0.46 mmol) were dissolved in THF (5 ml) and diisopropylethylamine (0.34 ml, 1.9 mmol) was added followed by EDC (89 mg, 0.46 mmol). After stirring for ten minutes a solution of the benzothiazolylarginol trifluoroacetic acid salt (structure (17) 273 mg, 0.372 mmol) in THF (1 ml) was added along with a THF (0.5 ml) rinse. The mixture was stirred at room temperature for 15 h then diluted with ethyl acetate and extracted sequentially with 5% aqueous citric acid, saturated aqueous sodium bicarbonate, water and brine. The organic

solution was dried over anhydrous sodium sulfate, filtered and concentrated under vacuum to 297 mg of a yellow glass. <sup>1</sup>H NMR analysis indicated a mixture of four diastereomeric amides which included structure (18b).

5 MS (ES+): m/z 877 (M<sup>+</sup>).

Synthesis of Structure (19b):



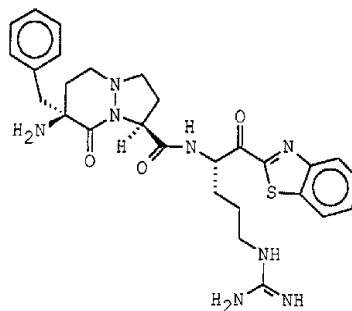
(19b)

10

Structure (19b) was synthesized as follows. The crude hydroxybenzothiazole (247 mg, 0.282 mmol) was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (5 ml) and Dess-Martin periodinane (241 mg, 0.588 mmol) was added. The mixture was stirred at room temperature for 6h then diluted with ethyl acetate and stirred vigorously with 10% aqueous sodium thiosulfate for 10 minutes. The organic solution was separated and extracted with saturated aqueous sodium bicarbonate, water and brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded 252 mg of yellow glass. <sup>1</sup>H NMR analysis indicated a mixture of two diastereomeric ketobenzothiazoles which included structure (19b).

15

20

Synthesis of Structure (20b):

(20b)

5           The ketobenzothiazole, structure (20), was  
synthesized as follows. Ketobenzothiazole (19) (41 mg,  
0.047 mmol) was dissolved in 95% aqueous trifluoroacetic  
0.95 ml) acid and thioanisole (0.05 ml) was added. The  
resulting dark solution was stirred for 30 hours at room  
10 temperature then concentrated under vacuum to a dark brown  
gum. The gum was triturated with diethyl ether and  
centrifuged. The solution was removed and the solid  
remaining was triturated and collected as above two more  
times. The yellow solid was dried in a vacuum desiccator  
15 for 2 hours then purified by HPLC (Vydac reverse phase C-4  
column (22 x 250 mm ID). Mobile phase: A = 0.05% TFA in  
water; B = 0.05% TFA in acetonitrile. The flow rate was  
10.0 mL/min. The gradient used was 8% B to 22% B over 25  
min, and isocratic at 22% thereafter. The peak of  
20 interest (structure (20b)) eluted at 42 minutes) to give  
2.5 mg of the deprotected product, structure (20b).

MS (ES<sup>+</sup>): 563.5 (M + H<sup>+</sup>).

Example 3Activity of a Representative  $\beta$ -Sheet Mimetic  
as a Proteolytic Substrate

5           This example illustrates the ability of a representative  $\beta$ -sheet mimetic of this invention to selectively serve as a substrate for thrombin and Factor VII. The  $\beta$ -sheet mimetic of structure (11b) above was synthesized according to the procedures disclosed in Example  
10 1, and used in this experiment without further modification.

Both the thrombin and Factor VII assays of this experiment were carried out at 37°C using a Hitachi UV/Vis spectrophotometer (model U-3000). Structure (11b) was  
15 dissolved in deionized water. The concentration was determined from the absorbance at 342 nm. Extinction coefficient of 8270 liters/mol/cm was employed. The rate of structure (11b) hydrolysis was determined from the change in absorbance at 405 nm using an extinction  
20 coefficient for p-nitroaniline of 9920 liters/mol/cm for reaction buffers. Initial velocities were calculated from the initial linear portion of the reaction progress curve. Kinetic parameters were determined by unweighted nonlinear least-squares fitting of the simple Michaelis-Menten  
25 equation to the experimental data using GraFit (Version 3.0, Erithacus Software Limited).

For the thrombin assay, experiments were performed in pH 8.4 Tris buffer (Tris, 0.05M; NaCl, 0.15M). 6.4 NIH units of bovine thrombin (from Sigma)  
30 were dissolved into 10 ml of the assay buffer to yield 10 nM thrombin solution. In a UV cuvette, 130 to 148  $\mu$ l of the buffer and 100  $\mu$ l of the thrombin solutions were added, preincubated at 37°C for 2 minutes, and finally 2 to 20 microliters (to make the final volume at 250  $\mu$ l) of

0.24 mM structure (11b) solution was added to initiate the reaction. The first two minutes of the reactions were recorded for initial velocity determination. Eight structure (11b) concentration points were collected to  
5 obtain the kinetic parameters.  $k_{cat}$  and  $K_M$  were calculated to be  $50 \text{ s}^{-1}$  and  $3 \text{ }\mu\text{M}$ , respectively.  $k_{cat}/K_M$  was found to be  $1.67 \times 10^7 \text{ M}^{-1} \text{ s}^{-1}$ .

For the Factor VII assay, pH 8.0 Tris buffer (0.05 M Tris, 5 mM  $\text{CaCl}_2$ , 0.15 M NaCl, 0.1% TWEEN 20, 0.1%  
10 BSA) was used. 10  $\mu\text{l}$  of 20  $\mu\text{M}$  human Factor VIIa (FVIIa) and 22  $\mu\text{M}$  of human tissue factor (TF) was brought to assay buffer to make 160 nM FVIIa and TF solutions, respectively. 40 to 48  $\mu\text{l}$  of buffer, 25  $\mu\text{l}$  of FVIIa and  
25  $\mu\text{l}$  TF solution were added to a cuvette, and incubated at 37°C for 5 minutes, then 2 to 10  $\mu\text{l}$  of 2.4 mM structure  
15 (11b) solution was added to the cuvette to initiate reaction (final volume was 100  $\mu\text{l}$ ). The initial 3 minutes reaction progress curves were recorded. Five structure (11b) concentration points were collected. The initial  
20 rates were linear least-square fitted against the concentrations of structure (11b) with GraFit. The  $k_{cat}/K_M$  was calculated from the slope and found to be  $17,500 \text{ M}^{-1} \text{ s}^{-1}$ .

In both the thrombin and Factor VII assay of  
25 this experiment, (D)FPR-PNA was run as a control. Activity of structure (11b) compared to the control was 0.76 and 1.38 for thrombin and Factor VII, respectively (Factor VII:  $K_{cat}/K_M = 1.27 \times 10^4 \text{ M}^{-1} \text{ s}^{-1}$ ; thrombin:  $K_{cat}/K_M = 2.20 \times 10^7 \text{ M}^{-1} \text{ s}^{-1}$ ).

30

Example 4  
Activity of a Representative  $\beta$ -Sheet Mimetic  
as a Protease Inhibitor

5           This example illustrates the ability of a representative  $\beta$ -sheet mimetic of this invention to function as a protease inhibitor for thrombin, Factor VII, Factor X, urokinase, tissue plasminogen activator (t-PA), protein C, plasmin and trypsin. The  $\beta$ -sheet mimetic of  
10 structure (13b) above was synthesized according to the procedures disclosed in Example 1, and used in this experiment.

          All inhibition assays of this experiment were performed at room temperature in 96 well microplates using  
15 a Bio-Rad microplate reader (Model 3550). 0.29 mg of structure (13b) was dissolved into 200 ml of 0.02 N hydrochloric acid deionized water solution. This solution (2.05 mM) served as the stock solution for all the inhibition assays. The hydrolysis of chromogenic  
20 substrates was monitored at 405 nm. The reaction progress curves were recorded by reading the plates typically 90 times with 30 seconds to 2 minute intervals. The initial rate were determined by unweighted nonlinear least-squares fitting to a first order reaction in GraFit. The  
25 determined initial velocities were then nonlinear least-square fitted against the concentrations of structure (13b) using GraFit to obtain IC<sub>50</sub>. Typically, eight structure (13b) concentration points were employed for IC<sub>50</sub> determination.

30           For the thrombin assay, N-p-tosyl-Gly-Pro-Arg-pNA (from Sigma) was used at 0.5 mM concentration in 1% DMSO (v/v) pH 8.4 Tris buffer as substrate. From structure (13b) stock solution two steps of dilution were made. First, 1:2000 dilution into 0.02 N hydrochloride

solution, then 1:100 dilution into pH 8.4 Tris buffer. The final dilution of structure (13b) served as the first point (10 nM). Seven sequential dilutions were made from the first point with a dilution factor of 2. Into each  
5 reaction well, 100  $\mu$ l of 10 nM thrombin solution and 50  $\mu$ l of structure (13b) solution was added. The mixture of the enzyme and inhibitor was incubated for 20 minutes, then 100  $\mu$ l of 0.5 mM substrate solution was added to initiate the reaction. The  $IC_{50}$  of structure (13b) against  
10 thrombin was found to be  $1.2 \pm 0.2$  nM.

In the Factor VII assay, S-2288 (from Pharmacia), D-Ile-Pro-Arg-pNA was used at 20  $\mu$ M in deionized water as substrate. From the stock of structure (13b), a 1:100 dilution was made into pH 8.0 Tris buffer.  
15 This dilution served as the first point of the inhibitor (20  $\mu$ M). From this concentration point 6 more sequential dilutions were made with a dilution factor of 2. 50  $\mu$ l of 16 nM FVIIa and TF complex solution and 40  $\mu$ l of the inhibitor solutions were added into each well, the  
20 mixtures were incubated for 20 minutes before 10  $\mu$ l of 20 mM S-2288 was added.  $IC_{50}$  of structure (13b) against factor VII was found to be  $140 \pm 3$  nM.

In the Factor X assay, buffer and substrate are the same as used for thrombin assay. A 1:100 dilution was  
25 made into pH 8.4 Tris buffer to serve as the first point. Seven dilutions with a dilution factor of 2 were made. The assay protocol is the same as for thrombin except 25 nM of bovine factor Xa (from Sigma) in pH 8.4 Tris buffer was used instead of thrombin.  $IC_{50}$  of structure (13b)  
30 against factor X was found to be  $385 \pm 17$  nM.

In the urokinase assay, buffer was pH 8.8 0.05 M Tris and 0.05 M NaCl in deionized water. S-2444 (from Sigma), pyroGlu-Gly-Arg-pNA at 0.5 mM in water was utilized as substrate. The same dilution procedure was

used as for Factor VII and Factor X. Assay protocol is the same as for thrombin except 18.5 nM of human urokinase (from Sigma) was utilized. IC<sub>50</sub> was found to be 927±138 nM.

5           Tissue Plasminogen Activator (t-PA): Buffer, substrate and the dilution scheme of structure (13b) were the same as utilized for Factor VII assay.

          Activated Protein C (aPC): Buffer was the same as used in thrombin assay. 1.25 mM S-2366 in the assay  
10       buffer was utilized as substrate. Dilutions of structure (13b) were the same as in urokinase assay.

          Plasmin: Buffer (see thrombin assay); S-2551 (from Pharmacia), D-Val-Leu-Lys-pNA at 1.25 mM in assay buffer was utilized as substrate. For dilutions of  
15       structure (13b) (see urokinase assay).

          In the trypsin assay, pH 7.8 Tris (0.10 M Tris and 0.02 M CaCl<sub>2</sub>) was utilized as the buffer. BAPNA (from Sigma) was used at 1 mg/ml in 1% DMSO (v/v) deionized water solution as substrate. The same dilutions of  
20       structure (13b) were made as for Factor VII assay. 40 µl of 50 µg/ml bovine trypsin (from Sigma) and 20 µl of structure (13b) solution were added to a reaction well, the mixture was incubated for 5 minutes before 40 µl of 1 mg/ml BAPNA was added to initiate the reaction. The IC<sub>50</sub>  
25       of structure (13b) against trypsin was found to be 160±8 nM.

          In the above assays, (D)FPR-CH<sub>2</sub>Cl ("PPACK") was run as a control. Activity of structure (13b) compared to the control was enhanced (see Table 4).

