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LACTAM COMPOUNDS AS EP4 RECEPTOR-SELECTIVE AGONISTS FOR USE IN THE TREATMENT OF EP4-MEDIATED DISEASES AND CONDITIONS

LACTAM-VERBINDUNGEN ALS EP4 REZEPTOR SELEKTIVE AGONISTEN ZUR VERWENDUNG BEI DER BEHANDLUNG VON EP4-VERMITTELTEN KRANKHEITEN UND ZUSTÄNDEN

COMPOSÉS DE LACTAME EN TANT QU’ANTAGONISTES SÉLECTIFS DU RÉCEPTEUR EP4 POUR UNE UTILISATION DANS LE TRAITEMENT DE MALADIES ET D’ÉTATS MÉDIÉS PAR L’EP4

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FIELD OF THE INVENTION


BACKGROUND OF THE INVENTION

[0002] Arachidonic acid (abbreviated as AA herein) is a ubiquitous polyunsaturated fatty acid (PUFA) that is found esterified to phospholipids at the secondary alcohol of glycerol in all mammalian cellular membranes. Enzymatic hydrolysis of esterified AA by calcium (Ca\(^{2+}\))-induced cytosolic phospholipase 2 (cPLA2) releases free AA, which may be further catalytically converted by the cyclooxygenase (COX) into the intermediate prostaglandin H2 followed by subsequent enzymatic isomerization into the naturally occurring prostaglandins (PGs) and thromboxanes. The five primary prostanoids include prostaglandin F\(_2\alpha\) (PGF\(_{2\alpha}\)), prostaglandin D\(_2\) (PGD\(_2\)), prostaglandin I\(_2\) (PGI\(_2\)), thromboxane A\(_2\) (TXA\(_2\)), and prostaglandin E\(_2\) (PGE\(_2\)) (Jahn, U. et al., Angew. Chem. Int. Ed. 2008, 47, 5894-5955; Wymann, M. P. et al., Nat. Rev. Mol. Cell. Biol. 2008, 9, 162-176; Samuelsson, B. et al., Ann. Rev. Biochem. 1978, 47, 997-1029). These five prostanoids are lipid mediators that interact with nine specific members of a distinct prostanoid subfamily of G-protein-coupled receptors (GPCRs), designated FP, DP1-2, IP, TP, and EP1-4, respectively (Breyer, R. M. et al., Annu. Rev. Pharmacol. Toxicol. 2001, 41, 661-690). Prostaglandin and PG receptor pharmacology, signaling, and physiology have been studied and well documented (Hata, A. N. et al., Pharmacol. Ther. 2004, 103(2), 147-166; ElAttar, T. M. A., J. Oral Pathol. Med. 1978, 7(5), 239-252; Poyser, N. L., Clinics in Endocrinology and Metabolism 1973, 2(3), 393-410). Prostaglandins are short-lived local signaling molecules that are not stored in cells or tissues but are produced as needed by specific cells of virtually all body tissues. Their target cells reside in the immediate vicinity of their secretion sites. Well-known PG functions include regulation of cell stimulation, growth, and differentiation, immune response and inflammation, allergy, asthma, pain, vasomotor action, neuromodulation, intraocular pressure, and platelet aggregation, as well as mediation of fever, managing of renal blood flow, and induction of labor (Negishi, M. et al., Prog. Lipid Res. 1993, 32(4), 417-434).

[0003] As is the case for most prostanoids, the biosynthesis of PGE\(_2\) commences with liberation of free AA from its esterified form in the cell membrane. One key enzyme involved in PGE\(_2\) biosynthesis is prostaglandin H synthase (PGHS). PGHS possesses both a COX and a peroxidase function. The COX activity promotes conversion of free AA to the unstable endoperoxide prostaglandin G\(_2\) (PGG\(_2\)) via double oxygen insertion. One inserted oxygen molecule is subsequently reduced by the peroxidase activity of PGHS to provide the versatile biosynthetic cascade intermediate PGH\(_2\). The glutathione-dependent enzyme prostaglandin E synthase (PGES) promotes isomerization of PGH\(_2\) to PGE\(_2\) via peroxide ring opening of PGH\(_2\) to provide the highly functionalized hydroxypentanone scaffold of PGE\(_2\).

\[
\text{PGE}_2
\]

chain analog of PGE$_2$), the major eicosanoid synthesized biologically from dihomo-$\gamma$-linolenic acid (DGLA) in response to various stimuli, also binds efficiently to all four EP receptor subtypes.

![Diagram of PGE$_1$]


[0008] WO 03/103604 describes 1,2-substituted 5-pyrrolidinone compounds which may be useful for treating or preventing osteoporosis and other destructive bone diseases or disorders.

[0009] WO 2011/003058 describes prostacyclin derivatives which may be useful for treating diseases and conditions beneficially treated by prostacyclin. Such conditions and diseases may include bone diseases, such as bone marrow edema, osteonecrosis and osteoarthritis.

SUMMARY OF THE INVENTION

[0010] In one aspect, the present invention provides compounds of formula (I)

![Diagram of formula (I)]

or a pharmaceutically acceptable salt thereof, wherein:

L$^1$ is
a) C₃-C₇alkylene, C₃-C₇alkenylene, or C₃-C₇alkynylene, wherein the C₃-C₇alkylene, C₃-C₇alkenylene, or C₃-C₇alkynylene are each optionally substituted with 1, 2, 3, or 4 fluoro substituents;

b) -(CH₂)ₜ-G-(CH₂)ₚ--; wherein t is 0, 1, or 2, p is 0, 1, 2, or 3, and t+p = 0, 1, 2, 3, or 4; or

c) -(CH₂)ₙ-G¹-(CH₂)ₚ--; -(CH₂)ₙ-G²-(CH₂)ₚ--; -(CH₂)ₙ-C≡C-G²--; or -(CH₂)ₙ-C(R₁₂)=C(R₁₂)-G²--; wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6;

G is

![Chemical Structures]

G¹ is O, C(O), S, S(O), S(O)₂, or NR⁷; wherein R⁷ is H, C₁-C₄ alkyl, or C₄-C₉ alkylcarbonyl;

G² is

![Chemical Structures]

wherein G² is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C₁-C₄ alkyl, C₁-C₃ haloalkyl, cyano, halogen, C₃-C₅ alkoxy, and C₃-C₅ haloalkoxy;

R¹ is COOR⁸, CONR⁹R¹⁰, CH₂OR⁸, SO₃R⁸, SO₂NR⁹R¹⁰, PO(OR⁹)₂, or tetrazol-5-yl;

R⁸ is H, C₁-C₄ alkyl, or aryl;

R¹⁰ is H, C₁-C₄ alkyl, COR¹¹, OR⁸, or SO₂R¹¹;

R¹¹ is C₁-C₄ alkyl;

R¹², at each occurrence, is independently H or C₁-C₄ alkyl;

L⁴ is -C(R²)₂-C(R³)₂-, -C(R²)=C(R³)₂-, -C=C-, or
wherein R² and R³ are each H, CH₃, fluoro, or chloro;

L² is -CH₂- or a bond;

