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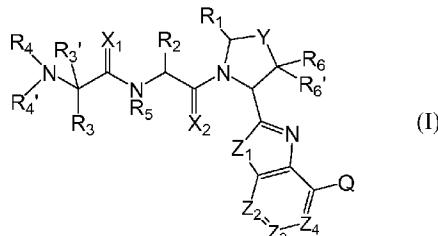
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(54) Title: INHIBITORS OF IAP

(57) Abstract: The invention provides novel inhibitors of IAP that are useful as therapeutic agents for treating malignancies where the compounds have the general formula (I): wherein Q, X₁, X₂, Y, Z₁, Z₂, Z₃, Z₄, R₁, R₂, R₃, R_{3'}, R₄, R_{4'}, R₅, R₆, R_{6'} and n are as described herein.

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INHIBITORS OF IAP

This application claims priority to provisional United States patent application no. 60/751,801 filed December 19, 2005, the entirety of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to organic compounds useful for therapy and/or prophylaxis in a mammal, and in particular to inhibitors of IAP proteins useful for treating cancers.

BACKGROUND OF THE INVENTION

Apoptosis or programmed cell death is a genetically and biochemically regulated mechanism that plays an important role in development and homeostasis in invertebrates as well as vertebrates. Aberrancies in apoptosis that lead to premature cell death have been linked to a variety of developmental disorders. Deficiencies in apoptosis that result in the lack of cell death have been linked to cancer and chronic viral infections (Thompson et al., (1995) *Science* 267, 1456-1462).

One of the key effector molecules in apoptosis are the caspases (cysteine containing aspartate specific proteases). Caspases are strong proteases, cleaving after aspartic acid residues and once activated, digest vital cell proteins from within the cell. Since caspases are such strong proteases, tight control of this family of proteins is necessary to prevent premature cell death. In general, caspases are synthesized as largely inactive zymogens that require proteolytic processing in order to be active. This proteolytic processing is only one of the ways in which caspases are regulated. The second mechanism is through a family of proteins that bind and inhibit caspases.

A family of molecules that inhibit caspases are the Inhibitors of Apoptosis (IAP) (Deveraux et al., *J Clin Immunol* (1999), 19:388-398). IAPs were originally discovered in baculovirus by their

functional ability to substitute for P35 protein, an anti-apoptotic gene (Crook et al. (1993) *J Virology* 67, 2168-2174). IAPs have been described in organisms ranging from *Drosophila* to human. Regardless of their origin, structurally, IAPs comprise one to three Baculovirus IAP repeat (BIR) domains, and most of them also possess a carboxyl-terminal RING finger motif. The BIR domain itself is a zinc binding domain of about 70 residues comprising 4 alpha-helices and 3 beta strands, with cysteine and histidine residues that coordinate the zinc ion (Hinds et al., (1999) *Nat. Struct. Biol.* 6, 648-651). It is the BIR domain that is believed to cause the anti-apoptotic effect by inhibiting the caspases and thus inhibiting apoptosis. As an example, human X-chromosome linked IAP (XIAP) inhibits caspase 3, caspase 7 and the Apaf-1-cytochrome C mediated activation of caspase 9 (Deveraux et al., (1998) *EMBO J.* 17, 2215-2223). Caspases 3 and 7 are inhibited by the BIR2 domain of XIAP, while the BIR3 domain of XIAP is responsible for the inhibition of caspase 9 activity. XIAP is expressed ubiquitously in most adult and fetal tissues (Liston et al, *Nature*, 1996, 379(6563):349), and is overexpressed in a number of tumor cell lines of the NCI 60 cell line panel (Fong et al, *Genomics*, 2000, 70:113; Tamm et al, *Clin. Cancer Res.* 2000, 6(5):1796). Overexpression of XIAP in tumor cells has been demonstrated to confer protection against a variety of pro-apoptotic stimuli and promotes resistance to chemotherapy (LaCasse et al, *Oncogene*, 1998, 17(25):3247). Consistent with this, a strong correlation between XIAP protein levels and survival has been demonstrated for patients with acute myelogenous leukemia (Tamm et al, *supra*). Down-regulation of XIAP expression by antisense oligonucleotides has been shown to sensitize tumor cells to death induced by a wide range of pro-apoptotic agents, both *in vitro* and *in vivo* (Sasaki et al, *Cancer Res.*, 2000, 60(20):5659; Lin et al, *Biochem J.*, 2001, 353:299; Hu et al, *Clin. Cancer Res.*, 2003, 9(7):2826). Smac/DIABLO-derived peptides have also been demonstrated to sensitize a number of different tumor cell lines to apoptosis induced by a variety of pro-apoptotic drugs (Arnt et al, *J. Biol. Chem.*, 2002, 277(46):44236; Fulda et al, *Nature Med.*, 2002, 8(8):808; Guo et al, *Blood*, 2002, 99(9):3419; Vucic et al, *J. Biol. Chem.*, 2002, 277(14):12275; Yang et al, *Cancer Res.*, 2003, 63(4):831).

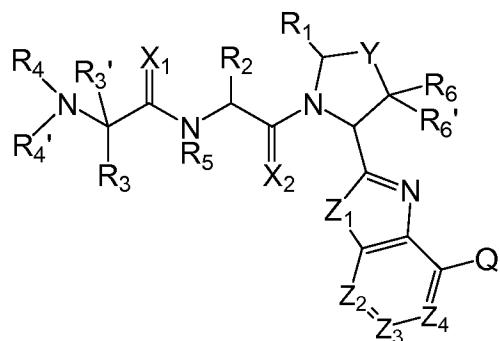
Melanoma IAP (ML-IAP) is an IAP not detectable in most normal adult tissues but is strongly upregulated in melanoma (Vucic et al., (2000) *Current Bio* 10:1359-1366). Determination of protein structure demonstrated significant homology of the ML-IAP BIR and RING finger domains to corresponding domains present in human XIAP, C-IAP1 and C-IAP2. The BIR domain of ML-IAP appears to have the most similarities to the BIR2 and BIR3 of XIAP, C-IAP1 and C-IAP2, and appears to be responsible for the inhibition of apoptosis, as determined by deletional analysis. Furthermore, Vucic et al., demonstrated that ML-IAP could inhibit chemotherapeutic agent induced apoptosis. Agents such as adriamycin and 4-tertiary butylphenol

(4-TBP) were tested in a cell culture system of melanomas overexpressing ML-IAP and the chemotherapeutic agents were significantly less effective in killing the cells when compared to a normal melanocyte control. The mechanism by which ML-IAP produces an anti-apoptotic activity is in part through inhibition of caspase 3 and 9. ML-IAP did not effectively inhibit caspases 1, 2, 6, or 8.

Since apoptosis is a strictly controlled pathway with multiple interacting factors, the discovery that IAPs themselves are regulated was not unusual. In the fruit fly *Drosophila*, the Reaper (rpr), Head Involution Defective (hid) and GRIM proteins physically interact with and inhibit the anti-apoptotic activity of the *Drosophila* family of IAPs. In the mammal, the proteins SMAC/DIABLO act to block the IAPs and allow apoptosis to proceed. It was shown that during normal apoptosis, SMAC is processed into an active form and is released from the mitochondria into the cytoplasm where it physically binds to IAPs and prevents the IAP from binding to a caspase. This inhibition of the IAP allows the caspase to remain active and thus proceed with apoptosis. Interestingly, sequence homology between the IAP inhibitors shows that there is a four amino acid motif in the N-terminus of the processed, active proteins. This tetrapeptide appears to bind into a hydrophobic pocket in the BIR domain and disrupts the BIR domain binding to caspases (Chai et al., (2000) *Nature* 406:855-862, Liu et al., (2000) *Nature* 408:1004-1008, Wu et al., (2000) *Nature* 408 1008-1012).

SUMMARY OF THE INVENTION

In one aspect of the present invention there is provided novel inhibitors of IAP proteins having the general formula (I)



I

wherein

X_1 and X_2 are each independently O or S;

Y is a bond, $(CR_7R_7)_n$, O or S;

Z_1 is NR_8 , O , S , SO or SO_2 ;

Z_2 , Z_3 and Z_4 are independently CQ or N;

Q is H, halogen, hydroxyl, carboxyl, amino, nitro, cyano, alkyl, a carbocycle, a heterocycle; wherein one or more CH_2 or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)-; and an alkyl, carbocycle and heterocycle is optionally substituted with one or more hydroxyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle;

R_1 is H, OH or alkyl; or R_1 and R_2 together form a 5-8 member heterocycle;

R_2 is alkyl, a carbocycle, carbocyclalkyl, a heterocycle or heterocyclalkyl each optionally substituted with halogen, hydroxyl, oxo, thione, mercapto, carboxyl, alkyl, haloalkyl, acyl, alkoxy, alkylthio, sulfonyl, amino and nitro, wherein said alkyl, acyl, alkoxy, alkylthio and sulfonyl are optionally substituted with hydroxy, mercapto, halogen, amino, alkoxy, hydroxyalkoxy and alkoxyalkoxy;

R_3 is H or alkyl optionally substituted with halogen or hydroxyl; or R_3 and R_4 together form a 3-6 heterocycle;

R_3' is H, or R_3 and R_3' together form a 3-6 carbocycle;

R_4 and R_4' are independently H, hydroxyl, amino, alkyl, carbocycle, carbocycloalkyl, carbocycloalkyloxy, carbocycloalkyloxycarbonyl, heterocycle, heterocycloalkyl, heterocycloalkyloxy or heterocycloalkyloxycarbonyl; wherein each alkyl, carbocycloalkyl, carbocycloalkyloxy, carbocycloalkyloxycarbonyl, heterocycle, heterocycloalkyl, heterocycloalkyloxy and heterocycloalkyloxycarbonyl is optionally substituted with halogen, hydroxyl, mercapto, carboxyl, alkyl, alkoxy, amino, imino and nitro; or R_4 and R_4' together form a heterocycle;

R_5 is H or alkyl;

R_6 , and R_6' are each independently H, alkyl, aryl or aralkyl;

R_7 is H, cyano, hydroxyl, mercapto, halogen, nitro, carboxyl, amidino, guanidino, alkyl, a carbocycle, a heterocycle or -U-V; wherein U is -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)- and V is alkyl, a carbocycle or a heterocycle; and wherein one or more CH_2 or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -C(O)-O- or -O-C(O)-; and an alkyl, carbocycle and heterocycle is optionally substituted with hydroxyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle;

R_8 is H, alkyl, a carbocycle or a heterocycle wherein one or more CH_2 or CH groups of said alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R_8), or -C(O)-; and said alkyl, carbocycle and heterocycle is optionally substituted with hydroxyl, alkoxy, acyl, halogen, mercapto, oxo (=O), carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle; and n is 0 to 4.

In another aspect of the invention, there are provided compositions comprising compounds of formula I and a carrier, diluent or excipient.

In another aspect of the invention, there is provided a method of inducing apoptosis in a cell comprising introducing into said cell a compound of formula I.

In another aspect of the invention, there is provided a method of sensitizing a cell to an apoptotic signal comprising introducing into said cell a compound of formula I.

In another aspect of the invention, there is provided a method for inhibiting the binding of an IAP protein to a caspase protein comprising contacting said IAP protein with a compound of formula I.

In another aspect of the invention, there is provided a method for treating a disease or condition associated with the overexpression of an IAP protein in a mammal, comprising administering to said mammal an effective amount of a compound of formula I.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

“Acy1” means a carbonyl containing substituent represented by the formula -C(O)-R in which R is H, alkyl, a carbocycle, a heterocycle, carbocycle-substituted alkyl or heterocycle-substituted alkyl wherein the alkyl, alkoxy, carbocycle and heterocycle are as defined herein. Acyl groups include alkanoyl (e.g. acetyl), aroyl (e.g. benzoyl), and heteroaroyl.

“Alkyl” means a branched or unbranched, saturated or unsaturated (i.e. alkenyl, alkynyl) aliphatic hydrocarbon group, having up to 12 carbon atoms unless otherwise specified. When used as part of another term, for example “alkylamino”, the alkyl portion may be a saturated hydrocarbon

chain, however also includes unsaturated hydrocarbon carbon chains such as “alkenylamino” and “alkynylamino. Examples of particular alkyl groups are methyl, ethyl, n-propyl, isopropyl, n-butyl, iso-butyl, sec-butyl, tert-butyl, n-pentyl, 2-methylbutyl, 2,2-dimethylpropyl, n-hexyl, 2-methylpentyl, 2,2-dimethylbutyl, n-heptyl, 3-heptyl, 2-methylhexyl, and the like. The terms “lower alkyl” “C₁-C₄ alkyl” and “alkyl of 1 to 4 carbon atoms” are synonymous and used interchangeably to mean methyl, ethyl, 1-propyl, isopropyl, cyclopropyl, 1-butyl, sec-butyl or t-butyl. Unless specified, substituted, alkyl groups may contain one, for example two, three or four substituents which may be the same or different. Examples of substituents are, unless otherwise defined, halogen, amino, hydroxyl, protected hydroxyl, mercapto, carboxy, alkoxy, nitro, cyano, amidino, guanidino, urea, sulfonyl, sulfinyl, aminosulfonyl, alkylsulfonylamino, arylsulfonylamino, aminocarbonyl, acylamino, alkoxy, acyl, acyloxy, a carbocycle, a heterocycle. Examples of the above substituted alkyl groups include, but are not limited to; cyanomethyl, nitromethyl, hydroxymethyl, trityloxymethyl, propionyloxymethyl, aminomethyl, carboxymethyl, carboxyethyl, carboxypropyl, alkyloxycarbonylmethyl, allyloxycarbonylaminomethyl, carbamoyloxymethyl, methoxymethyl, ethoxymethyl, t-butoxymethyl, acetoxymethyl, chloromethyl, bromomethyl, iodomethyl, trifluoromethyl, 6-hydroxyhexyl, 2,4-dichloro(n-butyl), 2-amino(iso-propyl), 2-carbamoyloxyethyl and the like. The alkyl group may also be substituted with a carbocycle group. Examples include cyclopropylmethyl, cyclobutylmethyl, cyclopentylmethyl, and cyclohexylmethyl groups, as well as the corresponding -ethyl, -propyl, -butyl, -pentyl, -hexyl groups, etc. Substituted alkyls include substituted methyls e.g. a methyl group substituted by the same substituents as the “substituted C_n-C_m alkyl” group. Examples of the substituted methyl group include groups such as hydroxymethyl, protected hydroxymethyl (e.g. tetrahydropyranoyloxymethyl), acetoxymethyl, carbamoyloxymethyl, trifluoromethyl, chloromethyl, carboxymethyl, bromomethyl and iodomethyl.

“Amidine” means the group -C(NH)-NHR in which R is H, alkyl, a carbocycle, a heterocycle, carbocycle-substituted alkyl or heterocycle-substituted alkyl wherein the alkyl, alkoxy, carbocycle and heterocycle are as defined herein. A particular amidine is the group -NH-C(NH)-NH₂.

“Amino” means primary (i.e. -NH₂), secondary (i.e. -NRH) and tertiary (i.e. -NRR) amines in which R is H, alkyl, a carbocycle, a heterocycle, carbocycle-substituted alkyl or heterocycle-substituted alkyl wherein the alkyl, alkoxy, carbocycle and heterocycle are as defined herein. Particular secondary and tertiary amines are alkylamine, dialkylamine, arylamine, diarylamine, aralkylamine and diaralkylamine wherein the alkyl is as herein defined and optionally substituted. Particular secondary and tertiary amines are methylamine, ethylamine, propylamine,

isopropylamine, phenylamine, benzylamine dimethylamine, diethylamine, dipropylamine and disopropylamine.

“Amino-protecting group” as used herein refers to a derivative of the groups commonly employed to block or protect an amino group while reactions are carried out on other functional groups on the compound. Examples of such protecting groups include carbamates, amides, alkyl and aryl groups, imines, as well as many N-heteroatom derivatives which can be removed to regenerate the desired amine group. Particular amino protecting groups are Boc, Fmoc and Cbz. Further examples of these groups are found in T. W. Greene and P. G. M. Wuts, “Protective Groups in Organic Synthesis”, 2nd ed., John Wiley & Sons, Inc., New York, NY, 1991, chapter 7; E. Haslam, “Protective Groups in Organic Chemistry”, J. G. W. McOmie, Ed., Plenum Press, New York, NY, 1973, Chapter 5, and T.W. Greene, “Protective Groups in Organic Synthesis”, John Wiley and Sons, New York, NY, 1981. The term “protected amino” refers to an amino group substituted with one of the above amino-protecting groups.

“Aryl” when used alone or as part of another term means a carbocyclic aromatic group whether or not fused having the number of carbon atoms designated or if no number is designated, up to 14 carbon atoms. Particular aryl groups are phenyl, naphthyl, biphenyl, phenanthrenyl, naphthacenyl, and the like (see e.g. *Lang's Handbook of Chemistry* (Dean, J. A., ed) 13th ed. Table 7-2 [1985]). A particular aryl is phenyl. Substituted phenyl or substituted aryl means a phenyl group or aryl group substituted with one, two, three, four or five, for example 1-2, 1-3 or 1-4 substituents chosen, unless otherwise specified, from halogen (F, Cl, Br, I), hydroxy, protected hydroxy, cyano, nitro, alkyl (for example C₁-C₆ alkyl), alkoxy (for example C₁-C₆ alkoxy), benzyloxy, carboxy, protected carboxy, carboxymethyl, protected carboxymethyl, hydroxymethyl, protected hydroxymethyl, aminomethyl, protected aminomethyl, trifluoromethyl, alkylsulfonylamino, alkylsulfonylaminooalkyl, arylsulfonylamino, arylsulfonylaminooalkyl, heterocyclsulfonylamino, heterocyclsulfonylaminooalkyl, heterocycl, aryl, or other groups specified. One or more methyne (CH) and/or methylene (CH₂) groups in these substituents may in turn be substituted with a similar group as those denoted above. Examples of the term “substituted phenyl” includes but is not limited to a mono- or di(halo)phenyl group such as 2-chlorophenyl, 2-bromophenyl, 4-chlorophenyl, 2,6-dichlorophenyl, 2,5-dichlorophenyl, 3,4-dichlorophenyl, 3-chlorophenyl, 3-bromophenyl, 4-bromophenyl, 3,4-dibromophenyl, 3-chloro-4-fluorophenyl, 2-fluorophenyl and the like; a mono- or di(hydroxy)phenyl group such as 4-hydroxyphenyl, 3-hydroxyphenyl, 2,4-dihydroxyphenyl, the protected-hydroxy derivatives thereof and the like; a nitrophenyl group such as 3- or 4-nitrophenyl; a cyanophenyl group, for example, 4-cyanophenyl; a mono- or

di(lower alkyl)phenyl group such as 4-methylphenyl, 2,4-dimethylphenyl, 2-methylphenyl, 4-(iso-propyl)phenyl, 4-ethylphenyl, 3-(n-propyl)phenyl and the like; a mono or di(alkoxy)phenyl group, for example, 3,4-dimethoxyphenyl, 3-methoxy-4-benzyloxyphenyl, 3-methoxy-4-(1-chloromethyl)benzyloxy-phenyl, 3-ethoxyphenyl, 4-(isopropoxy)phenyl, 4-(t-butoxy)phenyl, 3-ethoxy-4-methoxyphenyl and the like; 3- or 4- trifluoromethylphenyl; a mono- or dicarboxyphenyl or (protected carboxy)phenyl group such 4-carboxyphenyl, ; a mono- or di(hydroxymethyl)phenyl or (protected hydroxymethyl)phenyl such as 3-(protected hydroxymethyl)phenyl or 3,4-di(hydroxymethyl)phenyl; a mono- or di(aminomethyl)phenyl or (protected aminomethyl)phenyl such as 2-(aminomethyl)phenyl or 2,4-(protected aminomethyl)phenyl; or a mono- or di(N-(methylsulfonylamino))phenyl such as 3-(N-methylsulfonylamino))phenyl. Also, the term “substituted phenyl” represents disubstituted phenyl groups where the substituents are different, for example, 3-methyl-4-hydroxyphenyl, 3-chloro-4-hydroxyphenyl, 2-methoxy-4-bromophenyl, 4-ethyl-2-hydroxyphenyl, 3-hydroxy-4-nitrophenyl, 2-hydroxy-4-chlorophenyl, and the like, as well as trisubstituted phenyl groups where the substituents are different, for example 3-methoxy-4-benzyloxy-6-methyl sulfonylamino, 3-methoxy-4-benzyloxy-6-phenyl sulfonylamino, and tetrasubstituted phenyl groups where the substituents are different such as 3-methoxy-4-benzyloxy-5-methyl-6-phenyl sulfonylamino. Particular substituted phenyl groups include the 2-chlorophenyl, 2-aminophenyl, 2-bromophenyl, 3-methoxyphenyl, 3-ethoxy-phenyl, 4-benzyloxyphenyl, 4-methoxyphenyl, 3-ethoxy-4-benzyloxyphenyl, 3,4-diethoxyphenyl, 3-methoxy-4-benzyloxyphenyl, 3-methoxy-4-(1-chloromethyl)benzyloxy-phenyl, 3-methoxy-4-(1-chloromethyl)benzyloxy -6- methyl sulfonyl aminophenyl groups. Fused aryl rings may also be substituted with any, for example 1, 2 or 3, of the substituents specified herein in the same manner as substituted alkyl groups.

“Carbocyclyl”, “carbocyclylie”, “carbocycle” and “carbocyclo” alone and when used as a moiety in a complex group such as a carbocycloalkyl group, refers to a mono-, bi-, or tricyclic aliphatic ring having 3 to 14 carbon atoms, for example 3 to 7 carbon atoms, which may be saturated or unsaturated, aromatic or non-aromatic. Particular saturated carbocyclic groups are cyclopropyl, cyclobutyl, cyclopentyl and cyclohexyl groups. A particular saturated carbocycle is cyclopropyl. Another particular saturated carbocycle is cyclohexyl. Particular unsaturated carbocycles are aromatic e.g. aryl groups as previously defined, for example phenyl. The terms “substituted carbocyclyl”, “carbocycle” and “carbocyclo” mean these groups substituted by the same substituents as the “substituted alkyl” group.

“Carboxy-protecting group” as used herein refers to one of the ester derivatives of the carboxylic acid group commonly employed to block or protect the carboxylic acid group while reactions are

carried out on other functional groups on the compound. Examples of such carboxylic acid protecting groups include 4-nitrobenzyl, 4-methoxybenzyl, 3,4-dimethoxybenzyl, 2,4-dimethoxybenzyl, 2,4,6-trimethoxybenzyl, 2,4,6-trimethylbenzyl, pentamethylbenzyl, 3,4-methylenedioxybenzyl, benzhydryl, 4,4'-dimethoxybenzhydryl, 2,2',4,4'-tetramethoxybenzhydryl, alkyl such as t-butyl or t-amyl, trityl, 4-methoxytrityl, 4,4'-dimethoxytrityl, 4,4',4"-trimethoxytrityl, 2-phenylprop-2-yl, trimethylsilyl, t-butyldimethylsilyl, phenacyl, 2,2,2-trichloroethyl, beta-(trimethylsilyl)ethyl, beta-(di(n-butyl)methylsilyl)ethyl, p-toluenesulfonylethyl, 4-nitrobenzylsulfonylethyl, allyl, cinnamyl, 1-(trimethylsilylmethyl)prop-1-en-3-yl, and like moieties. The species of carboxy-protecting group employed is not critical so long as the derivatized carboxylic acid is stable to the condition of subsequent reaction(s) on other positions of the molecule and can be removed at the appropriate point without disrupting the remainder of the molecule. In particular, it is important not to subject a carboxy-protected molecule to strong nucleophilic bases, such as lithium hydroxide or NaOH, or reductive conditions employing highly activated metal hydrides such as LiAlH₄. (Such harsh removal conditions are also to be avoided when removing amino-protecting groups and hydroxy-protecting groups, discussed below.) Particular carboxylic acid protecting groups are the alkyl (e.g. methyl, ethyl, t-butyl), allyl, benzyl and p-nitrobenzyl groups. Similar carboxy-protecting groups used in the cephalosporin, penicillin and peptide arts can also be used to protect a carboxy group substituents. Further examples of these groups are found in T. W. Greene and P. G. M. Wuts, "Protective Groups in Organic Synthesis", 2nd ed., John Wiley & Sons, Inc., New York, N.Y., 1991, chapter 5; E. Haslam, "Protective Groups in Organic Chemistry", J. G. W. McOmie, Ed., Plenum Press, New York, N.Y., 1973, Chapter 5, and T.W. Greene, "Protective Groups in Organic Synthesis", John Wiley and Sons, New York, NY, 1981, Chapter 5. The term "protected carboxy" refers to a carboxy group substituted with one of the above carboxy-protecting groups.

"Guanidine" means the group -NH-C(NH)-NHR in which R is H, alkyl, a carbocycle, a heterocycle, carbocycle-substituted alkyl or heterocycle-substituted alkyl wherein the alkyl, alkoxy, carbocycle and heterocycle are as defined herein. A particular guanidine is the group -NH-C(NH)-NH₂.

"Hydroxy-protecting group" as used herein refers to a derivative of the hydroxy group commonly employed to block or protect the hydroxy group while reactions are carried out on other functional groups on the compound. Examples of such protecting groups include tetrahydropyranloxy, benzoyl, acetoxy, carbamoyloxy, benzyl, and silylethers (e.g. TBS, TBDPS) groups. Further examples of these groups are found in T. W. Greene and P. G. M.

Wuts, "Protective Groups in Organic Synthesis", 2nd ed., John Wiley & Sons, Inc., New York, NY, 1991, chapters 2-3; E. Haslam, "Protective Groups in Organic Chemistry", J. G. W. McOmie, Ed., Plenum Press, New York, NY, 1973, Chapter 5, and T.W. Greene, "Protective Groups in Organic Synthesis", John Wiley and Sons, New York, NY, 1981. The term "protected hydroxy" refers to a hydroxy group substituted with one of the above hydroxy-protecting groups.

"Heterocyclic group", "heterocyclic", "heterocycle", "heterocycl", or "heterocyclo" alone and when used as a moiety in a complex group such as a heterocycloalkyl group, are used interchangeably and refer to any mono-, bi-, or tricyclic, saturated or unsaturated, aromatic (heteroaryl) or non-aromatic ring having the number of atoms designated, generally from 5 to about 14 ring atoms, where the ring atoms are carbon and at least one heteroatom (nitrogen, sulfur or oxygen), for example 1 to 4 heteroatoms. Typically, a 5-membered ring has 0 to 2 double bonds and 6- or 7-membered ring has 0 to 3 double bonds and the nitrogen or sulfur heteroatoms may optionally be oxidized (e.g. SO, SO₂), and any nitrogen heteroatom may optionally be quaternized. Particular non-aromatic heterocycles are morpholinyl (morpholino), pyrrolidinyl, oxiranyl, oxetanyl, tetrahydrofuranyl, 2,3-dihydrofuranyl, 2H-pyranyl, tetrahydropyranyl, thiiranyl, thietanyl, tetrahydrothietanyl, aziridinyl, azetidinyl, 1-methyl-2-pyrrolyl, piperazinyl and piperidinyl. A "heterocycloalkyl" group is a heterocycle group as defined above covalently bonded to an alkyl group as defined above. Particular 5-membered heterocycles containing a sulfur or oxygen atom and one to three nitrogen atoms are thiazolyl, in particular thiazol-2-yl and thiazol-2-yl N-oxide, thiadiazolyl, in particular 1,3,4-thiadiazol-5-yl and 1,2,4-thiadiazol-5-yl, oxazolyl, for example oxazol-2-yl, and oxadiazolyl, such as 1,3,4-oxadiazol-5-yl, and 1,2,4-oxadiazol-5-yl. Particular 5-membered ring heterocycles containing 2 to 4 nitrogen atoms include imidazolyl, such as imidazol-2-yl; triazolyl, such as 1,3,4-triazol-5-yl; 1,2,3-triazol-5-yl, 1,2,4-triazol-5-yl, and tetrazolyl, such as 1H-tetrazol-5-yl. Particular benzo-fused 5-membered heterocycles are benzoxazol-2-yl, benzthiazol-2-yl and benzimidazol-2-yl. Particular 6-membered heterocycles contain one to three nitrogen atoms and optionally a sulfur or oxygen atom, for example pyridyl, such as pyrid-2-yl, pyrid-3-yl, and pyrid-4-yl; pyrimidyl, such as pyrimid-2-yl and pyrimid-4-yl; triazinyl, such as 1,3,4-triazin-2-yl and 1,3,5-triazin-4-yl; pyridazinyl, in particular pyridazin-3-yl, and pyrazinyl. The pyridine N-oxides and pyridazine N-oxides and the pyridyl, pyrimid-2-yl, pyrimid-4-yl, pyridazinyl and the 1,3,4-triazin-2-yl groups, are a particular group. Substituents for "optionally substituted heterocycles", and further examples of the 5- and 6-membered ring systems discussed above can be found in W. Druckheimer *et al.*, U.S. Patent No. 4,278,793. In a particular embodiment, such optionally

substituted heterocycle groups are substituted with hydroxyl, alkyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino and guanidino.