30

Table 4

| Enzymes    | IC <sub>50</sub> (nM) |                 |
|------------|-----------------------|-----------------|
|            | PPACK                 | Structure (13b) |
| Thrombin   | 1.5                   | 1.2             |
| Factor VII | 200                   | 140             |
| Factor X   | 165                   | 385             |
| Protein C  | 281                   | 528             |
| Plasmin    | 699                   | 978             |
| Trypsin    | 212                   | 16              |
| Urokinase  | 508                   | 927             |
| t-PA       | 106                   | 632             |

With respect to prothrombin time (PT), this was  
 5 determined by incubating (30 minutes at 37°C) 100 µl of  
 control plasma (from Sigma) with 1-5 µl of buffer (0.05 M  
 Tris, 0.15 M NaCl, pH=8.4) or test compound (i.e., PPACK  
 or structure (13b)) in buffer. Then 200 µl of prewarmed  
 (at 37°C for ~10 minutes) thromboplastin with calcium (from  
 10 Sigma) was rapidly added into the plasma sample. The time  
 required to form clot was manually recorded with a stop  
 watch (see Table 5), and was found to be comparable with  
 PPACK.

15

Table 5

| Concentration | PT (second) |                 |
|---------------|-------------|-----------------|
|               | PPACK       | Structure (13b) |
| 0 (Control)   | 13          | 13              |
| 1 pM          | --          | 13              |
| 10 pM         | --          | 17              |
| 50 pM         | --          | 18              |
| 100 pM        | --          | 23              |
| 200 pM        | --          | 24              |
| 500 pM        | 15          | 27              |
| 1 nM          | 18          | 30              |
| 10 nM         | 22          | 31              |
| 20 nM         | 25          | --              |
| 30 nM         | --          | 31              |
| 40 nM         | 28          | --              |
| 50 nM         | --          | 30              |
| 60 nM         | 30          | --              |
| 80 nM         | 31          | 33              |

Example 5Activity of a Representative  $\beta$ -Sheet Mimetic  
as a Protease Inhibitor

5

This example illustrates the ability of a further representative  $\beta$ -sheet mimetic of this invention to function as an inhibitor for thrombin, Factor VII, Factor X, urokinase, Tissue Plasminogen Activator, 10 Activated Protein C, plasmin, tryptase and trypsin. The  $\beta$ -sheet mimetic of structure (20b) above was synthesized according to the procedures disclosed in Example 2, and used in this experiment.

All inhibition assays were performed at room 15 temperature in 96 well microplates using Bio-Rad microplate reader (Model 3550). A 1 mM solution of structure (20b) in water served as the stock solution for all the inhibition assays. The hydrolysis of chromogenic substrates was monitored at 405 nm. The reaction progress 20 curves were recorded by reading the plates, typically 60 times with 30 second to 2 minute intervals. Initial rates were determined by unweighted nonlinear least-squares fitting to a first order reaction in GraFit (Erithacus Software Limited, London, England). The determined 25 initial velocities were then nonlinear least-square fitted against the concentrations of structure (20b) using GraFit to obtain  $K_i$ . The general format of these assays are: 100  $\mu$ l of a substrate solution and 100  $\mu$ l of structure (20b) solution were added in a microplate well, then 50  $\mu$ l 30 of enzyme solution was added to initiate the reaction. Typically, eight structure (20b) concentration points were employed for  $K_i$  determination. The values of  $K_i$  of structure (20b) against nine serine proteases are tabulated in Table 6.

Thrombin: N-p-tosyl-Gly-Pro-Arg-pNA (from Sigma) was used at 0.5 mM concentration in 1% DMSO (v/v) pH8.0 tris buffer (tris, 50 mM, TWEEN 20, 0.1%, BSA, 0.1%, NaCl, 0.15 M, CaCl<sub>2</sub>, 5 mM) as substrate. From structure (20b) 5 stock solution two steps of dilution were made, first, 1:100 dilution in water, then 1:50 dilution in the pH8.0 tris buffer to serve as the first point (200 nM). Seven sequential dilutions were made from the first point for the assay.

10 Factor VII: S-2288 (from Pharmacia), D-Ile-Pro-Arg-pNA was used at 2.05 mM in the pH 8.0 tris buffer (see thrombin assay). From the stock of structure (20b), a 1:100 dilution was made in the tris buffer. From this concentration point seven more sequential dilutions were 15 made for the assay.

Factor X: Buffer and substrate were the same as used for thrombin assay. A 1:100 dilution was made in the pH8.0 tris buffer to serve as the first point. Seven more dilutions from the first were made for the assay.

20 Urokinase: Buffer, 50 mM tris, 50 mM NaCl, pH=8.8. S-2444 (from Sigma), pyroGlu-Gly-Arg-pNA at 0.25 mM in buffer was utilized as substrate. 1:10 dilution in buffer was made from the stock of structure (20b) as the first point, then seven more dilutions from the first 25 point were made for the assay.

Tissue Plasminogen Activator (t-PA): Buffer, substrate and the dilution scheme of structure (20b) were the same as utilized for Factor VII assay.

Activated Protein C (aPC): Buffer was the same 30 as used in thrombin assay. 1.25 mM S-2366 in the assay buffer was utilized as substrate. Dilutions of structure (20b) were the same as in urokinase assay.

Plasmin: Buffer (see thrombin assay); S-2251 (from Pharmacia), D-Val-Leu-Lys-pNA at 1.25 mM in assay

buffer was utilized as substrate. For dilutions of structure (20b) (see urokinase assay).

Tryptase: 0.1 M tris, 0.2 M NaCl, 0.1 mg/ml heparin, pH=8.0 was utilized as buffer. 0.5 mM S-2366 (from Pharmacia), L-pyroGlu-Pro-Arg-pNA in buffer was used as substrate. From the 1 mM stock of structure (20b), 10 mM solution was made in water, then 1 mM solution was made in buffer from the 10 mM solution to serve as the first concentration point. From this point seven more dilutions were made for the assay.

Trypsin: Buffer, substrate and the dilution scheme of structure (20b) were the same as used for thrombin.

15

Table 6

| Enzyme     | Source          | K <sub>i</sub> (nM) |                 |
|------------|-----------------|---------------------|-----------------|
|            |                 | Assay Conc. (nM)    | Structure (20b) |
| thrombin   | bovine plasma   | 2                   | 0.66            |
| factor VII | human           | 4                   | 270             |
| factor X   | bovine plasma   | 8                   | 966             |
| urokinase  | human kidney    | 3.7                 | 600             |
| t-PA       | human           | 10                  | 495             |
| APC        | human plasma    | 1                   | 3320            |
| plasmin    | bovine plasma   | 4                   | 415             |
| tryptase   | human lung      | 2                   | 12.4            |
| trypsin    | bovine pancreas | 5                   | 0.64            |

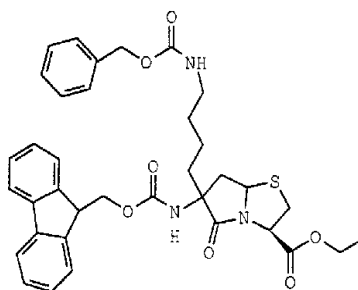
As illustrated by the data presented in Table 6 above, structure (20b) functioned as a good thrombin inhibitor, with good specificity against fibrinolytic enzymes.

20

Example 6Synthesis of Representative  $\beta$ -Sheet Mimetic

5

This example illustrates the synthesis of a representative  $\beta$ -sheet mimetic of this invention having the following structure (21):



10

Structure (21) was synthesized as follows. A solution of 48 mg (0.859 mmol)  $N^{\alpha}$ -Fmoc- $N^{\epsilon}$ -Cbz- $\alpha$ -ethanal-Lys-Ome [synthesized from  $N^{\epsilon}$ -Cbz-Lys-OME by the same method used for the preparation of structure (5) from Phe-OME], 15.9 mg (0.0859 mmol) Cys-OEt.HCl, and 13.2  $\mu$ L (0.0945 mmol) TEA were in 0.43 mL  $\text{CH}_2\text{Cl}_2$  were stirred under Ar for 2 hr at room temperature. Bis(bis(trimethylsilyl)amino)tin(II) (39.8  $\mu$ L) was added and the reaction stirred overnight. The reaction solution was diluted with 10 mL EtOAc and washed with 6 mL each 10% citrate, water, and brine. The organic layer was dried over  $\text{Na}_2\text{SO}_4$ , filtered, and concentrated. The resulting residue was purified by flash chromatography on silica gel using 40% EtOAc/hexanes to give, after drying in vacuo, 12.9 mg of colorless oil (23%) as a mixture of

25

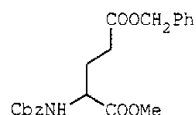
diastereomers by  $^1\text{H}$  NMR ( $\text{CDCl}_3$ ). MS ES(+)  $m/z$  658.2 ( $\text{MH}^+$ , 30), 675.3 ( $\text{M} + \text{Na}^+$ , 100), 696.1 ( $\text{M} + \text{K}^+$ , 45).

5

Example 7Synthesis of Representative  $\beta$ -Sheet Mimetic

This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

10

Synthesis of Structure (22):

(22)

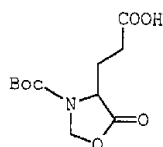
15

Structure (22) was synthesized as follows. To a stirred solution of Cbz-Glu(OBn)-OH (5 g, 13.5 mmol) with DMAP (270 mg) and methanol (3 ml) in dichloromethane (100 ml) was added EDCI (3g) at 0°C. After stirring at 0°C for 3h, the solution was stirred at room temperature (rt) overnight. After concentration, the residue was taken up into EtOAc (100 ml) and 1N HCl (100 ml). The aqueous phase was separated and extracted with EtOAc (100 ml). The combined organic extracts were washed with sat. NaHCO<sub>3</sub> (100 ml), brine (100 ml), dried (MgSO<sub>4</sub>), passed through a short pad of silica gel, and concentrated to provide 4.95 g an oil (95%). The product was pure enough to use for the next reaction without any further purification.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.00 (m, 1H), 2.25 (m, 1H), 2.50 (m, 2H), 3.74 (s, 3H, OCH<sub>3</sub>), 4.42 (m, 1H, CHNH), 5.10 and 5.11 (two s, 4H, CH<sub>2</sub>Ph), 5.40 (d, 1H, NH), 7.35 (s, 10H, phenyls); MS CI(isobutane)  $m/z$  386 ( $\text{M} + \text{H}^+$ ).

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25

30

Synthesis of Structure (23):

(23)

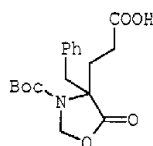
5

Structure (23) was synthesized as follows: To a stirred solution of L-Glu-OH (4.41g, 30 mmol) with triethylamine (8.4 ml, 60 mmol) in 1,4-dioxane (40 ml) and H<sub>2</sub>O (20 ml) was added Boc<sub>2</sub>O (7 g, 32 mmol) at rt. After stirring for 1.5h, the solution was acidified with 6N HCl (pH 2), and extracted with EtOAc (3x100 ml). The combined organic extracts were washed with H<sub>2</sub>O (100 ml), brine (50 ml), dried (Na<sub>2</sub>SO<sub>4</sub>), and concentrated to provide an oil (9.5 g). Without further purification, the oil was used in the next reaction.

A mixture of above oil (9.5 g) with paraformaldehyde (5 g) and p-TsOH·H<sub>2</sub>O (400 mg) in 1,2-dichloroethane (200 ml) was heated at reflux with a Dean-Stark condenser, which was filled with molecular sieve 4A, for 6h. After addition of EtOAc (100 ml) and sat. NaHCO<sub>3</sub> (50 ml), the solution was extracted with sat. NaHCO<sub>3</sub> (3x50 ml). The combined aqueous extracts were acidified with 6N HCl (pH 2), and extracted with EtOAc (3x100 ml). The combined organic extracts were washed with brine (100 ml), dried (Na<sub>2</sub>SO<sub>4</sub>), and concentrated to provide an oil. The crude oil was purified by flash chromatography (hexane:EtOAc = 80:20 to 70:30 to 60:40) to provide an oil (4.04 g, 52%) which solidified slowly upon standing. <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 1.49 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>), 2.18 (m, 1H, -CH<sub>2</sub>CH<sub>2</sub>), 2.29 (m, 1H, CH<sub>2</sub>CH<sub>2</sub>), 2.52 (m, 2H, -CH<sub>2</sub>CH<sub>2</sub>-), 4.33 (m, 1H, NHCHCH<sub>2</sub>), 5.16 (d, 1H, J = 4.5 Hz, NCH<sub>2</sub>O), 5.50 (br, 1H,

NCH<sub>2</sub>O); <sup>13</sup>C NMR (CDCl<sub>3</sub>) δ 25.85, 28.29, 29.33, 54.16, 79.10, 82.69, 152.47, 172.37, 178.13; MS (ES+) m/z 260 (M+H<sup>+</sup>), 282 (M+Na<sup>+</sup>), 298 (M+K<sup>+</sup>).