R⁴ and R⁵ are each independently H, F, CF₃, or C₁-C₄ alkyl; or R⁴ and R⁵ together with the carbon to which they are attached form a C₃-C₅ cycloalkyl,

or

L³ is C₂-C₆ alkynylene, wherein the C₂-C₆ alkynylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents;

R⁶ is aryl, heteroaryl, heterocyclyl, C₁-C₁₀ alkyl, C₃-C₈ cycloalkyl, C₂-C₄ alkenyl, C₂-C₄ alkenyl, C₁-C₆ haloalkyl, C₃-C₆ haloalkyl, C₂-C₆ haloalkenyl, C₂-C₆ haloalkenyl, or C₂-C₆ haloalkynyl; wherein the aryl and heteroaryl are optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C₁-C₄ alkyl, C₁-C₃ haloalkyl, cyano, halogen, C₁-C₃ alkoxy, C₁-C₃ haloalkoxy; and -C₁-C₃ alkyl-C₁-C₃ alkoxy; and wherein the C₁-C₆ alkyl, C₃-C₆ alkenyl, C₂-C₄ alkenyl, C₁-C₆ haloalkyl, C₃-C₆ haloalkyl, C₂-C₆ haloalkenyl, C₂-C₆ haloalkynyl, and C₂-C₆ haloalkynyl are optionally substituted with a substituent selected from the group consisting of COOR⁹, CONR⁹'R¹₀, CH₂OR⁹, SO₂R⁹, SO₂NR⁹'R¹₀, PO(OR⁹)₂, and tetrazol-5-yl;

R⁹ is H, C₁-C₄ alkyl, or aryl;

R¹₀ is H, C₁-C₄ alkyl, COR¹¹, OR⁹, or SO₂R¹¹;

R¹¹ is C₁-C₄ alkyl;

r is 0 or 1; and

s is 0 or 1;

for use in treating osteoporosis, bone fracture, bone loss, bone loss due to periodontal disease, a tooth socket having undergone implantation, a joint that is to undergo or that has undergone orthopedic implantation, or vertebrate that have undergone spinal fusion, or for increasing bone density.

[0011] In another aspect, the present invention provides compounds of formula (Ia)
or a pharmaceutically acceptable salt thereof, wherein R₁, R₄, R₅, L₁, L₂, L₃, L₄, and s are as defined herein for use according to the first aspect.

[0012] In another aspect of the invention are compounds of formula (II)

or a pharmaceutically acceptable salt thereof, wherein R₁, R₄, R₅, L₁, and L₃, are as defined herein for use according to the first aspect.

[0013] Another aspect of the present invention relates to pharmaceutical compositions comprising therapeutically effective amounts of a compound described herein or a pharmaceutically acceptable salt, solvate, salt of a solvate, or solvate of a salt thereof, in combination with a pharmaceutically acceptable carrier.

[0014] In another aspect, the invention provides compounds that bind to the EP₄ receptor with high affinity and agonist activity. In certain embodiments, compounds of the invention may possess selectivity for the EP₄ receptor over other EP receptors. In other certain embodiments, compounds of the invention may possess selectivity for the EP₄ receptor versus other EP receptors and other prostaglandin receptors.

[0015] In another aspect, the present disclosure provides a method of treating a disease or disorder related to the EP₄ receptor by administering to a patient a therapeutically effective amount of a compound or composition of formula (I), (Ia), or (II). Such diseases or disorders include those related to elevated intraocular pressure such as glaucoma. Other diseases or conditions treatable by the compounds and compositions of the invention include those associated with excessive bone loss, such as osteoporosis.

[0016] The present disclosure also provides methods of preparing compounds of formula (I), (Ia), (II).

[0017] In another aspect, the disclosure provides intermediates useful in the preparation of EP₄ agonists. In still another aspect, the disclosure provides methods of preparing the intermediates.

[0018] Further provided herein are the use of the present compounds or pharmaceutically acceptable salts, solvates, salts of solvates, or solvates of salts thereof, in the manufacture of a medicament for the treatment of the diseases or conditions described herein, alone or in combination with one or more pharmaceutically acceptable carrier(s).

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Figure 1 depicts data showing the effect of Compound 2E on stimulation of bone growth in the rat calvarial defect model.

DETAILED DESCRIPTION

Definition of Terms

[0020] The term “agonist” as used herein refers to a compound, the biological effect of which is to mimic the action of the natural agonist PGE₂. An agonist may have full efficacy (i.e., equivalent to PGE₂), partial efficacy (lower maximal efficacy compared to PGE₂), or super maximal efficacy (higher maximal efficacy compared to PGE₂). An agonist with
partial efficacy is referred to as a "partial agonist." An agonist with super maximal efficacy is referred to as a "super agonist."

**[0021]** The term "alkyl" as used herein, means a straight or branched chain saturated hydrocarbon. Representative examples of alkyl include, but are not limited to, methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, tert-butyl, n-pentyl, isopentyl, neopentyl, n-hexyl, 3-methylhexyl, 2,2-dimethylpentyl, 2,3-dimethylpentyl, n-heptyl, n-octyl, n-nonyl, and n-decyl.

**[0022]** The term "alkenyl" as used herein, means a straight or branched chain hydrocarbon containing at least one carbon-carbon double bond. Representative examples of alkenyl include, but are not limited to, ethenyl, 2-propenyl, 2-methyl-2-propenyl, 3-butenyl, 4-pentenyl, 5-hexenyl, 2-heptenyl, 2-methyl-1-heptenyl, and 3-decenyl.

**[0023]** The term "alkynyl," as used herein, means a straight or branched chain hydrocarbon containing at least one carbon-carbon triple bond. Representative examples include propynyl, butynyl, pentynyl, and the like.

**[0024]** The term "alkylene," as used herein, means a divalent group derived from a straight or branched chain saturated hydrocarbon. Representative examples of alkylene include, but are not limited to, -CH=CH-,-CH2CH=CH-, -CH2CH=CH(CH3)-, -C≡C-, -CH2CH2-, -CH2CH2CH2-, -CH2CH(CH3)CH2-, and -CH2CH(CH3)CH(CH3)CH2-.

**[0025]** The term "alkylidene," as used herein, means a divalent group derived from a straight or branched chain hydrocarbon containing at least one carbon-carbon double bond. Representative examples of alkylidene include, but are not limited to -CH=CH-, -CH2CH=CH-, and -CH2CH=CH(CH3)-.

**[0026]** The term "alkynylene," as used herein, means a divalent group derived from a straight or branched chain hydrocarbon containing at least one carbon-carbon triple bond. Representative examples of alkynylene include, but are not limited to -C≡C-, -CH2CH2CH2-, -CH2CH2CH2CH2-, and -CH2CH(CH3)CH(CH3)CH2-.

**[0027]** The term "alkoxy" as used herein, means an alkyl group, as defined herein, appended to the parent molecular moiety through an oxygen atom. Representative examples of alkoxy include, but are not limited to, methoxy, ethoxy, propoxy, isopropoxy, butoxy, isobutoxy, tert-butoxy, pentyloxy, and hexyloxy.

**[0028]** The term "alkylcarbonyl" as used herein, means an alkyl group, as defined herein, appended to the parent molecular moiety through a C(O) group.