“Heteroaryl” alone and when used as a moiety in a complex group such as a heteroaralkyl group, refers to any mono-, bi-, or tricyclic aromatic ring system having the number of atoms designated where at least one ring is a 5-, 6- or 7-membered ring containing from one to four heteroatoms selected from the group nitrogen, oxygen, and sulfur, and in a particular embodiment at least one heteroatom is nitrogen (*Lang's Handbook of Chemistry, supra*). Included in the definition are any bicyclic groups where any of the above heteroaryl rings are fused to a benzene ring. Particular heteroaryls incorporate a nitrogen or oxygen heteroatom. The following ring systems are examples of the heteroaryl (whether substituted or unsubstituted) groups denoted by the term “heteroaryl”: thienyl, furyl, imidazolyl, pyrazolyl, thiazolyl, isothiazolyl, oxazolyl, isoxazolyl, triazolyl, thiadiazolyl, oxadiazolyl, tetrazolyl, thiatriazolyl, oxatriazolyl, pyridyl, pyrimidyl, pyrazinyl, pyridazinyl, thiazinyl, oxazinyl, triazinyl, thiadiazinyl, oxadiazinyl, dithiazinyl, dioxazinyl, oxathiazinyl, tetrazinyl, thiatriazinyl, oxatriazinyl, dithiadiazinyl, imidazolinyl, dihydropyrimidyl, tetrahydropyrimidyl, tetrazolo[1,5-b]pyridazinyl and purinyl, as well as benzo-fused derivatives, for example benzoxazolyl, benzofuryl, benzothiazolyl, benzothiadiazolyl, benzotriazolyl, benzoimidazolyl and indolyl. A particular “heteroaryl” is: 1,3-thiazol-2-yl, 4-(carboxymethyl)-5-methyl-1,3-thiazol-2-yl, 4-(carboxymethyl)-5-methyl-1,3-thiazol-2-yl sodium salt, 1,2,4-thiadiazol-5-yl, 3-methyl-1,2,4-thiadiazol-5-yl, 1,3,4-triazol-5-yl, 2-methyl-1,3,4-triazol-5-yl, 2-hydroxy-1,3,4-triazol-5-yl, 2-carboxy-4-methyl-1,3,4-triazol-5-yl sodium salt, 2-carboxy-4-methyl-1,3,4-triazol-5-yl, 1,3-oxazol-2-yl, 1,3,4-oxadiazol-5-yl, 2-methyl-1,3,4-oxadiazol-5-yl, 2-(hydroxymethyl)-1,3,4-oxadiazol-5-yl, 1,2,4-oxadiazol-5-yl, 1,3,4-thiadiazol-5-yl, 2-thiol-1,3,4-thiadiazol-5-yl, 2-(methylthio)-1,3,4-thiadiazol-5-yl, 2-amino-1,3,4-thiadiazol-5-yl, 1H-tetrazol-5-yl, 1-methyl-1H-tetrazol-5-yl, 1-(dimethylamino)eth-2-yl)-1H-tetrazol-5-yl, 1-(carboxymethyl)-1H-tetrazol-5-yl, 1-(carboxymethyl)-1H-tetrazol-5-yl sodium salt, 1-(methylsulfonic acid)-1H-tetrazol-5-yl, 1-(methylsulfonic acid)-1H-tetrazol-5-yl sodium salt, 2-methyl-1H-tetrazol-5-yl, 1,2,3-triazol-5-yl, 1-methyl-1,2,3-triazol-5-yl, 2-methyl-1,2,3-triazol-5-yl, 4-methyl-1,2,3-triazol-5-yl, pyrid-2-yl N-oxide, 6-methoxy-2-(n-oxide)-pyridaz-3-yl, 6-hydroxypyridaz-3-yl, 1-methylpyrid-2-yl, 1-methylpyrid-4-yl, 2-hydroxypyrimid-4-yl, 1,4,5,6-tetrahydro-5,6-dioxo-4-methyl-as-triazin-3-yl, 1,4,5,6-tetrahydro-4-(formylmethyl)-5,6-dioxo-as-triazin-3-yl, 2,5-dihydro-5-oxo-6-hydroxy-astriazin-3-yl, 2,5-dihydro-5-oxo-6-hydroxy-as-triazin-3-yl sodium salt, 2,5-dihydro-5-oxo-6-hydroxy-2-methyl-astriazin-3-yl sodium salt, 2,5-dihydro-5-oxo-6-hydroxy-2-methyl-as-triazin-3-yl, 2,5-dihydro-5-oxo-6-methoxy-2-methyl-as-triazin-3-yl, 2,5-

dihydro-5-oxo-as-triazin-3-yl, 2,5-dihydro-5-oxo-2-methyl-as-triazin-3-yl, 2,5-dihydro-5-oxo-2,6-dimethyl-as-triazin-3-yl, tetrazolo[1,5-b]pyridazin-6-yl and 8-aminotetrazolo[1,5-b]pyridazin-6-yl. An alternative group of “heteroaryl” includes; 4-(carboxymethyl)-5-methyl-1,3-thiazol-2-yl, 4-(carboxymethyl)-5-methyl-1,3-thiazol-2-yl sodium salt, 1,3,4-triazol-5-yl, 2-methyl-1,3,4-triazol-5-yl, 1H-tetrazol-5-yl, 1-methyl-1H-tetrazol-5-yl, 1-(1-(dimethylamino)ethyl-2-yl)-1H-tetrazol-5-yl, 1-(carboxymethyl)-1H-tetrazol-5-yl, 1-(carboxymethyl)-1H-tetrazol-5-yl sodium salt, 1-(methylsulfonic acid)-1H-tetrazol-5-yl, 1-(methylsulfonic acid)-1H-tetrazol-5-yl sodium salt, 1,2,3-triazol-5-yl, 1,4,5,6-tetrahydro-5,6-dioxo-4-methyl-as-triazin-3-yl, 1,4,5,6-tetrahydro-4-(2-formylmethyl)-5,6-dioxo-as-triazin-3-yl, 2,5-dihydro-5-oxo-6-hydroxy-2-methyl-as-triazin-3-yl sodium salt, 2,5-dihydro-5-oxo-6-hydroxy-2-methyl-as-triazin-3-yl, tetrazolo[1,5-b]pyridazin-6-yl, and 8-aminotetrazolo[1,5-b]pyridazin-6-yl. Heteroaryl groups are optionally substituted as described for heterocycles.

“Inhibitor” means a compound which reduces or prevents the binding of IAP proteins to caspase proteins or which reduces or prevents the inhibition of apoptosis by an IAP protein. Alternatively, “inhibitor” means a compound which prevents the binding interaction of X-IAP with caspases or the binding interaction of ML-IAP with SMAC.

“Optionally substituted” unless otherwise specified means that a group may be unsubstituted or substituted by one or more (e.g. 0, 1, 2, 3 or 4) of the substituents listed for that group in which said substituents may be the same or different. In an embodiment an optionally substituted group has 1 substituent. In another embodiment an optionally substituted group has 2 substituents. In another embodiment an optionally substituted group has 3 substituents.

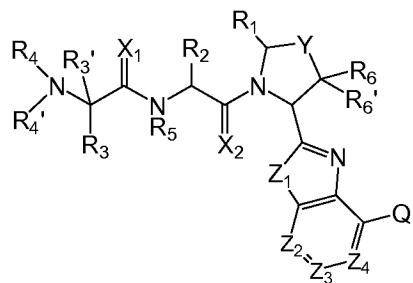
“Pharmaceutically acceptable salts” include both acid and base addition salts. “Pharmaceutically acceptable acid addition salt” refers to those salts which retain the biological effectiveness and properties of the free bases and which are not biologically or otherwise undesirable, formed with inorganic acids such as hydrochloric acid, hydrobromic acid, sulfuric acid, nitric acid, carbonic acid, phosphoric acid and the like, and organic acids may be selected from aliphatic, cycloaliphatic, aromatic, araliphatic, heterocyclic, carboxylic, and sulfonic classes of organic acids such as formic acid, acetic acid, propionic acid, glycolic acid, gluconic acid, lactic acid, pyruvic acid, oxalic acid, malic acid, maleic acid, maloneic acid, succinic acid, fumaric acid, tartaric acid, citric acid, aspartic acid, ascorbic acid, glutamic acid, anthranilic acid, benzoic acid, cinnamic acid, mandelic acid, embonic acid, phenylacetic acid, methanesulfonic acid, ethanesulfonic acid, p-toluenesulfonic acid, salicylic acid and the like.

“Pharmaceutically acceptable base addition salts” include those derived from inorganic bases such as sodium, potassium, lithium, ammonium, calcium, magnesium, iron, zinc, copper, manganese, aluminum salts and the like. Particularly base addition salts are the ammonium, potassium, sodium, calcium and magnesium salts. Salts derived from pharmaceutically acceptable organic nontoxic bases includes salts of primary, secondary, and tertiary amines, substituted amines including naturally occurring substituted amines, cyclic amines and basic ion exchange resins, such as isopropylamine, trimethylamine, diethylamine, triethylamine, tripropylamine, ethanolamine, 2-diethylaminoethanol, trimethamine, dicyclohexylamine, lysine, arginine, histidine, caffeine, procaine, hydrabamine, choline, betaine, ethylenediamine, glucosamine, methylglucamine, theobromine, purines, piperazine, piperidine, N-ethylpiperidine, polyamine resins and the like. Particularly organic non-toxic bases are isopropylamine, diethylamine, ethanolamine, trimethamine, dicyclohexylamine, choline, and caffeine.

“Sulfonyl” means a $-\text{SO}_2\text{-R}$ group in which R is H, alkyl, a carbocycle, a heterocycle, carbocycle-substituted alkyl or heterocycle-substituted alkyl wherein the alkyl, alkoxy, carbocycle and heterocycle are as defined herein. Particular sulfonyl groups are alkylsulfonyl (i.e. $-\text{SO}_2\text{-alkyl}$), for example methylsulfonyl; arylsulfonyl, for example phenylsulfonyl; aralkylsulfonyl, for example benzylsulfonyl.

The phrase "and salts and solvates thereof" as used herein means that compounds of the inventions may exist in one or a mixture of salts and solvate forms. For example a compound of the invention may be substantially pure in one particular salt or solvate form or else may be mixtures of two or more salt or solvate forms.

The present invention provides novel compounds having the general formula I:



I

wherein Q, X₁, X₂, Y, Z₁, Z₂, Z₃, Z₄, R₁, R₂, R₃, R₃', R₄, R₄', R₅, R₆, R₆' and n are as described herein. Compounds of the invention include salts, solvates and polymorphs thereof unless otherwise specified.

X_1 and X_2 are each independently O or S. In a particular embodiment, X_1 and X_2 are both O. In another particular embodiment X_1 and X_2 are both S. In another particular embodiment, X_1 is S while X_2 is O. In another particular embodiment, X_1 is O while X_2 is S.

Y is a bond, $(CR_7R_7)_n$, O or S. In an embodiment Y is a bond, $(CR_7R_7)_n$, O or S; wherein n is 1 or 2 and R_7 is as defined herein or is H, halogen, alkyl, aryl, aralkyl, amino, arylamino, alkylamino, aralkylamino, alkoxy, aryloxy or aralkyloxy. In a particular embodiment, Y is $(CHR_7)_n$, O or S; wherein n is 1 or 2 and R_7 is H, halogen, alkyl, aryl, aralkyl, amino, arylamino, alkylamino, aralkylamino, alkoxy, aryloxy or aralkyloxy. In a particular embodiment, Y is CH_2 . In a particular embodiment n is 1. In a particular embodiment Y is a bond. In a particular embodiment n is 1 and Y is CHR_7 wherein R_7 is aralkyloxy, for example benzyloxy. In a particular embodiment n is 1 and Y is CHR_7 wherein R_7 is F. In a particular embodiment n is 1 and Y is CHR_7 wherein R_7 is aralkylamino, for example benzylamino. In another particular embodiment Y is O. In another particular embodiment Y is S.

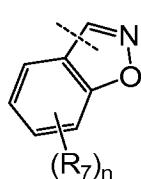
Z_1 is NR_8 , O, S, SO or SO_2 ; wherein R_8 is defined herein. In an embodiment, Z_1 is NR_8 , O or S. In an embodiment, Z_1 is NR_8 wherein R_8 is H, alkyl, aryl or aralkyl. In a particular embodiment, Z_1 is NR_8 wherein R_8 is benzyl. In a particular embodiment, Z_1 is NR_8 wherein R_8 is Me. In a particular embodiment, Z_1 is NR_8 wherein R_8 is H. In a particular embodiment, Z_1 is O. In a particular embodiment, Z_1 is S.

Z_2 , Z_3 and Z_4 are independently CQ or N. In a particular embodiment, Z_2 is N. In a particular embodiment, Z_3 is N. In a particular embodiment, Z_4 is N. In an embodiment, Z_2 , Z_3 and Z_4 are CQ. In an embodiment, Z_2 is N, Z_3 is CQ and Z_4 is CQ. In an embodiment, Z_2 is CQ, Z_3 is N and Z_4 is CQ. In an embodiment, Z_2 is CQ, Z_3 is CQ and Z_4 is N. In an embodiment, Z_2 is N, Z_3 is CQ and Z_4 is N.

Q is H, halogen, hydroxyl, carboxyl, amino, nitro, cyano, alkyl, a carbocycle, a heterocycle; wherein one or more CH_2 or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R_8)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)-; and wherein any of the foregoing alkyl, carbocycle and heterocycle is optionally substituted with one or more hydroxyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle. Substituents of the “optionally substituted carbocycle” and “optionally substituted heterocycle”

are as defined herein. In a particular embodiment such carbocycle and heterocycle groups are substituted with hydroxyl, alkyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino and guanidino. In a particular embodiment Q is a carbocycle or heterocycle optionally substituted with halogen, amino, oxo, alkyl, a carbocycle or a heterocycle; wherein one or more CH₂ or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)-; and wherein said alkyl, carbocycle or heterocycle is optionally substituted with halogen, amino, hydroxyl, mercapto, carboxyl, alkoxy, alkoxyalkoxy, hydroxyalkoxy, alkylthio, acyloxy, acyloxyalkoxy, alkylsulfonyl, alkylsulfonylalkyl, alkylsulfinyl, and alkylsulfinylalkyl. In a particular embodiment at least one instance of Q is a carbocycle or a heterocycle as defined herein which is optionally substituted as described herein while any other instances of Q are independently selected from the group consisting of H, halogen, carboxyl, amino, nitro and cyano. In a particular embodiment one instance of Q is aryl or heteroaryl while any other instances of Q are independently selected from the group consisting of H, halogen, carboxyl, amino, nitro and cyano. In a particular embodiment such other instances of Q are H. In another particular embodiment, such other instances of Q are H, halogen or alkyl.

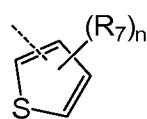
In a particular embodiment, Q is a carbocycle or heterocycle selected from the group consisting of III-1 - III-16



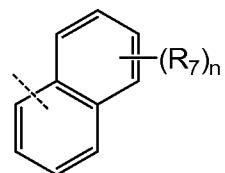
III-1



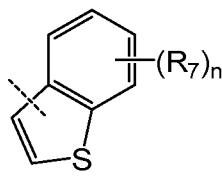
III-2



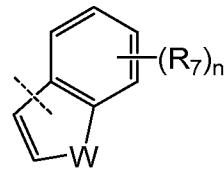
III-3



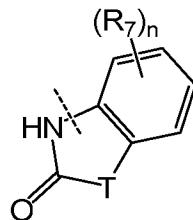
III-4



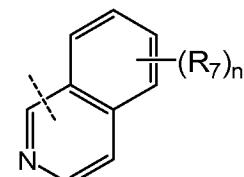
III-5



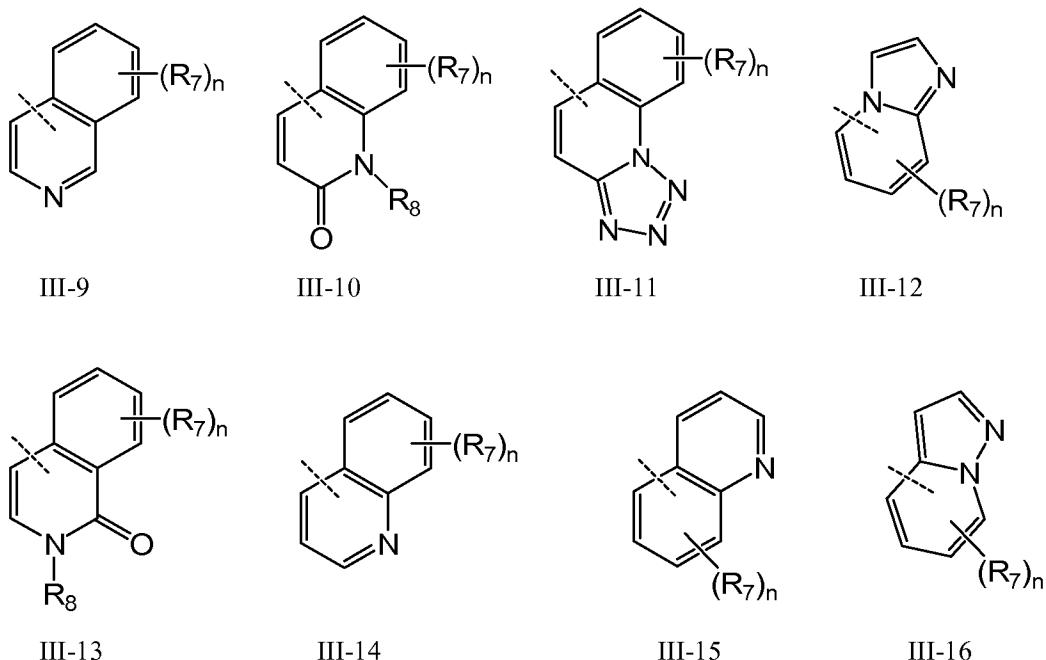
III-6



III-7

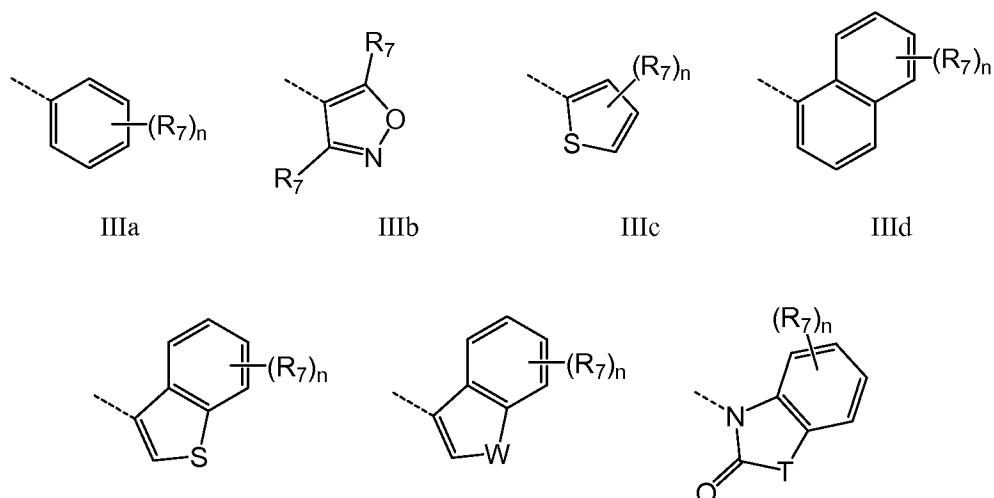


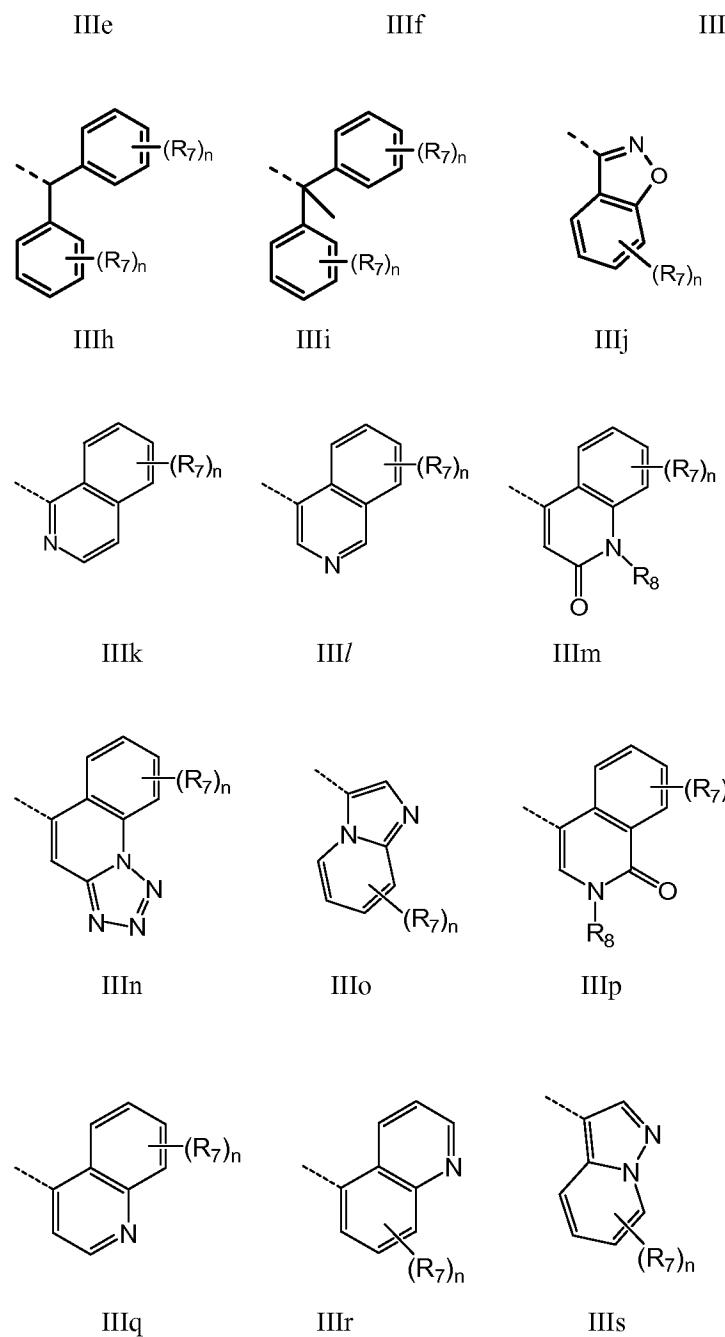
III-8



wherein n is 1-4, for example 1-3, for example 1-2, for example 1; T is O, S, NR₈ or CR₇R₇; W is O, NR₈ or CR₇R₇; and R₇ and R₈ are as defined herein. In an embodiment, compounds of the invention comprise one Q group having the general formulae III-1 to III-16. In another embodiment, compounds of the invention have one Q group having the general formulae III-1 to III-16 while other instances of Q are independently selected from the group consisting of H, halogen, carboxyl, amino, nitro and cyano. In a particular embodiment such other instances of Q are H. In another particular embodiment, such other instances of Q are H, halogen or alkyl.

In a particular embodiment, Q is a carbocycle or heterocycle selected from the group consisting of IIIa - IIIi:





wherein n is 1-4, for example 1-3, for example 1-2, for example 1; T is O, S, NR₈ or CR₇R₇; W is O, NR₈ or CR₇R₇; and R₇ and R₈ are as defined herein. In a particular embodiment Q is any one of IIIa - IIIi wherein R₈ is H and R₇ is selected from the group consisting of H, F, Cl, Me, methoxy, hydroxyethoxy, methoxyethoxy, acetoxyethoxy, methylsulfonyl methylsulfonylmethyl, phenyl and morpholin-4-yl. In another particular embodiment Q is IIId. In a particular embodiment Q is IIId which is substituted at the 4-position with R₇. In another particular embodiment Q is IIId which is substituted at the 5-position with R₇. In a particular embodiment

Q is F, Me, iPr, phenyl, phenyl substituted as follows: 2-Cl, 3-Cl, 4-Cl, 2-F, 3-F or 4-F substituted, benzyl, pyrid-3-yl or pyrid-4-yl. In an embodiment, compounds of the invention comprise one Q group having the general formulae IIIa to IIIs. In another embodiment, compounds of the invention have one Q group having the general formulae IIIa to IIIs while other instances of Q are independently selected from the group consisting of H, halogen, carboxyl, amino, nitro and cyano. In a particular embodiment such other instances of Q are H. In another particular embodiment, such other instances of Q are H, halogen or alkyl.

R₁ is H, OH or alkyl; or R₁ and R₂ together form a 5-8 member heterocycle. In a particular embodiment, R₁ is H. In a particular embodiment, R₁ and R₂ together form a 6-member ring. In a particular embodiment, R₁ and R₂ together form a 7-member ring. In another particular embodiment, R₁ and R₂ together form an 8-member ring. In another particular embodiment, R₁ and R₂ together form a 7-member ring while Y is S. In another particular embodiment, R₁ is H, while Y is CH₂. In another particular embodiment, R₁ is H, while Y is S. In another particular embodiment, R₁ is H, while Y is O.

R₂ is alkyl, a carbocycle, carbocyclalkyl, a heterocycle or heterocyclalkyl each optionally substituted with halogen, hydroxyl, oxo, thione, mercapto, carboxyl, alkyl, haloalkyl, acyl, alkoxy, alkylthio, sulfonyl, amino and nitro, wherein said alkyl, acyl, alkoxy, alkylthio and sulfonyl are optionally substituted with hydroxy, mercapto, halogen, amino, alkoxy, hydroxyalkoxy and alkoxyalkoxy. In an embodiment, R₂ is alkyl, a carbocycle, carbocyclalkyl, a heterocycle or heterocyclalkyl each optionally substituted with halogen, hydroxyl, oxo, thione, mercapto, carboxyl, alkyl, haloalkyl, alkoxy, alkylthio, sulfonyl, amino and nitro. In a particular embodiment R₂ is alkyl, a carbocycle, carbocyclalkyl, a heterocycle or heterocyclalkyl each optionally substituted with halogen, hydroxyl, oxo, mercapto, thione, carboxyl, alkyl, haloalkyl, alkoxy, acyl, alkylthio, acyl, hydroxyacyl, methoxyacyl, sulfonyl, amino and nitro. In an embodiment R₂ is alkyl, a carbocycle, carbocyclalkyl, a heterocycle or heterocyclalkyl each optionally substituted with halogen, hydroxyl, mercapto, carboxyl, alkyl, alkoxy, acyl, amino and nitro. In a particular embodiment R₂ is alkyl, cycloalkyl, cycloalkylalkyl, aryl, aralkyl, a heterocycle or heterocyclalkyl. In a particular embodiment R₂ is alkyl, cycloalkyl or a heterocycle. In a particular embodiment R₂ is selected from the group consisting of t-butyl, isopropyl, cyclohexyl, tetrahydropyran-4-yl, N-methylsulfonylpiperidin-4-yl, tetrahydrothiopyran-4-yl, tetrahydrothiopyran-4-yl (in which the S is in oxidized form SO or SO₂), cyclohexan-4-one, 4-hydroxycyclohexane, 4-hydroxy-4-methylcyclohexane, 1-methyltetrahydropyran-4-yl, 2-hydroxyprop-2-yl, but-2-yl, thiophen-3-yl, piperidin-4-yl, N-

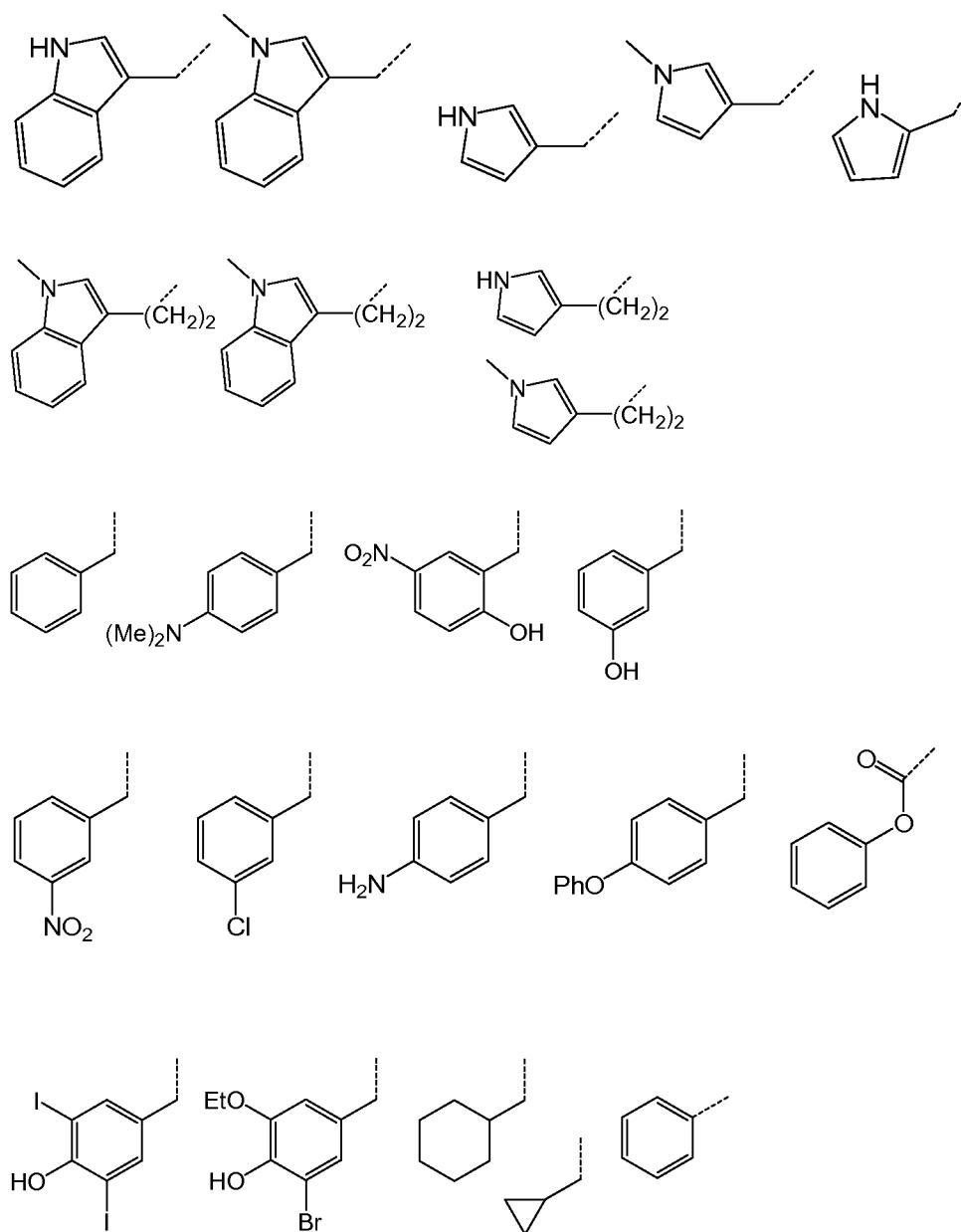
acetyl piperidin-4-yl, N-hydroxyethyl piperidin-4-yl, N-(2-hydroxyacetyl)piperidin-4-yl, N-(2-methoxyacetyl)piperidin-4-yl, pyridin-3-yl, phenyl, tetrahydrofuran-2-yl-carbonyl, methoxyethanone, 2-methoxyethoxyethanone and 1-hydroxyeth-1-yl. In an embodiment of the invention R₂ is t-butyl, isopropyl, cyclohexyl, cyclopentyl, phenyl or tetrahydropyran-4-yl. In a particular embodiment, R₂ is phenyl. In a particular embodiment, R₂ is cyclohexyl. In another embodiment R₂ is tetrahydropyran-4-yl. In another particular embodiment, R₂ is isopropyl (i.e. the valine amino acid side chain). In another particular embodiment, R₂ is t-butyl. In a particular embodiment R₂ is oriented such that the amino acid, or amino acid analogue, which it comprises is in the L-configuration.

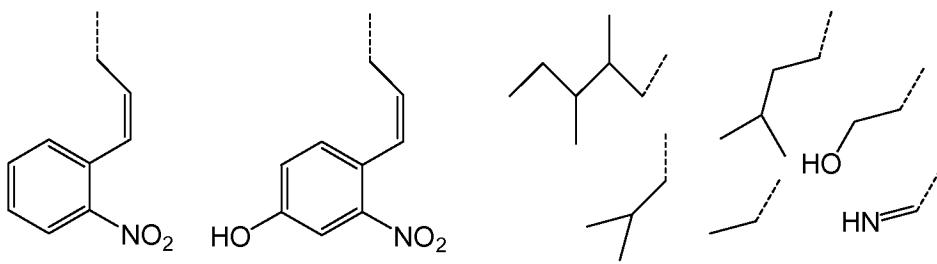
R₃ is H or alkyl optionally substituted with halogen or hydroxyl; or R₃ and R₄ together form a 3-6 heterocycle. In an embodiment R₃ is H or alkyl; or R₃ and R₄ together form a 3-6 heterocycle. In an embodiment R₃ is H or methyl, ethyl, propyl or isopropyl. In a particularly particular embodiment R₃ is H or methyl. In another particular embodiment R₃ is methyl. In another particular embodiment R₃ is fluoromethyl. In another particular embodiment, R₃ is ethyl. In another particular embodiment R₃ is hydroxyethyl. In a particular embodiment R₃ is fluoromethyl. In a particular embodiment R₃ is hydroxyethyl. In another embodiment R₃ is oriented such that the amino acid, or amino acid analogue, which it comprises is in the L-configuration. In a particular embodiment R₃ and R₄ together with the atoms from which they depend form a 3-6 heterocycle. In a particular embodiment R₃ and R₄ together form an azetidine ring. In a particular embodiment R₃ and R₄ together form a pyrrolidine.

R₃' is H, or R₃ and R₃' together form a 3-6 carbocycle. In an embodiment, R₃' is H. In another embodiment R₃ and R₃' together form a 3-6 carbocycle, for example a cyclopropyl ring. In a particular embodiment R₃ and R₃' are both methyl.

R₄ and R₄' are independently H, hydroxyl, amino, alkyl, carbocycle, carbocycloalkyl, carbocycloalkyloxy, carbocycloalkyloxycarbonyl, heterocycle, heterocycloalkyl, heterocycloalkyloxy or heterocycloalkyloxycarbonyl; wherein each alkyl, carbocycloalkyl, carbocycloalkyloxy, carbocycloalkyloxycarbonyl, heterocycle, heterocycloalkyl, heterocycloalkyloxy and heterocycloalkyloxycarbonyl is optionally substituted with halogen, hydroxyl, mercapto, carboxyl, alkyl, alkoxy, amino, imino and nitro; or R₄ and R₄' together form a heterocycle. In an embodiment R₄ and R₄' are independently H, hydroxyl, amino, alkyl, aryl, aralkyl, cycloalkyl, cycloalkylalkyl, heteroaryl, or heteroarylalkyl wherein each alkyl, aryl, aralkyl, cycloalkyl, cycloalkylalkyl, heteroaryl and heteroarylalkyl is optionally substituted with halogen, hydroxyl, mercapto, carboxyl, alkyl, alkoxy, amino and nitro; or R₄ and R₄' together

form a heterocycle. In a particular embodiment R_4 and R_4' together form a heterocycle, for example an azetidine ring, or a pyrrolidine ring. In a particular embodiment R_4 and R_4' are both H. In another particular embodiment R_4 is methyl and R_4' is H. In a particular embodiment one of R_4 and R_4' is hydroxyl (OH) while the other is H. In another embodiment, one of R_4 and R_4' is amino, such as NH_2 , NHMe and NHEt , while the other is H. In a particular embodiment, R_4' is H and R_4 is H, alkyl, aryl, aralkyl, cycloalkyl, cycloalkylalkyl, heteroaryl or heteroarylalkyl. In a particular embodiment R_4 is a group selected from the group consisting of:





R_5 is H or alkyl. In a particular embodiment, R_5 is H or methyl. In a particular embodiment, R_5 is H. In another particular embodiment, R_5 is methyl.