5

Synthesis of Structure (24):

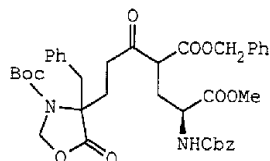
(24)

Structure (24) was synthesized as follows. To a stirred solution of 1,1,1,3,3,3-hexamethyldisilazane (2.1 ml, 10 mmol) in THF (10 ml) was added n-BuLi (4 ml of 2.5M in hexane, 10 mmol) at 0°C. The resulting solution was stirred at the same temperature for 30 min. After cooling to -78°C, to this stirred solution was added a solution of carboxylic acid (23) (1.02 g, 3.94 mmol) in THF (10 ml) followed by rinsings of the addition syringe with 5 ml THF. The resulting solution was stirred at -78°C for 1h, and PhCH<sub>2</sub>Br (0.46 ml, 3.9 mmol) was added. After stirring at -30°C for 3h, to this solution was added 1N HCl (50 ml) and the resulting solution was extracted with EtOAc (100 ml). The organic extract was washed with brine (50 ml), dried (Na<sub>2</sub>SO<sub>4</sub>), and concentrated to provide an oil. The crude product was purified by flash chromatography (hexane:EtOAc = 80:20 to 60:40 to 50:50) to provide a foamy solid (1.35 g, 98%): <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 1.55 and 1.63 (two s, 9H, ratio 1.5:1 by rotamer, OC(CH<sub>3</sub>)<sub>3</sub>), 2.2-2.4 (m, 3H, -CH<sub>2</sub>CH<sub>2</sub>-), 2.6-2.9 (set of m, 1H, -CH<sub>2</sub>CH<sub>2</sub>-), 3.04 (d, 1H, J = 13.5Hz, -CH<sub>2</sub>Ph), 3.33 and 3.58 (two d, 1H, J = 13 Hz, ratio 2:1, -CH<sub>2</sub>Ph), 4.03 (two d, 1H, J = 4Hz, A of ABq,

-NCH<sub>2</sub>O-), 4.96 (two d, 1H,  $J = 4\text{ Hz}$ , B of ABq, -NCH<sub>2</sub>O-); MS (ES-)  $m/z$  348 ( $M-H^+$ ).

Synthesis of Structure (25):

5



(25)

Synthesis of structure (25) was carried out as follows. To a stirred solution of carboxylic acid (24) (1.05 g, 3.0 mmol) in dry THF (5 ml) was added 1,1'-carbonyldiimidazole (500 mg, 3.1 mmol) at rt. The resulting solution was stirred at rt for 30 min. The solution of acyl imidazole was used for the next reaction without purification.

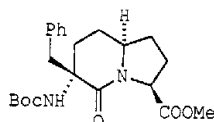
15 Meanwhile, to a stirred solution of 1,1,1,3,3,3-hexamethyldisilazane (1.6 ml, 7.5 mmol) in THF (5 ml) was added n-BuLi (3 ml of 2.5 M solution in hexane, 7.5 mmol) at 0°C. After stirring at the same temperature for 30 min, the solution was cooled to -78°C. To the stirred solution was added a solution of Cbz-Glu(OBn)-OMe (1.16 g, 3 mmol) in THF (5 ml) followed by rinsings of the addition syringe with 2 ml THF. The resulting solution was stirred at the same temperature for 15 min. To this stirred solution was added the above acyl imidazole in 3 ml THF. After stirring 30 min. at -78°C, to this solution was added sat. NH<sub>4</sub>Cl (50 ml) and extracted with EtOAc (2x75 ml). The combined organic extracts were washed with sat. NaHCO<sub>3</sub> (50 ml), brine (50 ml), dried (Na<sub>2</sub>SO<sub>4</sub>), passed through a short pad of silica gel, and concentrated to provide an oil.

30 The crude product was purified by flash chromatography

(hexane: EtOAc = 90:10 to 80:20 to 70:30 to 60:40) to provide an oil (1.48 g, 69%): MS (ES+) m/z 734.4 (M+NH<sub>4</sub><sup>+</sup>).

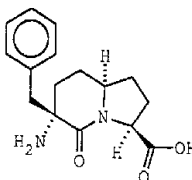
Synthesis of Structure (26a):

5



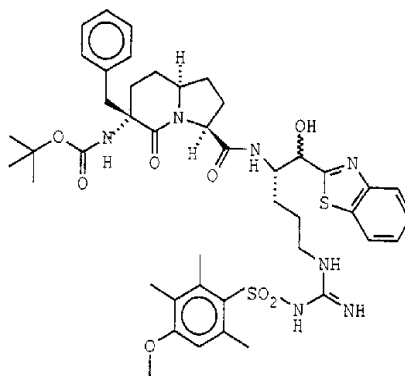
(26a)

Structure (26a) was synthesized as follows. A stirred solution of above starting keto ester (25) (530 mg, 0.7mmol) in EtOH/AcOH (10/1 ml) was treated with 10% Pd/C (ca. 100 mg) under 20 atm pressure of H<sub>2</sub> for 2 days. After filtration through a short pad of Celite, the filtrate was concentrated and dissolved in EtOAc (50 ml). The solution was washed with 1N HCl (30 ml), sat. NaHCO<sub>3</sub> (30 ml), brine (30 ml), dried (Na<sub>2</sub>SO<sub>4</sub>), and concentrated to provide an oil. The crude product was purified by flash chromatography (hexane: EtOAc = 80:20 to 60:40 to 50:50 to 20:80 to 0:100) to provide a foamy solid (95 mg, 34%). TLC (EtOAc) R<sub>f</sub> 0.68; NMR (CDCl<sub>3</sub>) δ 1.38 (two s, 9H, OC(CH<sub>3</sub>)<sub>3</sub>), 1.63 (s, 1H), 1.75 (m, 2H), 2.05 (m, 5H), 2.1-2.3 (set of m, 1H), 3.00 (d, 1H, J = 14 Hz, CH<sub>2</sub>Ph), 3.21 (d, 1H, J = 13.5 Hz, CH<sub>2</sub>Ph), 3.74 (collapsed two s, 4H, OCH<sub>3</sub> and NCH), 4.53 (d, 1H, J = 9.5 Hz), 5.01 (br, 1H, NH); MS (ES+) m/z 403 (M+H<sup>+</sup>), 425 (M+Na<sup>+</sup>). Stereochemistry was assigned by 2D NMR.

Synthesis of Structure (27a):

(27a)

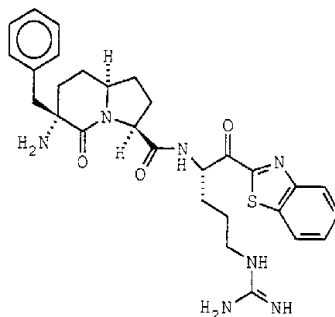
5           Structure (27a) was synthesized as follows. To  
a solution of 28 mg (0.070 mmol) of the bicyclic ester  
(26a) stirred in 1 ml THF at room temperature was added  
0.14 ml 1.0 M aqueous lithium hydroxide solution. The  
mixture was stirred vigorously for 20 h then quenched with  
10 5% aqueous citric acid (1 ml). The mixture was extracted  
with ethyl acetate (3 x 25 ml) then the combined extracts  
were washed with water and brine and dried over anhydrous  
sodium sulfate. Filtration and concentration of the  
filtrate under vacuum gave 26 mg of white foam, used  
15 without further purification.

Synthesis of Structure (28a):

(28a)

Structure (28a) was synthesized as follows. The bicyclic acid (27a) (26 mg, 0.067 mmol), benzothiazolylarginol trifluoroacetic acid salt (structure (17) 61 mg, 0.083 mmol) EDC (21 mg, 0.11 mmol) and HOBt hydrate (16 mg, 0.10 mmol) were dissolved in THF (5 ml) and diisopropylethylamine (0.34 ml, 1.9 mmol) was added. The mixture was stirred at room temperature for 15h then diluted with ethyl acetate and extracted sequentially with 5% aqueous citric acid, saturated aqueous sodium bicarbonate, water and brine. The organic solution was dried over anhydrous sodium sulfate, filtered and concentrated under vacuum to 60 mg of a yellow glass. <sup>1</sup>H NMR analysis indicated a mixture of four diastereomeric amides. MS (ES<sup>+</sup>): m/z 898 (M + Na<sup>+</sup>).

Synthesis of Structure (29a):



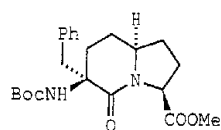
(29a)

A  $\beta$ -sheet mimetic of structure (29a) was synthesized as follows. The crude hydroxybenzothiazole (28a) (60 mg, 0.068 mmol) was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (2 ml) and Dess-Martin periodinane (58 mg, 0.14 mmol) was added. The mixture was stirred at room temperature for 6h then diluted with ethyl acetate and stirred vigorously with 10% aqueous sodium thiosulfate for 10 minutes. The organic

solution was separated and extracted with saturated aqueous sodium bicarbonate, water and brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded 42 mg of yellow glass. <sup>1</sup>H NMR analysis indicated a mixture of two diastereomeric ketobenzothiazoles.

The ketobenzothiazole (42 mg, 0.048 mmol) was dissolved in 95% aqueous trifluoroacetic (0.95 ml) acid and thioanisole (0.05 ml) was added. The resulting dark solution was stirred for 18 hours at room temperature then concentrated under vacuum to a dark brown gum. The gum was triturated with diethyl ether and centrifuged. The solution was removed and the solid remaining was triturated and collected as above two more times. The yellow solid was dried in a vacuum desiccator for 2 hours then purified by HPLC to give 1.4 mg of the deprotected product. MS (ES<sup>+</sup>): 562.4 (M + H<sup>+</sup>). HPLC: (t<sub>R</sub>=21.17 min.)

Synthesis of Structure (26b):



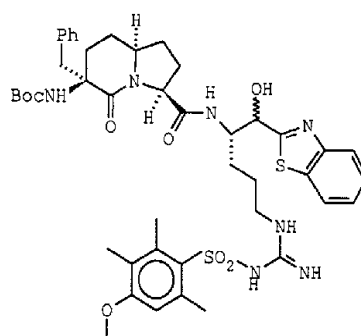
(26b)

Structure (26b) was synthesized as follows. A stirred solution of above starting keto ester (25) (615 mg, 0.86 mmol) in MeOH/AcOH (10/1 ml) was treated with 10 % Pd/C (ca. 60 mg) under 20 atm pressure of H<sub>2</sub> for 3 days. After filtration through a short pad of Celite, the filtrate was concentrated to provide an oil. The crude product was purified by flash chromatography (hexane : EtOAc =80 : 20 to 60 :40 to 50:50 to 0:100) to collect the

more polar fraction (50 mg). Rf 0.12 (hexane: EtOAc=60:40); MS (ES+) m/z 433 (M+H+).

Above oil was treated with p-TsOH·H<sub>2</sub>O (5 mg) in 1,2-dichloroethane (10 ml) at reflux temperature for 2 days. After concentration, the oily product was purified by preparative TLC (hexane: EtOAc = 80:20 to 60:40) to give an oil (10 mg). TLC Rf 0.36 (hexane : EtOAc =60:40); <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 1.43 (s, 9H), 1.66 (m, 3H), 1.89 (m, 3H), 2.14 (m, 1H), 2.75 (m, 1H), 2.98 (m, 1H, CHN), 3.72 (s, 3H, Me), 4.30 (m, 1H), 5.59 (d, 1H, NH), 7.1-7.3 (m, 5H, phenyl); MS CI(NH<sub>3</sub>) 403.2 (M+H+). Stereochemistry was assigned by 2D NMR.

Synthesis of Structure (28b):



(28b)

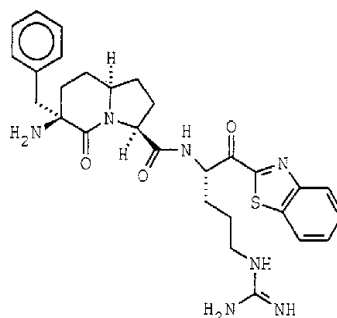
Structure (28b) was synthesized as follows. To a solution of 12 mg (0.030 mmol) of the bicyclic ester (26b) stirred in THF 1 ml at room temperature was added 0.060 ml 1.0 M aqueous lithium hydroxide solution. The mixture was stirred vigorously for 25h then quenched with 5% aqueous citric acid (1 ml). The mixture was extracted with ethyl acetate (3 x 25 ml) then the combined extracts were washed with water and brine and dried over anhydrous

sodium sulfate. Filtration and concentration of the filtrate under vacuum gave 19 mg of white foam.

The foam, benzothiazolylarginol trifluoroacetic acid salt (30 mg, 0.041 mmol) EDC (10 mg, 0.052 mmol) and  
5 HOBt hydrate (9 mg, 0.059 mmol) were dissolved in THF (2 ml) and diisopropylethylamine (0.026 ml, 0.15 mmol) was added. The mixture was stirred at room temperature for 30h then diluted with ethyl acetate and extracted sequentially with 5% aqueous citric acid, saturated  
10 aqueous sodium bicarbonate, water and brine. The organic solution was dried over anhydrous sodium sulfate, filtered and concentrated under vacuum to 28 mg of a yellow glass.  
<sup>1</sup>H NMR analysis indicated a mixture of four diastereomeric amides. MS (ES<sup>+</sup>): m/z 898 (M + Na<sup>+</sup>).