**[0029]** The terms "haloalkyl," "haloalkenyl," and "haloalkynyl" as used herein, mean, respectively an alkyl, alkenyl, or alkynyl group, as defined herein, in which one, two, three, four, five, six, or seven hydrogen atoms are replaced by halogen. For example, representative examples of haloalkyl include, but are not limited to, 2-fluoroethyl, 2,2-difluoroethyl, trifluoromethyl, 2,2,2-trifluoroethyl, 2,2,2-trifluoro-1,1-dimethylethyl, and the like.

**[0030]** The term "haloalkoxy," as used herein, means a haloalkoxy group, as defined herein, in which one, two, three, four, five, or six hydrogen atoms are replaced by halogen. Representative examples of haloalkoxy include, but are not limited to, trifluoromethoxy, difluoromethoxy, 2,2,2-trifluoroethoxy, 2,2-difluoroethoxy, and pentafluorothoxy.

**[0031]** The term "aryl," as used herein, means phenyl or a bicyclic aryl. The bicyclic aryl is naphthyl, dihydronaphthalenyl, tetrahydroazaphenalenyl, indanyl, or indenyl. The phenyl and bicyclic aryls are attached to the parent molecular moiety through any carbon atom contained within the phenyl or bicyclic aryl.

**[0032]** The term "heteroaryl" as used herein, means a monocyclic heteroaryl or a fused bicyclic heteroaryl. The monocyclic heteroaryl is a 5 or 6 membered ring containing at least one heteroatom independently selected from the group consisting of O, N, and S. The 5-membered ring contains two double bonds, and one, two, three, or four heteroatoms as ring atoms. The 6-membered ring contains three double bonds, and one, two, three, or four heteroatoms as ring atoms. Representative examples of monocyclic heteroaryl include, but are not limited to, furan, imidazolyl, isoxazolyl, isothiazolyl, oxadiazolyl, oxazolyl, pyridinyl, pyridazine, pyrimidinyl, pyrazinyl, pyrazolyl, pyrrolyl, thiazolyl, thiazolyl, thienyl, triazolyl, and triazinyl. The bicyclic heteroaryl is an 8- to 12-membered ring system having a monocyclic heteroaryl fused to an additional ring; wherein the additional ring may be aromatic or partially saturated, and may contain additional heteroatoms. Representative examples of bicyclic heteroaryl include, but are not limited to, benzo[1,3]dioxolo[4,5-c]benzoxazolyl, 1,3-benzothiazolyl, benzimidazolyl, benzoxazolyl, benzothienyl, chromenyl, furopyridinyl, indolyl, indazolyl, isoquinolinyl, naphthyridinyl, oxazolopyridine, quinolinyl, thiopyridinyl, pyridinyl, 5,6,7,8-tetrahydroquinolinyl, 6,7-dihydro-5H-cyclopenta[b]pyridinyl, and 2,3-dihydrofuro[3,2-b]pyridinyl. The monocyclic and the bicyclic heteroaryl groups are connected to the parent molecular moiety through any substitutable carbon atom or any substitutable nitrogen atom contained within the monocyclic and the bicyclic heteroaryl groups.

**[0033]** The term "cyloalkyl" as used herein, means a carbocyclic ring system containing 3, 4, 5, 6, 7, or 8 carbon atoms and zero heteroatoms as ring atoms, and zero double bonds. Examples of cycloalkyls include, but are not limited to, cyclopentyl, cyclohexyl, cycloheptyl, and cyclooctyl. The cycloalkyl groups of the present invention may contain an alkylene bridge of 1, 2, 3, or 4 carbon atoms, linking two non adjacent carbon atoms of the group. Examples of such bridged systems include, but are not limited to, bicyclo[2.2.1]heptanyl and bicyclo[2.2.2]octanyl. The cycloalkyl groups described herein can be appended to the parent molecular moiety through any substitutable carbon atom.

**[0034]** The term "heterocycle" or "heterocyclic" as used herein, refers to a monocyclic heterocycle, a bicyclic heterocycle, or a spirocyclic heterocycle. The monocyclic heterocycle is a 3, 4, 5, 6, 7, or 8-membered ring containing at least
one heteroatom selected from O, N, or S. The 3 or 4 membered ring contains one heteroatom and optionally one double bond. The 5-membered ring contains zero or one double bond and one, two or three heteroatoms. The 6, 7, or 8-membered ring contains zero, one or two double bonds, and one, two, or three heteroatoms. Representative examples of monocyclic heterocycle include, but are not limited to, azetidinyl, azepanyl, aziridinyl, diazepanyl, 1,3-dioxanyl, 1,4-dioxanyl, 1,3-dioxolanyl, 4,5-dihydroisoxazol-5-yl, 3,4-dihydropropyranyl, 1,3-dithiolanyl, 1,3-dithianyl, imidazolinyl, imidazolidinyl, isothiazolinyl, isothiazolidinyl, isoxazolinyl, isoxazolyl, morpholinyl, oxadiazolinyl, oxadiazolidinyl, oxazolinyl, oxazolidinyl, oxetanyl, pyrrolinyl, pyrrolinyl, pyrazolidinyl, pyrrolyl, tetrahydrofuranyl, tetrahydropyranyl, tetrahydrothieryl, thiadiazolinyl, thiadiazolidinyl, thiazolinyl, thiazolidinyl, thiomorpholinyl, 1,1-dioxidothiomorpholinyl, thiopyranyl, and trithianyl. The bicyclic heterocycle is a 5-12-membered ring system having a monocyclic heterocycle fused to a phenyl, a saturated or partially saturated carbocyclic ring, or another monocyclic heterocyclic ring. Representative examples of bicyclic heterocycle include, but are not limited to, 1,3-benzodioxol-4-yl, 1,3-benzodithiolyl, 3-azabicyclo[3.1.0]hexanyl, hexahydro-1H-furo[3,4-c]pyrrolyl, 2,3-dihydro-1,4-benzodioxinyl, 2,3-dihydro-1-benzo- furanyl, 2,3-dihydro-1-benzothenyl, 2,3-dihydro-1H-indolyl, and 1,2,3,4-tetrahydroquinoxolinyl. Spirocyclic heterocycle means a 4, 5-, 6-, 7-, or 8-membered monocyclic heterocycle ring wherein two of the substituents on the same carbon atom form a 3-, 4-, 5-, or 6-membered monocyclic ring selected from the group consisting of cycloalkyl and heterocycle, each of which is optionally substituted with 1, 2, 3, 4, or 5 alkyl groups. Examples of a spiroheterocycle include, but are not limited to, 5-oxaspiro[3,4]octane and 8-azaspiro[4,5]decane. The monocyclic and bicyclic heterocycle groups of the present invention may contain an alkylene bridge of 1, 2, 3, or 4 carbon atoms, linking two non-adjacent atoms of the group. Examples of such a bridged heterocycle include, but are not limited to, 2-azabicyclo[2.2.1]heptanyl, 2-azabicyclo[2.2.2]octanyl, 1,2,3,4-tetrahydro-1,4-methanoisoquinolinyl, and oxabicyclo[2.2.1]heptanyl. The monocyclic, bicyclic, and spirocyclic heterocycle groups are connected to the parent molecular moiety through any substitutable carbon atom or any substitutable nitrogen atom contained within the monocyclic, bicyclic, and spirocyclic heterocycle groups.