R_6 , and R_6' are each independently H, alkyl, aryl or aralkyl. In a particular embodiment, R_6 is alkyl, for example methyl. In another particular embodiment R_6 is aryl, for example phenyl. In another particular embodiment R_6 is aralkyl, for example benzyl. In a particular embodiment R_6 and R_6' are the same, for example both alkyl, e.g. both methyl. In another particular embodiment R_6 is methyl and R_6' is H.

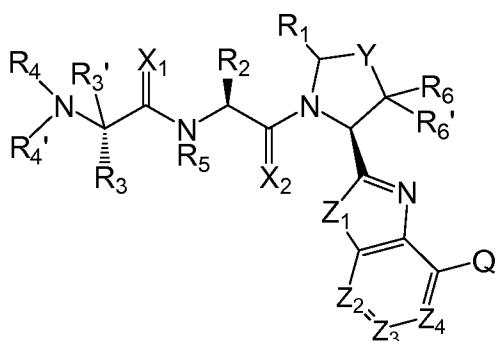
R_7 in each occurrence is independently H, cyano, hydroxyl, mercapto, halogen, nitro, carboxyl, amidino, guanidino, alkyl, a carbocycle, a heterocycle or -U-V; wherein U is -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)- and V is alkyl, a carbocycle or a heterocycle; and wherein one or more CH₂ or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)-; and an alkyl, carbocycle and heterocycle is optionally substituted with hydroxyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle. Substituents of the "optionally substituted carbocycle" and "optionally substituted heterocycle" are as defined herein. In a particular embodiment such carbocycle and heterocycle groups are substituted with hydroxyl, alkyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino and guanidino. In an embodiment R_7 is H, halogen, alkyl, aryl, aralkyl, amino, arylamino, alkylamino, aralkylamino, alkoxy, aryloxy or aralkyloxy.

R_8 is H, alkyl, a carbocycle or a heterocycle wherein one or more CH₂ or CH groups of said alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈), or -C(O)-; and said alkyl, carbocycle and heterocycle is optionally substituted with hydroxyl, alkoxy, acyl, halogen, mercapto, oxo (=O), carboxyl, acyl, halo-substituted alkyl, amino, cyano nitro, amidino, guanidino an optionally

substituted carbocycle or an optionally substituted heterocycle. Substituents of the “optionally substituted carbocycle” and “optionally substituted heterocycle” are as defined herein. In a particular embodiment such carbocycle and heterocycle groups are substituted with hydroxyl, alkyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano, nitro, amidino and guanidino. In a particular embodiment R_8 is H, alkyl, or acyl. In an embodiment R_8 is methyl. In another embodiment R_8 is acetyl. In a particular embodiment R_8 is H. In an embodiment R_7 is H, halogen, amino, hydroxyl, carboxyl, alkyl, haloalkyl or aralkyl. In a particular embodiment R_7 is halogen, for example Cl or F. In a particular embodiment R_7 is H. It is understood that substitutions defined for R_7 and R_8 as well as all other variable groups herein are subject to permissible valency.

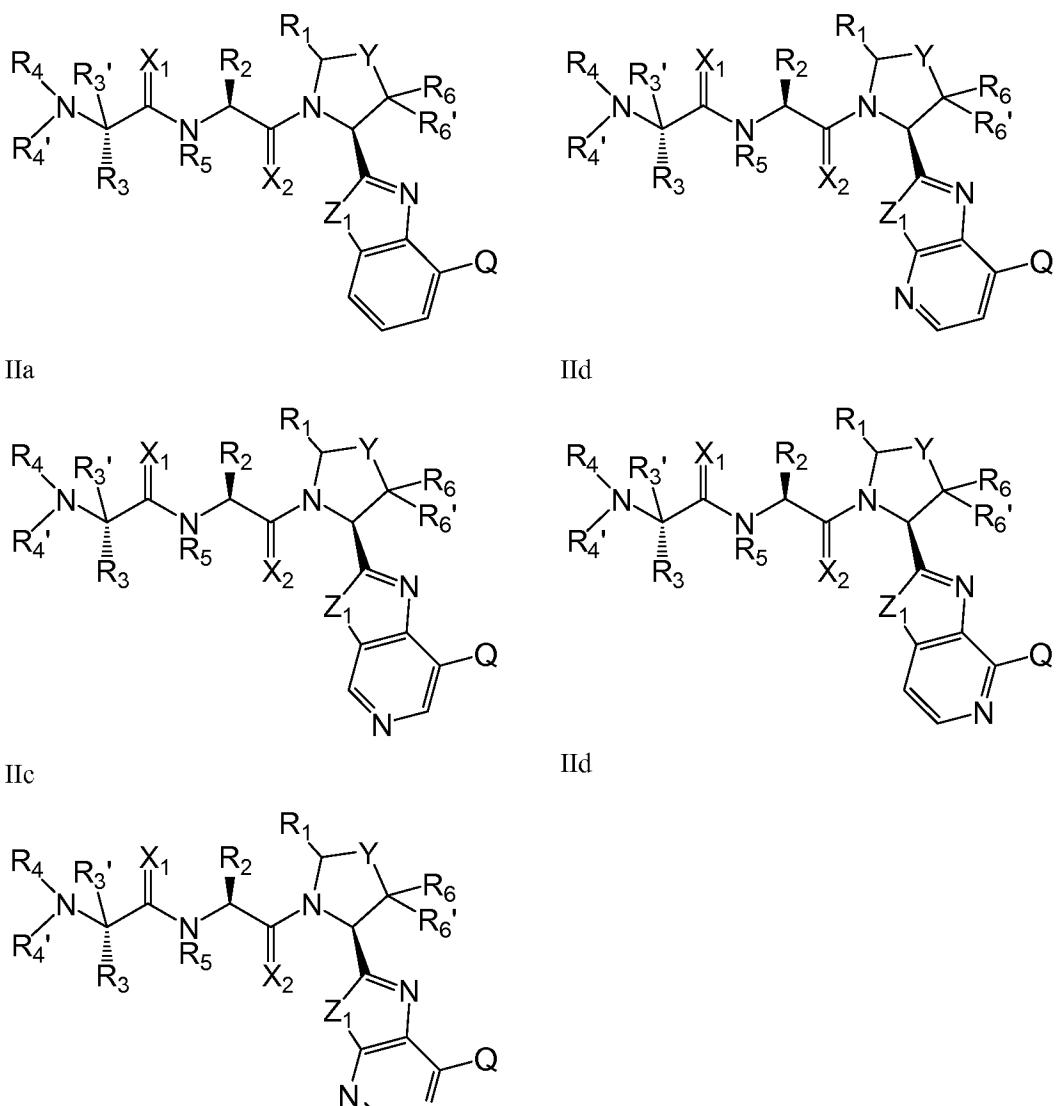
n is 0 to 4. In an embodiment n is 0. In an embodiment n is 1. In an embodiment n is 2. In an embodiment n is 3. In an embodiment n is 4.

Compounds of the invention contain one or more asymmetric carbon atoms. Accordingly, the compounds may exist as diastereomers, enantiomers or mixtures thereof. The syntheses of the compounds may employ racemates, diastereomers or enantiomers as starting materials or as intermediates. Diastereomeric compounds may be separated by chromatographic or crystallization methods. Similarly, enantiomeric mixtures may be separated using the same techniques or others known in the art. Each of the asymmetric carbon atoms may be in the R or S configuration and both of these configurations are within the scope of the invention. In a particular embodiment, compounds of the invention have the following stereochemical configuration of formula I'



wherein $X_1, X_2, Y, Z_1, Z_2, Z_3, Q, R_1, R_2, R_3, R_4, R_4', R_5, R_6$ and R_6' are as described herein.

In particular embodiments, compounds of the invention have the general formula IIa -IIe

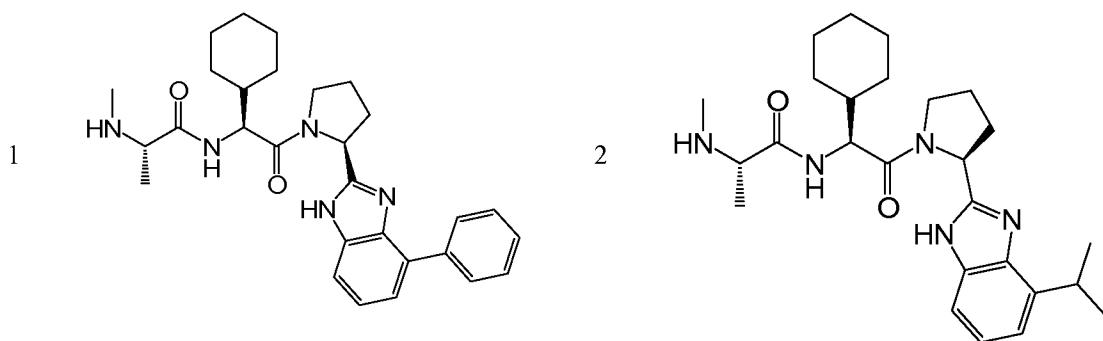


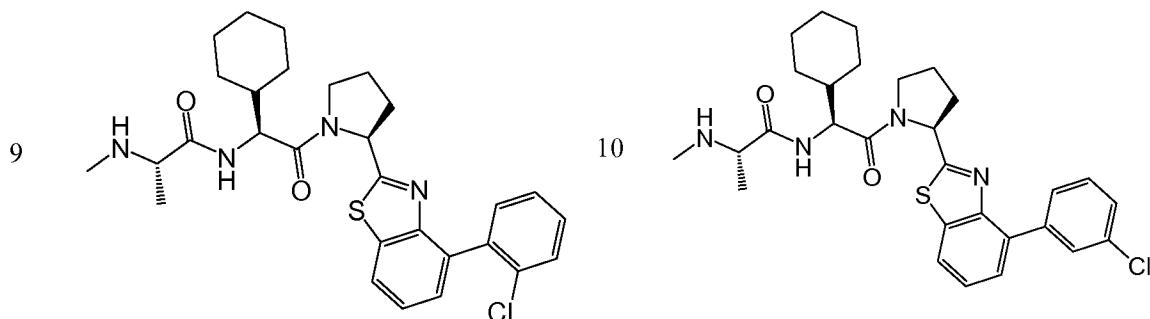
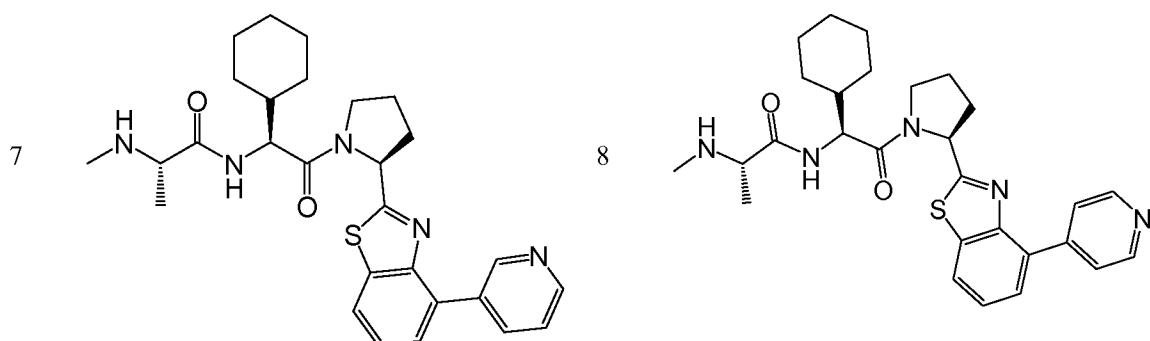
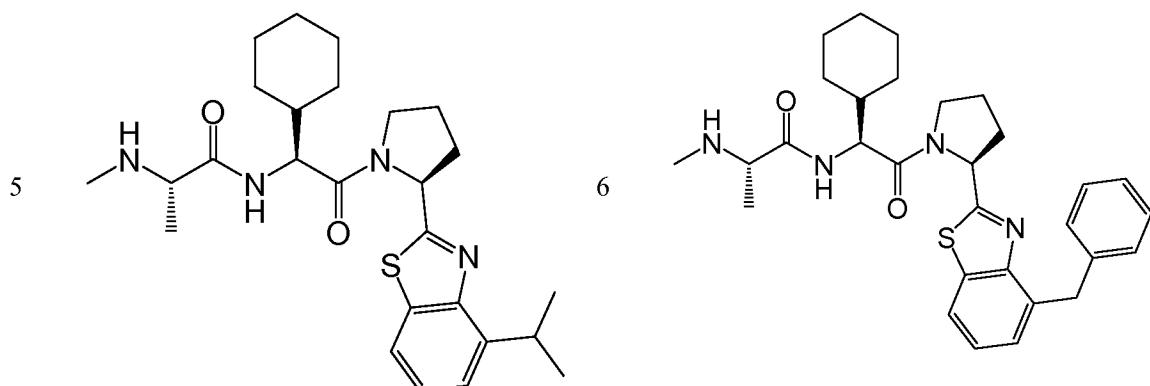
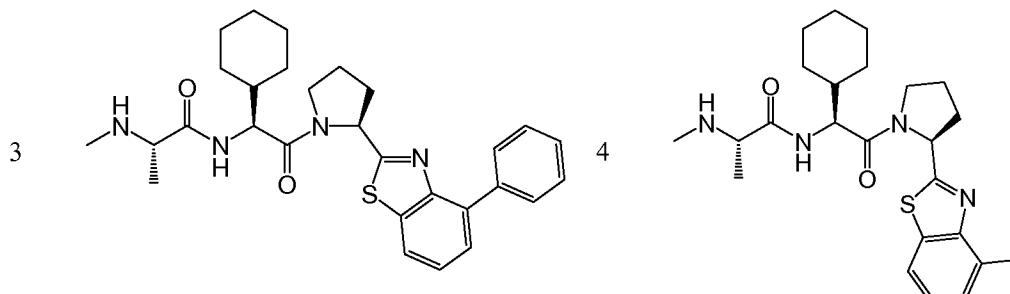
wherein X₁, X₂, Y, Z₁, Q R₁, R₂, R₃, R₄, R₄', R₅, R₆ and R₆' are as described herein.

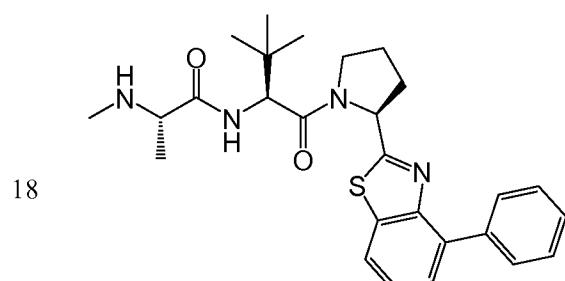
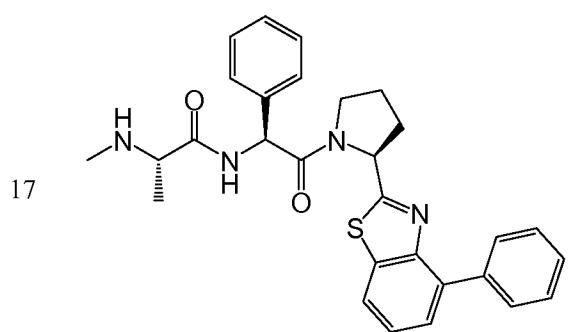
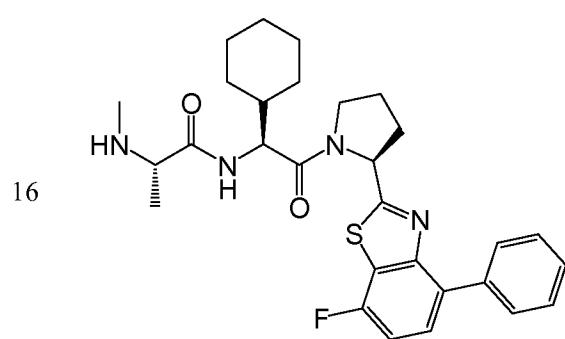
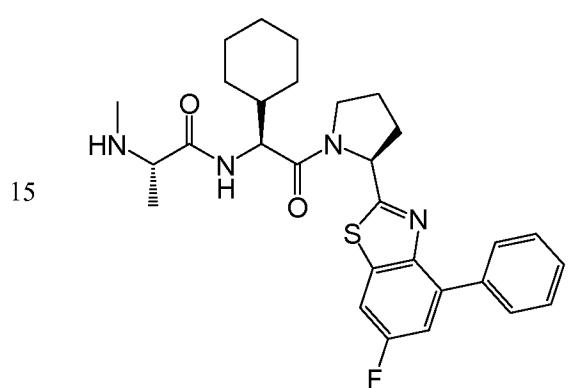
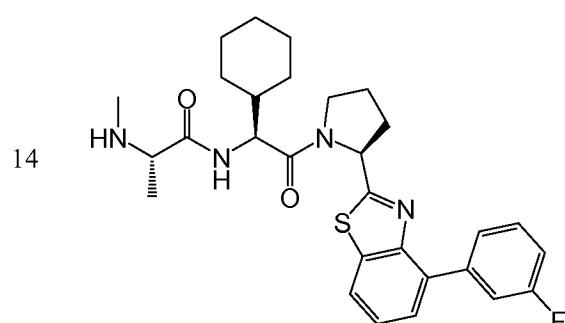
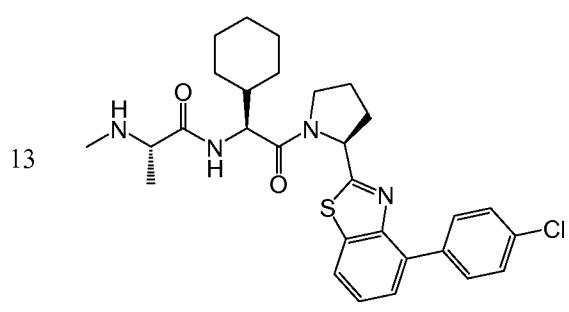
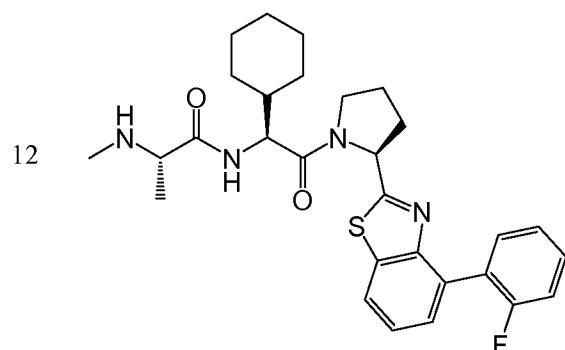
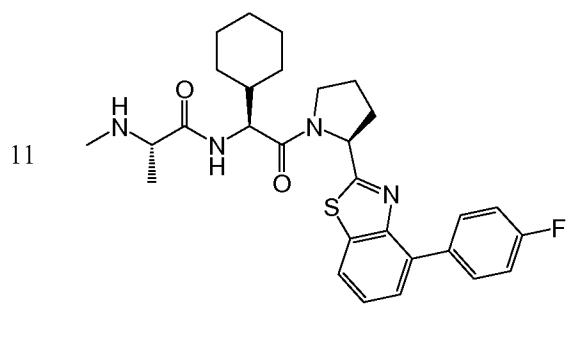
The invention also encompasses prodrugs of the compounds described above. Suitable prodrugs where applicable include known amino-protecting and carboxy-protecting groups which are released, for example hydrolyzed, to yield the parent compound under physiologic conditions. A particular class of prodrugs are compounds in which a nitrogen atom in an amino, amidino, aminoalkyleneamino, iminoalkyleneamino or guanidino group is substituted with a hydroxy (OH) group, an alkylcarbonyl (-CO-R) group, an alkoxy carbonyl (-CO-OR), an acyloxyalkyl-alkoxy carbonyl (-CO-O-R-O-CO-R) group where R is a monovalent or divalent group and as defined above or a group having the formula -C(O)-O-CP₁P₂-haloalkyl, where P₁ and P₂ are the same or different and are H, lower alkyl, lower alkoxy, cyano, halo lower alkyl or aryl. In a

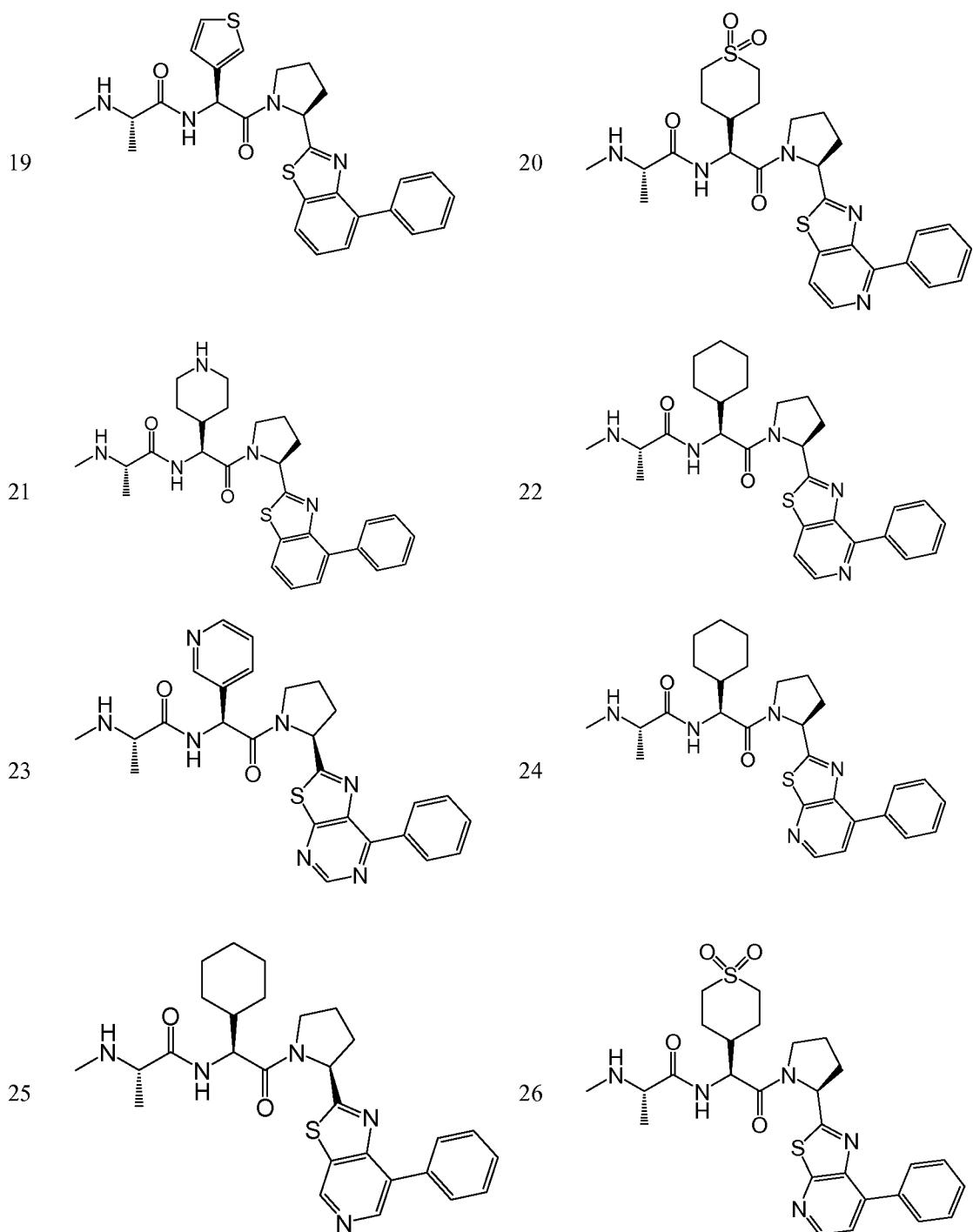
particular embodiment, the nitrogen atom is one of the nitrogen atoms of the amidino group of the compounds of the invention. These prodrug compounds are prepared reacting the compounds of the invention described above with an activated acyl compound to bond a nitrogen atom in the compound of the invention to the carbonyl of the activated acyl compound. Suitable activated carbonyl compounds contain a good leaving group bonded to the carbonyl carbon and include acyl halides, acyl amines, acyl pyridinium salts, acyl alkoxides, in particular acyl phenoxides such as p-nitrophenoxy acyl, dinitrophenoxy acyl, fluorophenoxy acyl, and difluorophenoxy acyl. The reactions are generally exothermic and are carried out in inert solvents at reduced temperatures such as -78 to about 50C. The reactions are usually also carried out in the presence of an inorganic base such as potassium carbonate or sodium bicarbonate, or an organic base such as an amine, including pyridine, triethylamine, etc. One manner of preparing prodrugs is described in USSN 08/843,369 filed April 15, 1997 (corresponding to PCT publication WO9846576) the contents of which are incorporated herein by reference in their entirety.

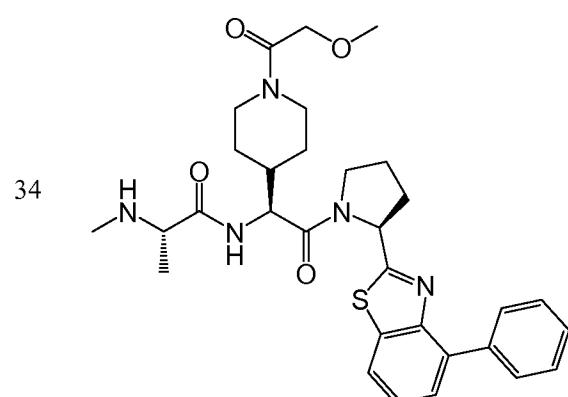
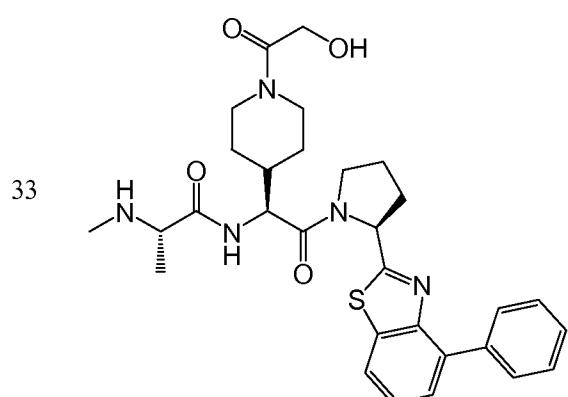
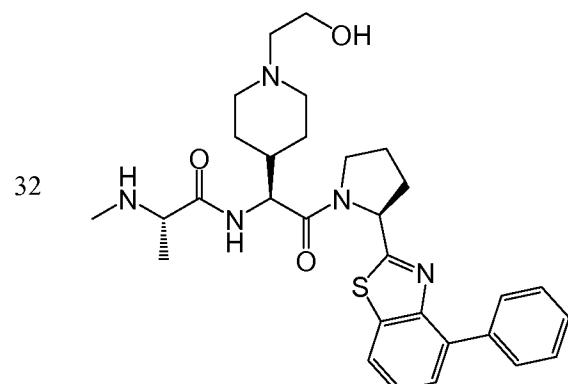
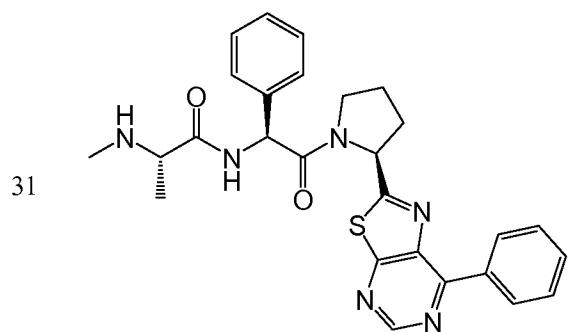
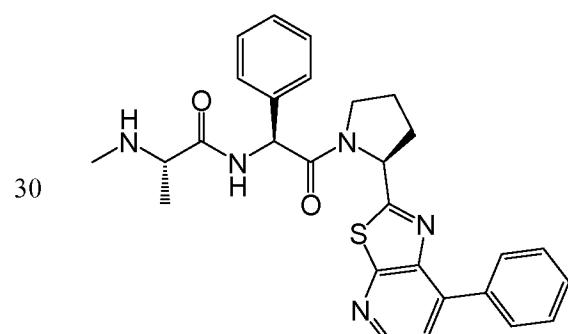
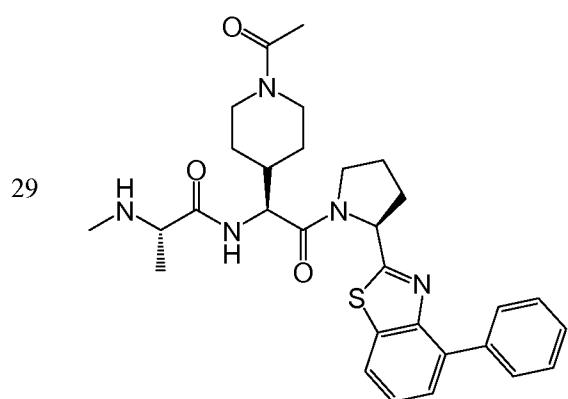
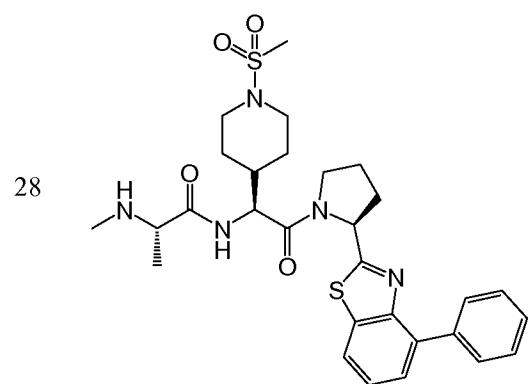
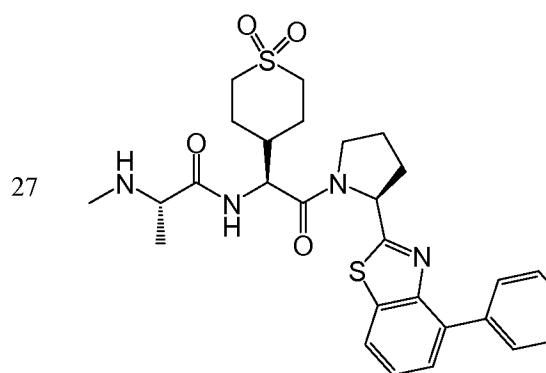
Particular compounds of formula I include the following:

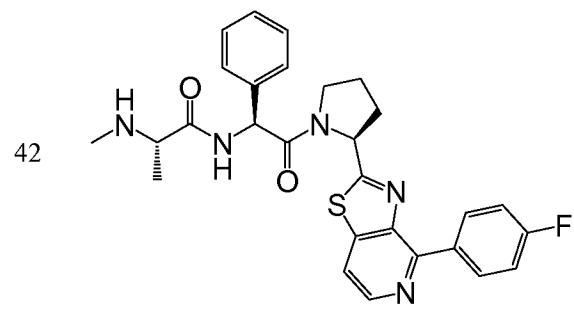
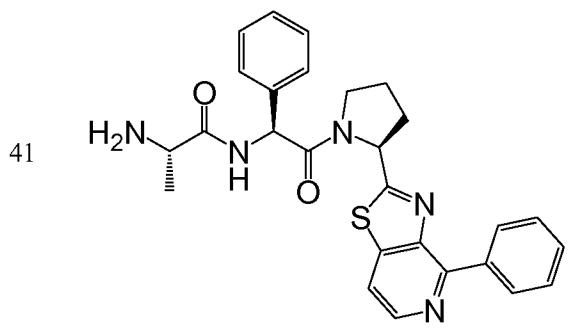
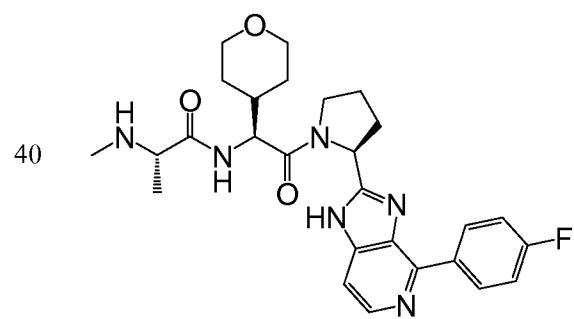
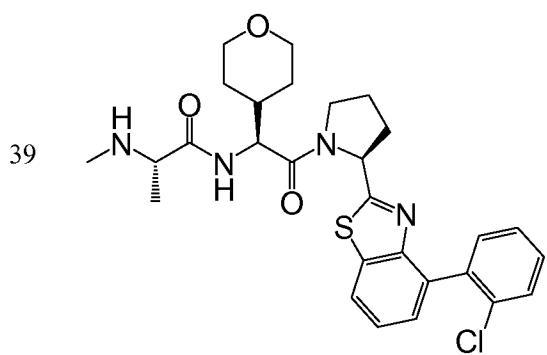
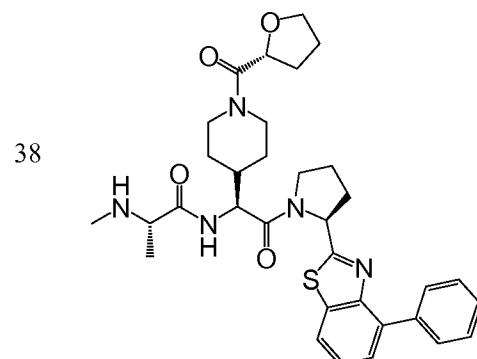
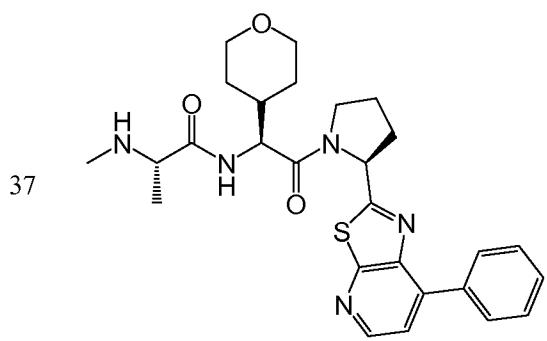
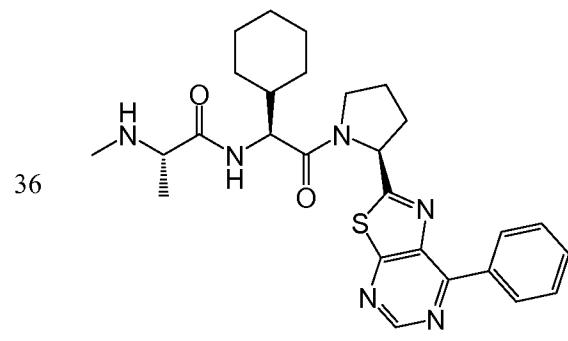
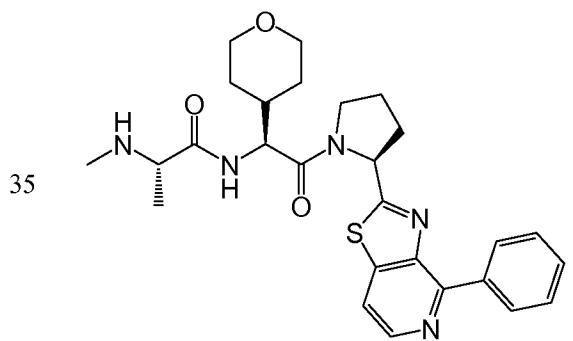


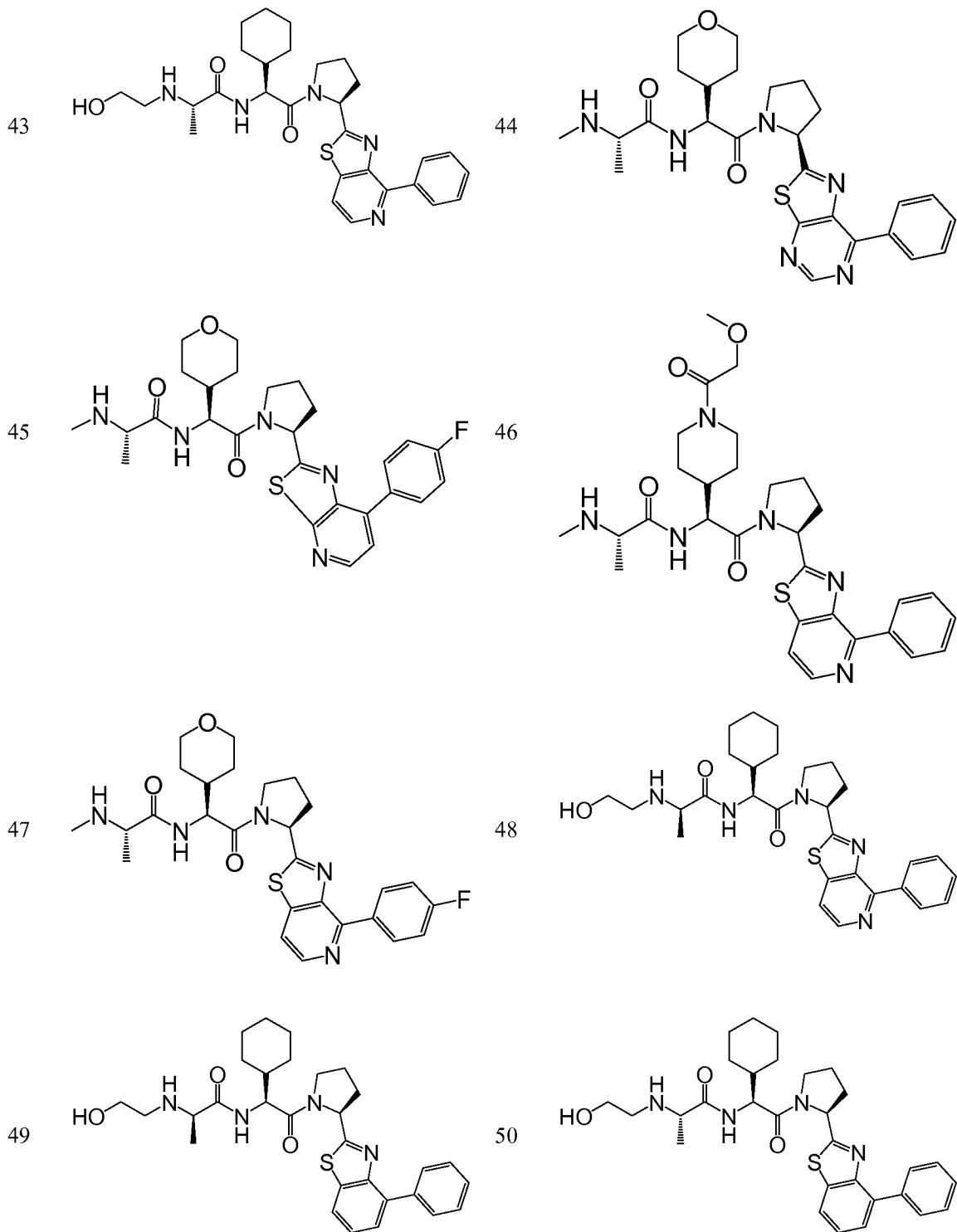


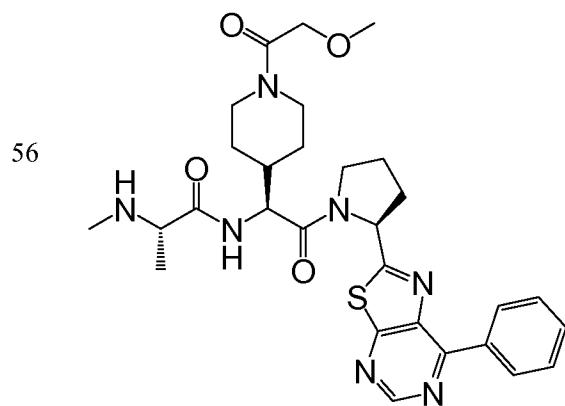
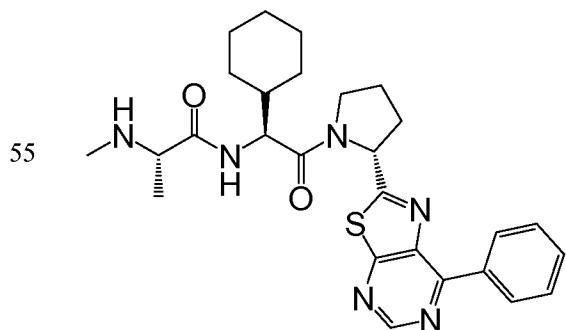
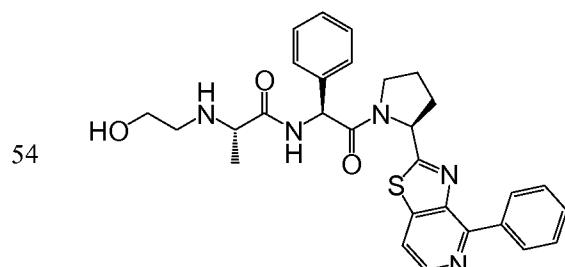
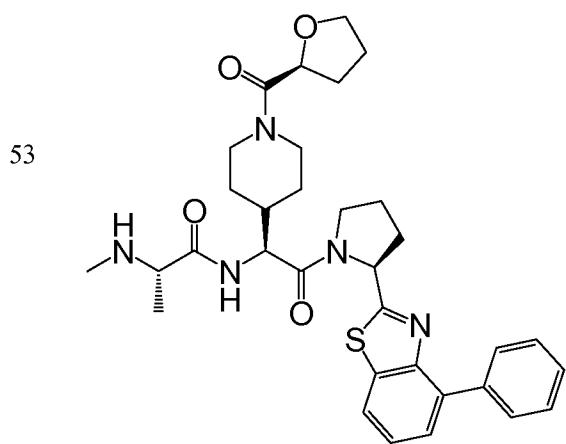
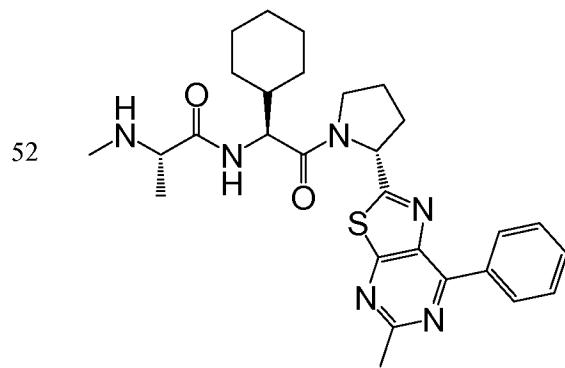
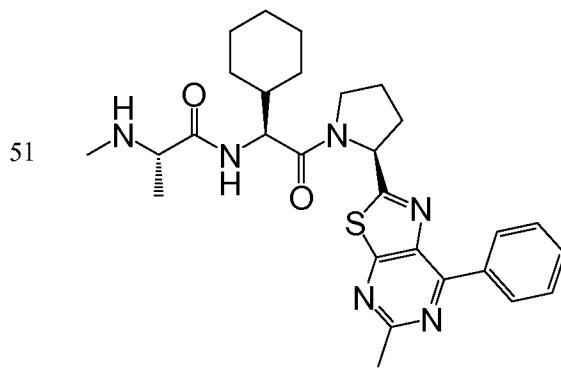


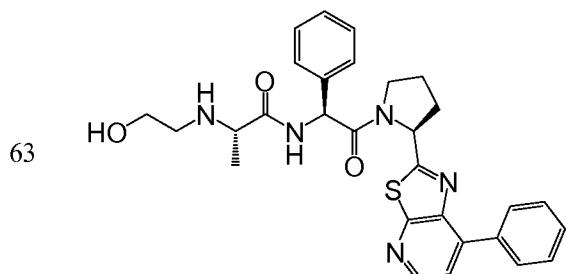
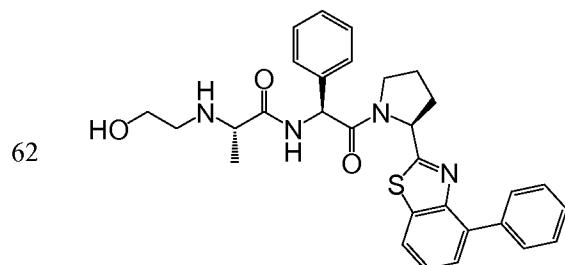
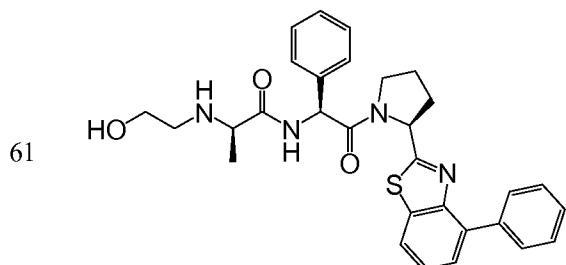
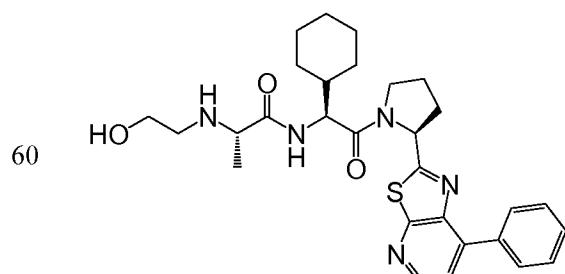
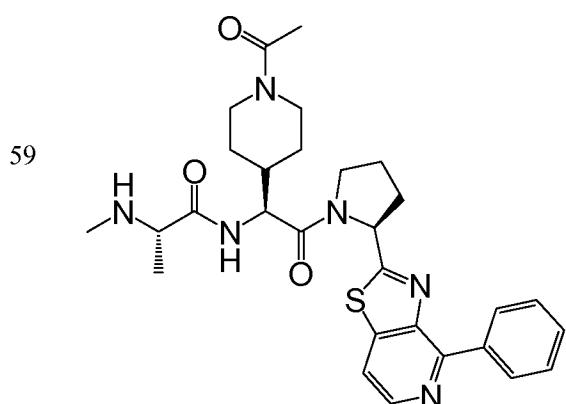
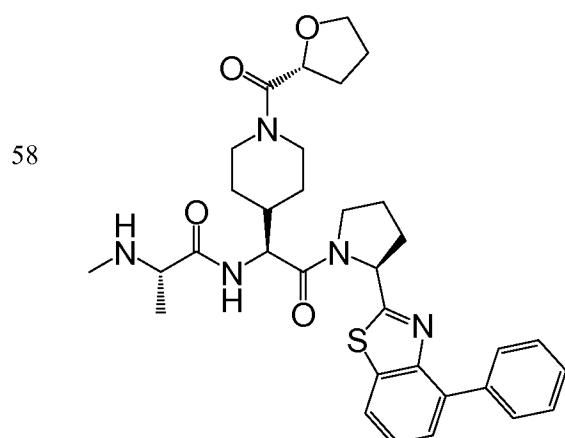
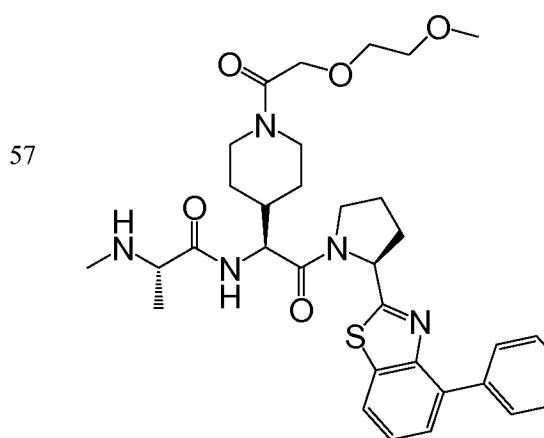










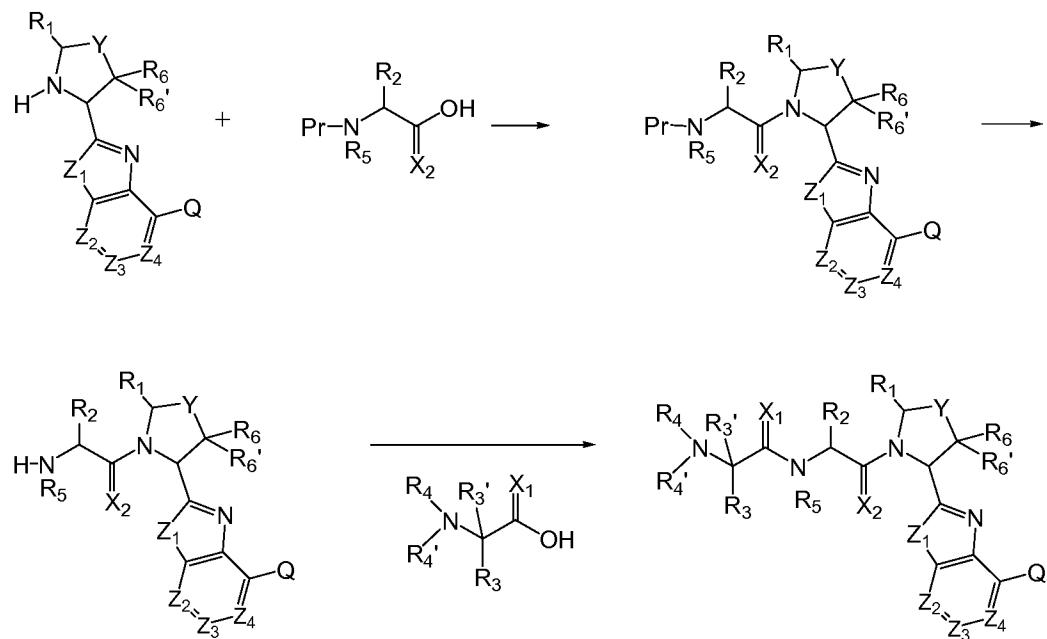


Compounds of the invention may exist in different resonance forms and that all such resonance forms are within the scope of the invention herein.

SYNTHESIS

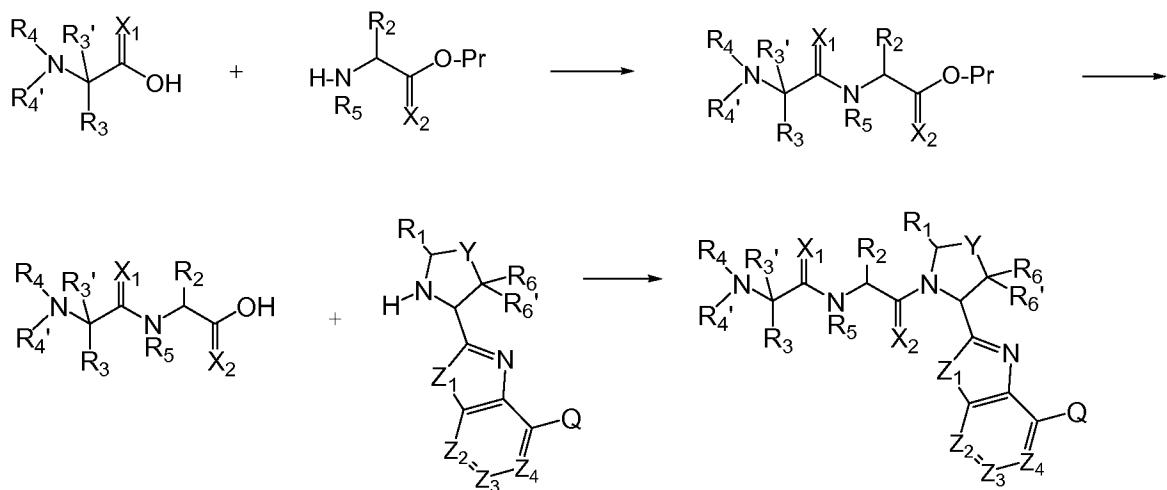
Compounds of the invention are prepared using standard organic synthetic techniques from commercially available starting materials and reagents. It will be appreciated that synthetic procedures employed in the preparation of compounds of the invention will depend on the particular substituents present in a compound and that various protection and deprotection steps that are standard in organic synthesis may be required but may not be illustrated in the following general schemes. In a particular general synthetic scheme, compounds of the invention may be prepared by coupling amino acid residue analogues employing typical amide coupling procedures. In scheme 1, wherein Q, Y, Z₁, Z₂, Z₃, Z₄, R₁, R₆ and R₆' are as defined herein and Pr is a suitable protecting group, amine-protected amino acid residue analogues are coupled and deprotected sequentially to give the final compounds.

Scheme 1



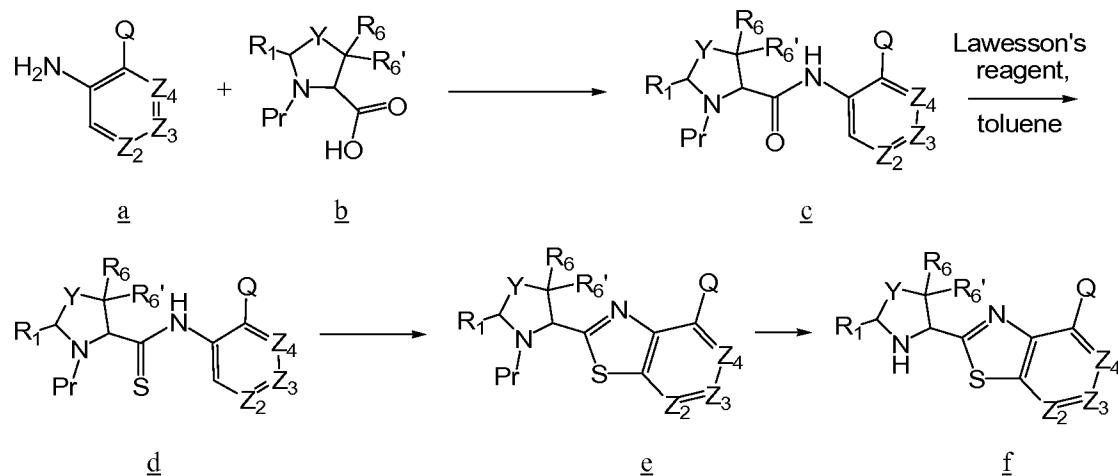
It will be appreciated that the amino acid analogs may be coupled in any order and may be prepared using solid phase support which is routine in the art. For example, Scheme 2 illustrates an alternative amino acid residue analogue coupling route in which R₄ or R₄' is an amino-protecting group or other group as defined herein which renders the amine non-reactive with carboxyl groups.

Scheme 2



Thiazole intermediates for preparing compounds of the invention in which Z_1 is S may be prepared according to scheme 3 wherein Q, Y, Z1, Z2, Z3, Z4, R1, R6 and R6' are as defined herein and Pr is a suitable protecting group.

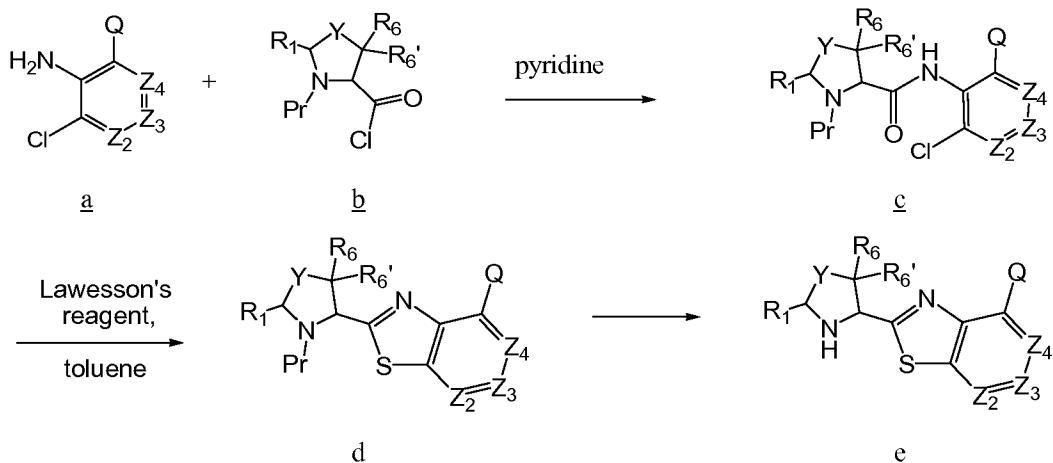
Scheme 3



Amine a is coupled with b using standard amide formation procedures, to form amide c which is converted to the corresponding thioamide d by reacting with Lawesson's reagent. Thioamide d is cyclized, for example with $K_3Fe(CN)_6$ in EtOH to form e which is deprotected to give the desired thiazole f to be used in preparing compounds of the invention.

Alternatively, thiazole intermediates for preparing compounds of the invention in which Z_1 is S may be prepared according to Scheme 4.

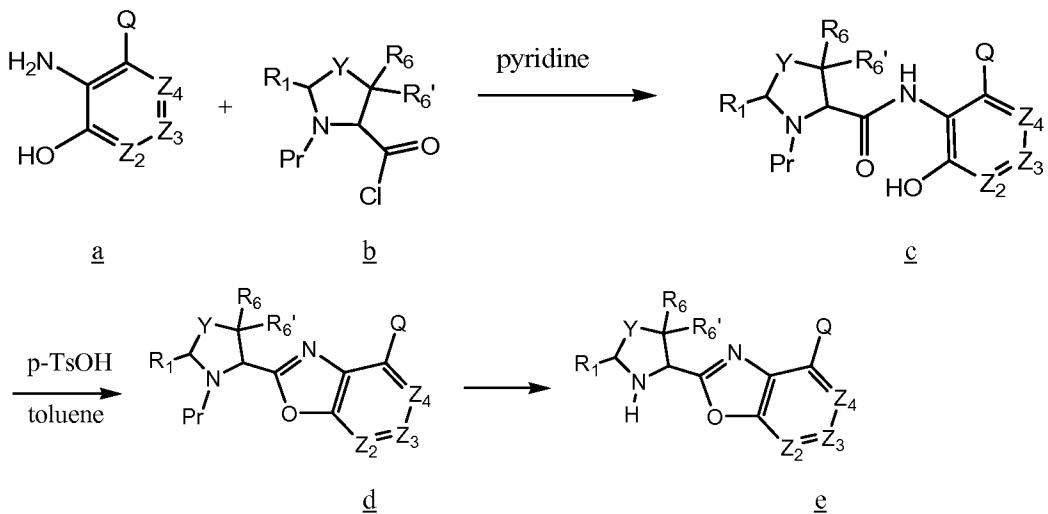
Scheme 4



Chloro-substituted amine **a** is coupled with acid chloride **b** to give amide **c** which is reacted with Lawesson's reagent and heated to give cyclized compound **d**. Compound **d** is then deprotected to give the desired thiazole intermediate **e** to be used in preparation of compounds of the invention.

Oxazole intermediates for preparing compounds of the invention in which Z_1 is O may be prepared according to the procedures described by Wang et al.(Bioorganic & Medicinal Chemistry (2004), 12(1):17-21) as illustrated in Scheme 5.

Scheme 5

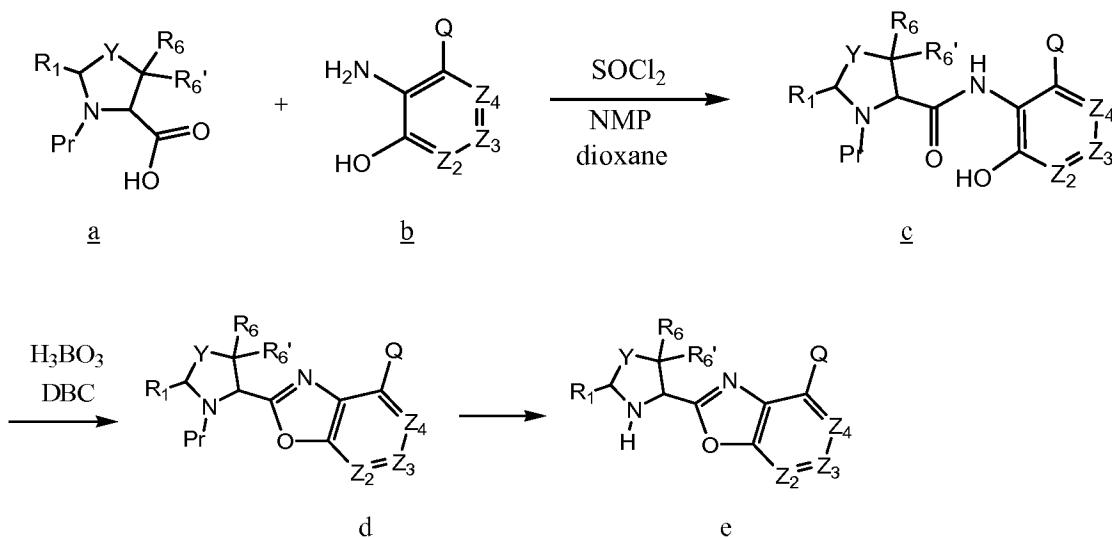


Similar to schemes 3 and 4, an acid chloride **b** is coupled with amine **a** to give amide **c**. However, amide **c** is refluxed in a solution of p-toluenesulfonic acid in toluene to give **d** and the protecting

group Pr is removed to give the desired oxazole e to be used in preparing compounds of the invention.

Alternatively, oxazole intermediates for preparing compounds of the invention in which Z_1 is O may be prepared according to the procedures described by Kauffman et al. (Journal of Heterocyclic Chemistry (2002), 39(5), 981-988) illustrated in Scheme 6.

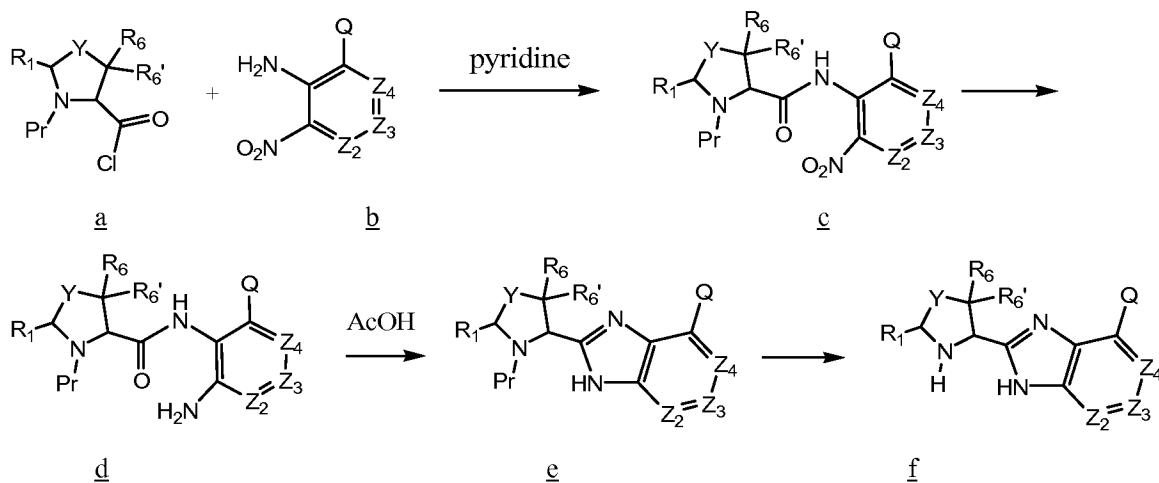
Scheme 6



Acid a with dioxane, thionylchloride and N-methylpyrrolidinone are refluxed under inert gas and the resulting acid chloride is coupled with hydroxy/amine b to give amide c. This is then heated with boric acid in dibutylcarbitol to give d and the protecting group Pr is removed to give the desired oxazole intermediate e which may be used for preparing compounds of the invention.