15

Synthesis of Structure (29b):



(29b)

20 Structure (29b) was synthesized as follows. The crude hydroxybenzothiazole (28b) (28 mg) was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (2 ml) and Dess-Martin periodinane (29 mg, 0.071 mmol) was added. The mixture was stirred at room  
temperature for 18h then diluted with ethyl acetate and  
25 stirred vigorously with 10% aqueous sodium thiosulfate for 10 minutes. The organic solution was separated and extracted with saturated aqueous sodium bicarbonate, water

and brine then dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded 32 mg of yellow glass.  $^1\text{H}$  NMR analysis indicated a mixture of two diastereomeric ketobenzothiazoles.

5 The ketobenzothiazole (32 mg) was dissolved in 95% aqueous trifluoroacetic (0.95 ml) acid and thioanisole (0.05 ml) was added. The resulting dark solution was stirred for 20 hours at room temperature then concentrated under vacuum to a dark brown gum. The gum was triturated  
10 with diethyl ether and centrifuged. The solution was removed and the remaining solid was triturated and collected as above two more times. The yellow solid was dried in a vacuum desiccator for 2 hours then purified by HPLC to give 1.3 mg of the deprotected product. MS (FB+):  
15 562.36 ( $\text{M} + \text{H}^+$ ); HPLC:  $t_R$ =21.51 min. (Gradient 0 to 90% 0.1% TFA in  $\text{CH}_3\text{CN}$  / 0.1% TFA in  $\text{H}_2\text{O}$  over 40 min.)

#### Example 8

#### Activity of Representative $\beta$ -Sheet Mimetic as a Protease Inhibitor

20 This example illustrates the ability of a further representative  $\beta$ -sheet mimetic of this invention to function as an inhibitor for thrombin, Factor VII,  
25 Factor X, Factor XI, and trypsin. The  $\beta$ -sheet mimetics of structures (29a) and (29b) above were synthesized according to the procedures disclosed in Example 7, and used in this experiment.

The proteinase inhibitor assays were performed  
30 as described in Example 5 except as described below for Factor XI. The results are presented in Table 7.

Factor XI. The same buffer was utilized in this assay as in the thrombin assay. 1 mM S-2366 (from Pharmacia), L-pyroGlu-Pro-Arg-pNA, solution in water was

used as substrate. From a 1mM stock solution of structure (29a) or (29b) in water, a 1:10 dilution was made in buffer. From this 100  $\mu$ M solution, seven serial 1:5 dilutions were made in buffer for assay.

5

Table 7

| Enzymes    | K <sub>i</sub> (nM) |                 |
|------------|---------------------|-----------------|
|            | Structure (29a)     | Structure (29b) |
| Thrombin   | 10.4                | 0.085           |
| Trypsin    | 0.54                | 0.20            |
| Factor VII | 1800                | -               |
| Factor X   | 4600                | 17              |
| Factor XI  | 391                 | -               |

## Example 9

10

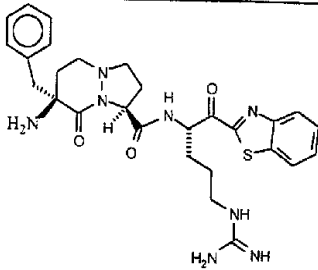
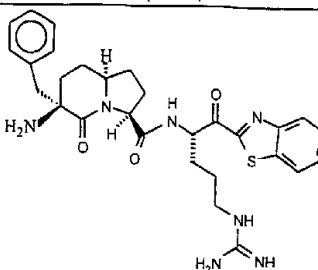
Activities of Representative  $\beta$ -Sheet Mimetics  
as a Protease Inhibitor

This example illustrates the ability of further representative  $\beta$ -sheet mimetics of this invention to function as an inhibitor for thrombin, Factor VII, Factor X, Factor XI, tryptase, aPC, plasmin, tPA, urokinase and trypsin. The  $\beta$ -sheet mimetics of structures (20) and (29b) above were synthesized according to the procedures disclosed in Examples 2 and 7, respectively, and used in this experiment.

20

The proteinase inhibitor assays were performed as described in Example 5 except as described in Example 8 for Factor XI. The results are presented in Table 8.

Table 8

|            | Structure (20b)                                                                   |               | Structure (29b)                                                                    |               |
|------------|-----------------------------------------------------------------------------------|---------------|------------------------------------------------------------------------------------|---------------|
|            |  |               |  |               |
|            | Ki (nM)                                                                           | Selectivity * | Ki (nM)                                                                            | Selectivity * |
| Thrombin   | 0.65                                                                              | 1             | 0.085                                                                              | 1             |
| Trypsin    | 0.62                                                                              | 0.95          | 0.23                                                                               | 2.7           |
| Factor VII | 270                                                                               | 415           | 200                                                                                | 2353          |
| Factor X   | 222                                                                               | 342           | 19.3                                                                               | 227           |
| Factor XI  | 27.0                                                                              | 42            | 75.3                                                                               | 886           |
| Tryptase   | 12.3                                                                              | 18.9          | 9.0                                                                                | 106           |
| aPC        | 3320                                                                              | 5108          | 1250                                                                               | 14706         |
| Plasmin    | 415                                                                               | 638           | 251                                                                                | 2953          |
| tPA        | 495                                                                               | 762           | 92.9                                                                               | 1093          |
| Urokinase  | 600                                                                               | 923           | 335                                                                                | 3941          |

\*selectivity is the ratio of Ki of an enzyme to the Ki of thrombin

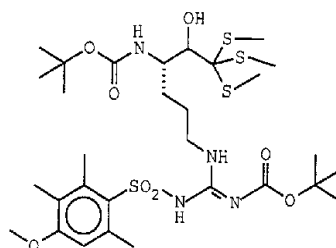
5

#### Example 10

#### Synthesis of Representative $\beta$ -Sheet Mimetics

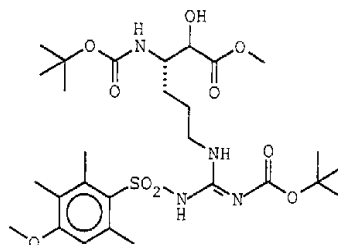
10

This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (30):

(30)

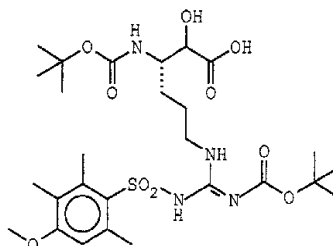
5  
 Structure (30) was synthesized as follows. n-Butyllithium (700  $\mu$ L, 1.75 mmol, 2.5M in hexanes) was added over 5 min to a solution of tris(methylthio)methane (256  $\mu$ L, 1.95 mmol) in THF (1 ml) at -78  $^{\circ}$ C. The mixture  
 10 was stirred for 40 min then treated with a solution of bis-Boc-argininal (structure (16) from Example 2) (100 mg, 1.75 mmol) in 2 ml THF, dropwise, over a period of 5 min. After stirring for 1.5 h, the reaction was quenched with saturated  $\text{NH}_4\text{Cl}$  solution and allowed to warm to room  
 15 temperature. The layers were separated and the aqueous layer extracted with EtOAc (3x), washed with brine (1x), dried ( $\text{Na}_2\text{SO}_4$ ) and concentrated. Purification by flash chromatography (EtOAc:Hexane 1:4) yielded 93 mg (73%) of the orthothiomethyl ester (structure (30)) and 8 mg of  
 20 recovered aldehyde (structure (16)).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ .)  $\delta$  9.80 (s, 1H), 8.32 (t,  $J = 5.0$  Hz, 1H), 6.54 (s, 1H), 5.23 (d,  $J = 9.0$  Hz, 1H), 4.0 (m, 1H), 3.84 (s, 3H), 3.64 (br s, 1H), 3.38 (br s, 1H), 3.31 (m, 2H), 2.70 (s, 3H), 2.62 (s, 3H), 2.19 (s, 9H), 2.14 (s, 3H), 1.68-1.50  
 25 (m, 4H), 1.49 (s, 9H), 1.43 (s, 9H).

Synthesis of Structure (31):

(31)

5

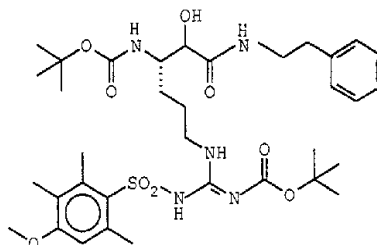
Structure (31) was synthesized as follows. A mixture of 77 mg (0.11 mmol) of the orthothiomethyl ester (structure (30)), 117 mg (0.43 mmol) of mercuric chloride, and 39 mg (0.18 mmol) of mercuric oxide in 2.5 ml of 12:1 methanol/water was stirred at rt for 4 h. The mixture was filtered through Celite and the residue washed with EtOAc (3x). The filtrate was diluted with water and extracted with EtOAc (3x). The organic layer was washed twice with 75% NH<sub>4</sub>OAc/NH<sub>4</sub>Cl, then with NH<sub>4</sub>Cl and dried (Na<sub>2</sub>SO<sub>4</sub>). The solvent was removed in vacuo and the residue purified by flash chromatography (EtOAc/Hex, 1:3) to give 48 mg (72%) of the two diastereomers of structure (31) in a 1:2.7 ratio. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) (major diastereomer) δ 9.80 (s, 1H), 8.33 (t, J = 5.0 Hz, 1H), 6.54 (s, 1H), 4.66 (d, J = 10.5 Hz, 1H), 4.08 (dd, J = 5.0, 2.0 Hz, 1H), 3.97 (m, 1H), 3.84 (s, 3H), 3.77 (s, 3H), 3.30 (m, 2H), 3.06 (d, J = 5.0 Hz, 1H), 2.70 (s, 3H), 2.63 (s, 3H), 2.14 (s, 3H), 1.68-1.50 (m, 4H), 1.49 (s, 9H), 1.40 (s, 9H); MS (ES+) m/z 631.5 (M+H<sup>+</sup>).

Synthesis of Structure (32):

(32)

5

Structure (32) was synthesized as follows. A solution of 32 mg of the methyl ester (structure (31)) (0.051 mmol) in THF/water (4 ml, 1:3) was treated with 5 mg (0.119 mmol) of LiOH·H<sub>2</sub>O. After stirring for 45 min, the reaction was diluted with 5% citric acid and extracted with ethyl acetate (3x). The combined extracts were washed with brine, dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated to give 30 mg (96%) of structure (32) as a white solid. The product was used without further purification. <sup>1</sup>H NMR 500 MHz, CDCl<sub>3</sub>) δ 9.80 (br s, 1H), 8.29 (br s, 1H), 6.54 (s, 1H), 5.62 (br s, 1H), 4.08 (m, 1H), 3.82 (s, 3H), 3.27 (br s, 3H), 2.69 (s, 3H), 2.62 (s, 3H), 2.13 (s, 3H), 1.65-1.50 (m, 4H), 1.48 (s, 9H), 1.37 (s, 9H); MS (ES-) m/z 615.5 (M-H<sup>+</sup>).

Synthesis of Structure (33):

(33)

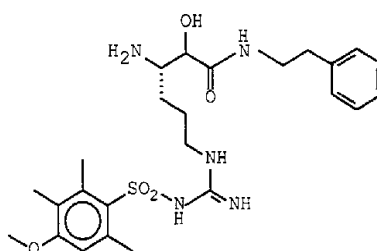
5

Structure (33) was synthesized as follows. To a solution of the compound of structure (32) (29 mg, 0.047 mmol), HOBt (8 mg, 0.056 mmol) and EDC (11 mg, 0.056 mmol) in THF (5 ml), phenethylamine (7 ml, 0.056 mmol) was added followed by diisopropylethylamine (12  $\mu$ L, 0.071 mmol). The reaction mixture was stirred at rt overnight and diluted with 5% citric acid. The organic layer was separated and the aqueous phase extracted with EtOAc (3x).

15 The combined extracts were washed with a saturated solution of  $\text{NaHCO}_3$ , brine, dried over  $\text{Na}_2\text{SO}_4$ , and filtered. After concentration the crude product was purified by chromatography (EtOAc/Hex, 1:1) to give 26 mg (77%) of structure (33) over two steps.  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$

20 9.84 (s, 1H), 8.34 (t,  $J = 5$  Hz, 1H), 7.28 (m, 3H), 7.21 (m, 2 H), 7.04 (m, 1H), 6.55 (s, 1H), 5.16 (d,  $J = 8.5$  Hz, 1H), 4.56 (d,  $J = 5$  Hz, 1H), 4.11 (dd,  $J = 5.0, 3.0$  Hz, 1H), 3.98 (m, 1H), 3.84 (s, 3H), 3.66 (m, 1H), 3.51 (m, 2H), 3.17 (m, 1H), 2.81 (t,  $J = 7.5$  Hz, 2H), 2.71 (s, 3H),

25 2.65 (s, 3H), 2.14 (s, 3H), 1.68-1.52 (m, 4H), 1.49 (s, 9H), 1.39 (s, 9H); MS (FAB+)  $m/z$  720.6 ( $\text{M}+\text{H}^+$ ) (FAB-)  $m/z$  718.5 ( $\text{M}-\text{H}^+$ ).