[0035] Terms such as "alkyl," "cycloalkyl," "alkylene," etc. may be preceded by a designation indicating the number of atoms present in the group in a particular instance (e.g., "C_3-C_10alkyl," "C_3-C_10cycloalkyl," "C_2-C_9alkynylene," "C_2-C_9alkylene"). These designations are used as generally understood by those skilled in the art. For example, the representation "C" followed by a subscripted number indicates the number of carbon atoms present in the group that follows. Thus, "C_3alkyl" is an alkyl group with three carbon atoms (i.e., n-propyl, isopropyl). Where a range is given, as in "C_3-C_{10}alkyl," the members of the group that follows may have any number of carbon atoms falling within the recited range. A "C_3-C_{10}alkyl," for example, is an alkyl group having from 3 to 10 carbon atoms, however arranged.

[0036] A "patient" as used herein refers to a mammal (e.g., a human) or a bird having a condition that may be treated with compounds of the invention.

Compounds

[0037] According to a general aspect of the present invention, there are provided compounds useful as EP4 receptor agonists, as well as compositions and methods relating thereto. Compounds of the invention have the structure set forth in formula (I), (Ia), (II).

[0038] Formula (I) refers to compounds having either β stereochemistry or a substantially equal mixture of β and α stereochemistries at the γ-position of the lactam ring. Excluded are compounds having pure or substantially pure α stereochemistry at the γ-position.

[0039] In some embodiments of the invention, L^1 is C_3-C_7alkylene, C_3-C_7alkynylene, or C_3-C_7alkyl, wherein the C_3-C_7alkylene C_3-C_7alkynylene, or C_3-C_7alkylene are each optionally substituted with 1, 2, 3, or 4 fluoro substituents. In other embodiments, L^1 is C_3-C_7alkylene, optionally substituted. In some groups of compounds, L^1 is n-pentylene, n-
hexylene, or n-heptylene each optionally substituted with 1, 2, 3, or 4 fluoro substituents. In subgroups of compounds, L1 is n-hexylene.

[0040] In other embodiments, L1 is -(CH₂)ₙ-G-(CH₂)ₚ-; wherein t, p, and G are as defined herein. In some groups of compounds, t and p are both 0. In other groups of compounds, t is 0 and p is 0, 1, 2, or 3. In still other groups of compounds, p is 0 and t is 0, 1, or 2.

[0041] In other embodiments, L1 is -(CH₂)ₙ-G¹-(CH₂)ₚ-, wherein G¹ is as defined herein, n is 1, 2, 3, 4, or 5 and p is 1, 2, or 3.

[0042] In still other embodiments, L1 is -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²-, or -(CH₂)ₙ-C(H)=C(H)-G²- wherein G², n and p are as defined herein.

[0043] In still other embodiments, L1 is -(CH₂)ₙ-G²-(CH₂)ₚ-, -CH₂-C≡C-G²-, or -CH₂-C(H)=C(H)-G²-.

[0044] In still other embodiments, L1 is -(CH₂)ₙ-G²-, -CH₂-C≡C-G²-, or -CH₂-C(H)=C(H)-G²-.

[0045] In some embodiments L1 is -(CH₂)ₙ-G²-(CH₂)ₚ-. For example, in some groups of compounds, G² is

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 n is 2 and p is 0. In other groups, G² is
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 n is 3 and p is 0. In still other groups, G² is
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 or
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 n is 2 and p is 0, 1, 2, or 3. In yet other groups, G² is
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 or
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 p is 0, and n is 2, 3, 4, or 5. In some subgroups, G² is
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 n is 2 and p is 0. In other subgroups, G² is
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 or
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n is 3 and p is 0. In other subgroups, G² is

![Diagram](image1)

n is 1 and p is 1.

[0046] In still other embodiments, L¹ is -(CH₂)ₙ-C≡C-G²- or -(CH₂)ₙ-C(H)=C(H)-G²-. For example, in some groups of compounds G² is

![Diagram](image2)

and n is 1. In certain subgroups of compounds G² is

![Diagram](image3)

and n is 1. In other subgroups, L¹ is -(CH₂)ₙ-C≡C-G²-, G² is

![Diagram](image4)

and n is 1. In still other subgroups, L¹ is -(CH₂)ₙ-C(H)=C(H)-G²-, G² is

![Diagram](image5)

and n is 1.

[0047] In compounds of formula (I), (Ia), or (II), R¹ is COOR⁹, CONR⁹R¹⁰, CH₂OR⁹, SO₂R⁹, SO₂NR⁹R¹⁰, PO(OR⁹)₂, or tetrazol-5-yl; wherein R⁹ is H, C₆-H, alkyl (e.g., methyl, ethyl) or aryl (e.g., phenyl) and R¹⁰ is H, C₆-H, alkyl (e.g., methyl, ethyl). In one group of compounds, R¹ is COOH or COOCH₃. In another group of compounds, R¹ is COOH.

[0048] In compounds of formula (I) or (Ia), L⁴ is -C(R²)₂-C(R³)₂-, -C(R²)=C(R³)-, -C=C-, or

![Diagram](image6)

wherein R² and R³ are each H, CH₃, fluoro, or chloro. In some embodiments, L⁴ is -C(R²)₂-C(R³)₂- and R² and R³ are each hydrogen. In other embodiments, L⁴ is -C(R²)=C(R³)- and R² and R³ are each independently H, CH₃, fluoro or chloro. In some groups of compounds, L⁴ is -C(R²)=C(R³)- and R² and R³ are hydrogen. In certain subgroups, L⁴ is

![Diagram](image7)

In other embodiments, L⁴ is -C=C-. In yet other embodiments, L⁴ is
In compounds of formula (I) or (Ia), L2 is -CH2- or a bond. In some embodiments, L2 is a bond.

In compounds of formula (I), (Ia), or (II), R4 and R5 are each independently H, F, CF3, or C1-C4 alkyl (e.g., methyl, ethyl, etc.); or R4 and R5 together with the carbon to which they are attached form a C3-C5 cycloalkyl (e.g., cyclopropyl),

or

In some embodiments, R4 and R5 are each independently hydrogen or CH3. In other embodiments R4 is C1-C4 alkyl (e.g., methyl, ethyl, etc.) and R5 is hydrogen. In yet other embodiments, R4 is hydrogen and R5 is C1-C4 alkyl (e.g., methyl, ethyl, etc.). In still other embodiments, R4 and R5 are fluoro. In some embodiments, R4 is methyl and R5 is hydrogen. In other embodiments, R4 is hydrogen and R5 is methyl.

In the compounds of formula (I), (Ia), or (II), the stereochemistry of the hydroxyl group on the lower chain may be either α or β or a mixture of α and β.

In some embodiments, L3 is C2-C6alkynylene, wherein the C2-C6alkynylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents. In other embodiments, L3 is C2-C6alkynylene. For example, in some groups of compounds, L3 is ethynylene, propynylene, or butynylene. In some subgroups of compounds, L3 is -C≡C-, or -CH2-C≡C-. In other subgroups, L3 is -C=C-. In other subgroups, L3 is -CH2-C≡C-.