Imidazole intermediates for preparing compounds of the invention in which Z_1 is NH may be prepared according to the procedures described by Kumar et al. (Bioorganic & Medicinal Chemistry (2002), 10(12), 3997-4004) as illustrated in Scheme 7.

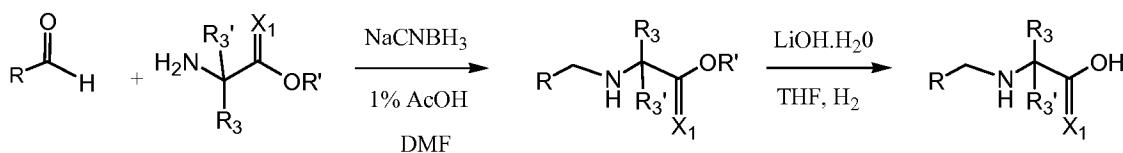
Scheme 7



Acid chloride a is coupled with nitro/amine b to give amide c. The nitro group of amide c is reduced to the corresponding amine, for example with iron, and is then cyclized by heating with acetic acid to give d. The protecting group Pr of d is removed to give the desired imidazole intermediate e which may be used in preparing compounds of the invention.

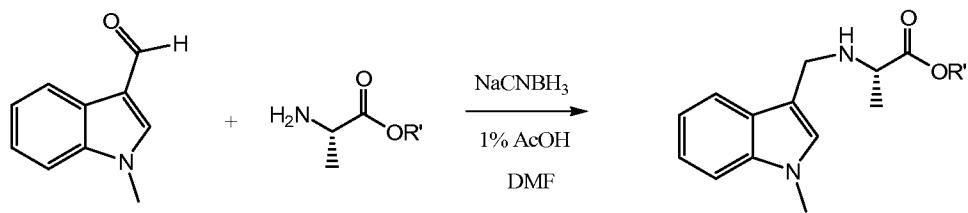
Compounds of the invention in which R₄ or R_{4'} are other than H may be prepared according to standard organic chemistry techniques, for example by reductive amination in which a starting amino acid residue analog e.g. NH₂-CH(R₃)-C(O)-OH is reacted with a suitable aldehyde or ketone to give the desired R₄ and R_{4'} substituents. See scheme 8. The resulting R₄/R_{4'} substituted amino acid intermediate can then be conjugated to the next amino acid intermediate or the remainder of the compound using standard peptide coupling procedures.

Scheme 8



In a particular embodiment, alanine is reacted with 1-methylindole-2-carboxaldehyde and reduced with sodium cyanoborohydride dissolved in 1% HOAc/DMF to give the N-substituted alanine residue which may be used in preparing compounds of the invention. See scheme 9.

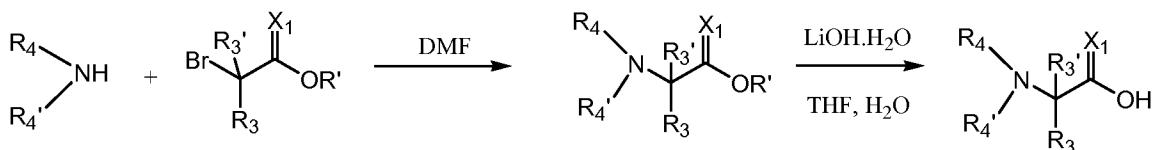
Scheme 9



Alternatively, the reductive amination procedure to introduce R_4/R_4' substituents is the final step in the preparation of the compound.

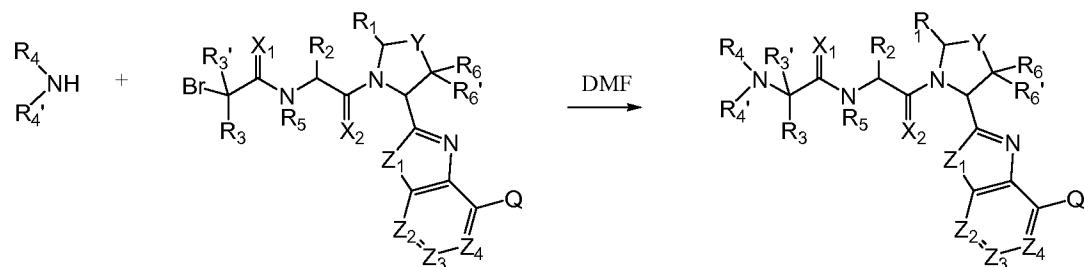
When compounds of the invention incorporate R_4 or R_4' substituents other than H, they may also be prepared by substitution of a suitable acid intermediate which incorporates a leaving group with a desired amine. For example $Br-CH(R_3)-C(O)-OH$ is substituted with an amine R_4-NH_2 or R_4-NH-R_4' according to scheme 10.

Scheme 10

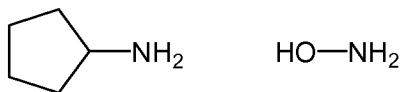
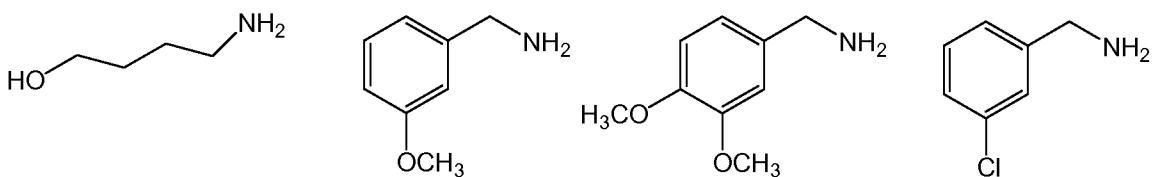
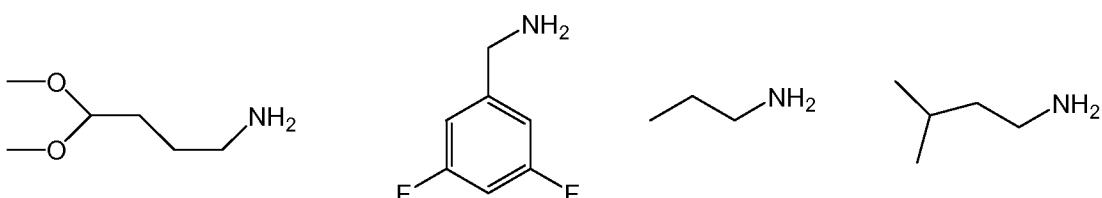
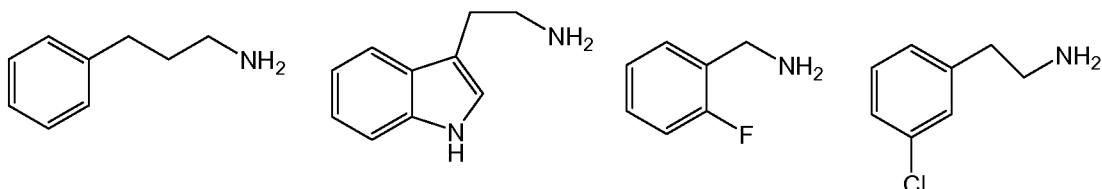


Alternatively, the substitution reaction introducing R_4 or R_4' substituents may be performed as a final step in the preparation of the compound as illustrated in scheme 11.

Scheme 11



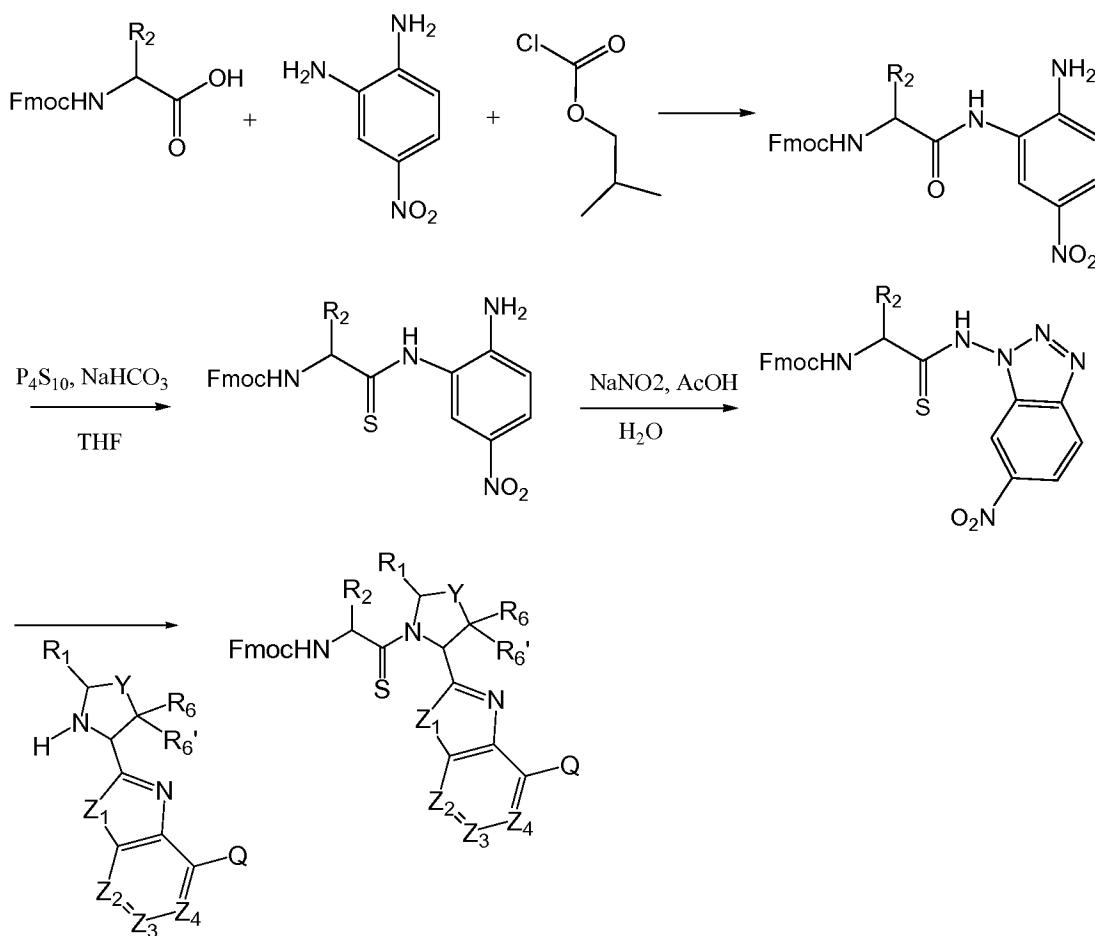
In a particular embodiment, 2-bromopropionic acid is reacted with the following amines dissolved in DMF and bubbled for until substitution is complete to form N-substituted alanine residues:



Compounds of the invention in which either X_1 or X_2 is sulfur, i.e. the compound incorporates a thioamide, may be prepared according to established organic chemistry techniques. For example, compounds in which X_2 is sulfur can be prepared according to scheme 12 starting from an Fmoc protected amino acid residue analog $\text{NH}_2\text{-CH}(\text{R}_2)\text{-COOH}$ which is dissolved in THF and cooled to -25°C , with addition of DIPEA followed by addition of isobutylchloroformate. After 10 minutes, the diamine, 4-nitrobenzene-1,2-diamine, is added and the reaction mixture is continuously stirred at -25°C for 2 hours, then at room temperature overnight. THF is vacuumed off and the mixture is then subjected to flash chromatography using 50% EtOAc/Hexane to yield the product. The Fmoc-alanine derivative, phosphorus pentasulfide and sodium carbonate are mixed in THF and stirred overnight. The solution is concentrated and direct chromatography using 80% EtOAc/Hexane yields the activated thioalanine. The activated thioalanine and sodium nitrite are then mixed in acetic acid and diluted with H_2O . The resulting precipitant is filtered and dried to yield the product. The thioalanine is coupled to an A ring substituted proline amino acid residue analog by dissolving both in DMF. The thioamide product may then be deprotected with 20% PIP/DMA for 15 minutes and used to conjugate to the $\text{R}_4/\text{R}_4'\text{-N-C}(\text{R}_3)(\text{R}_3')\text{-COOH}$.

Alternatively the Fmoc-protected thioamide is first coupled to the A ring substituted proline amino acid residue analog followed by Fmoc deprotection and subsequent coupling to the R₄/R₄'-R₄/R₄'-N-C(R₃)(R₃')-COOH amino acid residue analog.

Scheme 12



UTILITY

The compounds of the invention inhibit the binding of IAP proteins to caspases, in particular X-IAP binding interaction with caspases 3 and 7. The compounds also inhibit the binding of ML-IAP to Smac protein. Accordingly, the compounds of the invention are useful for inducing apoptosis in cells or sensitizing cells to apoptotic signals, in particular cancer cells. Compounds of the invention are useful for inducing apoptosis in cells that overexpress IAP proteins. Alternatively, compounds of the invention are useful for inducing apoptosis in cells in which the mitochondrial apoptotic pathway is disrupted such that release of Smac from ML-IAP proteins is

inhibited, for example by up regulation of Bcl-2 or down regulation of Bax/Bak. More broadly, the compounds can be used for the treatment of all cancer types which fail to undergo apoptosis. Examples of such cancer types include neuroblastoma, intestine carcinoma such as rectum carcinoma, colon carcinoma, familial adenomatous polyposis carcinoma and hereditary non-polyposis colorectal cancer, esophageal carcinoma, labial carcinoma, larynx carcinoma, hypopharynx carcinoma, tong carcinoma, salivary gland carcinoma, gastric carcinoma, adenocarcinoma, medullary thyroidea carcinoma, papillary thyroidea carcinoma, renal carcinoma, kidney parenchym carcinoma, ovarian carcinoma, cervix carcinoma, uterine corpus carcinoma, endometrium carcinoma, chorion carcinoma, pancreatic carcinoma, prostate carcinoma, testis carcinoma, breast carcinoma, urinary carcinoma, melanoma, brain tumors such as glioblastoma, astrocytoma, meningioma, medulloblastoma and peripheral neuroectodermal tumors, Hodgkin lymphoma, non-Hodgkin lymphoma, Burkitt lymphoma, acute lymphatic leukemia (ALL), chronic lymphatic leukemia (CLL), acute myeloid leukemia (AML), chronic myeloid leukemia (CML), adult T-cell leukemia lymphoma, hepatocellular carcinoma, gall bladder carcinoma, bronchial carcinoma, small cell lung carcinoma, non-small cell lung carcinoma, multiple myeloma, basalioma, teratoma, retinoblastoma, choroidea melanoma, seminoma, rhabdomyo sarcoma, craniopharyngeoma, osteosarcoma, chondrosarcoma, myosarcoma, liposarcoma, fibrosarcoma, Ewing sarcoma and plasmocytoma.

Compounds of the invention are useful for sensitizing cells to apoptotic signals. Accordingly, the compounds may be administered prior to, concomitantly with, or following administration of radiation therapy or cytostatic or antineoplastic chemotherapy. Suitable cytostatic chemotherapy compounds include, but are not limited to (i) antimetabolites, such as cytarabine, fludarabine, 5-fluoro-2'-deoxyuridine, gemcitabine, hydroxyurea or methotrexate; (ii) DNA-fragmenting agents, such as bleomycin, (iii) DNA-crosslinking agents, such as chlorambucil, cisplatin, cyclophosphamide or nitrogen mustard; (iv) intercalating agents such as adriamycin (doxorubicin) or mitoxantrone; (v) protein synthesis inhibitors, such as L-asparaginase, cycloheximide, puromycin or diphtheria toxin; (Vi) topoisomerase I poisons, such as camptothecin or topotecan; (vii) topoisomerase II poisons, such as etoposide (VP-16) or teniposide; (viii) microtubule-directed agents, such as colcemid, colchicine, paclitaxel, vinblastine or vincristine; (ix) kinase inhibitors such as flavopiridol, staurosporin, ST1571 (CPG 57148B) or UCN-01 (7-hydroxystaurosporine); (x) miscellaneous investigational agents such as thioplatin, PS-341, phenylbutyrate, ET-18-OCH₃, or farnesyl transferase inhibitors (L-739749, L-744832); polyphenols such as quercetin, resveratrol, piceatannol, epigallocatechine gallate, theaflavins, flavanols, procyanidins, betulinic acid and derivatives thereof; (xi) hormones such as glucocorticoids or fenretinide; (xii) hormone antagonists, such as tamoxifen, finasteride or LHRH

antagonists. In a particular embodiment, compounds of the present invention are coadministered with a cytostatic compound selected from the group consisting of cisplatin, doxorubicin, taxol, taxotere and mitomycin C. In a particular embodiment, the cytostatic compound is doxorubicin.

Another class of active compounds which can be used in the present invention are those which are able to sensitize for or induce apoptosis by binding to death receptors ("death receptor agonists"). Such agonists of death receptors include death receptor ligands such as tumor necrosis factor α (TNF- α), tumor necrosis factor β (TNF- β , lymphotoxin- α), LT- β (lymphotoxin- β), TRAIL (Apo2L, DR4 ligand), CD95 (Fas, APO-1) ligand, TRAMP (DR3, Apo-3) ligand, DR6 ligand as well as fragments and derivatives of any of said ligands. In an embodiment, the death receptor ligand is TNF- α . In a particular embodiment, the death receptor ligand is Apo2L/TRAIL. Furthermore, death receptors agonists comprise agonistic antibodies to death receptors such as anti-CD95 antibody, anti-TRAIL-R1 (DR4) antibody, anti-TRAIL-R2 (DR5) antibody, anti-TRAIL-R3 antibody, anti-TRAIL-R4 antibody, anti-DR6 antibody, anti-TNF-R1 antibody and anti-TRAMP (DR3) antibody as well as fragments and derivatives of any of said antibodies.

For the purpose of sensitizing cells for apoptosis, the compounds of the present invention can be also used in combination with radiation therapy. The phrase "radiation therapy" refers to the use of electromagnetic or particulate radiation in the treatment of neoplasia. Radiation therapy is based on the principle that high-dose radiation delivered to a target area will result in the death of reproducing cells in both tumor and normal tissues. The radiation dosage regimen is generally defined in terms of radiation absorbed dose (rad), time and fractionation, and must be carefully defined by the oncologist. The amount of radiation a patient receives will depend on various consideration but the two most important considerations are the location of the tumor in relation to other critical structures or organs of the body, and the extent to which the tumor has spread. Examples of radiotherapeutic agents are provided in, but not limited to, radiation therapy and is known in the art (Hellman, Principles of Radiation Therapy, Cancer, in Principles I and Practice of Oncology, 24875 (Devita et al., 4th ed., vol 1, 1993). Recent advances in radiation therapy include three-dimensional conformal external beam radiation, intensity modulated radiation therapy (IMRT), stereotactic radiosurgery and brachytherapy (interstitial radiation therapy), the latter placing the source of radiation directly into the tumor as implanted "seeds". These newer treatment modalities deliver greater doses of radiation to the tumor, which accounts for their increased effectiveness when compared to standard external beam radiation therapy.

Ionizing radiation with beta-emitting radionuclides is considered the most useful for radiotherapeutic applications because of the moderate linear energy transfer (LET) of the ionizing

particle (electron) and its intermediate range (typically several millimeters in tissue). Gamma rays deliver dosage at lower levels over much greater distances. Alpha particles represent the other extreme, they deliver very high LET dosage, but have an extremely limited range and must, therefore, be in intimate contact with the cells of the tissue to be treated. In addition, alpha emitters are generally heavy metals, which limits the possible chemistry and presents undue hazards from leakage of radionuclide from the area to be treated. Depending on the tumor to be treated all kinds of emitters are conceivable within the scope of the present invention.

Furthermore, the present invention encompasses types of non-ionizing radiation like e.g. ultraviolet (UV) radiation, high energy visible light, microwave radiation (hyperthermia therapy), infrared (IR) radiation and lasers. In a particular embodiment of the present invention UV radiation is applied.

The invention also includes pharmaceutical compositions or medicaments containing the compounds of the invention and a therapeutically inert carrier, diluent or excipient, as well as methods of using the compounds of the invention to prepare such compositions and medicaments. Typically, the compounds of formula I used in the methods of the invention are formulated by mixing at ambient temperature at the appropriate pH, and at the desired degree of purity, with physiologically acceptable carriers, i.e., carriers that are non-toxic to recipients at the dosages and concentrations employed into a galenical administration form. The pH of the formulation depends mainly on the particular use and the concentration of compound, but may range anywhere from about 3 to about 8. Formulation in an acetate buffer at pH 5 is a suitable embodiment. In an embodiment, the inhibitory compound for use herein is sterile. The compound ordinarily will be stored as a solid composition, although lyophilized formulations or aqueous solutions are acceptable.

The composition of the invention will be formulated, dosed, and administered in a fashion consistent with good medical practice. Factors for consideration in this context include the particular disorder being treated, the particular mammal being treated, the clinical condition of the individual patient, the cause of the disorder, the site of delivery of the agent, the method of administration, the scheduling of administration, and other factors known to medical practitioners. The "effective amount" of the compound to be administered will be governed by such considerations, and is the minimum amount necessary to inhibit IAP interaction with caspases, induce apoptosis or sensitize a malignant cell to an apoptotic signal. Such amount is may be below the amount that is toxic to normal cells, or the mammal as a whole.

Generally, the initial pharmaceutically effective amount of the compound of the invention administered parenterally per dose will be in the range of about 0.01-100 mg/kg, for example about 0.1 to 20 mg/kg of patient body weight per day, with the typical initial range of compound used being 0.3 to 15 mg/kg/day. Oral unit dosage forms, such as tablets and capsules, may contain from about 25 to about 1000 mg of the compound of the invention.

The compound of the invention may be administered by any suitable means, including oral, topical, transdermal, parenteral, subcutaneous, intraperitoneal, intrapulmonary, and intranasal, and, if desired for local treatment, intralesional administration. Parenteral infusions include intramuscular, intravenous, intraarterial, intraperitoneal, or subcutaneous administration. An example of a suitable oral dosage form is a tablet containing about 25mg, 50mg, 100mg, 250mg, or 500mg of the compound of the invention compounded with about 90-30 mg anhydrous lactose, about 5-40 mg sodium croscarmellose, about 5-30mg polyvinylpyrrolidone (PVP) K30, and about 1-10 mg magnesium stearate. The powdered ingredients are first mixed together and then mixed with a solution of the PVP. The resulting composition can be dried, granulated, mixed with the magnesium stearate and compressed to tablet form using conventional equipment. An aerosol formulation can be prepared by dissolving the compound, for example 5-400 mg, of the invention in a suitable buffer solution, e.g. a phosphate buffer, adding a tonicifier, e.g. a salt such sodium chloride, if desired. The solution is typically filtered, e.g. using a 0.2 micron filter, to remove impurities and contaminants.

EXAMPLES

The invention will be more fully understood by reference to the following examples. They should not, however, be construed as limiting the scope of the invention. Reagents and solvents were obtained from commercial sources and used as received. Unless otherwise noted, chromatographic purifications were performed using pre-packed silica gel columns on a CombiFlash Companion system by Teledyne-Isco, Inc. Lincoln, Nebraska. The identity and purity of compounds were checked by LCMS and ¹H NMR analysis.

Abbreviations used herein are as follows:

AcOH: acetic acid;

ACN: acetonitrile;

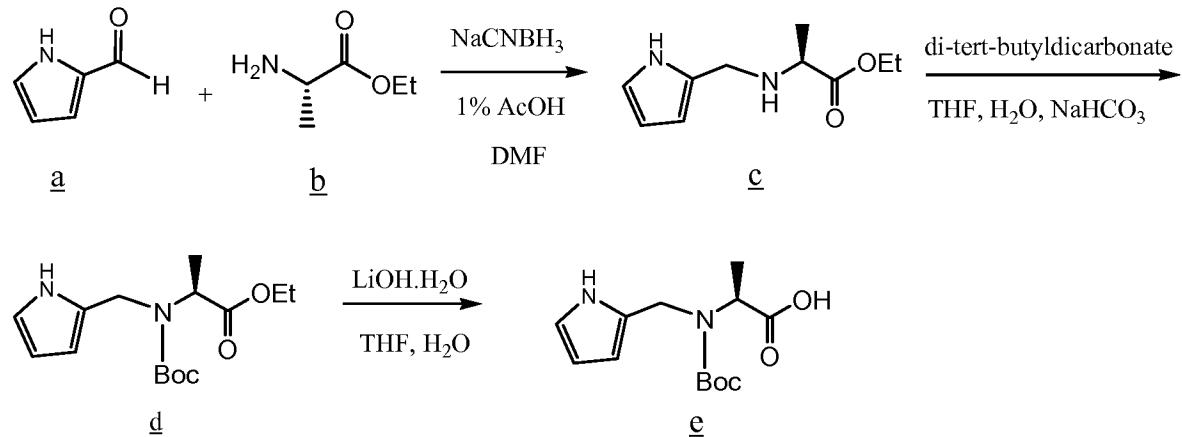
Chg: cyclohexylglycine;

DCM: dichloromethane

DIPEA: diisopropylethylamine;

DMAP: 4- dimethylaminopyridine;
 DME: 1,2-dimethoxyethane;
 DMF: dimethylformamide;
 DMSO: dimethylsulfoxide
 EDC: 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide;
 EEDQ: 2-ethoxy-1-ethoxycarbonyl-1,2-dihydroquinoline;
 EtOAc: ethylacetate
 EtOH: ethanol;
 LCMS: liquid chromatography mass spectrometry;
 HATU: O-(7-Azobenzotriazol-1-yl)-1,1,3,3-tetramethyluronium hexafluorophosphate;
 HOBr: N-Hydroxybenzotriazole
 HBTU: 2-(1H-Benzotriazol-1-yl)-1,1,3,3-Tetramethyl-uronium Hexafluorophosphate;
 HPLC: high performance liquid chromatography;
 MeOH: methanol;
 NBS: N-bromosuccinamide;
 TASF: tris(dimethylamino)sulfonium difluorotrimethylsilicate;
 TEA: triethylamine;
 TFA: trifluoroacetic acid;
 THF: tetrahydrofuran;

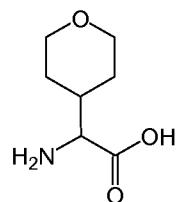
Example 1 2-[tert-Butoxycarbonyl-(1H-pyrrol-2-ylmethyl)-amino]-propionic acid



Alanine ethyl ester **b** (5g, 32.5mmol), pyrrole-2-carbaldehyde **a** (3.1g, 32.5mmol), sodium cyanoborohydride (2.04g, 32.5mmol) and AcOH (1%) were mixed in DMF and stirred overnight. The reaction was quenched with H₂O, and DMF was evaporated. The mixture was diluted with EtOAc, washed by 0.1N NaOH, dried and concentrated to yield product **c** 2.5g. The resulting ester **c** (2.5g, 12.8mmol), di-tert-butyldicarbonate (3.06g, 14mmol) were mixed in THF, H₂O with

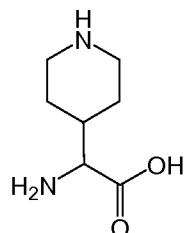
NaHCO₃ and stirred overnight. THF was evaporated, and the mixture was diluted with EtOAc, washed by 1N NaOH, sat. NH₄Cl and brine. After dried, the mixture was concentrated to yield the Boc-protected ester d 3.3g. The Boc-protected ester d (1.67g, 5.6mol), lithium hydroxide mono hydrate (284mg, 6.77mmol) were mixed in THF and H₂O at 0°C. THF was vacuumed off, and the solution was acidified by dilute H₂SO₄, extracted by EtOAc twice. Organic layers were combined, dried and evaporated giving product 2-[tert-butoxycarbonyl-(1H-pyrrol-2-ylmethyl)-amino]-propionic acid e.

Example 2 tetrahydropyranylglycine



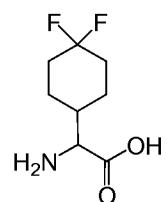
Tetrahydropyranylglycine was purchased from NovaBiochem, or synthesized according to the literature: Ghosh, A. K.; Thompson, W. J.; holloway, M. K.; McKee, S. P.; Duong, T. T.; Lee, H. Y.; Munson, P. M.; Smith, A. M.; Wai, J. M; Darke, P. L.; Zugay, J. A.; Emini, E. A.; Schleife, W. A.; Huff, J. R.; Anderson, P. S. *J. Med. Chem.*, 1993, 36, 2300-2310.

Example 3 piperidinylglycine



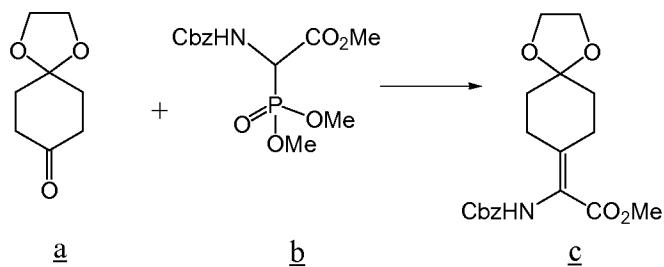
Piperidinylglycine was synthesized according to the procedures described by Shieh et al. (*Tetrahedron: Asymmetry*, 2001, 12, 2421-2425.

Example 4 4,4-difluorocyclohexylglycine

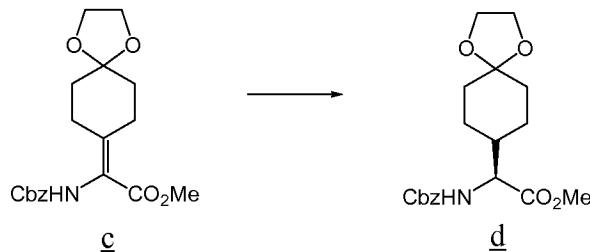


4,4-difluorocyclohexylglycine was made according to the procedures described in patent application US 20030216325.

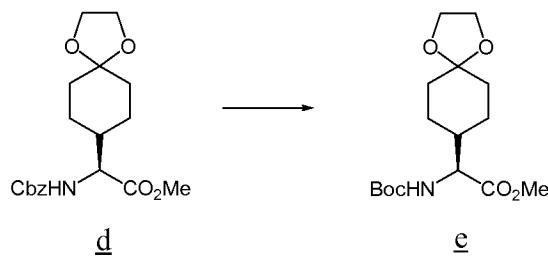
Example 5 Boc (S)-2-amino-2-(4-hydroxycyclohexyl)acetic acid



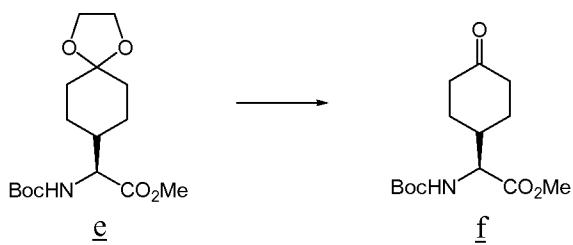
Following the procedure described by Sheih et al. (*Tetrahedron: Asymmetry*, 2001, 12, 2421-2425), a solution of ketone a (8.4 g) and EtOAc (30 mL) was added to a solution of *N*-Cbz-phosphonoglycine methyl ester b, TMG (4.5 mL) and EtOAc (30 mL). The solution was maintained at rt for 48h, then washed with 1N HCl (3x50 mL), brine (1x50 mL) dried (Na_2SO_4), filtered, and concentrated. The residue was adsorbed onto Celite, and purified by chromatography, then further purified by re-crystallization from EtOAc/hexanes to afford 5.2 g of product c.