Synthesis of Structure (34):

5

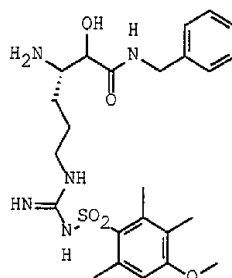
(34)

Structure (34) was synthesized as follows. To a solution of phenethylamide (structure (33), 25 mg, 0.035 mmol) in THF (5 ml) was added 18 mg of p-toluenesulfonic acid monohydrate (0.093 mmol). The reaction mixture was stirred at rt overnight to give a baseline spot by TLC. The solution was concentrated *in vacuo*, and the residue washed twice with ether removing excess pTsOH to give structure (34) as a yellowish-white solid, which was used without further purification. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) was consistent with the expected product, however, individual peak assignment was difficult due to broadening. MS (ES+) *m/z* 520.4 (M+H<sup>+</sup>).

Structure (34) was reacted with structure (9a) of Example 1 (in an analogous manner to the procedure described in Example 2 for the synthesis of structure (18)), followed by oxidation and deprotection (in an analogous manner as described with respect to the oxidation and deprotection of structures (18) and (19), respectively) to provide structure (35) as identified in Table 9 below.

Example 11Synthesis of Representative  $\beta$ -Sheet Mimetics

This example illustrates the synthesis of a  
5 further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (36):

10

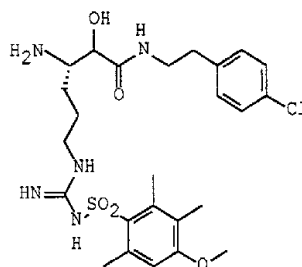
(36)

Structure (36) was synthesized in an analogous  
fashion to compound (34) starting with benzylamine and  
15 structure (32).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ ) was consistent  
with the expected product, however, individual peak  
assignment was difficult due to broadening. MS (FAB+)  $m/z$   
506.4 ( $\text{M}+\text{H}^+$ ).

Structure (36) was reacted with structure (9a)  
20 of Example 1 (in an analogous manner to the procedure  
described in Example 2 for the synthesis of structure  
(18)), followed by oxidation and deprotection (in an  
analogous manner as described with respect to the  
oxidation and deprotection of structures (18) and (19),  
25 respectively) to provide structure (37) as identified in  
Table 9 below.

Example 12Synthesis of Representative  $\beta$ -Sheet Mimetics

5            This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (38):

10

(38)

Structure (38) was synthesized in an analogous fashion to structure (34) starting with  
15 p-chlorophenethylamine and structure (32). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) was consistent with the expected product, individual peak assignment was difficult due to broadening. MS (ES+) m/z 554.5 (M+H<sup>+</sup>).

Structure (38) was reacted with structure (9a)  
20 of Example 1 (in an analogous manner to the procedure described in Example 2 for the synthesis of structure (18)), followed by oxidation and deprotection (in an analogous manner as described with respect to the oxidation and deprotection of structures (18) and (19),  
25 respectively) to provide structure (39) as identified in Table 9 below.

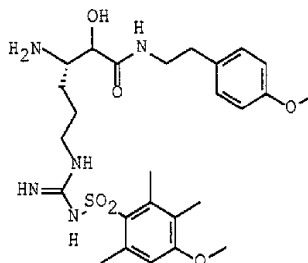
Example 13Synthesis of Representative  $\beta$ -Sheet Mimetics

5

This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (40):

10



(40)

Structure (40) was synthesized in an analogous fashion to compound (34) using p-methoxyphenethylamine and structure (32).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ ) was consistent with the expected product, however, individual assignment was difficult due to broadening. MS (ES+)  $m/z$  550.5 ( $\text{M}+\text{H}^+$ ).

20 Structure (40) was reacted with structure (9a) of Example 1 (in an analogous manner to the procedure described in Example 2 for the synthesis of structure (18)), followed by oxidation and deprotection (in an analogous manner as described with respect to the  
25 oxidation and deprotection of structures (18) and (19), respectively) to provide structure (41) as identified in Table 9 below.

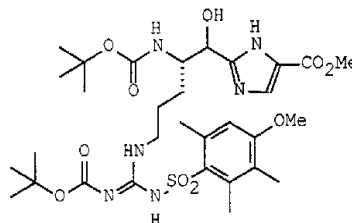
Example 14Synthesis of Representative  $\beta$ -Sheet Mimetics

5

This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (42):

10

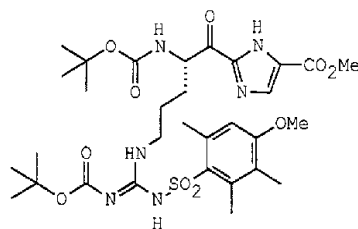


(42)

Structure (42) was prepared as follows. In a 10  
15 ml round-bottomed flask were added  $\text{CH}_2\text{Cl}_2$  (10 ml), methyl  
2,3-dimethylaminopropionate dihydrochloride (19.9 mg,  
0.103 mmol, 1.5 eq), and diisopropylethylamine (53 ml,  
0.304 mmol, 4.4 eq). This suspension was stirred  
magnetically at room temperature for 1 h at which time was  
20 added the compound of structure (30) (50 mg, 0.068 mmol, 1  
eq), mercury(II)chloride (82.4 mg, 0.304 mmol, 4.4 eq),  
and mercury(II)oxide (25.7 mg, 0.120 mmol, 1.7 eq). The  
resulting yellow suspension was stirred for 16.5 h during  
which time the suspension turned gray. The reaction was  
25 diluted with  $\text{CH}_2\text{Cl}_2$  (50 ml), washed with saturated aqueous  
 $\text{NH}_4\text{Cl}$  (5 ml), saturated aqueous  $\text{NaCl}$  (5 ml) and dried over  
 $\text{Na}_2\text{SO}_4$ . The cloudy suspension was filtered and the solvent  
removed in vacuo. The white solid was purified on

preparative thin-layer chromatography to produce the imidazoline structure (42) (25.3 mg, 52% yield) as a clear amorphous solid.:  $R_f$  0.11 (10% MeOH/ $\text{CHCl}_3$ );  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  9.82 (s, 0.6H,  $\text{N}^{\text{H}}$ , mixture of tautomers), 9.78 (s, 0.4H,  $\text{N}^{\text{H}}$ ), 8.35 (dd,  $J=4.3$ , 11 Hz,  $^1\text{H}$ , N-5), 6.54 (s, 1H, ArH), 5.08 (d,  $J=11$  Hz, 1H,  $\text{CHOH}$ ), 4.52 (m, 1H, imidazoline  $\text{CH}_2$ ), 4.38 (d,  $J=21$  Hz, 1H), 3.8-4.0 (m, 2H), 3.86 (s, 3H,  $\text{CO}_2\text{CH}_3$ ), 3.767 (s, 3H,  $\text{ArOCH}_3$ ), 3.5-3.7 (m, 2H, C-5  $\text{CH}_2$ ), 3.16-3.27 (m, C-5  $\text{CH}_2$ ), 2.70 (s, 3H,  $\text{ArCH}_3$ ), 2.63 (s, 3H,  $\text{ArCH}_3$ ), 2.14 (s, 3H,  $\text{ArCH}_3$ ), 1.5-1.7 (m, 4H, C-3 and C-4  $\text{CH}_2$ ), 1.49 (s, 9H, Boc), 1.46 (s, 9H, Boc); IR (film) 1725.56, 1685.68, 1618.36, 1585.45, 1207.09, 1148.85  $\text{cm}^{-1}$ ; MS (ES+)  $m/e$  699.4 ( $\text{M}+\text{H}^+$ ).

15                    Synthesis of Structure (43):



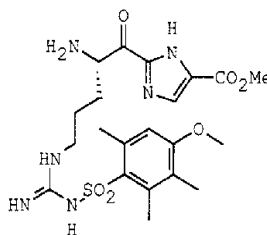
(43)

20                    Structure (43) was synthesized as follows. In a 25 ml round-bottomed flask was placed the compound of structure (42) (230 mg, 0.33 mmol),  $\text{CHCl}_3$  (5 ml) and  $\text{MnO}_2$  (500 mg, 5.75 mmol, 17.4 eq). After stirring for 5 h the suspension was filtered and the solid washed with 25 methanol. The solvent was removed in vacuo and the residue was dissolved in ethyl acetate (5 ml) and methanol (1 ml) and a fresh portion of  $\text{MnO}_2$  (500 mg) was introduced and the reaction stirred for 15 h at room temperature.

The solid was filtered and the solvent removed *in vacuo*. The residue was purified via column chromatography on silica gel, eluting with 1:1 ethyl acetate:hexane, then pure ethyl acetate, then 1:9 methanol:ethyl acetate to obtain the desired product (structure (43), 190 mg, 83% yield) as an amorphous solid.:  $R_f$  0.64 (70:30-ethyl acetate:hexane);  $^1H$  NMR (500 MHz,  $CDCl_3$ )  $\delta$  10.70 (bs, 1H, imidazole NH), 9.70 (s, 1H), 8.28 (s, 1H), 7.84 (s, 1H), 6.54 (s, 1H, ArH), 5.35 (m, 1H, aH), 5.25 (s, 1H, BocNH), 3.926 (s, 3H), 3.840 (s, 3H), 3.15-3.40 (m, 2H), 2.682 (s, 3H), 2.133 (s, 3H), 1.52-1.70 (m, 4H), 1.470 (s, 9H), 1.424 (s, 9H); IR (film) 1724.68, 1619.03, 1277.72, 1151.93, 1120.61  $cm^{-1}$ ; MS (ES+)  $m/e$  695.2 ( $M+H^+$ , 22), 717.2 ( $M+Na^+$ , 100).

15

Synthesis of Structure (44):



Structure (44) was synthesized by the same method used to construct structure (33) to structure (34). The product was used in the coupling without further purification.

Structure (44) was reacted with structure (9a) of Example 1 (in an analogous manner to the procedure described in Example 2 for the synthesis of structure (18)), followed by deprotection (in an analogous manner as described with respect to the deprotection of structure (19) respectively) to provide structure (45) as identified

in Table 9 below. In the preparation of structure (45), the coupling step was performed with the carbonyl compound of structure (44), rather than with the analogous hydroxy compound.

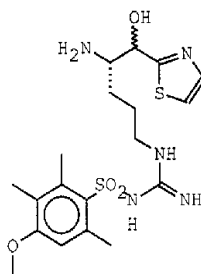
5

#### Example 15

##### Synthesis of Representative $\beta$ -Sheet Mimetics

10 This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

##### Synthesis of Structure (46):



15

Structure (46) was synthesized in an analogous fashion to structure (17) starting from structure (16) and thiazole. This compound was used in the coupling step without further purification.

20 Structure (46) was reacted with structure (9a) of Example 1 (in an analogous manner to the procedure described in Example 2 for the synthesis of structure (18)), followed by oxidation and deprotection (in an analogous manner as described with respect to the  
25 oxidation and deprotection of structures (18) and (19), respectively) to provide structure (47) as identified in Table 9 below.

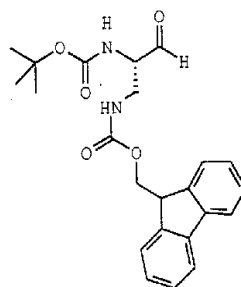
Example 16Synthesis of Representative  $\beta$ -Sheet Mimetics

5

This example illustrates the synthesis of a further representative  $\beta$ -sheet mimetic of this invention.

Synthesis of Structure (48):

10



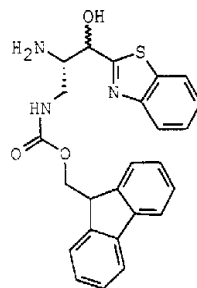
To a solution of  $\alpha$ -Boc- $\beta$ -Fmoc-2,3-diaminopropionic acid (818 mg, 1.92 mmol) stirred in THF  
15 (5 ml) at  $-25^{\circ}\text{C}$  was added 4-methylmorpholine (0.23 ml, 2.1 mmol) followed by isobutylchloroformate (0.25 ml, 1.9 mmol). The resulting suspension was stirred for 5 minutes and then filtered with the aid of 5 ml of THF. The filtrate was cooled in an ice/water bath then sodium  
20 borohydride (152 mg, 0.40 mmol) dissolved in water (2.5 ml) was added dropwise. The mixture was stirred for 15 minutes then water (50 ml) was added and the mixture was extracted with  $\text{CH}_2\text{Cl}_2$  (3 x 50 ml). The combined extracts were washed with brine, dried over anhydrous sodium  
25 sulfate and filtered. Concentration of the filtrate under vacuum yielded a pale yellow solid that was purified by

flash chromatography (50% ethyl acetate/hexanes eluent) to give 596 mg of the alcohol as a white solid.