In some embodiments of the invention, R6 is aryl or C1-C10alkyl, wherein the aryl is optionally substituted as described herein. In other embodiments, R6 is aryl, C1-C10alkyl, C2-C6Cycloalkyl, C2-C10alkenyl, C2-C10alkynyl, C1-C10haloalkyl, C3-C8halocycloalkyl, C2-C10haloalkenyl, or C2-C10haloalkynyl, wherein the aryl is optionally substituted as described herein. In one groups of compounds, R6 is phenyl or C1-C6alkyl, wherein the phenyl is optionally substituted as described herein. In certain subgroups, R6 is phenyl, methyl, ethyl, or propyl.

In some embodiments of the invention, R6 is aryl or heteroaryl, each optionally substituted as described herein. In some groups of compounds, R6 is aryl, optionally substituted as described herein. In some groups of compounds, R6 is phenyl optionally substituted with halogen (e.g., fluoro, chloro), C1-C3haloalkyl (e.g., CF3), or -C1-C3alkylene-C1-C3alkoxy (e.g., CH2OCH3). In other embodiments of the invention, R6 is heterocycl C1-C10alkyl, C2-C6Cycloalkyl, C2-C10alkenyl, C2-C10alkynyl, C1-C10haloalkyl, C3-C8halocycloalkyl, C2-C10haloalkenyl, or C2-C10haloalkynyl, each optionally substituted as described herein. In other embodiments, R6 is C1-C10alkyl (e.g., methyl, ethyl, propyl, butyl, pentyl, octyl, etc.). In some groups of compounds, R6 is methyl, ethyl, n-propyl, n-butyl, or n-pentyl. In a particular subgroups of compounds, R6 is methyl, ethyl, or n-propyl.

In one aspect of the invention are compounds of formula (I), (Ia), or (II), wherein L1-R1 is C3-C7alkylene-R1, wherein the C3-C7alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents; or L1-R1 is -(CH2)n-G2-(CH2)p-R1, -(CH2)n-C=C-G2-R1, or -(CH2)n-C(H)=C(H)-G2-R1, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; G2 is
wherein \( G^2 \) is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of \( C_1-C_4 \) alkyl, \( C_1-C_3 \) haloalkyl, cyano, halogen, \( C_1-C_3 \) alkoxy, and \( C_1-C_3 \) haloalkoxy; \( R^1 \) is \( COOR^9 \); and \( R^9 \) is \( H \) or \( C_1-C_4 \) alkyl. In one embodiment of this aspect of the invention \( L^1-R^1 \) is \( n \)-hexylene-\( COOR^9 \), \(-(CH_2)_n-G^2-(CH_2)_p-COOR^9\), \(-(CH_2)_n-C(=C(H))=C(H)-G^2-COOR^9\); wherein \( n \) is 1, 2 or 3, \( p \) is 0 or 1; \( G^2 \) is and \( R^9 \) is \( H \) or \( CH_3 \).

[0056] In another embodiment of this aspect of the invention, \( L^1-R^1 \) is \( C_3-C_7 \) alkylene-\( R^1 \) and the \( C_3-C_7 \) alkylene is optionally substituted with 1-4 fluoro substituents. In one group of compounds, for example, \( L^1-R^1 \) is \( n \)-pentylene-\( COOR^9 \), \( n \)-hexylene-\( COOR^9 \), \( n \)-heptylene-\( COOR^9 \), etc., and \( R^9 \) is \( H \), \( CH_3 \), or \(-CH_2CH_3 \). In one embodiment, \( L^1-R^1 \) is \( n \)-hexylene-COOH, \( n \)-hexylene-COOCH_3, or \( n \)-hexylene-COOCH_2CH_3.

[0057] In another embodiment of this aspect of the invention, \( L^1-R^1 \) is \(-(CH_2)_n-G^2-(CH_2)_p-R^1 \); and \( G^2 \) is

In another embodiment, \( L^1-R^1 \) is \(-(CH_2)_n-G^2-COOR^9 \) (i.e., \( p \) is 0), \( G^2 \) is

\( n \) is 2 or 3, and \( R^9 \) is \( H \) or \( CH_3 \). In one embodiment, \( L^1-R^1 \) is

In another embodiment, \( L^1-R^1 \) is

[0058] In another embodiment of this aspect of the invention \( L^1-R^1 \) is \(-(CH_2)_n-G^2-(CH_2)_p-R^1 \) and \( G^2 \) is

In another embodiment, \( L^1-R^1 \) is \(-(CH_2)_n-G^2-COOR^9 \) (i.e., \( p \) is 0), \( G^2 \) is

\( n \) is 2 or 3; and \( R^9 \) is \( H \) or \( CH_3 \). In still another embodiment, \( L^1-R^1 \) is
In yet another embodiment, $L^1-R^1$ is

$$\text{[0059]}$$ In another embodiment, $L^1-R^1$ is $-\text{CH}_2\text{-G}_2\text{-CH}_2\text{-COOR}^9$, $G^2$ is and $R^9$ is H or CH$_3$. In another embodiment, $L^1-R^1$ is $-\text{CH}_2\text{-G}_2\text{-CH}_2\text{-COOR}^9$, $G^2$ is and $R^9$ is H.

$$\text{[0060]}$$ In still another embodiment of this aspect of the invention, $L^1-R^1$ is $-(\text{CH}_2)_n\text{-C}=\text{C}\text{-G}_2\text{-COOR}^9$ and $G^2$ is

In yet another embodiment, $L^1-R^1$ is $-(\text{CH}_2)_n\text{-C}=\text{C}\text{-G}_2\text{-COOR}^9$, $G^2$ is $n$ is 1, and $R^9$ is H or CH$_3$. In another embodiment, $L^1-R^1$ is $-(\text{CH}_2)_n\text{-C}=\text{C}\text{-G}_2\text{-COOR}^9$, $G^2$ is $n$ is 1, and $R^9$ is H.

$$\text{[0061]}$$ In another embodiment of this aspect of the invention, $L^1-R^1$ is $-(\text{CH}_2)_n\text{-C}(\text{H})=\text{C}(\text{H})\text{-G}_2\text{-COOR}^9$ and $G^2$ is