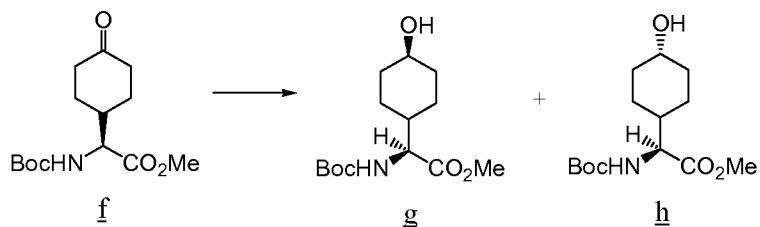
Following the procedure described by Sheih, (*Tetrahedron: Asymmetry*, 2001, 12, 2421-2425), a solution of enamide c (5.0 g), (S,S)-Me-BPE-Rh(I) (1.5g, Strem Chemicals, Newburyport, MA), and MeOH (100 mL) was shaken vigorously under 70psi of H_2 for 48h. The solvent was removed under reduced pressure. The residue was taken up in EtOAc, and filtered through SiO_2 with more EtOAc. The solvent was removed under reduced pressure to afford 4.0g of product d as a colorless solid.



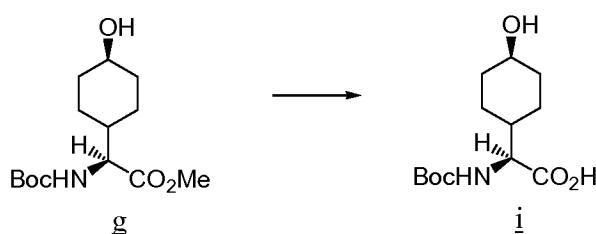
A mixture of Cbz-carbamate d, (4.0g) Boc₂O, (2.9g), 20% Pd(OH)₂•C (1.0g) and MeOH (30 mL) was maintained under an atmosphear of H₂ for 6h. The mixture was filtered through Celite with MeOH. The solvent was removed under reduced pressure to afford 4.5 g of residue e, which was taken on directly.



The residue e from above was dissolved in H₂O (10 mL), AcOH (30 mL), THF (5 mL), and dichloroacetic acid (3 mL) and maintained at rt overnight. Water (5 mL) was added and the solution and maintained until hyrolysis was complete, as monitored by HPLC-MS. Solid Na₂CO₃ was added cautiously until gas evolution ceased, the mixture was diluted with aq NaHCO₃, and extracted with 10%EtOAc/DCM. The combined organic phases were washed once with brine, dried (Na₂SO₄), filtered, and concentrated. The residue was purified by chromatography to afford 2.9g of product f.



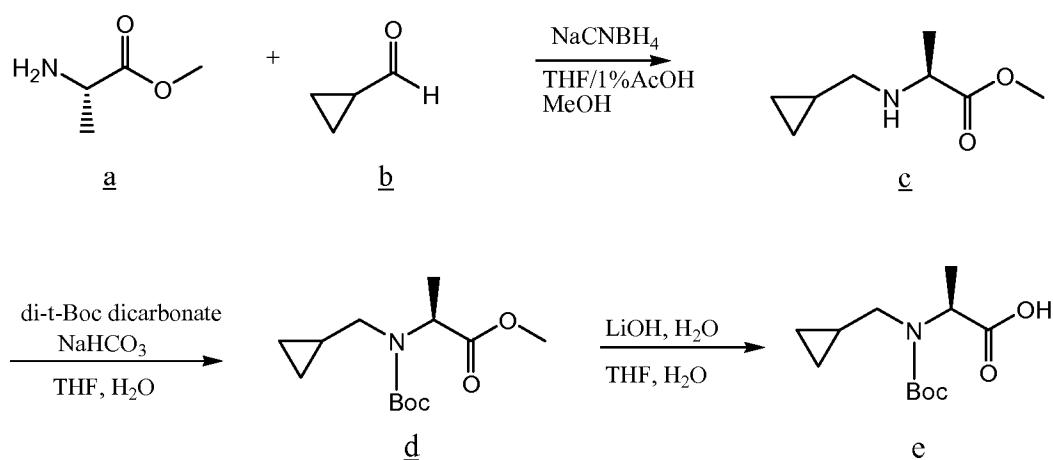
A mixture of ketone f (1.5g) MeOH (50 ml) was treated with NaBH₄ (290 mg) at 0 °C for 20 min. The mixture was acidified to ~pH1 with 10%aq citric acid and the MeOH was removed under reduced pressure. The residue was diluted with water and extraced with 20%EtOAc/DCM. The combined organic phases were washed once with brine, dried (Na₂SO₄), filtered, and concentrated. The residue was purified by chromatography to afford 1.17g of product g and 0.23g of product h.



A mixture of ester g (1.17g) LiOH•H₂O (160mg), THF (3 mL) and water (4.5 mL) was stirred vigorously at rt overnight. The mixture was diluted with brine and exaustivly extracted with

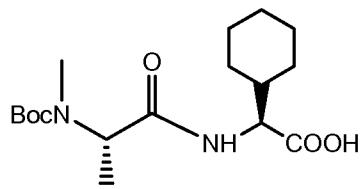
EtOAc. The combined organic phases were washed once with brine, dried (Na_2SO_4), filtered, and concentrated to afford acid j (525mg).

Example 6 N-Boc-N-cyclopropylmethyl-L-alanine



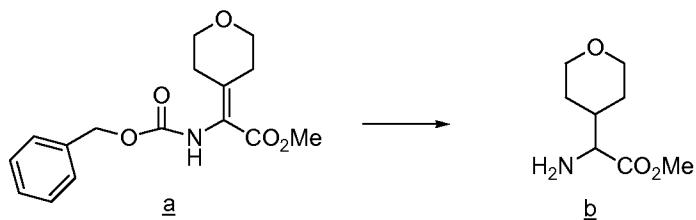
L-alanine methyl ester hydrochloride **a** (5g, 35.8mmol) and cyclopropanecarbaldehyde **b** (2.67ml, 35.8mmol) were suspended in 50ml THF w/1% AcOH. Addition of 5ml of CH_3OH made the cloudy solution turned to clear. NaCNBH_4 (2.25g, 35.8mmol) was added and the reaction mixture stirred overnight. The reaction was quenched by addition of 1N aq. NaOH , extracted by EtOAc twice, organic layers were dried over Na_2SO_4 and concentrated to dryness. The crude material was purified by chromatography using 30% EtOAc/hexane (stained by ninhydrin) to obtain the compound **c** (1g, 18%). The compound **c** (1g, 6.37mmol) and di-t-bocdicarbonate (2.1g, 9.55mmol) were diluted in THF (20ml) and H_2O (20ml), NaHCO_3 (1.3g, 15.9mmol) was added. The reaction mixture stirred overnight for completion. THF was removed under reduced pressure, and the aqueous layer was extracted by EtOAc 3 times. Combined organic layers were washed by 1N NaOH , sat, NH_4Cl followed by brine, the concentrated to dryness. The Boc-protected compound **d** (1.39g, 5.40mmol) was stirred with $\text{LiOH.H}_2\text{O}$ (1.14g, 27mmol) in THF (20ml) and H_2O (20ml) overnight at room temperature. THF was stripped off, and the aqueous layer was adjusted to pH=4 by adding 10% citric acid, then extracted by EtOAc 3 times. Combined organic layers were washed by brine and concentrated. The crude was purified by reverse phase C-18 column eluted by 0%-50% acetonitrile/ H_2O to give pure compound **e** as a white solid (794mg).

Example 7 N-Boc-N-methyl-L-alanine-L-cyclohexylglycine

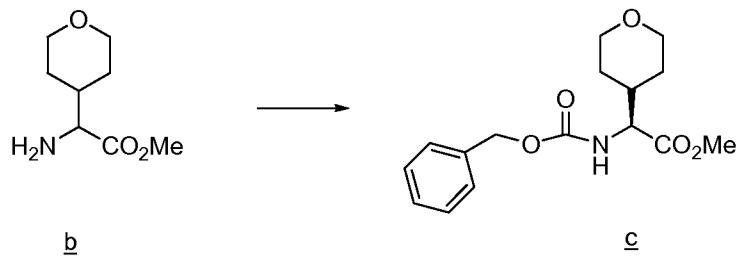


A solution of Fmoc-L-cyclohexylglycine (3.6 g, 9.6 mmol) dissolved in DCM (50 mL) and DIPEA (5.6 mL, 32 mmol) was added to 2-chlorotriptyl chloride resin (5 g, 8 mmol) and gently agitated for 3 hours at room temperature. The resin was washed with DCM 4 times, DCM/MeOH/DIPEA (17:2:1) 3 times, DCM 3 times, and 2 times dimethylacetamide (DMA). The Fmoc group was removed by treating the resin with 20% piperidine/DMA (50 mL) for 15 minutes. The resin was washed with DMA 6 times. A solution of Boc-N-methylalanine (3.3 g, 16 mmol), HBTU (6.1 g, 16 mmol), and DIPEA (5.6 mL, 32 mmol) and DMA/DCM (1:1, 50 mL) was added to the resin and gently agitated for 2 hours at room temperature. The resin was washed with DMA 5 times, DCM 2 times, and dried under reduced pressure. The dipeptide was cleaved from the resin by gentle agitation with HOAc/TFE/DCM (1:1:3, 100 mL) for 2 hours at room temperature. The resin was removed by filtration and the solution concentrated. Residual AcOH was removed by azeotroping with hexanes (15 times volume). The solid residue was purified by reverse-phase HPLC (C₁₈, MeCN-H₂O, 0.1%TFA) and the solvents removed by lyophilization to provide 1.2 g (43%) of dipeptide N-Boc-N-methyl-L-alanine-L-cyclohexylglycine as a white powder.

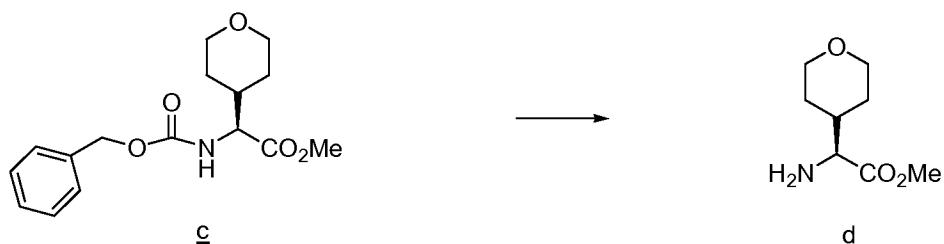
Example 8 N-Boc-N-methyl-L-alanine-L-dehydropyranylglycine



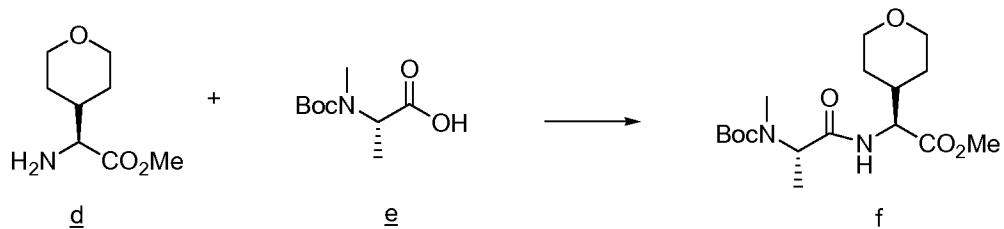
A mixture of N-Cbz-dehydropyranylglycine methyl ester a (Burk, M. J.; Gross, M. F.; Martinez, J. P. *J. Am Chem. Soc.* 1995, 117, 9375, and references therein) (5.2 g, 17 mmol), 5% Pd·C (500 mg), MeOH (75 mL) and THF (25 mL) was maintained under an atmosphere of H₂ for 24 h. The mixture was filtered through Celite and the Celite washed with MeOH, and concentrated under reduced pressure to afford a quantitative yield of amine b as a colorless oil, which was carried on directly.



The amine **b** prepared above was combined with CH₂Cl₂ (40 mL), saturated aqueous NaHCO₃ (40 mL) and cooled to 0 °C. Benzyloxy carbonyl chloride (3.0 mL) was then added dropwise and the mixture stirred vigorously overnight. The phases were separated and the aqueous phase extracted with CH₂Cl₂ (3 × 20 mL). The combined organic phases were washed with brine (1 × 50 mL), dried (Na₂SO₄), filtered, adsorbed onto Celite and chromatographed (ISCO, 120 g silica column, gradient elution 5-55% EtOAc-hexanes) to afford 4.15 g (80%) of racemic Cbz-pyranylglycine methyl ester. The enantiomers were separated on a Chiracel OD column eluting with 10% EtOH-hexanes. The desired *S*-enantiomer **c** elutes first under these conditions.

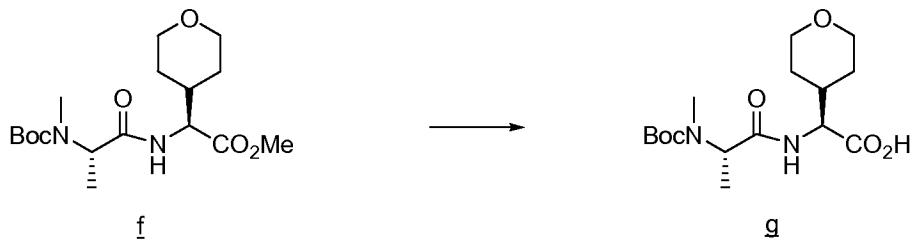


A mixture of (*S*)-*N*-Cbz-pyranyl glycine c methyl ester (2.4 g, 7.82 mmol) 10% Pd·C (700 mg), MeOH (80 mL) was maintained under 1 atmosphere of H₂ for 24 h. The mixture was filtered through Celite with MeOH, and concentrated under reduced pressure to afford 1.35 g (100%) of amine d as a colorless oil. Alternatively, pyranyl glycine can be synthesized in enantiopure form following the procedure of Ghosh (Ghosh, A. K.; Thompson, W. J.; Holloway, M. K.; McKee, S. P.; Duong, T. T.; Lee, H. Y.; Munson, P. M.; Smith, A. M.; Wai, J. M.; Darke, P. L.; Zugay, J. A.; Imini, E. A.; Schleif, W. A.; Huff, J. R.; Anderson, P. S. *J. Med. Chem.*, 1993, **36**, 2300).



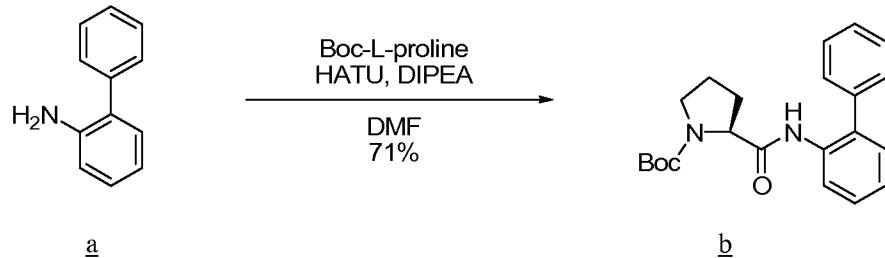
A mixture of amine d (1.35 g, 7.8 mmol), *N*-Boc-*N*-methyl alanine e (1.74 g, 8.6 mmol), EDC (1.65 g 8.8 mmol) and MeCN (50 mL) was maintained at rt overnight. The MeCN was removed under reduced pressure, and the residue diluted with EtOAc, washed with 0.5 N HCl (3 × 10 mL),

0.5 N NaOH (3 × 10 mL), dried (MgSO₄), filtered, and concentrated to provide 2.1 g (75%) of protected dipeptide f, as a clear oil.

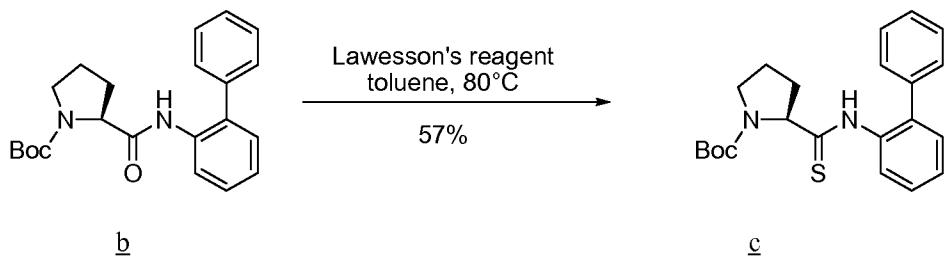


To a 0 °C solution of ester f (2.10 g, 5.86 mmol) and THF (50 mL) were added LiOH·H₂O (1.23 g, 29.3 mmol) and water (2 mL). The mixture was maintained at 0 °C for 2 h, then the cooling bath was removed and the mixture was stirred overnight. Most of the THF was then removed under reduced pressure and the residue was diluted with CH₂Cl₂, washed with 0.5 N HCl, dried (MgSO₄), filtered, and concentrated to provide 1.53 g (78%) of dipeptide N-Boc-N-methyl-L-alanine-L-dehydropyranylglycine g, as a colorless solid.

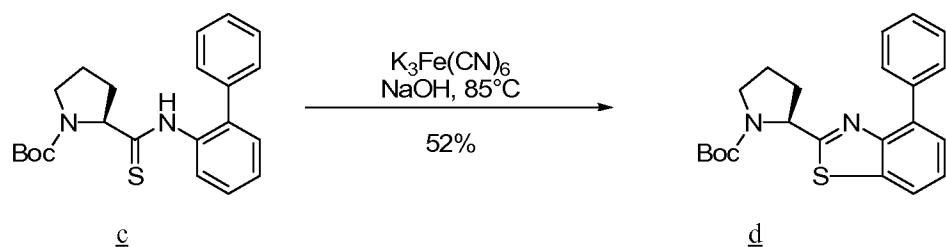
Example 9 (S)-tert-butyl 2-(4-phenylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate



To a stirred solution of Boc-L-proline (1.0 g, 4.6 mmol) in 50 ml of dry DMF was added DIPEA (2.4 ml, 13.8 mmol), followed by HATU (1.75 g, 4.6 mmol). The resulting solution was stirred for 5 minutes at room temperature. 2-amino-biphenyl a (0.89 g, 5.3 mmol) was then added in a single portion, and stirring was continued at room temperature for 2h. The solution was then heated to 45°C for 5h and cooled to room temperature over 16h. The reaction was then poured into 250 ml of water, to which was added 50 ml of brine. The aqueous phase was extracted 3 times with 50 ml EtOAc, and the organics combined. The organic phases were then washed with 100 ml 1 M HCl and 100 ml brine before being dried with MgSO₄, filtered and concentrated to an oil. This oil was adsorbed onto silica gel and purified by flash chromatography (40g SiO₂, 0% to 40% EtOAc in hexanes) to afford the desired amide b as a clear oil (1.2 g, 3.3 mmol, 71%).

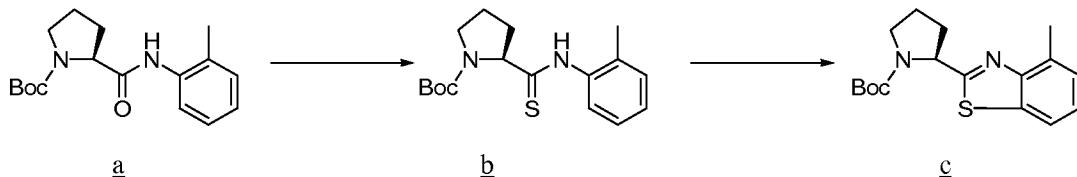


To a stirred solution of b (1.06g, 2.9 mmol) in 30 ml toluene was added Lawesson's reagent (0.69g, 1.7 mmol) in a single portion. The reaction was warmed to 80°C on an oil bath for 3h, then cooled to room temperature over 16h. The solution was adsorbed onto silica gel and purified by flash chromatography (40g SiO₂, 0% to 40% EtOAc in hexanes) to afford the desired thioamide c as a clear oil (0.63g, 1.6 mmol, 57%).



To a stirred solution of K₃Fe(CN)₆ (1.51g, 4.6 mmol) in 4 ml water at 85°C was slowly added a suspension of c obtained by initially wetting c (0.42g, 1.1 mmol) with a few drops of EtOH, then adding a 30% solution of NaOH (1.2 ml, 9.0 mmol) and pipetting vigorously for a several minutes. After addition was complete, the reaction was stirred for 2 ½ hours at 85°C, after which the reaction was diluted with 25 ml water and filtered. The filtrate was dissolved in dichloromethane and adsorbed onto silica gel and purified by flash chromatography (12g SiO₂, 0% to 25% EtOAc in hexanes) to give (S)-tert-butyl 2-(4-phenylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate d (0.22g, 0.58 mmol, 52%).

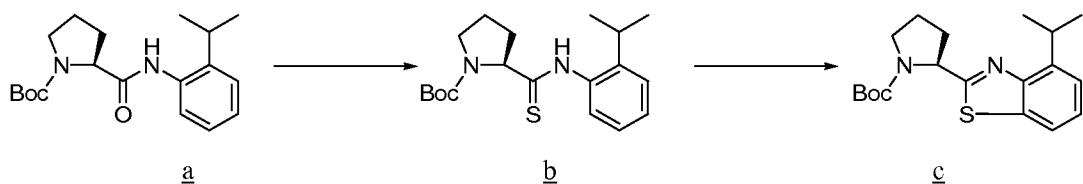
Example 10 (S)-tert-butyl 2-(4-methylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate



Compound c was prepared according to procedures in example 9, above. Ortho-toluidine (0.72 ml, 6.7 mmol) was converted to compound a (1.49g, 4.9 mmol, 87%). Compound a (1.14g, 3.7

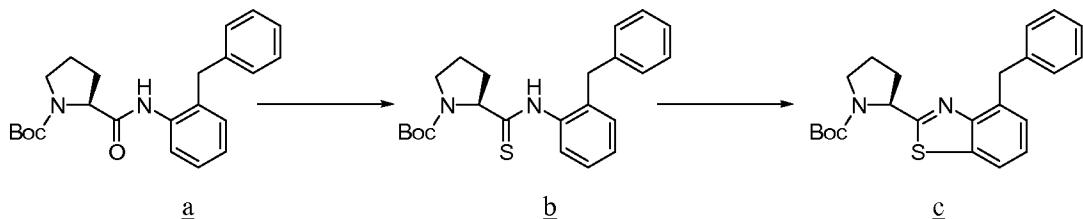
mmol) was then converted to compound **b** (0.27g, 0.84 mmol, 23%). Compound **b** (0.27g, 0.84 mmol), was converted to compound **c**.

Example 11 (S)-tert-butyl 2-(4-isopropylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate



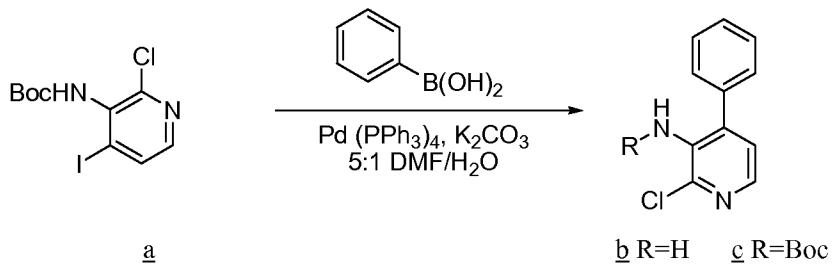
Compound c was prepared according to procedures in example 9. 2-isopropylaniline (0.9 ml, 5.2 mmol) was converted to compound a (1.53g, 4.9 mmol, 87%). Compound a (1.53g, 4.9 mmol) was then converted to compound b (1.14g, 3.3 mmol, 67%). Compound b (1.14g, 3.3 mmol), was converted to (S)-tert-butyl 2-(4-isopropylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate c (0.35g, 1.0 mmol, 31%).

Example 12 (S)-tert-butyl 2-(4-benzylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate

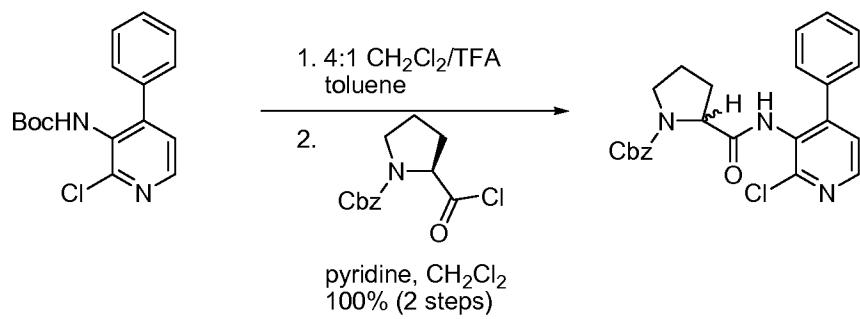


Compound c was prepared according to procedures in example 9. 2-benzyl aniline (1.18g, 6.4 mmol) was converted to compound a (1.43g, 3.8 mmol, 59%). Compound a (1.18g, 3.1 mmol) was then converted to compound b (0.85g, 2.1 mmol, 69%). Compound b (0.85g, 2.1 mmol), was converted to (S)-tert-butyl 2-(4-benzylbenzo[d]thiazol-2-yl)pyrrolidine-1-carboxylate c (0.18g, 0.46 mmol, 22%).

Example 14 7-phenyl-2-(pyrrolidin-2-yl)thiazolo[5,4-b]pyridine



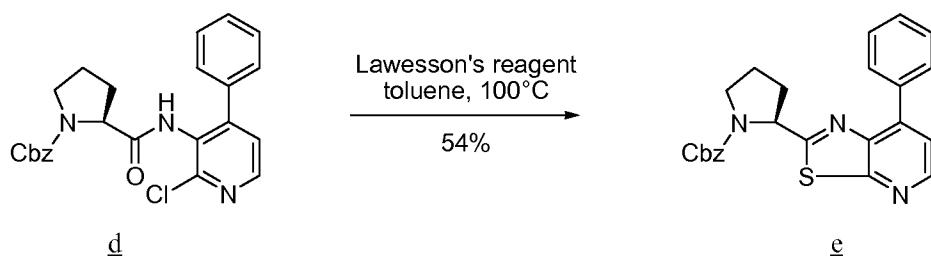
(2-chloro-4-iodo-pyridin-3-yl)-carbamic acid tert-butyl ester a (4.20g, 11.8 mmol), phenyl boronic acid (1.90g, 15.6 mmol), potassium carbonate (2.42g, 17.5 mmol) and tetrakis(triphenylphosphine) palladium(0) (0.68g, 0.59 mmol) were weighed into a 20 ml microwave vial. The vial was evacuated, then purged with nitrogen gas 3 times. 16.7 ml dry DMF was added, then 3.3 ml of water, which had been degassed by bubbling nitrogen through it overnight. The vial was then capped and microwaved at 130°C for 40 minutes. The resulting solution was poured into 250 ml water and extracted with EtOAc (3x50 ml). The combined organics were dried with MgSO₄, filtered and concentrated. The resulting oil was adsorbed onto silica gel and purified by flash chromatography (150g SiO₂, 0% to 40% EtOAc in hexanes) to give 2-chloro-3-amino-4-phenyl pyridine b (0.84g, 4.1 mmol, 35%) and the Boc-protected 2-chloro-3-amino-4-phenyl pyridine c (1.74g, 5.7 mmol, 48%) as yellow and white solids, respectively.



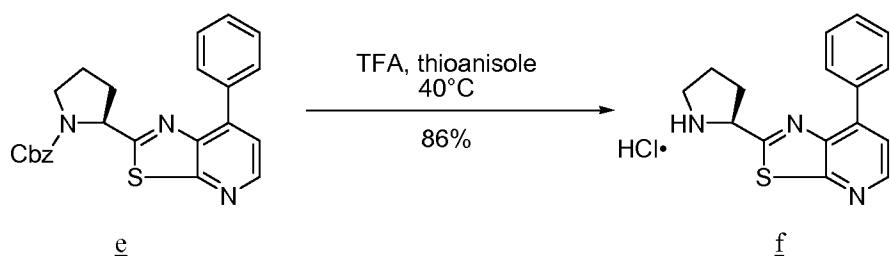
Compound 2 (1.74g, 5.7 mmol) was dissolved in 50 ml of 4:1 methylene chloride/TFA and 1 ml of toluene was added. The resulting solution was heated to 40°C for 2h, after which the reaction mixture was concentrated to a yellowish solid. This solid was dissolved in 50 ml methylene chloride and washed with 100 ml aqueous 1N NaOH. After the layers were separated, the aqueous phase was extracted a further two times with 50 ml methylene chloride. The organic extracts were combined, dried with MgSO₄, filtered and concentrated to a yellow solid, which was carried on without further purification.

To a stirred solution of 2-chloro-3-amino-4-phenyl pyridine in dry methylene chloride was added pyridine (2.5 ml, 30.9 mmol) and then (S)-benzyl 2-(chlorocarbonyl)pyrrolidine-1-carboxylate (1.83g, 6.8 mmol) prepared in example 15, dropwise. The reaction mixture was stirred 16h under a nitrogen atmosphere, then poured into 200 ml of 1N HCl. The layers were separated, and the aqueous phase extracted with methylene chloride (3x50 ml). The combined organics were dried with MgSO_4 , filtered and concentrated. The resulting oil was adsorbed onto silica gel and purified

by flash chromatography (40g SiO₂, 0% to 60% EtOAc in hexanes) to give the desired amide **d** as a foam (2.51g, 5.8 mmol, 100%).

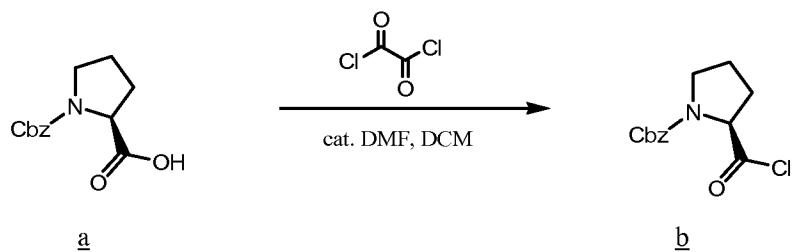


Compound **d** (1.78g, 4.08 mmol) and Lawesson's reagent (1.05g, 2.60 mmol) were dissolved in 10 mL of dry dimethoxyethane and heated to 40°C for 24 hours. A second portion of Lawesson's reagent (0.56g, 1.38 mmol) was added and heating was continued for 48 hours. The reaction was quenched through addition of 1 ml dimethylformamide, and stirring was continued for 1h at 40°C. The solution was cooled, then diluted with 100 ml EtOAc. This was washed with a 1% solution of NaClO (3x 50 ml), dried with MgSO₄, filtered and adsorbed onto silica gel and purified by flash chromatography (40g SiO₂, 0% to 60% EtOAc in hexanes) to give the desired 7-aza benzothiazole **e** as a white foam (1.06 g, 2.55 mmol, 62%).



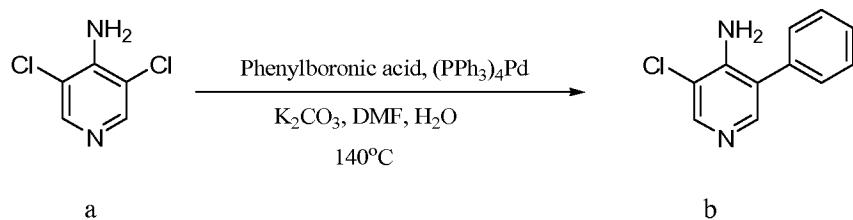
Compound e (1.30g, 3.1 mmol) was dissolved in 30 ml TFA. Thioanisole (2.9 ml, 24.7 mmol) was added, and the solution was warmed to 40°C for 16 hours. The volatiles were then removed under vacuum, and the resulting oil dissolved in diethyl ether (50 mL). The solution was poured into 1 N NaOH (200 ml) and the layers separated. The aqueous phase was extracted with diethyl ether (2 x 50 ml) and the organics combined. The organic phases were dried with MgSO₄, and filtered. 4 N HCl in dioxane (0.8 ml, 3.2 mmol) was added, and a white solid precipitated. The material was cooled to 4°C for 4 hours, then filtered, washing with cold diethyl ether (3 x 50 ml) to give 7-phenyl-2-(pyrrolidin-2-yl)thiazolo[5,4-b]pyridine hydrochloride salt f (0.852g, 2.7 mmol, 86%) as fine white crystals. The product contained 10-20% of the undesired proline stereoisomer, which was removed at this stage by purification using chiral SFC. Aliquots were injected on a Mettler-Toledo SFC Semi-Prep system equipped with a Chiraldpak OD column (21.2 x 250 mm) and eluted isocratically using 20% MeOH in supercritical CO₂.