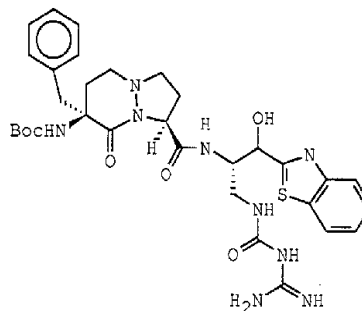
The alcohol (224 mg, 0.543 mmol) was dissolved in methylene chloride and Dess-Martin periodinane (262 mg, 5 0.64 mmol) was added. The mixture was stirred at room temperature for 1 h then diluted with ethyl acetate (50 ml) and extracted sequentially with 10% aqueous  $\text{Na}_2\text{S}_2\text{O}_3$ , saturated aqueous  $\text{NaHCO}_3$ , and brine. The organic solution was dried over anhydrous sodium sulfate, filtered and 10 concentrated under vacuum to a white solid. Purification of the solid by flash chromatography yielded 169 mg of the aldehyde structure (48) as a white solid.

Synthesis of Structure (49):

15



Structure (49) was synthesized in an analogous fashion to structure (17) starting from structure (48) and 20 benzothiazole. This compound was used as a 1:1 mixture of diastereomers in the coupling step (described below) without further purification. MS (EI+):  $m/z$  446.4 ( $M+H^+$ ).

Synthesis of Structure (50):

5           Structure (49) and bicyclic acid structure (9a)  
(27 mg, 0.069 mmol) and HOBt hydrate (71 mg, 0.46 mmol)  
were dissolved in THF (1 ml) and diisopropylethylamine  
(0.0059 ml, 0.34 mmol) was added followed by EDC (19 mg,  
0.099 mmol). The mixture was stirred at room temperature  
10 for 20 h then diluted with ethyl acetate and extracted  
sequentially with 5% aqueous citric acid, saturated  
aqueous sodium bicarbonate, water and brine. The organic  
solution was dried over anhydrous sodium sulfate, filtered  
and concentrated under vacuum to 61 mg of a yellow foam.  
15 <sup>1</sup>H NMR analysis indicated a mixture of diastereomeric  
amides.

The foam was dissolved in CH<sub>3</sub>CN and diethylamine  
was added. The solution was stirred at room temperature  
for 30 minutes then concentrated under vacuum to a yellow  
20 foam. The foam was rinsed with hexanes and dissolved in  
DMF (0.5 ml). In a separate flask, carbonyldiimidazole  
(16 mg, 0.99 mmol) and guanidine hydrochloride (10 mg,  
0.10 mmol) were dissolved in DMF (1 ml) and  
diisopropylethylamine (0.035 ml, 0.20 mmol) was added  
25 followed by DMAP (1 mg). The solution was stirred for 1.5  
h at room temperature then the solution of amine was added

and stirring was continued for 16 h. The solution was concentrated under vacuum then water was added to the residue and the mixture was extracted with ethyl acetate (3 x 25 ml). The combined extracts were washed with  
5 brine, dried over anhydrous sodium sulfate and filtered. Concentration of the filtrate under vacuum yielded 58 mg of structure (50) as a yellow foam. MS (ES+):  $m/z$  680.6 ( $M+H^+$ ).

Structure (50) was oxidized to provide the  
10 corresponding ketone of structure (51).

#### Example 17

#### Activities of Representative $\beta$ -Sheet Mimetics as a Protease Inhibitor

15

This example illustrates the ability of further representative  $\beta$ -sheet mimetics of this invention to function as an inhibitor for thrombin, Factor VII, Factor X, Factor XI, tryptase, aPC, plasmin, tPA, urokinase  
20 thrombin thrombomodulin complex and trypsin. The  $\beta$ -sheet mimetics of the structures listed in Table 9 had the inhibition activities shown in Table 10.

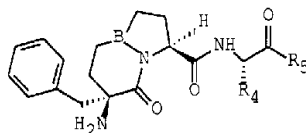
25

The proteinase inhibitor assays were performed as described in Example 9. The assay for thrombin-thrombomodulin complex was conducted as for thrombin except that prior to the addition of inhibitor and substrate, thrombin was preincubated with 4 nM thrombomodulin for 20 minutes at room temperature.

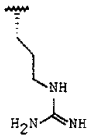
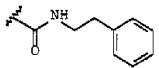
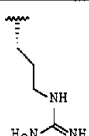
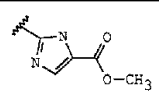
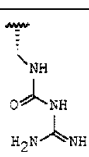
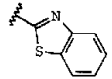
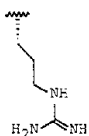
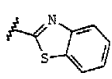
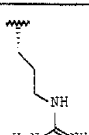
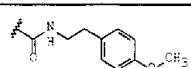
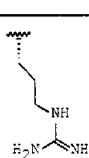
Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.



Table 9  
Structures, Synthetic Precursors, and Physical Data for  
Various Serine Protease Inhibitors



| Structure Number   | B <sup>δ</sup> | R <sub>4</sub> | R <sub>5</sub> | Precursor<br> | M.S.<br>(ES <sup>+</sup> )   | HPLC*<br>R.T.<br>(min) |
|--------------------|----------------|----------------|----------------|---------------|------------------------------|------------------------|
| (47)               | N              |                |                | (46)          | 513.5<br>(M+H <sup>+</sup> ) | 15.9                   |
| (20b)              | N              |                |                | (17)          | 563.5<br>(M+H <sup>+</sup> ) | 17.9                   |
| (37)               | N              |                |                | (36)          | 563.6<br>(M+H <sup>+</sup> ) | 16.9                   |
| (39)               | N              |                |                | (38)          | 611.3<br>(M+H <sup>+</sup> ) | 19.8                   |
| (29a) <sup>*</sup> | CH             |                |                | (17)          | 562.4<br>(M+H <sup>+</sup> ) | 21.2                   |

| Structure Number | B <sup>6</sup> | R <sub>4</sub>                                                                      | R <sub>5</sub>                                                                      | Precursor<br> | M.S.<br>(ES <sup>+</sup> )       | HPLC*<br>R.T.<br>(min) |
|------------------|----------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|----------------------------------|------------------------|
| (35)             | N              |    |    | (34)                                                                                            | 577.4<br>(M+H <sup>+</sup> )     | 18.1                   |
| (45)             | N              |    |    | (44)                                                                                            | 554.2<br>(M+H <sup>+</sup> )     | 15.7                   |
| (51)             | N              |    |    | (49)                                                                                            | 578.3<br>(M+H <sup>+</sup> )     | 22.3                   |
| (29b)            | CH             |  |  | (17)                                                                                            | FAB 562.4<br>(M+H <sup>+</sup> ) | 21.5                   |
| (41)             | N              |  |  | (40)                                                                                            | 607.4<br>(M+H <sup>+</sup> )     | 18.2                   |
| (13)             | N              |  |  | Arg (Mtr)-CH <sub>2</sub> Cl                                                                    | 477.9<br>(M+H <sup>+</sup> )     | 14.9                   |

<sup>6</sup>The stereochemistry of the template for B = CH is (3R, 6R, 9S) except where noted (see footnote 8).

<sup>6</sup>Template stereochemistry is (3S, 6R, 9S).

<sup>\*</sup>HPLC was performed on a reverse phase C-18 column 5 using a gradient of 0-90% acetonitrile/water, 0.1% TFA.

Table 10  
Ki (M) Inhibition Activity of Various Compounds Against Serine Proteases

| Structure Number | Thrombin | Factor VII | Factor X              | Factor XI | Urokinase | T.T.C. <sup>a</sup> | APC <sup>b</sup> | Plasmin  | tPA <sup>c</sup> | Trypsin  | Tryptase |
|------------------|----------|------------|-----------------------|-----------|-----------|---------------------|------------------|----------|------------------|----------|----------|
| 35               | 7.10E-11 | 1.64E-08   | 3.45E-07 <sup>c</sup> |           |           |                     |                  |          |                  | 2.70E-11 |          |
| 37               | 7.32E-11 |            |                       |           |           |                     |                  |          |                  | 7.73E-11 |          |
| 29b              | 8.50E-11 | 2.00E-07   | 1.93E-08              | 7.53E-08  | 3.35E-07  | 8.80E-11            | 1.25E-06         | 2.51E-07 | 9.29E-08         | 2.30E-10 | 9.00E-09 |
| 39               | 3.10E-10 |            |                       |           |           |                     |                  |          |                  |          |          |
| 41               | 4.50E-10 |            |                       |           |           |                     |                  |          |                  |          |          |
| 20b              | 6.50E-10 | 2.70E-07   | 2.22E-07              | 2.70E-08  | 6.00E-07  |                     | 3.32E-06         | 4.15E-07 | 4.95E-07         | 6.20E-10 | 1.24E-08 |
| 47               | 2.40E-09 | 9.68E-07   | 1.50E-06 <sup>c</sup> |           |           |                     |                  |          |                  | 1.90E-09 |          |
| 45               | 5.40E-09 | 2.96E-05   | 3.80E-05              | 1.24E-06  |           | 6.90E-09            | 2.56E-05         | 2.38E-05 | 1.72E-05         | 5.24E-08 | 1.65E-06 |
| 51               | 7.25E-09 | 4.26E-06   | 5.70E-05              | 1.73E-06  |           |                     |                  |          |                  | 3.79E-08 |          |
| 29a              | 1.04E-08 | 1.77E-06   | 4.65E-06 <sup>c</sup> | 3.91E-07  |           |                     |                  |          |                  | 5.40E-10 |          |
| 13 <sup>d</sup>  | 1.20E-09 | 1.40E-07   | 3.86E-07 <sup>c</sup> |           | 9.27E-07  |                     | 5.28E-07         | 9.78E-07 | 6.32E-07         | 1.60E-07 |          |

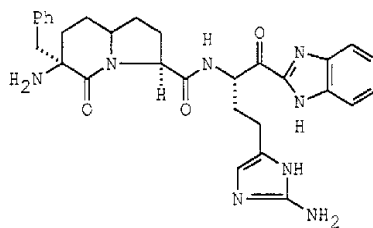
5 <sup>a</sup> Thrombin thrombomodulin complex, <sup>b</sup> activated Protein C, <sup>c</sup> tissue Plasminogen Activator, <sup>d</sup> IC50, <sup>e</sup> bovine plasma

Example 18Effect of Representative  $\beta$ -Sheet Mimetics on Platelet  
Deposition in a Vascular Graft

5           The effect of compounds of the invention on  
platelet deposition in a vascular graft was measured  
according to the procedure of Hanson et al. "Interruption  
of acute platelet-dependent thrombosis by synthetic  
antithrombin           D-phenylalanyl-L-prolyl-L-arginyl  
10 chloromethylketone" *Proc. Natl. Acad. Sci., USA* 85:3148-  
3188, (1988), except that the compound was introduced  
proximal to the shunt as described in Kelly et al., *Proc.*  
*Natl. Acad. Sci., USA* 89:6040-6044 (1992). The results  
are shown in Figures 1, 2 and 3 for structures (20b), (39)  
15 and (29b), respectively.

Example 19Synthesis of Representative  $\beta$ -Sheet Mimetics

20           This example illustrates the synthesis of a  
further representative  $\beta$ -sheet mimetic of this invention  
having the structure shown below.