In another embodiment, $L^1-R^1$ is $-(\text{CH}_2)_n\text{-C}(\text{H})=\text{C}(\text{H})\text{-G}_2\text{-COOR}^9$, $G^2$ is $n$ is 1, and $R^9$ is H or CH$_3$. In another embodiment, $L^1-R^1$ is $-(\text{CH}_2)_n\text{-C}(\text{H})=\text{C}(\text{H})\text{-G}_2\text{-COOR}^9$, $G^2$ is
In another aspect of the invention are compounds of formula (I) or (Ia), wherein L2 is a bond, L4 is \(-\text{C}(\text{R}^2)=\text{C}(\text{R}^3)\)-, R2 and R3 are each hydrogen, R4 and R5 are independently H or C1-C4 alkyl, L3 is C2-C6 alkyne, wherein the C2-C6 alkyne is optionally substituted with 1, 2, 3, or 4 fluoro substituents; and R6 is aryl or C1-C10 alkyl, wherein the aryl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C1-C4 alkyl, C1-C4 haloalkyl, cyano, halogen, C1-C3 alkoxy, C1-C3 haloalkoxy; and -C1-C3 alkyne-C1-C3 alkoxy. In a first embodiment of this aspect, L4 is

and R4 and R5 are independently H or CH3. In one group of compounds according to the first embodiment, L3 is ethynylene, propynylene, or butynylene. In a subgroup of compounds R6 is aryl optionally substituted as described herein. In another subgroup, R6 is phenyl optionally substituted as described herein. In another subgroup, R6 is C1-C10 alkyl (e.g., methyl, ethyl, propyl, butyl, pentyl, octyl, etc.). In a subgroup of compounds, R6 is aryl optionally substituted as described herein. In another subgroup, R6 is phenyl optionally substituted as described herein. In another group of compounds of this embodiment, R6 is C1-C10 alkyl (e.g., methyl, ethyl, propyl, butyl, pentyl, octyl, etc.). In a subgroup of compounds, R6 is aryl optionally substituted as described herein.
according to this aspect of the invention, L^3 is C_2-C_6 alkynylene; wherein the C_2-C_6 alkynylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents; and R^6 is aryl, heteroaryl, heterocyclcyl, C_1-C_{10} alkyl, C_2-C_6 cycloalkyl, C_2-C_{10} alkenyl, C_2-C_{10} alkynyl, C_1-C_{10} haloalkyl, C_2-C_6 halocycloalkyl, C_2-C_{10} haloalkenyl, or C_2-C_{10} haloalkynyl, (each optionally substituted as described herein).

[0065] In another aspect of the invention are compounds of formula (I) or (Ia) wherein:

L^1-R^1 is C_3-C_7 alkylene-R^1, wherein the C_3-C_7 alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents; or L^1-R^1 is -(CH_2)_n-G^2-(CH_2)_p-R^1, -(CH_2)_n-C≡C-G^2-R^1, or -(CH_2)_n-C(H)=C(H)-G^2-R^1, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; G^2 is wherein G^2 is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, cyano, halogen, C_1-C_3 alkoxy, and C_1-C_3 haloalkoxy; R^1 is COOR^9; R^9 is H or C_1-C_4 alkyl; L^2 is a bond; L^4 is -C(R^2)_2=C(R^3)=-C(R^2)=C(R^3)-, or -C=C-, wherein R^2 and R^3 are each H, CH_3, fluoro, or chloro; R^4 and R^5 are each independently H, F, CF_3, or C_1-C_4 alkyl; or R^4 and R^5 together with the carbon to which they are attached form a C_3-C_5 cycloalkyl; L^3 is C_2-C_6 alkynylene; wherein the C_2-C_6 alkynylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents; R^6 is aryl, C_1-C_{10} alkyl, C_2-C_6 cycloalkyl, C_2-C_{10} alkenyl, C_2-C_{10} alkynyl, C_1-C_{10} haloalkyl, C_2-C_6 halocycloalkyl, C_2-C_{10} haloalkenyl, or C_2-C_{10} haloalkynyl, wherein the aryl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, cyano, halogen, C_1-C_3 alkoxy, C_1-C_3 haloalkoxy; and s is 0 or 1.

[0066] In one embodiment of the foregoing aspect, 

[0067] In another embodiment according to the foregoing aspect of the invention, L^4 is
R^4 and R^5 are independently H or C_1-C_4 alkyl; L^3 is C_2-C_9 alkylene; and R^6 is aryl or C_1-C_10 alkyl; wherein the aryl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, cyano, halogen, C_1-C_3 alkoxy, C_1-C_3 haloalkoxy, and -C_1-C_3 alkenylene-C_1-C_3 haloxy.

[0068] In one group of compounds according to the foregoing embodiment, L^1-R^1 is C_9-C_7 alkylene-R^1; or L^1-R^1 is -(CH_2)_n-G^2-(CH_2)_p-R^1, -(CH_2)_n-C≡C-G^2-R^1, or -(CH_2)_n-C(H)=C(H)-G^2-R^1, wherein n is 1, 2 or 3, p is 0, 1, or 2, and n+p = 1, 2, 3 or 4; G^2 is

\[ \begin{align*}
&\text{or} \\
&\text{or} \\
&\text{or} \\
&\text{or}
\end{align*} \]

R^1 is COOR^6; R^3 is H or C_1-C_4 alkyl; R^4 and R^5 are independently H or CH_3; L^3 is ethynylene, propynylene, or butynylene; and R^6 is phenyl or C_1-C_6 alkyl, wherein the phenyl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, cyano, halogen, C_1-C_3 alkoxy, C_1-C_3 haloalkoxy; and -C_1-C_3 alkenylene-C_1-C_3 haloxy.

[0069] In one subgroup of compounds according to the foregoing embodiment, L^1 is n-hexylene, -(CH_2)_n-G^2-(CH_2)_p-, -(CH_2)_n-C≡C-G^2-, or -(CH_2)_n-C(H)=C(H)-G^2-, wherein n is 1, 2 or 3; p is 0 or 1, and n+p = 2 or 3; G^2 is

\[ \begin{align*}
&\text{or} \\
&\text{or} \\
&\text{or} \\
&\text{or}
\end{align*} \]

R^1 is COOR^6; R^3 is H or CH_3; L^3 is -C≡C- or -CH_2-C≡C-; and R^6 is phenyl, methyl, ethyl, or propyl. For example, in certain compounds of this subgroup, L^3 is -CH_2-C≡C- and s is 1. In yet other compounds of this subgroup L^3 is -C≡C- and s is 0.

[0070] In another subgroup of compounds according to the foregoing embodiment L^3 is -(CH_2)_n-C≡C- and s is 1.

[0071] In another subgroup of compounds according to the foregoing embodiment L^3 is -C≡C- and s is 0.

[0072] In another group of compounds according to the foregoing embodiment L^1 is C_9-C_7 alkylene, wherein the C_9-C_7 alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents.

[0073] In another group of compounds according to the foregoing embodiment L^1 is -(CH_2)_n-G^2-(CH_2)_p-, -(CH_2)_n-C≡C-G^2-, or -(CH_2)_n-C(H)=C(H)-G^2-, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; and G^2 is

\[ \begin{align*}
&\text{or} \\
&\text{or} \\
&\text{or} \\
&\text{or}
\end{align*} \]

wherein G^2 is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, cyano, halogen, C_1-C_3 alkoxy, and C_1-C_3 haloalkoxy.