Example 15 (S)-benzyl 2-(chlorocarbonyl)pyrrolidine-1-carboxylate

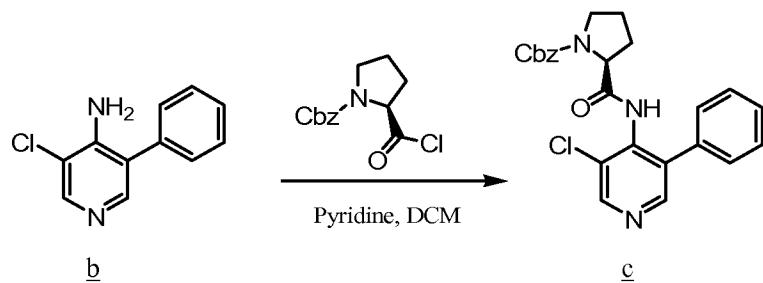


Cbz-Pro-OH a (2.0 g, 8.0 mmol) was dissolved in DCM (10 mL) and oxaly chloride (6 mL of a 2M solution, 12.0 mmol) was added. DMF (2 drops) was added and the mixture was stirred at room temperature for 30min. The solution was concentrated to afford 2.1 g (100%) of acid chloride (S)-benzyl 2-(chlorocarbonyl)pyrrolidine-1-carboxylate b as a pale yellow oil.

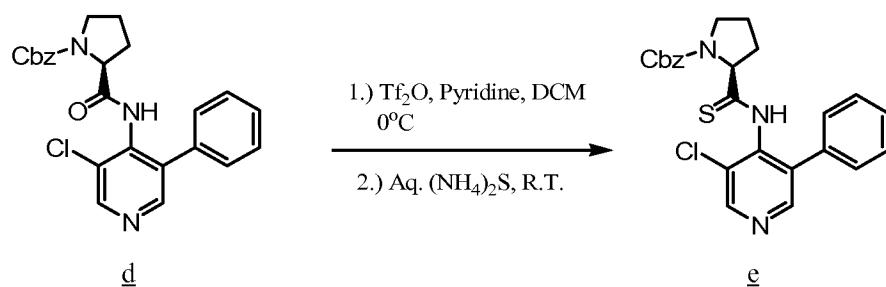
Example 16 7-phenyl-2-((S)-pyrrolidin-2-yl)thiazolo[5,4-c]pyridine



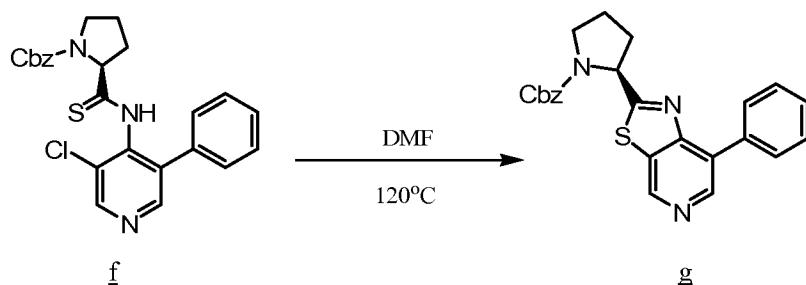
4-amino-3,5-dichloropyridine a (2.0 g, 12.3 mmol), tetrakis(triphenylphosphine)palladium (696 mg, 0.6 mmol), phenylboronic acid (1.9 g, 15.9 mmol) and potassium carbonate (2.2 g, 15.9 mmol) were mixed in a 10 mL microwave vial under N₂ atmosphere. DMF (6 mL) and deoxygenated H₂O (1.2 mL) were added. N₂ was bubbled through the mixture for 5min and the mixture was heated for 20min at 140°C in the microwave. The mixture was diluted with water (30 mL) and extracted with EtOAc (3x20 mL). The combined organic phases were washed with water (50 mL) and brine (50 mL), dried with MgSO₄, filtered and concentrated. The resulting brown oil was adsorbed on silica gel and purified by flash chromatography (SiO₂, 0% to 70% ethyl acetate/hexanes) to afford 970 mg (37%) of b as a colorless oil. MS: m/z = 205 (M+H).



4-amino-3-chloro-5-phenylpyridine b (650 mg, 3.16 mmol) was dissolved in DCM (10 mL). Cbz-Pro-Cl (1.6 g, 6.3 mmol), dissolved in DCM (5 mL) was added, followed by pyridine (467 mg, 6.3 mmol) and the mixture was stirred overnight at room temperature. The reaction was quenched with 0.5N HCl, the phases were separated and the aqueous phase was extracted with DCM (2x20 mL). The combined organic phases were dried with MgSO₄, filtered and concentrated. The resulting oil was adsorbed on silica gel and purified by flash chromatography (SiO₂, 0% to 100% EtOAc/hexanes) to afford 1.12 g (80%) of c as a colorless oil, MS: m/z = 436 (M+H).

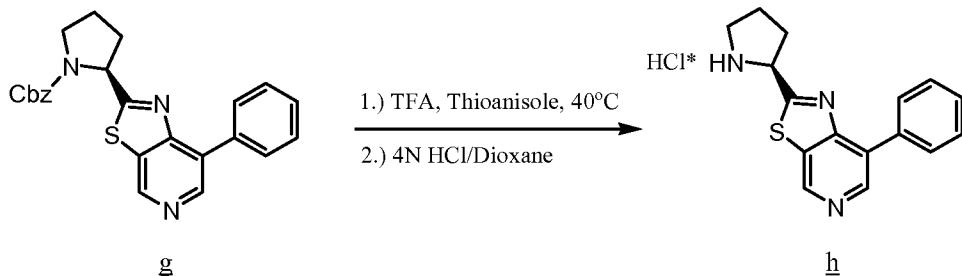


Following the general procedure of Charette (Charette, A.B. et al, *J. Org. Chem.*, 2003, **68**, 5792-5794), compound d (1.7 g, 3.9 mmol) and pyridine (0.89 mL, 4.7 mmol) were mixed together in DCM (20 mL) at 0°C and the solution was stirred for 5min. Trifluoromethanesulfonic anhydride (1.3 g, 4.7 mmol) was slowly added. The solution was stirred for 3h and allowed to warm up to room temperature. The reaction was quenched by rapid addition of 20% aqueous ammonium sulfide (2.0 mL, 5.8 mmol) and stirred overnight at room temperature. The mixture was filtered through a pad of silica gel and washed with DCM (50 mL). The filtrate was concentrated and the resulting oil was adsorbed on silica gel and purified by flash chromatography (SiO₂, 0% to 70% ethyl acetate/hexanes) to afford 500 mg (28%) of e as a yellow solid. MS: m/z = 452 (M+H).



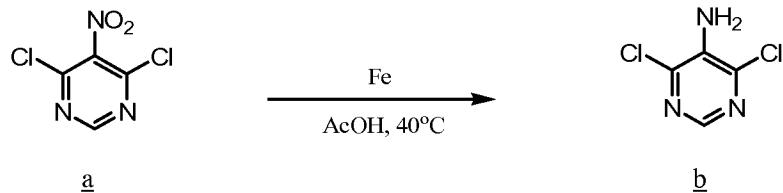
Compound f was dissolved in DMF (5 mL) and the solution was stirred at 120°C for 3 days. The mixture was cooled to room temperature, diluted with 20 mL of H₂O and extracted with EtOAc (3x25 mL). The combined organic phases were washed with water (50 mL) and brine (50 mL), dried with MgSO₄, filtered and concentrated. The resulting oil was adsorbed on silica gel and

purified by flash chromatography (SiO_2 , hexanes to ethyl acetate) to afford 423 mg (98%) of g as a yellow oil. MS: m/z = 415 ($\text{M}+\text{H}$).

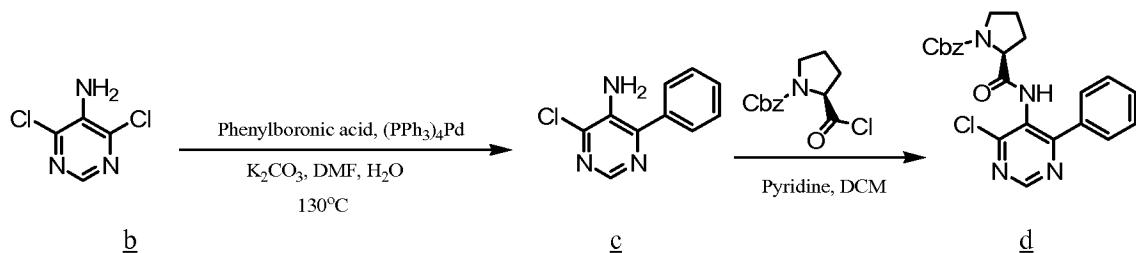


Compound g (423 mg, 1.0 mmol) and thioanisole (993 mg, 8.0 mmol) were dissolved in TFA (40 mL). The mixture was stirred at 40°C overnight. The mixture was cooled to room temperature and concentrated. The residual oil was dissolved in ether (20 mL) and washed with 1N NaOH (30 mL). The aqueous phase was extracted with ether (2x20 mL). The combined organic phases were dried with MgSO_4 and filtered. 4N HCl in dioxane was added until a solid precipitated. The solid was collected by filtration, washed with ether and air dried to afford 240 mg (76%) of 7-phenyl-2-((S)-pyrrolidin-2-yl)thiazolo[5,4-c]pyridine h as a pale yellow solid. MS: m/z = 282 ($\text{M}+\text{H}$).

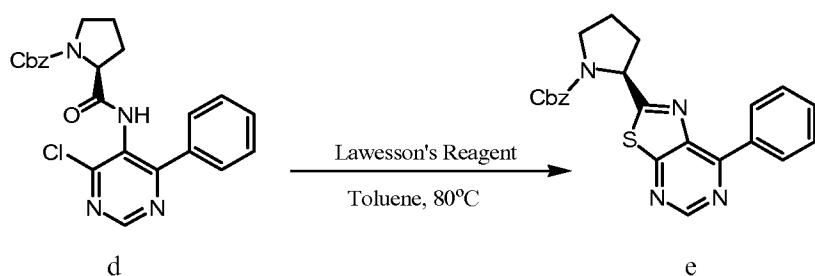
Example 17 7-phenyl-2-((S)-pyrrolidin-2-yl)thiazolo[5,4-d]pyrimidine



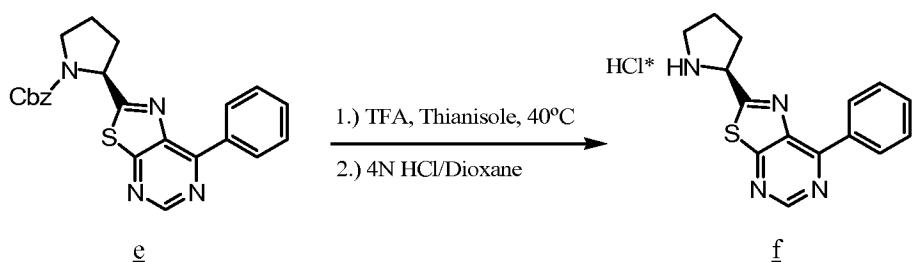
Iron powder (12.5 g, 112 mmol) was added to a suspension of 4,6-dichloro-5-nitropyrimidine a (7.0 g, 36.1 mmol) in acetic acid (70 mL). The mixture was stirred at 40°C for 45min. The mixture was poured onto ice and neutralized by addition of solid sodium bicarbonate. The aqueous phase was extracted with EtOAc (3x200 mL). The combined organic phases were dried with MgSO_4 , filtered and concentrated to afford a pale yellow solid. Recrystallization in hot ethyl acetate afforded 3.6 g (61%) of compound b as off-white needles. MS: m/z = 165 ($\text{M}+\text{H}$).



Compound c was prepared from compound b (1.0 g, 6.1 mmol) using the general procedure for preparing compound b in example 16. The procedure afforded 410 mg (28%) of c as a yellow solid. MS: m/z = 206 (M+H). Compound d was prepared from compound c (270 mg, 1.3 mmol) using the general procedure for preparing compound c in example 16. The procedure afforded 565 mg (99%) of d as a colorless oil. MS: m/z = 437 (M+H).

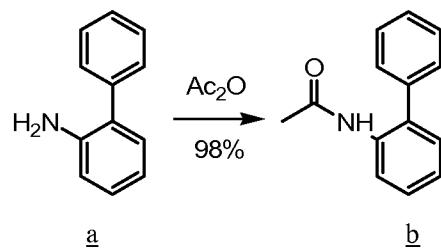


A mixture of compound **d** (550 mg, 1.26 mmol) and Lawesson's reagent (341 mg, 0.84 mmol) in toluene (10 mL) was heated at 80°C overnight. The solution was concentrated, adsorbed on silica gel and purified by flash chromatography (SiO₂, 0% to 60% ethyl acetate/hexanes) to afford 514 mg (98%) of **e** as a pale yellow solid. MS: m/z = 417 (M+H).

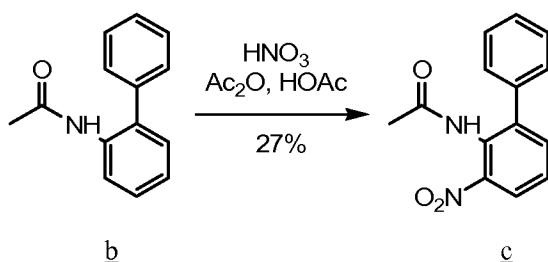


Compound f was prepared from compound e (510 mg, 1.2 mmol) using procedure for preparing compound h in example 16. The procedure afforded 378 mg (98%) of 7-phenyl-2-((S)-pyrrolidin-2-yl)thiazolo[5,4-d]pyrimidine f as an off-white solid. MS: m/z = 283 (M+H).

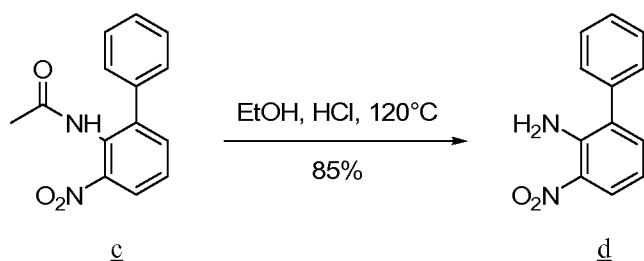
Example 18 2,3-diaminobiphenyl



2-Aminobiphenyl a (21.9289g, 130mmol) was dissolved in Ac₂O (30mL, 318mmol) and stirred 10 minutes. An additional portion of Ac₂O (10mL, 106mmol) was added then stirred for 10 more minutes. The sample was poured onto ice. The resulting solid was vacuum filtered and washed with H₂O to give N-acetyl-2-aminobiphenyl b (26.955g, 128mmol, 98%).

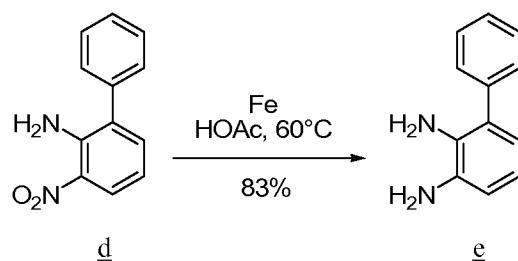


Following the general procedure of Stepan (Stepan, A. H., et al, *J. Am. Chem. Soc.*, 1949, 71, 2438), N-acetyl-2-aminobiphenyl b (7.198g, 34.1mmol), HOAc (6mL), and Ac₂O (5mL) were mixed and heated at 120°C for a few minutes until N-acetyl-2-aminobiphenyl b was dissolved. The sample was cooled to room temperature. HOAc (1.5mL) was added slowly to 2.3mL of fuming HNO₃ (2.3mL, 54.5mmol) in an ice bath. While maintaining a temperature of less than 26.5°C, 1.5mL of the HNO₃ mixture was added quickly then the remaining HNO₃ mixture was added drop wise to N-acetyl-2-aminobiphenyl b. The sample was stirred at room temperature for 4 hours then stored at 4°C overnight. The reaction mixture was poured into ice and extracted once with benzene. The benzene layer was stored at 4°C for 1 hour. The resulting solid was vacuum filtered and washed with cold benzene to give N-acetyl-2-amino-3-nitrobiphenyl c (2.346g, 9.15mmol, 27%).



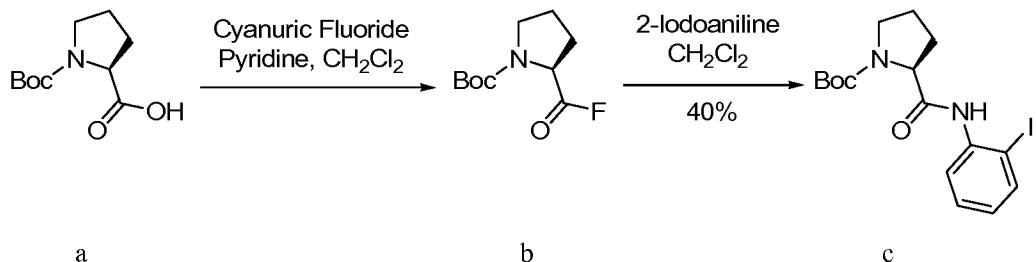
N-Acetyl-2-amino-3-nitrobiphenyl c (1.008g, 3.93mmol), EtOH (19mL, 325mmol), and concentrated HCl (5mL, 50mmol) were mixed and refluxed at 120°C overnight. The sample was

adsorbed onto silica gel and purified by flash chromatography (12g SiO₂, 0-33% EtOAc in hexanes) to give 2-amino-3-nitrobiphenyl d (0.720g, 3.36mmol, 85%)



2-Amino-3-nitrobiphenyl d (0.613g, 2.86mmol) was purged under nitrogen for 30 minutes then HOAc (5mL) was added followed by iron powder (0.4895g, 8.76mmol). The sample was heated at 60°C for 30 minutes then HOAc (5mL) was added. The sample was stirred at 60°C for 1 hour then poured into ice. The sample was extracted with EtOAc (3 X 100 mL). The EtOAc extracts were washed with saturated NaHCO₃ (3 X 100 mL). The EtOAc layer was dried over MgSO₄, filtered, and concentrated to give 2,3-diaminobiphenyl e (0.439g, 2.38mmol, 83%).

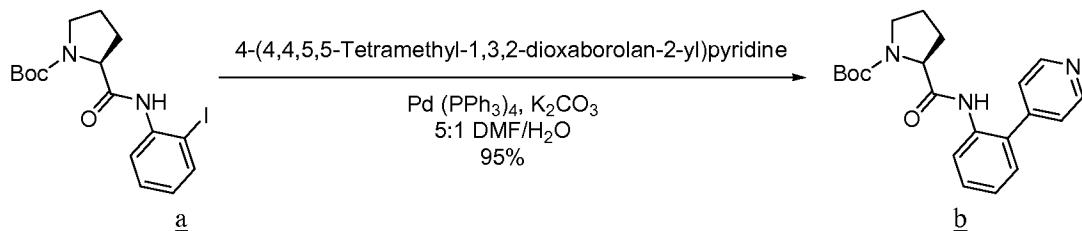
Example 19 2(S)-[[(2-Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



Boc-Pro-OH a (5.0030g, 23.2mmol) was dissolved in dry CH₂Cl₂ (50mL) then cooled to 0°C. Dry pyridine (3.8mL, 46.4mmol) was added. Cyanuric fluoride (2.2mL, 25.5mmol) was added drop wise. The sample was warmed to room temperature and stirred for 30 minutes. H₂O (5mL) was added to quench the reaction. The reaction mixture was diluted with H₂O and extracted three times with CH₂Cl₂. The CH₂Cl₂ extracts were washed with saturated NaCl, The CH₂Cl₂ layer was dried over MgSO₄, filtered, and concentrated to give the acid fluoride b which was used without further purification. The acid fluoride b was dissolved in dry CH₂Cl₂ (50mL). 2-Iodoaniline (4.9932g, 22.8mmol) was added, and the sample was stirred overnight. The reaction mixture was adsorbed onto silica gel and purified by flash chromatography (80g SiO₂, 0-50% EtOAc in

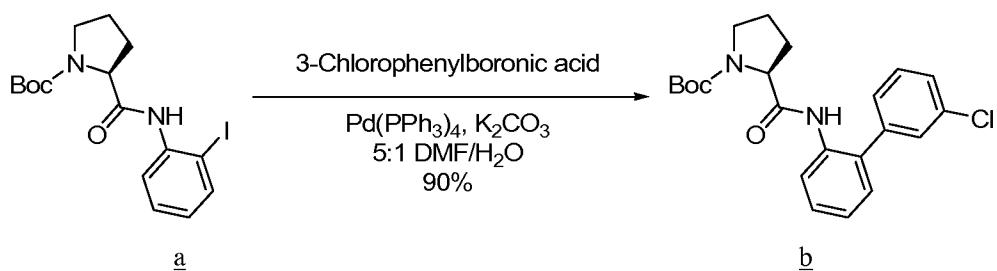
hexanes) to give 2(S)-[(2-iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid c (3.845g, 9.24mmol, 40%).

Example 20 2(S)-[[[2-(4-pyridyl)phenyl]amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



2(S)-[(2-Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **a** (0.4810g, 1.16mmol), 4-(4,4,5,5-Tetramethyl-1,3,2-dioxaborolan-2-yl)pyridine (0.3240g, 1.58mmol), K₂CO₃ (0.2190g, 1.58mmol), and Pd(PPh₃)₄ (0.0702g, 0.0607mmol) were combined in a 5 mL microwave vial. The sample was evacuated and purged with nitrogen three times, Dry DMF (2mL) and deoxygenated H₂O (0.4mL) were added. The sample was microwaved at 130°C for 10 minutes. The reaction mixture was diluted with H₂O and extracted three times with EtOAc. The EtOAc extracts was dried over MgSO₄, and filtered. The crude material was adsorbed onto silica gel and purified by flash chromatography (4g SiO₂, 0-100%EtOAc in hexanes) to give the 2(S)-[(2-(4-pyridyl)phenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **b** (0.404g, 1.10mmol, 95%).

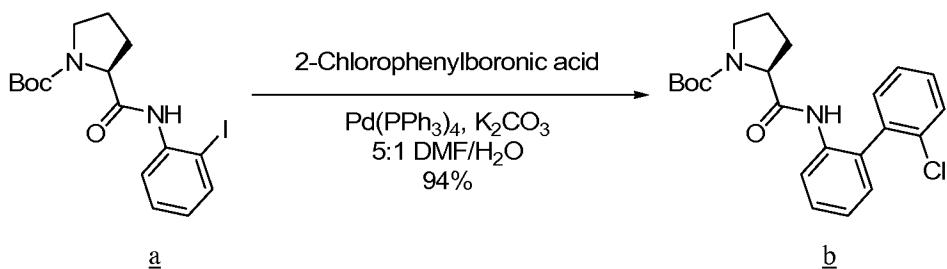
Example 21 2(S)-[[2-(3'-Chloro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



Following the procedure of example 20, 2(S)-[(2-Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **a** (0.4576g, 1.10mmol), 3-chlorophenylboronic acid (0.2520g, 1.61mmol), K_2CO_3 (0.2431g, 1.76mmol), and $Pd(PPh_3)_4$ (0.0725g, 0.0627mmol)

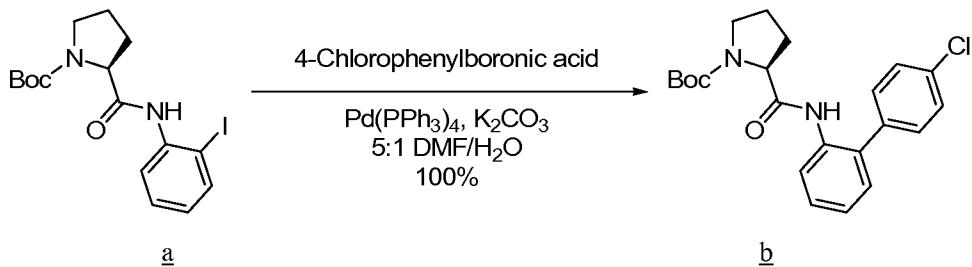
gave the 2(S)-[[2-(3'-chloro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid b (0.399g, 0.995mmol, 90%).

Example 22 2(S)-[[2-(2'-Chloro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



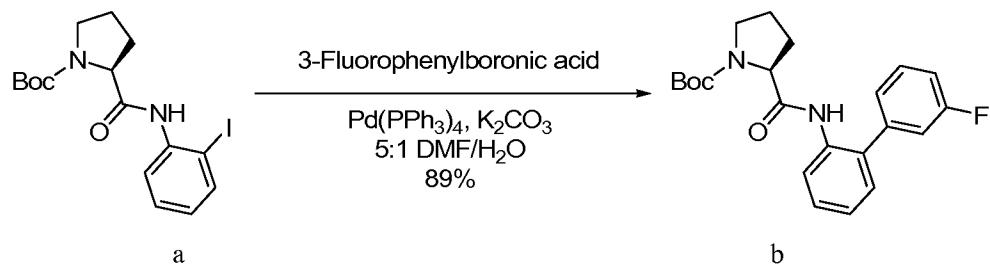
Following the procedure of example 20, 2(S)-[[2-(Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid a (0.4554g, 1.09mmol), 2-chlorophenylboronic acid (0.2518g, 1.59mmol), K_2CO_3 (0.2592g, 1.88mmol), and $\text{Pd}(\text{PPh}_3)_4$ (0.0752g, 0.0651mmol) gave the 2(S)-[[2-(2'-chloro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid b (0.414g, 1.03mmol, 94%).

Example 23 2(S)-[[2-(4'-Chloro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



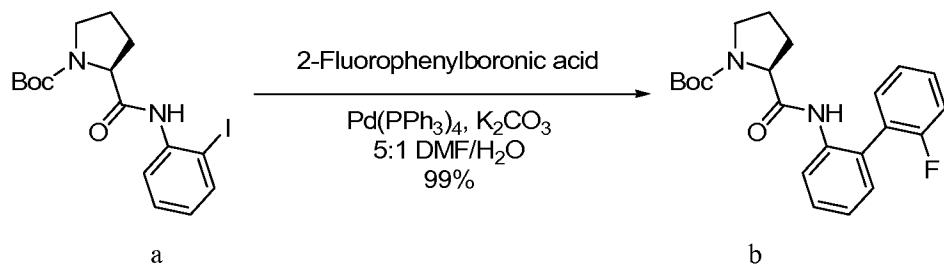
Following the procedure of example 20, 2(S)-[[2-(Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid a (0.4494g, 1.08mmol), 4-chlorophenylboronic acid (0.2561g, 1.62mmol), K_2CO_3 (0.2639g, 1.91mmol), and $\text{Pd}(\text{PPh}_3)_4$ (0.0732g, 0.0633mmol) gave the 2(S)-[[2-(4'-chloro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid b (0.411g, 1.08mmol, 100%).

Example 24 2(S)-[[2-(3'-Fluoro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



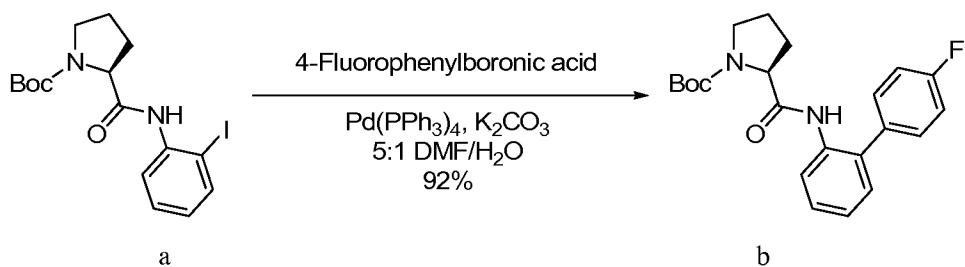
Following the procedure of example 20, 2(S)-[(2-Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **a** (0.4507g, 1.08mmol), 3-fluorophenylboronic acid (0.2158g, 1.54mmol), K_2CO_3 (0.2343g, 1.69mmol), and $Pd(PPh_3)_4$ (0.0756g, 0.0654mmol) gave the 2(S)-[(2-(3'-fluoro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **b** (0.387g, 1.01mmol, 89%).

Example 25 2(S)-[[2-(2'-Fluoro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid



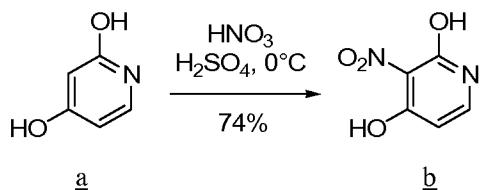
Following the procedure of example 20, 2(S)-[(2-Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **a** (0.4487g, 1.08mmol), 2-fluorophenylboronic acid (0.2154g, 1.54mmol), K_2CO_3 (0.2305g, 1.67mmol), and $Pd(PPh_3)_4$ (0.0663g, 0.0574mmol) gave the 2(S)-[(2-(2'-fluoro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid **b** (0.410g, 1.07mmol, 99%).

Example 26 2(S)-[[2-(4'-Fluoro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid

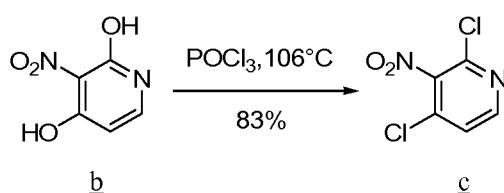


Following the procedure of example 20, 2(S)-[[2-Iodophenyl)amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid a (0.4467g, 1.07mmol), 4-fluorophenylboronic acid (0.2230g, 1.59mmol), K_2CO_3 (0.2434g, 1.76mmol), and $\text{Pd}(\text{PPh}_3)_4$ (0.0686g, 0.0594mmol) gave the 2(S)-[[2-(4'-fluoro(1,1'-biphenyl))amino]carbonyl]-1-(1,1-dimethylethylester)-1-pyrrolidinecarboxylic acid a (0.382g, 0.994mmol, 92%).

Example 27 3-Amino-4-chloro-2-phenylpyridine

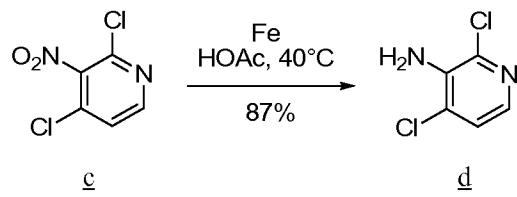


Following the general procedure of Norman (Norman, M. H., et al, *J. Med. Chem.*, 2000, **43**, 4288), 2,4-dihydroxypyridine (4.931g, 44.4mmol) and H_2SO_4 (20mL) were combined and cooled to 0°C. HNO_3 (20mL, 444mmol) was added dropwise. The sample was stirred for 30 minutes then poured onto ice. The resulting solid was stored at 4°C for 1 hour then vacuum filtered to give 2,4-dihydroxy-3-nitropyridine (5.143g, 32.9mmol, 74%).

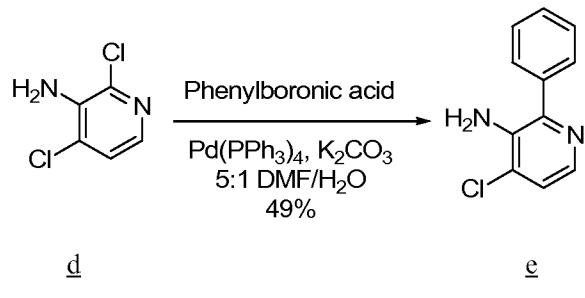


Following the general procedure of Norman (Norman, M. H., et al, *J. Med. Chem.*, 2000, **43**, 4288), 2,4-dihydroxy-3-nitropyridine b (2.0013g, 12.9mmol) and POCl_3 (25mL, 268mmol) were combined under nitrogen. The mixture was heated to 106°C and stirred overnight. The sample was concentrated and poured onto ice. The reaction mixture was extracted with EtOAc (3 X 100

mL). The EtOAc extracts were washed with saturated NaCl (1 X 100 mL). The EtOAc layer was dried over MgSO₄ and filtered. The crude material was adsorbed onto silica gel, filtered through a plug of silica gel (50%EtOAc in hexanes), and concentrated to give 2,4-dichloro-3-nitropyridine c (2.058g, 10.7mmol, 83%).