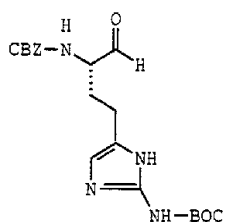


(52)

25

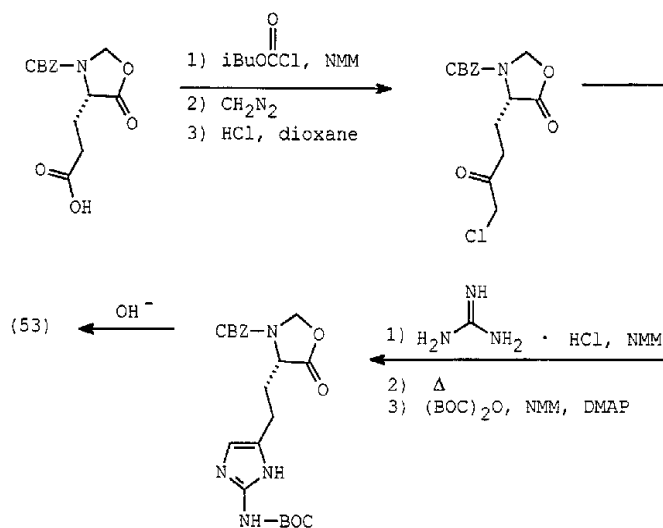
Structure (52) may be synthesized employing the  
following intermediate (53) in place of intermediate (16)  
in Example 2:

123

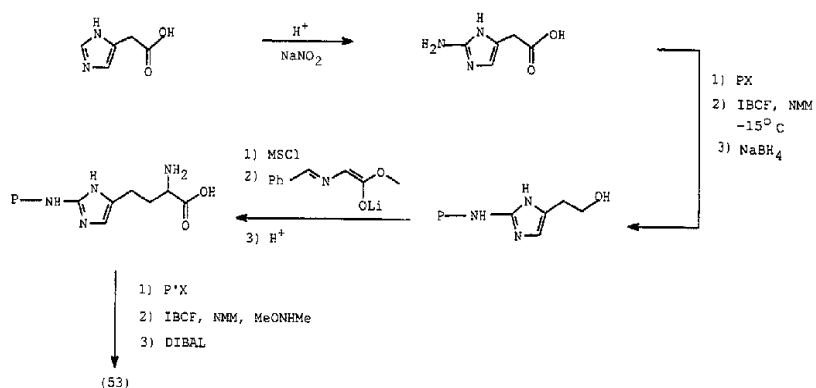


(53)

Intermediate (53) may be synthesized by the  
5 following reaction scheme:



Alternatively, intermediate (53) may be  
10 synthesized by the following reaction scheme:

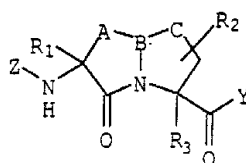


From the foregoing, it will be appreciated that, although specific embodiments of this invention have been described herein for purposes of illustration, various

5 modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except by the appended claims.

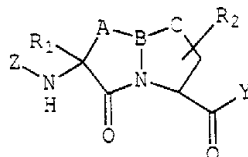
## THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A  $\beta$ -sheet mimetic including a bicyclic ring system, said  $\beta$ -sheet mimetic having the structure:



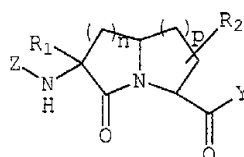
wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof; A is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-4}-$ ,  $-C(=O)(CH_2)_{1-3}-$ ,  $-(CH_2)_{1-2}O-$  and  $-(CH_2)_{1-2}S-$ ; B is selected from N and CH; C is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-3}-$ ,  $-O-$ ,  $-S-$ ,  $-O-(CH_2)_{1-2}-$  and  $-S(CH_2)_{1-2}-$ ; Y and Z represent the remainder of the molecule; and any two adjacent CH groups of the bicyclic ring may form a double bond; with the provisos that (i)  $R_1$  is an amino acid side chain moiety or derivative thereof other than hydrogen, (ii) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-CH_2CH_2-$  and B is CH, then C is not  $-CH_2-$ , (iii) when  $R_1$  is methyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-CH_2O-$  and B is CH, then C is not  $-CH_2-$ , and (iv) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-CH_2-$  and B is CH, then C is not  $-S-$ .

2. The  $\beta$ -sheet mimetic of claim 1 having the structure:



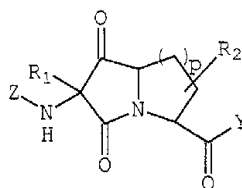
wherein A is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-4}-$  and  $-C(=O)(CH_2)_{1-3}-$ ; C is selected from  $-C(=O)-$  and  $-(CH_2)_{1-3}$  and the bicyclic ring system is saturated.

3. The  $\beta$ -sheet mimetic of claim 2 having the structure:



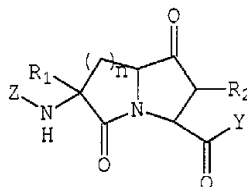
wherein n is an integer from 1 to 4 and p is an integer from 1 to 3.

4. The  $\beta$ -sheet mimetic of claim 2 having the structure:



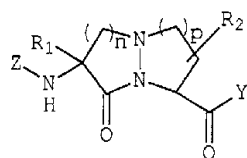
wherein p is an integer from 1 to 3.

5. The  $\beta$ -sheet mimetic of claim 2 having the structure:



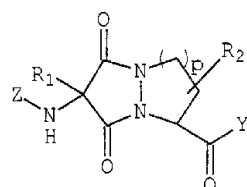
wherein n is an integer from 1 to 4.

6. The  $\beta$ -sheet mimetic of claim 2 having the structure:



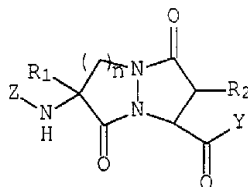
wherein n is an integer from 1 to 4 and p is an integer from 1 to 3.

7. The  $\beta$ -sheet mimetic of claim 2 having the structure:



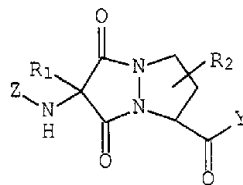
wherein p is an integer from 1 to 3.

8. The  $\beta$ -sheet mimetic of claim 2 having the structure:

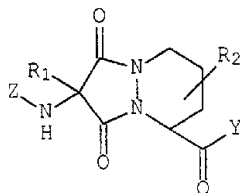


wherein n is an integer from 1 to 4.

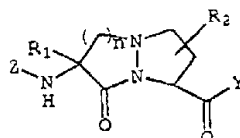
9. The  $\beta$ -sheet mimetic of claim 2 having the structure:



10. The  $\beta$ -sheet mimetic of claim 2 having the structure:



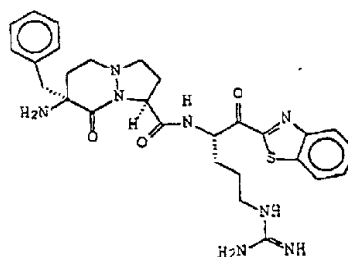
11. The  $\beta$ -sheet mimetic of claim 2 having the structure:



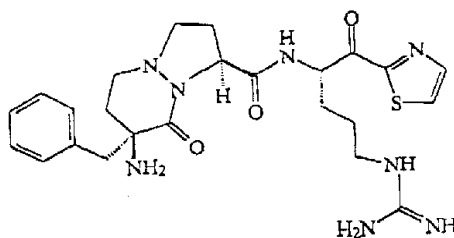
wherein n is an integer from 1 to 4.

12. The  $\beta$ -sheet mimetic of claim 11 wherein n is 2 and R<sub>2</sub> is hydrogen.

13. The  $\beta$ -sheet mimetic of claim 12 having the structure:

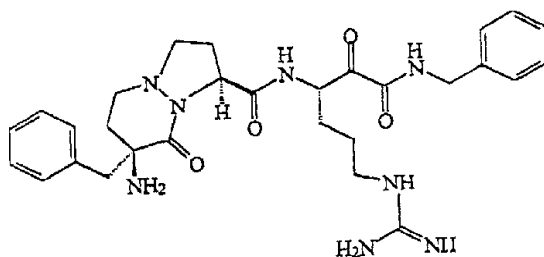


14. The  $\beta$ -sheet mimetic of claim 12 having the structure:

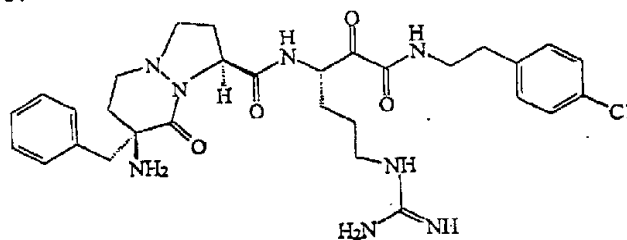


AMENDED SHEET  
IPEA/EP

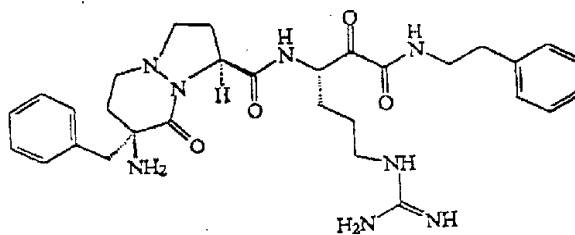
15. The  $\beta$ -sheet mimetic of claim 12 having the structure:



16. The  $\beta$ -sheet mimetic of claim 12 having the structure:

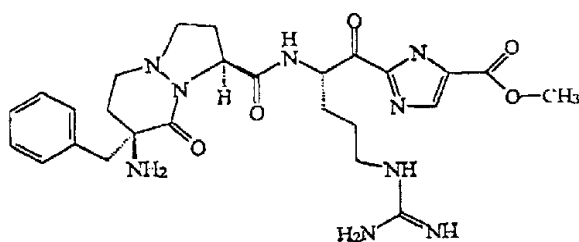


17. The  $\beta$ -sheet mimetic of claim 12 having the structure:

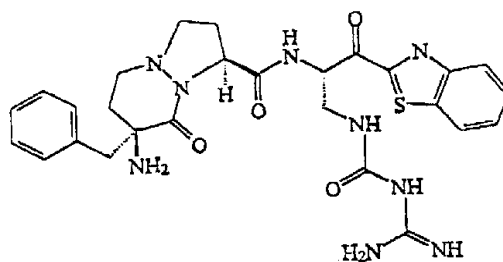


AMENDED SHEET  
IPEA/EP

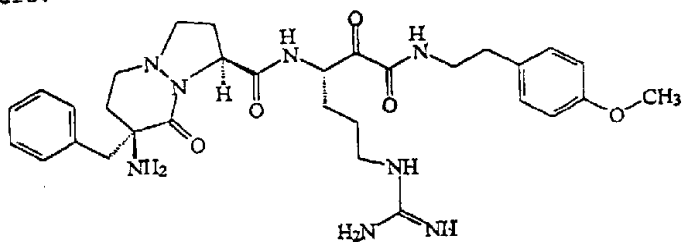
18. The  $\beta$ -sheet mimetic of claim 12 having the structure:



19. The  $\beta$ -sheet mimetic of claim 12 having the structure:

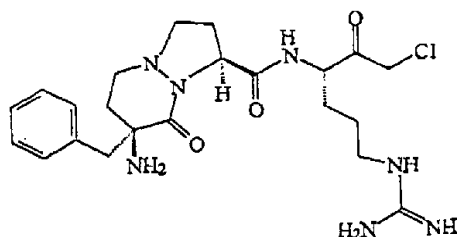


20. The  $\beta$ -sheet mimetic of claim 12 having the structure:

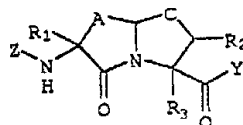


AMENDED SHEET  
IPEA/EP

21. The  $\beta$ -sheet mimetic of claim 12 having the structure:

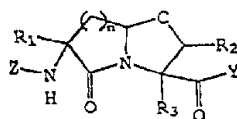


22. The  $\beta$ -sheet mimetic of claim 1 having the structure:



wherein A is selected from  $-(CH_2)_{1-4}-$ ,  $-(CH_2)_{1-2}O-$  and  $-(CH_2)_{1-2}S-$ ; C is selected from  $-(CH_2)_{1-3}-$ ,  $-O-$ ,  $-S-$ ,  $-O(CH_2)_{1-2}-$  and  $-S(CH_2)_{1-2}-$ , and the bicyclic ring system is saturated.

23. The  $\beta$ -sheet mimetic of claim 22 having the structure:

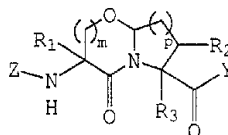


wherein n is an integer from 1 to 4.



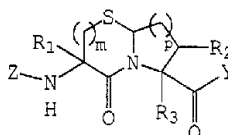
AMENDED SHEET  
IPEA/EP

24. The  $\beta$ -sheet mimetic of claim 22 having the structure:



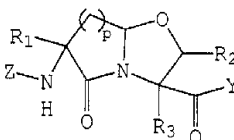
wherein m is an integer from 1 to 2; and p is an integer from 1 to 3.

25. The  $\beta$ -sheet mimetic of claim 22 having the structure:



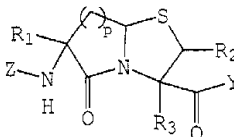
wherein m is an integer from 1 to 2; and p is an integer from 1 to 3.

26. The  $\beta$ -sheet mimetic of claim 22 having the structure:



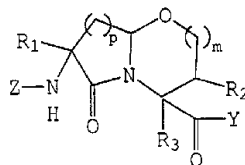
wherein p is an integer from 1 to 3.

27. The  $\beta$ -sheet mimetic of claim 22 having the structure:



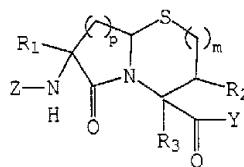
wherein p is an integer from 1 to 3.