[0074] In another group of compounds according to the foregoing embodiment L^3 is -CH_2-C=C-; s is 1; and L^1 is C_9-C_7 alkylene, wherein the C_9-C_7 alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents. In another subgroup of compounds according to the foregoing embodiment L^3 is -CH_2-C=C-; s is 1; L^1 is -(CH_2)_n-G^2-(CH_2)_p-, -(CH_2)_n-C≡C-G^2-, or -(CH_2)_n-C(H)=C(H)-G^2-, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; and G^2 is

\[ \begin{align*}
&\text{or} \\
&\text{or} \\
&\text{or} \\
&\text{or}
\end{align*} \]

and s is 1; and L^1 is C_9-C_7 alkylene, wherein the C_9-C_7 alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents. In another subgroup of compounds according to the foregoing embodiment L^3 is -CH_2-C=C-; s is 1; L^1 is -(CH_2)_n-G^2-(CH_2)_p-, -(CH_2)_n-C≡C-G^2-, or -(CH_2)_n-C(H)=C(H)-G^2-, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; and G^2 is

\[ \begin{align*}
&\text{or} \\
&\text{or} \\
&\text{or} \\
&\text{or}
\end{align*} \]
In another subgroup of compounds according to the foregoing embodiment $L_3$ is $-C$-$G_2$-$(-CH_2)_n$-$C$-$G_2$-$(-CH_2)_p$-$(-CH_2)_n$-$C$-$G_2$, wherein $G_2$ is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of $C_1$-$C_4$alkyl, $=1$, 2, 3, 4, 5, or 6; and $G_2$ is $C_1$-$C_3$haloalkyl, cyano, halogen, $C_1$-$C_3$alkoxy, and $C_1$-$C_3$haloalkoxy.

[0075] In another subgroup of compounds according to the foregoing embodiment $L_3$ is $-C$-$G_2$-$(-CH_2)_n$-$C$-$G_2$-$(-CH_2)_p$-$(-CH_2)_n$-$C$-$G_2$, wherein $G_2$ is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of $C_1$-$C_4$alkyl, $=1$, 2, 3, 4, 5, or 6; and $G_2$ is $C_1$-$C_3$haloalkyl, cyano, halogen, $C_1$-$C_3$alkoxy, and $C_1$-$C_3$haloalkoxy.

Wherein $G_2$ is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of $C_1$-$C_4$alkyl, $=1$, 2, 3, 4, 5, or 6; and $G_2$ is $C_1$-$C_3$haloalkyl, cyano, halogen, $C_1$-$C_3$alkoxy, and $C_1$-$C_3$haloalkoxy. 

[0076] In another aspect, the invention provides a compound selected from the group consisting of:

- methyl 7-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)heptanoate;
- methyl 7-((S,4R,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propylbenzoate;
- methyl 4-((2-((S,4R,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((S,4R,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
- methyl 5-((3-((R)-2-((S,4S,E)-3-hydroxy-4-methylcycloct-1-en-6-yn-1-yl)-5-oxo-4-pyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
(Z)-7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-enoic acid;
4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoic acid;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid;
5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid;
4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid;
3-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoic acid;
methyl 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate;
methyl 7-((R)-2-((3S,4R,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate;
(Z)-methyl 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-enoate;
methyl 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoate;
methyl 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-en-1-yl)thiophene-2-carboxylic acid;
methyl 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-en-1-yl)thiophene-2-carboxylic acid;
methyl 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-en-1-yl)thiophene-2-carboxylic acid;
methyl 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoate;
methyl 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoate;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid;
7-((R)-2-((3S,4R,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid;
(Z)-7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-enoic acid;
((Z)-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thiobutanoic acid;
5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-((3-((R)-2-((3S,4R,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-((3-((Z)-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid;
5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid;
5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid;
5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
The resulting mixture of diastereomers by recrystallization or chromatography, followed by liberation of the optically pure
Examples of resolution are, for example, (i) attachment of a mixture of enantiomers to a chiral auxiliary, separation of
commercially available starting materials that contain asymmetric or chiral centers or by preparation of racemic mixtures
described are also contemplated. Individual stereoisomers of compounds described may be prepared synthetically from
These stereoisomers are "R" or "S" depending on the configuration of substituents around the chiral carbon atom. The
terms "R" and "S" used herein are configurations as defined in IUPAC 1974 Recommendations for Section E, Fundamental
Compounds described herein may exist as stereoisomers wherein asymmetric (or chiral) centers are present. These stereoisomers are "R" or "S" depending on the configuration of substituents around the chiral carbon atom. The
terms "R" and "S" used herein are configurations as defined in IUPAC 1974 Recommendations for Section E, Fundamental
"R" depending on the configuration of substituents around the chiral carbon atom. The
terms "R" and "S" used herein are configurations as defined in IUPAC 1974 Recommendations for Section E, Fundamental
[0077] Compoundes described herein may exist as stereoisomers wherein asymmetric (or chiral) centers are present.
These stereoisomers are "R" or "S" depending on the configuration of substituents around the chiral carbon atom. The
terms "R" and "S" used herein are configurations as defined in IUPAC 1974 Recommendations for Section E, Fundamental
stereoisomer using methods that are known to those of ordinary skill in the art. Examples of resolution are, for example, (i) attachment of a mixture of enantiomers to a chiral auxiliary, separation of the
resulting mixture of diastereomers by recrystallization or chromatography, followed by liberation of the optically pure
product; or (ii) separation of the mixture of enantiomers or diastereomers on chiral chromatographic columns.
[0079] Geometric isomers may exist in the present compounds. All various geometric isomers and mixtures thereof resulting from the disposition of substituents around a carbon-carbon double bond, a carbon-nitrogen double bond, a
cycloalkyl group, or a heterocycle group are contemplated. Substituents around a carbon-carbon double bond or a
carbon-nitrogen bond are designated as being of cis or trans configuration.
[0080] It is to be understood that compounds disclosed herein may exhibit the phenomenon of tautomism.
[0081] Thus, the formulae within this specification can represent only one of the possible tautomeric forms. It is to be understood that encompassed herein are any tautomeric form, and mixtures thereof, and is not to be limited merely to any one tautomeric form utilized within the naming of the compounds or formulae.
[0082] Additionally, unless otherwise stated, the structures depicted herein are also meant to include compounds that
differ only in the presence of one or more isotopically enriched atoms. For example, compounds having the present
structures except for the replacement of hydrogen by deuterium or tritium, or the replacement of a carbon by a 13C- or
14C-enriched carbon are within the scope of this invention. Such compounds are useful, for example, as analytical tools,
probes in a biological assay, or as EP4 receptor agonists.
[0083] Also contemplated as part of the invention are compounds formed by synthetic means or formed in vivo by
biotransformation or by chemical means. For example, certain compounds of the invention may function as prodrugs
that are converted to other compounds of the invention upon administration to a subject.
Methods of Treatment
[0084] The compounds of the invention are EP4 receptor agonists and are useful in treating or preventing conditions
or diseases responsive to an EP4 receptor agonist. Conditions or diseases treatable with compounds of the invention include elevated intraocular pressure, glaucoma, ocular hypertension, dry eye, macular edema, macular degeneration, alopecia (alone or in combination with, for example, an L-PGDS inhibitor or an H-PGDS inhibitor or in combination with
The present invention provides methods of treatment comprising administering to a patient in need thereof: (i) a therapeutically effective amount of a compound of formula (I) or (Ia), or a pharmaceutically acceptable salt thereof, or a solvate of either; or (ii) a composition comprising any of the foregoing compound, salt, or solvate and a pharmaceutically acceptable carrier.

In one aspect, the invention provides a method of treating glaucoma, osteoporosis, bone fracture, bone loss or low bone density due to periodontal disease, alopecia, a tooth socket having undergone implantation, a joint that is to undergo or that has undergone orthopedic implantation, vertebrae that have undergone spinal fusion, or neuropathic pain.