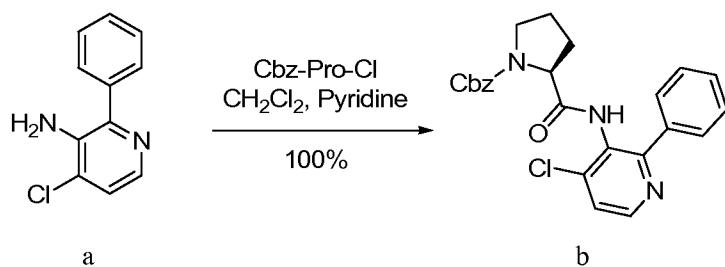


2,4-Dichloro-3-nitropyridine c (2.058g, 10.7mmol) was dissolved in HOAc (10mL) under nitrogen. Iron powder (1.9191g, 34.4mmol) was added. The sample was heated at 40°C for two hours. The reaction mixture was poured onto ice and then NaHCO₃ was added to give a neutral solution. The sample was extracted with EtOAc (3 X 100 mL). The EtOAc extracts were washed with saturated NaHCO₃ (1 X 100 mL). The combined aqueous layers were back extracted once with 100 mL EtOAc. The combined EtOAc extracts were dried over MgSO₄, filtered, and concentrated to give 3-amino-2,4-dichloropyridine d (1.510g, 9.26mmol, 87%).

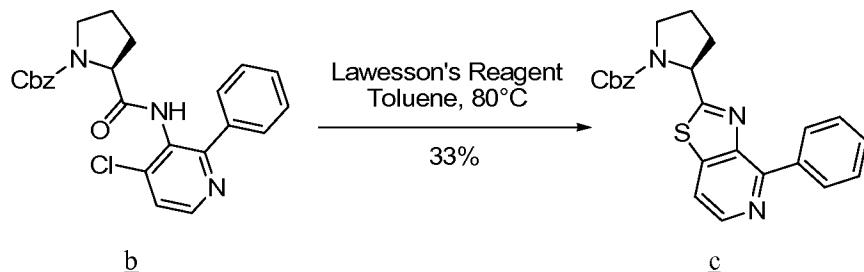


3-Amino-2,4-dichloropyridine d (0.7047g, 4.32mmol), phenylboronic acid (0.5177g, 4.24mmol), K₂CO₃ (0.8023g, 5.80mmol), and Pd(PPh₃)₄ (0.0702g, 0.0607mmol) were combined. The sample was evacuated and purged with nitrogen three times. Dry DMF (2mL) and deoxygenated H₂O (0.4mL) were added. The sample was microwaved at 130°C for 40 minutes. The reaction mixture was diluted with H₂O (50 mL) and extracted with EtOAc (3 X 50 mL). The EtOAc extracts was dried over MgSO₄ and filtered. The crude material was adsorbed onto silica gel and purified by flash chromatography (40g SiO₂, 0-30%EtOAc in hexanes) to give 3-amino-4-chloro-2-phenylpyridine e (0.435g, 2.12mmol, 49%).

Example 28 2(S)-[[4-phenyl-2-thiazolo[4,5-c]pyridinyl]-1-(9H-fluoren-9-ylmethyl)ester-1-pyrrolidinecarboxylic acid

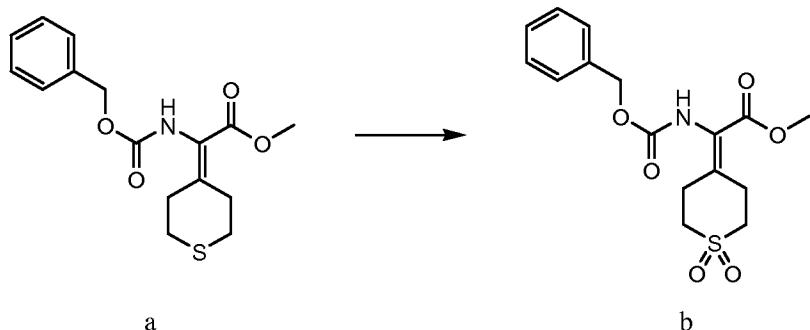


3-Amino-4-chloro-2-phenylpyridine a (0.435g, 2.12mmol) was dissolved in dry CH₂Cl₂ (10mL). Dry pyridine (0.86mL, 10.6mmol) was added. Cbz-Pro-Cl (1.0804g, 4.04mmol), prepared according to example 15, in CH₂Cl₂ (5mL) was added dropwise. The sample was stirred for one hour. The reaction mixture adsorbed onto silica gel and purified by flash chromatography (40g SiO₂, 0-100% EtOAc in hexanes) to give 2(S)-[[4-chloro-2-phenyl-3-pyridinyl]amino]carbonyl]-1-(9H-fluoren-9-ylmethyl)ester-1-pyrrolidinecarboxylic acid b (0.986g, 2.12mmol, 100%).

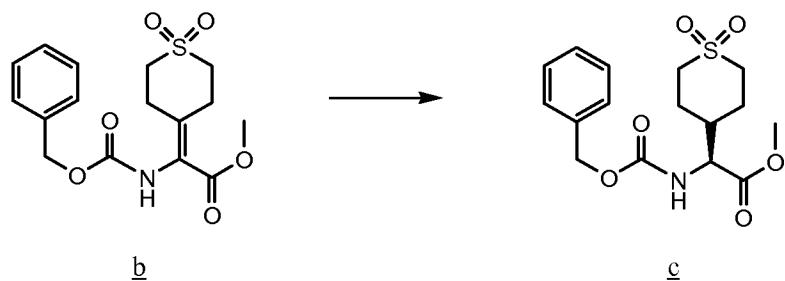


2(S)-[[4-Chloro-2-phenyl-3-pyridinyl]amino]carbonyl]-1-(9H-fluoren-9-ylmethyl)ester-1-pyrrolidinecarboxylic acid b (9.564g, 21.9 mmol) was dissolved in dry dimethoxyethane (240mL). Lawesson's reagent (5.83g, 14.3 mmol) was added. The sample was heated to 40°C and stirred overnight. The reaction mixture was adsorbed onto silica gel and purified by flash chromatography (330g SiO₂, hexanes to 10% MeOH in dichloromethane gradient) to give 2(S)-[[4-phenyl-2-thiazolo[4,5-c]pyridinyl]-1-(9H-fluoren-9-ylmethyl)ester-1-pyrrolidinecarboxylic acid c (11.88g, 28.6 mmol, >100%). The Cbz group in was subsequently removed under conditions identical to those in example 14.

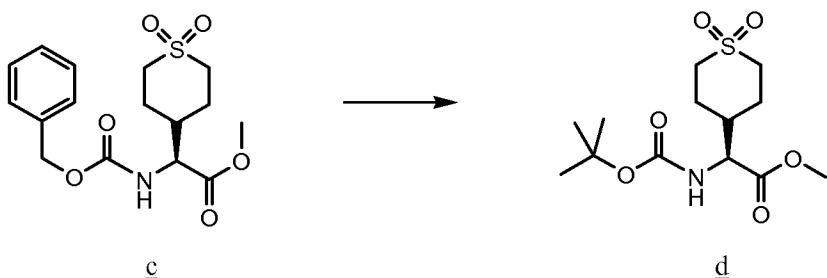
Example 29 N-Boc-protected cyclic sulfonyl amino acid



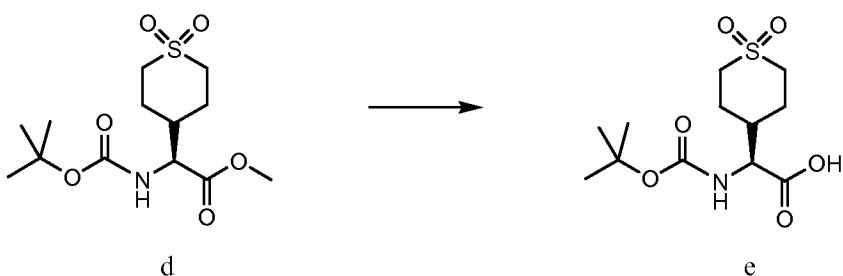
Sulfide **a** (810 mg, 2.5 mmol), synthesized according to the general procedure of Shieh [Shieh, W-C.; Xue, S.; Reel, N.; Wu, R.; Fitt, J.; Repic, O. *Tetrahedron: Asymmetry*, 2001, **12**, 2421-2425], was dissolved in methanol (25 mL). Oxone (4.5g) was dissolved in deionized water (25 mL). The methanol solution of substrate was cooled to -10 °C, and the aqueous solution of oxone was added to the reaction slowly. The reaction was kept on ice and gradually allowed to warm to room temperature while stirring overnight. Deionized water was used to dilute the reaction to approximately 150 mL, then poured into 90% ethyl acetate-hexanes for extraction. The organic phase was dried (Na_2SO_4), adsorbed onto Celite and purified by chromatography ISCO CombiFlash 40 g column, 5-90% ethyl acetate-hexanes over 30 min to afford 804 mg (2.27 mmol, 91%) of the product sulfone **b**.



Following the general procedure of Burk [Burk, M. J.; Gross, M. F.; Martinez, J. P. *J. Am. Chem. Soc.* 1995, 117, 9375–9376.], alkene **b** (774 mg 2.19 mmol), dry methanol (40 mL), and [(*S,S*)-Me-BPE–Rh(COD)]⁺OTf[–] (500 mg, 0.8 mmol) were mixed in a Parr shaker flask purged with nitrogen. The Parr flask was evacuated and subsequently charged to 60 psi with hydrogen gas and shaken vigorously overnight. Methanol was removed under reduced pressure, and crude product was filtered through a small plug of silica gel using ethyl acetate. Evaporation of the solvent yielded 730 mg (2.0 mmol, 94%) of product **c** with >98% yield.

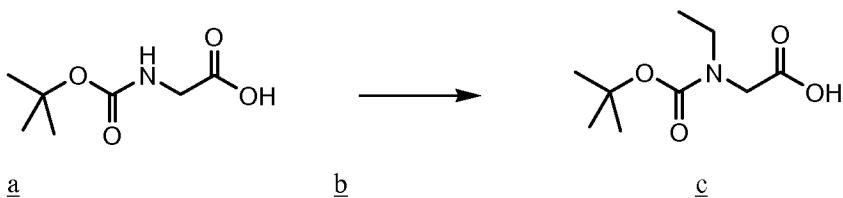


Z-protected amino ester c (804 mg, 2.27 mmol) was dissolved in methanol (16 mL). To this solution was added BOC-anhydride (1.5 g, 6.8 mmol), followed by 20% $\text{Pd}(\text{OH})_2\text{-C}$ (250 mg). All air was removed from the reaction flask by house vacuum, and the mixture was stirred vigorously for 5 min. The flask was then filled with hydrogen gas and allowed to stir vigorously at room temperature for 6 h. After evacuating the hydrogen atmosphere, the mixture was filtered through Celite using methanol, and crude product d was obtained by evaporation of the solvent (508 mg, 1.56 mmol, 70% yield).



Ester d (508 mg, 1.56 mmol) was dissolved in 8 mL of THF. Deionized water (4 mL) was added, followed by $\text{LiOH} \cdot \text{H}_2\text{O}$ (120 mg, 2.8 mmol). The mixture was stirred at room temperature overnight, acidified using aqueous 1 N HCl and extracted into ethyl acetate (3 X 25 mL). The organic extracts were dried further with Na_2SO_4 , filtered and concentrated to give 372 mg (1.21 mmol, 78% yield) of the N-Boc-protected cyclic sulfonyl amino acid e, which was carried on without purification.

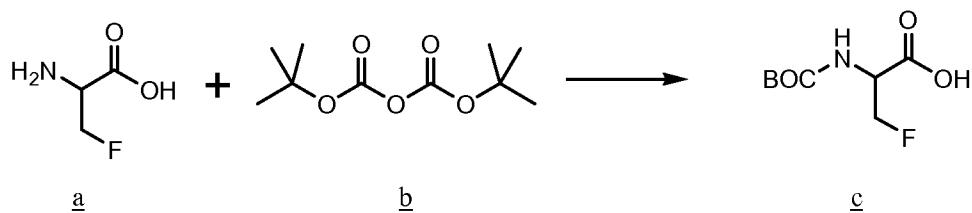
Example 30



Following the general procedure of Grigg [Blaney, P.; Grigg, R.; Rankovic, Z.; Thornton-Pett, M.; Xu, J. *Tetrahedron*, 2002, 58, 1719-1737] a roundbottom flask was charged with sodium hydride (480mg 60% dispersion in oil, 12.0 mmol, 4.0 equiv) and purged with nitrogen for 15

min. THF (6.0mL) was added to the flask, and the suspension was cooled to 0 °C using an ice water bath. A separate flask was charged with BOC-glycine **a** (525 mg, 3.0 mmol), dry THF (6.0 mL) and ethyl iodide (1.0 mL, 12 mmol, 4 equiv). This mixture was added dropwise to the NaH suspension in THF, with vigorous stirring at 0 °C. After 1 h of stirring, the reaction was warmed to room temperature and allowed to stir overnight. The reaction was again cooled to 0 °C, and methanol (4 mL) was added very slowly to quench the excess hydride. Deionized water was added to dilute the mixture, and methanol was removed under reduced pressure. Impurities were extracted into 90% ethyl acetate-hexanes, the aqueous layer was then acidified by adding solid citric acid until the pH reached 2-3. The product was extracted into 90% ethyl acetate-hexanes. This organic layer was dried (Na_2SO_4) and filtered. Removal of the solvents under reduced pressure afforded a quantitative yield of the product **b**.

Example 32



A mixture of unprotected amino acid a (775 mg, 7.24 mmol) and sodium carbonate (1.69 g, 16.0 mmol) was dissolved in a 1:1 solution of deionized water and THF (15 mL each). To this mixture was added BOC-anhydride b (1.73 g, 7.96 mmol). The mixture was stirred at room temperature overnight, and THF was removed under reduced pressure. The mixture was then acidified to pH 2–3 with saturated aqueous citric acid, and product was extracted into 10% ethyl acetate–dichloromethane. The organic layer was dried (Na_2SO_4), filtered and concentrated under reduced pressure to afford clean BOC-protected amino acid c (1.40 g, 6.7 mmol, 93%) to be used without further purification.

Example 33 IAP inhibition assays

In the following experiments was used a chimeric BIR domain referred to as MLXBIR3SG in which 11 of 110 residues correspond to those found in XIAP-BIR3, while the remainder correspond to ML-IAP-BIR. The chimeric protein MLXBIR3SG was shown to bind and inhibit caspase-9 significantly better than either of the native BIR domains, but bound Smac-based peptides and mature Smac with affinities similar to those of native ML-IAP-BIR. The improved caspase-9 inhibition of the chimeric BIR domain MLXBIR3SG has been correlated with

increased inhibition of doxorubicin-induced apoptosis when transfected into MCF7 cells.

MLXBIR3SG sequence:

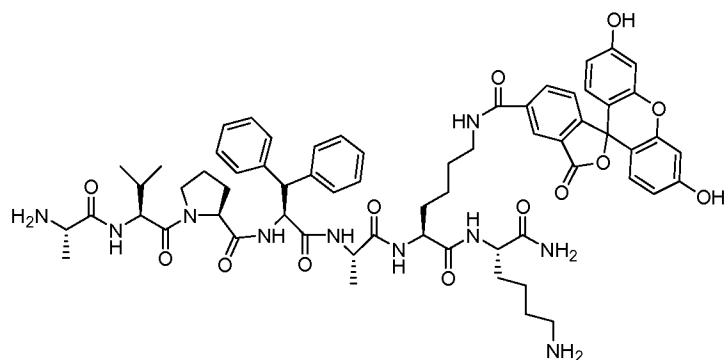
MGSSHHHHHSSGLVPRGSHMLETEEEEEEGAGATLSRGPAFPGMGSEELRLASFYDW
PLTAEVPPELLAAAGFFHTGHQDKVRCFFCYGGLQSWKRGDDPWTEHAKWFPGCQFLL
RSKGQEYINNIHLTHSL (SEQ ID NO.: 1)

TR-FRET Peptide Binding Assay

Time-Resolved Fluorescence Resonance Energy Transfer competition experiments were performed on the Wallac Victor2 Multilabeled Counter Reader (Perkin Elmer Life and Analytical Sciences, Inc.) according to the procedures of Kolb et al (Journal of Biomolecular Screening, 1996, 1(4):203). A reagent cocktail containing 300 nM his-tagged MLXBIR3SG; 200 nM biotinylated SMAC peptide (AVPI); 5 μ g/mL anti-his allophycocyanin (XL665) (CISBio International); and 200 ng/mL streptavidin-europium (Perkin Elmer) was prepared in reagent buffer (50 mM Tris [pH 7.2], 120 mM NaCl, 0.1% bovine globulins, 5mM DTT and 0.05% octylglucoside). (Alternatively, this cocktail can be made using europium-labeled anti-His (Perkin Elmer) and streptavidin-allophycocyanin (Perkin Elmer) at concentrations of 6.5 nM and 25nM, respectively). The reagent cocktail was incubated at room temperature for 30 minutes. After incubation, the cocktail was added to 1:3 serial dilutions of an antagonist compound (starting concentration of 50 μ M) in 384-well black FIA plates (Greiner Bio-One, Inc.). After a 90 minute incubation at room temperature, the fluorescence was read with filters for the excitation of europium (340 nm) and for the emission wavelengths of europium (615 nm) and a allophycocyanin (665 nm). Antagonist data were calculated as a ratio of the emission signal of allophycocyanin at 665 nm to that of the emission of europium at 615 nm (these ratios were multiplied by a factor of 10,000 for ease of data manipulation). The resulting values were plotted as a function of antagonist concentration and fit to a 4-parameter equation using Kaleidograph software (Synergy Software, Reading, PA). Indications of antagonist potency were determined from the IC₅₀ values.

Fluorescence Polarization Peptide Binding Assay

Polarization experiments were performed on an Analyst HT 96-384 (Molecular Devices Corp.) according to the procedure of Keating, S.M., Marsters, J, Beresini, M., Ladner, C., Zioncheck, K., Clark, K., Arellano, F., and Bodary., S.(2000) in *Proceedings of SPIE : In Vitro Diagnostic Instrumentation* (Cohn, G.E., Ed.) pp 128-137, Bellingham, WA. Samples for fluorescence polarization affinity measurements were prepared by addition of 1:2 serial dilutions starting at a final concentration of 5 μ M of MLXBIR3SG in polarization buffer (50 mM Tris [pH 7.2], 120 mM NaCl, 1% bovine globulins 5mM DTT and 0.05% octylglucoside) to 5-carboxyflourescein-conjugated AVPdi-Phe-NH₂ (AVP-diPhe-FAM) at 5 nM final concentration.

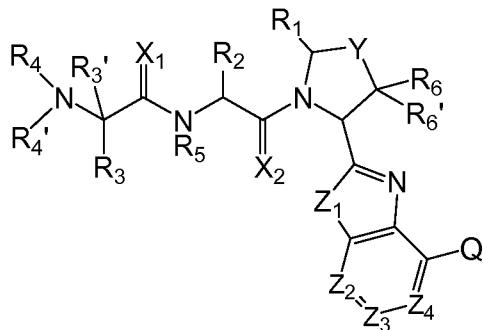


AVP-diPhe-FAM probe

The reactions were read after an incubation time of 10 minutes at room temperature with standard cut-off filters for the fluorescein fluorophore ($\lambda_{\text{ex}} = 485$ nm; $\lambda_{\text{em}} = 530$ nm) in 96-well black HE96 plates (Molecular Devices Corp.). Fluorescence values were plotted as a function of the protein concentration, and the IC₅₀s were obtained by fitting the data to a 4-parameter equation using Kaleidograph software (Synergy software, Reading, PA). Competition experiments were performed by addition of the MLXBIR3SG at 30 nM to wells containing 5 nM of the AVP-diPhe-FAM probe as well as 1:3 serial dilutions of antagonist compounds starting at a concentration of 300 μ M in the polarization buffer. Samples were read after a 10-minute incubation. Fluorescence polarization values were plotted as a function of the antagonist concentration, and the IC₅₀ values were obtained by fitting the data to a 4-parameter equation using Kaleidograph software (Synergy software, Reading, PA). Inhibition constants (K_i) for the antagonists were determined from the IC₅₀ values. Compounds of the invention that were tested in this assay exhibited a K_i or less than 100 μ M. For example, compound 48 had an K_i of 7.87, compound 54 had an K_i of 0.0556, compound 56 had an K_i of 0.0338 and compound 60 had an K_i of 0.1454.

WE CLAIM:

1. A compound of formula (I)



I

wherein

X₁ and X₂ are each independently O or S;

Y is a bond, (CR₇R₇)_n, O or S;

Z₁ is NR₈, O, S, SO or SO₂;

Z₂, Z₃ and Z₄ are independently CQ or N;

Q is H, halogen, hydroxyl, carboxyl, amino, nitro, cyano, alkyl, a carbocycle, a heterocycle; wherein one or more CH₂ or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)-; and an alkyl, carbocycle and heterocycle is optionally substituted with one or more hydroxyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle;

R₁ is H, OH or alkyl; or R₁ and R₂ together form a 5-8 member heterocycle;

R₂ is alkyl, a carbocycle, carbocyclalkyl, a heterocycle or heterocyclalkyl each optionally substituted with halogen, hydroxyl, oxo, thione, mercapto, carboxyl, alkyl, haloalkyl, acyl, alkoxy, alkylthio, sulfonyl, amino and nitro, wherein said alkyl, acyl, alkoxy, alkylthio and sulfonyl are optionally substituted with hydroxy, mercapto, halogen, amino, alkoxy, hydroxyalkoxy and alkoxyalkoxy;

R₃ is H or alkyl optionally substituted with halogen or hydroxyl; or R₃ and R₄ together form a 3-6 heterocycle;

R₃' is H, or R₃ and R₃' together form a 3-6 carbocycle;

R₄ and R₄' are independently H, hydroxyl, amino, alkyl, carbocycle, carbocycloalkyl, carbocycloalkyloxy, carbocycloalkyloxycarbonyl, heterocycle, heterocycloalkyl,

heterocycloalkyloxy or heterocycloalkyloxycarbonyl; wherein each alkyl, carbocycloalkyl, carbocycloalkyloxy, carbocycloalkyloxycarbonyl, heterocycle, heterocycloalkyl, heterocycloalkyloxy and heterocycloalkyloxycarbonyl is optionally substituted with halogen, hydroxyl, mercapto, carboxyl, alkyl, alkoxy, amino, imino and nitro; or R_4 and R_4' together form a heterocycle;

R_5 is H or alkyl;

R_6 , and R_6' are each independently H, alkyl, aryl or aralkyl;

R_7 is H, cyano, hydroxyl, mercapto, halogen, nitro, carboxyl, amidino, guanidino, alkyl, a carbocycle, a heterocycle or -U-V; wherein U is -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)- and V is alkyl, a carbocycle or a heterocycle; and wherein one or more CH₂ or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -C(O)-O- or -O-C(O)-; and an alkyl, carbocycle and heterocycle is optionally substituted with hydroxyl, alkoxy, acyl, halogen, mercapto, oxo, carboxyl, acyl, halo-substituted alkyl, amino, cyano nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle;

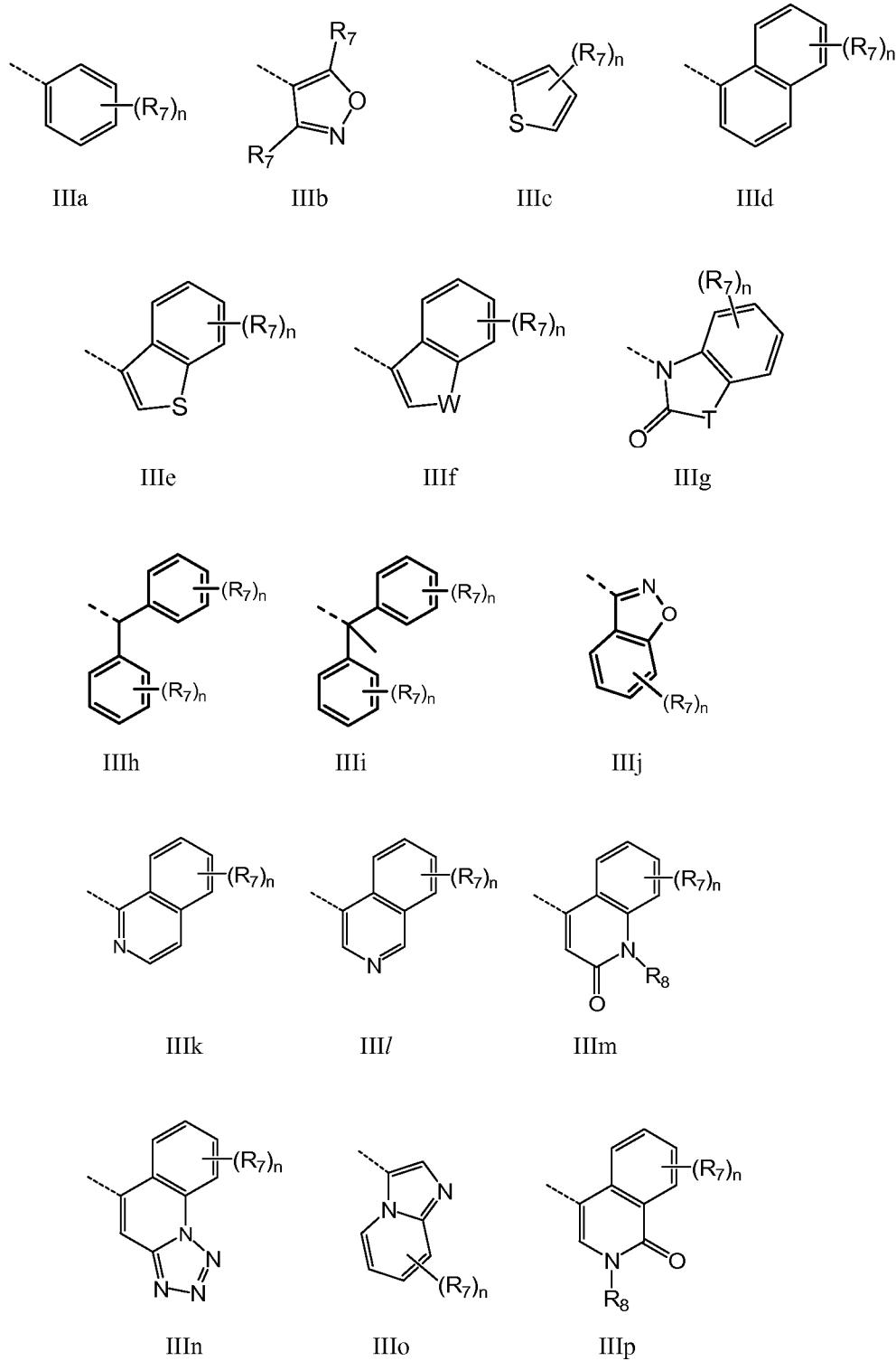
R_8 is H, alkyl, a carbocycle or a heterocycle wherein one or more CH₂ or CH groups of said alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈), or -C(O)-; and said alkyl, carbocycle and heterocycle is optionally substituted with hydroxyl, alkoxy, acyl, halogen, mercapto, oxo (=O), carboxyl, acyl, halo-substituted alkyl, amino, cyano nitro, amidino, guanidino an optionally substituted carbocycle or an optionally substituted heterocycle; and

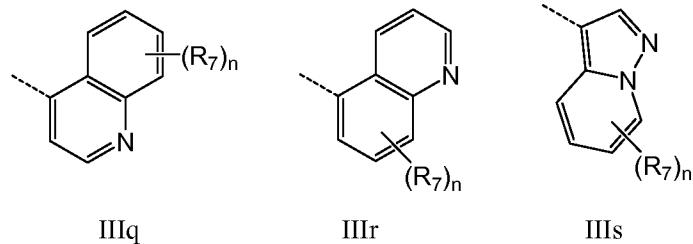
n is 0 to 4.

2. The compound of claim 1, wherein Z_1 is S and Z_2 , Z_3 and Z_4 are CQ or N.
3. The compound of claim 1, wherein Z_1 is S and Z_2 , Z_3 and Z_4 are CH.
4. The compound of claim 1, wherein Q is a carbocycle or heterocycle optionally substituted with halogen, amino, oxo, alkyl, a carbocycle or a heterocycle; wherein one or more CH₂ or CH groups of an alkyl is optionally replaced with -O-, -S-, -S(O)-, S(O)₂, -N(R₈)-, -C(O)-, -C(O)-NR₈-, -NR₈-C(O)-, -SO₂-NR₈-, -NR₈-SO₂-, -NR₈-C(O)-NR₈-, -NR₈-C(NH)-NR₈-, -NR₈-C(NH)-, -C(O)-O- or -O-C(O)-; and wherein said alkyl, carbocycle or heterocycle is optionally substituted with halogen, amino, hydroxyl,

mercapto, carboxyl, alkoxy, alkoxyalkoxy, hydroxyalkoxy, alkylthio, acyloxy, acyloxyalkoxy, alkylsulfonyl, alkylsulfonylalkyl, alkylsulfinyl, and alkylsulfinylalkyl.

5. The compound of claim 1, wherein Q is a carbocycle or heterocycle selected from the group consisting of IIIa - IIIp:





wherein n is 1-4; T is O, S, NR₈ or CR₇R₇; and W is O, NR₈ or CR₇R₇.

6. The compound of claim 1, wherein R₁ is H.
7. The compound of claim 1, wherein R₂ is alkyl, cycloalkyl or a heterocycle.
8. The compound of claim 1, wherein R₂ is selected from the group consisting of t-butyl, isopropyl, cyclohexyl, tetrahydropyran-4-yl, N-methylsulfonylpiperidin-4-yl, tetrahydrothiopyran-4-yl, tetrahydrothiopyran-4-yl (in which the S is in oxidized form SO or SO₂), cyclohexan-4-one, 4-hydroxycyclohexane, 4-hydroxy-4-methylcyclohexane, 1-methyl-tetrahydropyran-4-yl, 2-hydroxyprop-2-yl, but-2-yl, thiophen-3-yl, piperidin-4-yl, N-acetyl piperidin-4-yl, N-hydroxyethyl piperidin-4-yl, N-(2-hydroxyacetyl)piperidin-4-yl, N-(2-methoxyacetyl)piperidin-4-yl, pyridin-3-yl, phenyl, tetrahydrofuran-2-yl-carbonyl and 1-hydroxyeth-1-yl.
9. The compound of claim 1, wherein R₃ is methyl.
10. The compound of claim 1, wherein R₄ is H or methyl, and R₄' is H.
11. The compound of claim 1, wherein R₅ is H or methyl.
12. The compound of claim 1, wherein R₆ and R₆' are both H.
13. The compound of claim 1, wherein X₁ and X₂ are both O.
14. The compound of claim 2, wherein R₁ is H; R₂ is isopropyl, t-butyl, cyclohexyl or pyran; R₃ is methyl; R₄ is methyl, R₄' is H; R₅ is H; and X₁ and X₂ are both O.

15. A method of inducing apoptosis in a cell comprising introducing into said cell a compound of claim 1.
16. A method of sensitizing a cell to an apoptotic signal comprising introducing into said cell a compound of claim 1.
17. The method of claim 16, wherein said apoptotic signal is induced by contacting said cell with a compound selected from the group consisting of cytarabine, fludarabine, 5-fluoro-2'-deoxyuridine, gemcitabine, methotrexate, bleomycin, cisplatin, cyclophosphamide, adriamycin (doxorubicin), mitoxantrone, camptothecin, topotecan, colcemid, colchicine, paclitaxel, vinblastine, vincristine, tamoxifen, finasteride, taxotere and mitomycin C or radiation.
18. The method of claim 16, wherein said apoptotic signal is induced by contacting said cell with Apo2L/TRAIL.
19. A method for inhibiting the binding of an IAP protein to a caspase protein comprising contacting said IAP protein with a compound of claim 1.
20. A method for treating a disease or condition associated with the overexpression of an IAP in a mammal, comprising administering to said mammal an effective amount of a compound of claim 1.
21. A method for treating cancer, comprising administering to said mammal an effective amount of a compound of claim 1.