28. The  $\beta$ -sheet mimetic of claim 22 having the structure:



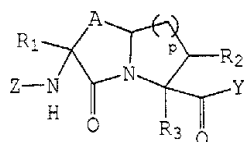
wherein p is an integer for 1 to 3; and m is an integer from 1 to 2.

29. The  $\beta$ -sheet mimetic of claim 22 having the structure:



wherein p is an integer for 1 to 3; and m is an integer from 1 to 2.

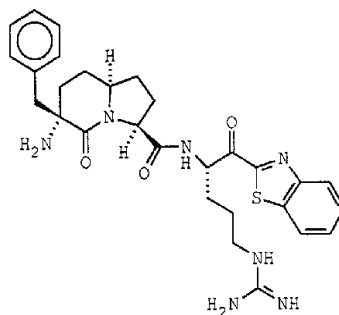
30. The  $\beta$ -sheet mimetic of claim 22 having the structure:



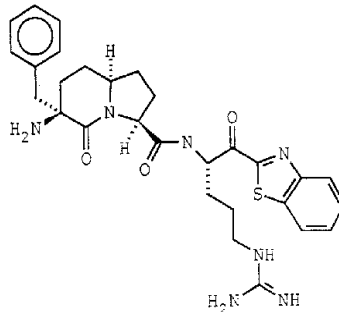
wherein p is an integer from 1 to 3.

31. The  $\beta$ -sheet mimetic of claim 30 wherein A is  $-\text{CH}_2\text{CH}_2-$ , p is 1 and  $\text{R}_2$  and  $\text{R}_3$  are both hydrogen.

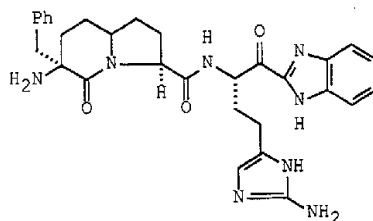
32. The  $\beta$ -sheet mimetic of claim 31 having the structure:



33. The  $\beta$ -sheet mimetic of claim 31 having the structure:



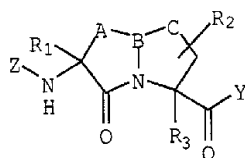
34. The  $\beta$ -sheet mimetic of claim 31 having the structure:



35. The  $\beta$ -sheet mimetic of claim 1 wherein Y and Z are each at least one amino acid.

36. The  $\beta$ -sheet mimetic of claim 35 wherein  $R_1$ ,  $R_2$ ,  $R_3$ , A, B and C are as defined in any one of claims 3 through 14 and 16 through 33.

37. A method for inhibiting a protease in a warm-blooded animal, comprising administering to the animal an effective amount of a  $\beta$ -sheet mimetic having the structure:



wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof; A is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-4}-$ ,  $-C(=O)(CH_2)_{1-3}-$ ,  $-(CH_2)_{1-2}O-$  and  $-(CH_2)_{1-2}S-$ ; B is selected from N and CH; C is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-3}-$ ,  $-O-$ ,  $-S-$ ,  $-O-(CH_2)_{1-2}-$  and  $-S(CH_2)_{1-2}-$ ; Y and Z represent the remainder of the molecule; and any two adjacent CH groups of the bicyclic ring may form a double bond; with the provisos that (i)  $R_1$  is an amino acid side chain moiety or derivative thereof other than hydrogen, (ii) when  $R_1$

is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-\text{CH}_2\text{CH}_2-$  and B is CH, then C is not  $-\text{CH}_2-$ , (iii) when  $R_1$  is methyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-\text{CH}_2\text{O}-$  and B is CH, then C is not  $-\text{CH}_2-$ , and (iv) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-\text{CH}_2-$  and B is CH, then C is not  $-\text{S}-$ .

38. The method of claim 37 wherein the protease is a serine protease.

39. The method of claim 38 wherein the serine protease is selected from thrombin, elastase and Factor X.

40. The method of claim 38 wherein the serine protease is thrombin.

41. The method of claim 37 wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 13.

42. The method of claim 37 wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 17.

43. The method of claim 37 wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 32.

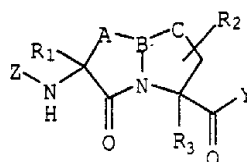
44. The method of claim 37 wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 33.

45. The method of claim 37 wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 34.

46. The method of claim 37 wherein the protease is selected from an aspartic, cysteine and metallo protease.

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47. Use of a  $\beta$ -sheet mimetic for preparation of a medicament for inhibiting a protease in a warm blooded animal, said  $\beta$ -sheet mimetic having the structure:



wherein  $R_1$ ,  $R_2$  and  $R_3$  are independently selected from amino acid side chain moieties and derivatives thereof; A is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-4}-$ ,  $-C(=O)(CH_2)_{1-3}-$ ,  $-(CH_2)_{1-2}O-$  and  $-(CH_2)_{1-2}S-$ ; B is selected from N and CH; C is selected from  $-C(=O)-$ ,  $-(CH_2)_{1-3}-$ ,  $-O-$ ,  $-S-$ ,  $-O-(CH_2)_{1-2}-$  and  $-S(CH_2)_{1-2}-$ ; Y and Z represent the remainder of the molecule; and any two adjacent CH groups of the bicyclic ring may form a double bond; with the provisos that (i)  $R_1$  is an amino acid side chain moiety or derivative thereof other than hydrogen, (ii) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-CH_2CH_2-$  and B is CH, then C is not  $-CH_2-$ , (iii) when  $R_1$  is methyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-CH_2O-$  and B is CH, then C is not  $-CH_2-$ , and (iv) when  $R_1$  is benzyl,  $R_2$  and  $R_3$  are both hydrogen, A is  $-CH_2-$  and B is CH, then C is not  $-S-$ .

48. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the protease is a serine protease.

49. Use of a  $\beta$ -sheet mimetic as claimed in claim 48, wherein the serine protease is selected from thrombin, elastase and Factor X.

50. Use of a  $\beta$ -sheet mimetic as claimed in claim 48, wherein the serine protease is thrombin.

51. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 13.



52. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the  $\beta$ -sheet mimetic is

P:10PERIVPA152729-96, CLM - 15/10/99

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the  $\beta$ -sheet mimetic of claim 17.

53. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 32.

54. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 33.

55. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the  $\beta$ -sheet mimetic is the  $\beta$ -sheet mimetic of claim 34.

56. Use of a  $\beta$ -sheet mimetic as claimed in claim 47, wherein the protease is selected from an aspartic, cysteine and metallo protease.

57. A  $\beta$ -sheet mimetic as claimed in any one of claims 1 to 36, substantially as described herein with reference to the accompanying figures and/or examples.

58. A method according to any one of claims 37 to 46, substantially as described herein with reference to the accompanying figures and/or examples.

59. Use of a  $\beta$ -sheet mimetic according to any one claims 47 to 56, substantially as described herein with reference to the accompanying figures and/or examples.

DATED this FIFTEENTH day of SEPTEMBER, 1999

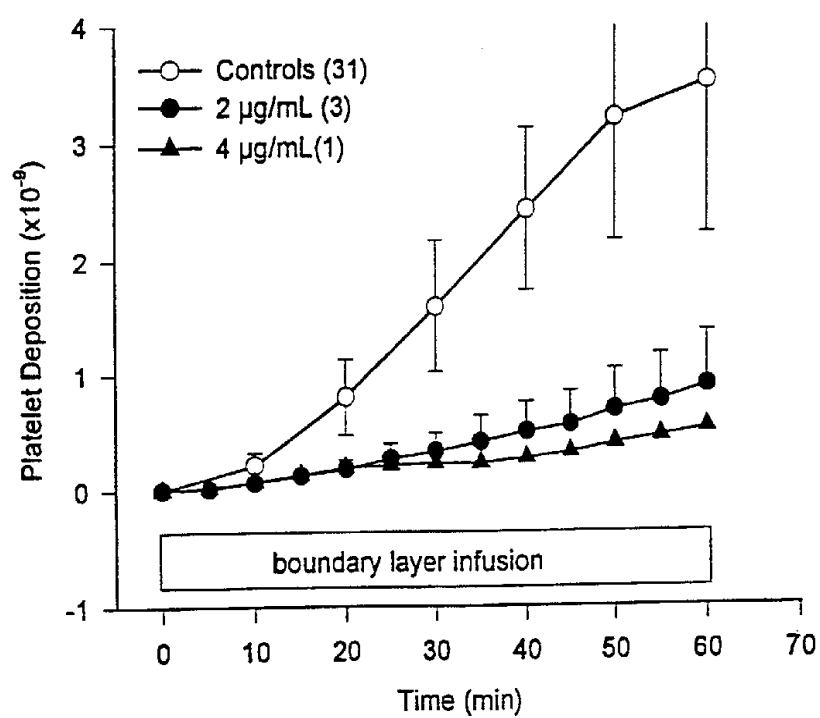
Molecumetics Ltd.

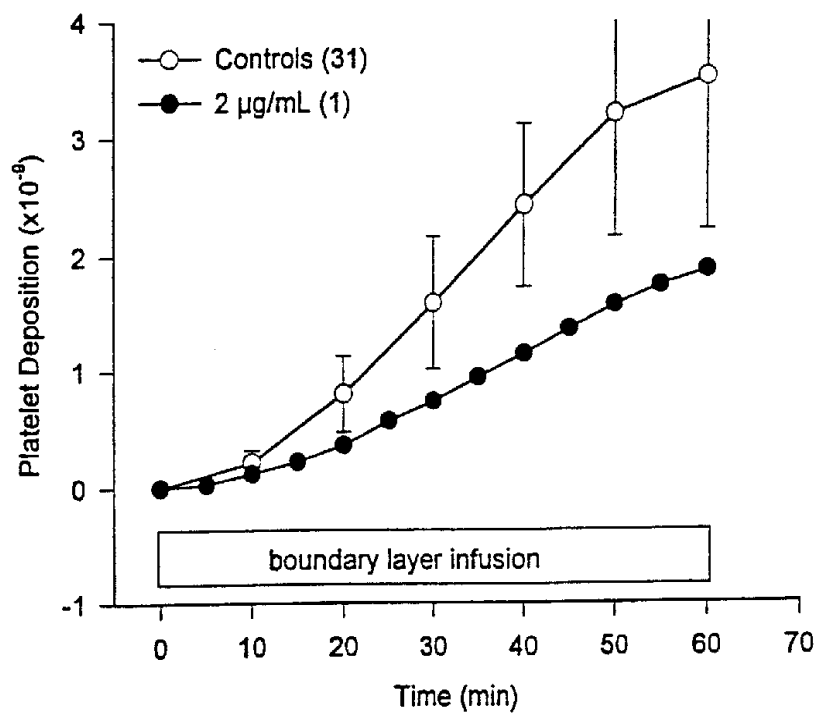
by DAVIES COLLISON CAVE

Patent Attorneys for the Applicants

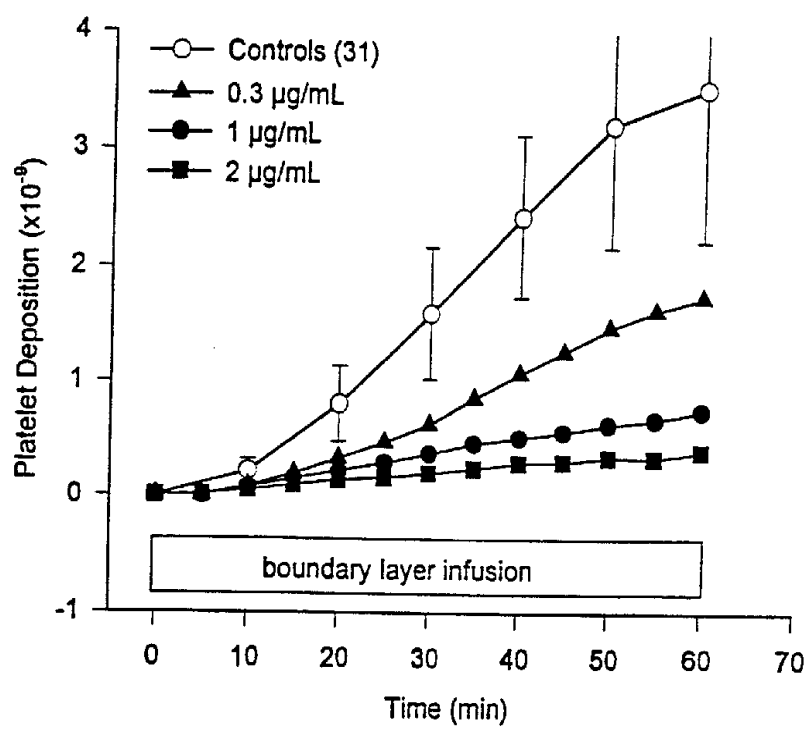


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*Fig. 1*

*Fig. 2*

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*Fig. 3*