In another aspect, the invention provides a method of stimulating bone formation. According to this aspect of the invention, one embodiment provides a method of treating osteoporosis, bone fracture, and periodontal disease. In another embodiment, the compound or composition of the invention is administered alone. In still another embodiment, the compound or composition is administered in combination with one or more additional therapeutic agents to treat bone loss or osteoporosis. Compounds of the invention can be used in combination with other agents useful in treating or preventing bone loss such as an organic bisphosphonate (e.g., alendronic acid or sodium alendronate); a cathepsin K inhibitor; an estrogen or an estrogen receptor modulator; calcitonin; an inhibitor of osteoclast proton ATPase; an inhibitor of HMG-CoA reductase; an integrin receptor antagonist; a RANKL inhibitor such as denosumab; a bone anabolic agent, such as PTH; a bone morphogenetic agent such as BMP-2, BMP-4, and BMP-7; Vitamin D or a synthetic Vitamin D analogue such as ED-70; an androgen or an androgen receptor modulator; a SOST inhibitor; and the pharmaceutically acceptable salts and mixtures thereof. A preferred combination is a compound of the present invention and an organic bisphosphonate.

In another aspect, the invention provides a method of lowering intraocular pressure. According to this aspect of the invention, one embodiment provides a method of treating glaucoma. In another embodiment, the compound or composition of the invention is administered alone. In still another embodiment, the compound or composition is administered in combination with one or more additional therapeutic agents that lower intraocular pressure such as a β-adrenergic blocking agent such as timolol, betaxolol, levobetaxolol, carteolol, levobunolol, a parasympathomimetic agent such as pilocarpine, a sympathomimetic agent such as epinephrine, iopidine, brimonidine, clonidine, or para-aminoclonidine, a carbonic anhydrase inhibitor such as dorzolamide, acetazolamide, metazolamide or brinzolamide; and a prostaglandin such as latanoprost, travoprost, or unoprostone, and the pharmaceutically acceptable salts and mixtures thereof.

In still another aspect, the invention provides a method of treating neuropathic pain. According to this aspect of the invention, one embodiment provides a method of treating diabetic neuropathy, sciatica, post-herpetic neuralgia, HIV-related neuropathy, trigeminal neuralgia, or chemotherapy-induced pain. In another embodiment, the compound or composition of the invention is administered alone. In still another embodiment, the compound or composition is administered in combination with one or more additional therapeutic agents that treat neuropathic pain such as gabapentin, pregabalin, duloxetine, and lamotrigine, and the pharmaceutically acceptable salts and mixtures thereof.

Compounds described herein can be administered as a pharmaceutical composition comprising the compounds of interest in combination with one or more pharmaceutically acceptable carriers. The phrase "therapeutically effective amount" of the present compounds means sufficient amounts of the compounds to treat disorders, at a reasonable benefit/risk ratio applicable to any medical treatment. It is understood, however, that the total daily dosage of the compounds and compositions can be decided by the attending physician within the scope of sound medical judgment. The specific therapeutically effective dose level for any particular patient can depend upon a variety of factors including the disorder being treated and the severity of the disorder; activity of the specific compound employed; the specific composition employed; the age, body weight, general health and prior medical history, sex and diet of the patient; the time of administration, route of administration, and rate of excretion of the specific compound employed; the duration of the treatment; drugs used in combination or coincidental with the specific compound employed; and like factors well-known in the medical arts. For example, it is well within the skill of the art to start doses of the compound at levels lower than required to achieve the desired therapeutic effect and to gradually increase the dosage until the desired effect is achieved. Actual dosage levels of active ingredients in the pharmaceutical compositions can be varied so as to obtain an amount of the active compound(s) that is effective to achieve the desired therapeutic response for a particular patient and a particular mode of administration. In the treatment of certain medical conditions, repeated or chronic administration of
compounds can be required to achieve the desired therapeutic response. "Repeated or chronic administration" refers to the administration of compounds daily (i.e., every day) or intermittently (i.e., not every day) over a period of days, weeks, months, or longer. In particular, the treatment of chronic painful conditions may require such repeated or chronic administration of the compounds. Compounds described herein may become more effective upon repeated or chronic administration such that the therapeutically effective doses on repeated or chronic administration can be lower than the therapeutically effective dose from a single administration.

[0091] Combination therapy includes administration of a single pharmaceutical dosage formulation containing one or more of the compounds described herein and one or more additional pharmaceutical agents, as well as administration of the compounds and each additional pharmaceutical agent, in its own separate pharmaceutical dosage formulation. For example, a compound described herein and one or more additional pharmaceutical agents, can be administered to the patient together, in a single oral dosage composition having a fixed ratio of each active ingredient, such as a tablet or capsule; or each agent can be administered in separate oral dosage formulations. Where separate dosage formulations are used, the present compounds and one or more additional pharmaceutical agents can be administered at essentially the same time (e.g., concurrently) or at separately staggered times (e.g., sequentially).

[0092] In one aspect of the invention, compounds of the invention, or a pharmaceutically acceptable salt thereof, or a solvate of either; or (ii) a composition comprising any of the foregoing compound, salt, or solvate and a pharmaceutically acceptable carrier are administered as the active pharmaceutical agent. In another aspect, compounds of the invention or a pharmaceutically acceptable salt thereof, or a solvate of either; or (ii) a composition comprising any of the foregoing compound, salt, or solvate and a pharmaceutically acceptable carrier are administered to a subject and the administered compounds are converted to the active pharmaceutical agent in the subject by chemical or biotransformation.

[0093] Ophthalmic formulations of this compound may contain from 0.001 to 5% and especially 0.001 to 0.1% of active agent. Higher dosages as, for example, up to about 10% or lower dosages can be employed provided the dose is effective in reducing intraocular pressure, treating glaucoma, increasing blood flow velocity or oxygen tension. For a single dose, from between 0.001 to 5.0 mg, preferably 0.005 to 2.0 mg, and especially 0.005 to 1.0 mg of the compound can be applied to the human eye.

[0094] Compounds may be administered orally once or several times per day each in an amount of from 0.001 mg to 100 mg per adult, preferably about 0.01 to about 10 mg per adult. Compounds may also be administered parenterally once or several times per day each in an amount of from 0.1 mg to 10 mg per adult or continuously administered into a vein for 1 hour to 24 hours per day. Compounds may also be administered locally to stimulate bone formation in an amount from 0.0001 μg to 500 μg.

### Pharmaceutical Compositions

[0095] Pharmaceutical compositions comprise compounds described herein, pharmaceutically acceptable salts thereof, or solvates of either. The pharmaceutical compositions comprising the compound, salt, or solvate described herein can be formulated together with one or more non-toxic pharmaceutically acceptable carriers, either alone or in combination with one or more other medicaments as described hereinabove.

[0096] Pharmaceutical compositions of the present invention may be manufactured by processes well known in the art, e.g., by means of conventional mixing, dissolving, granulating, dragee-making, levigating, emulsifying, encapsulating, entrapping or lyophilizing processes.

[0097] The pharmaceutical compositions can be administered to humans, other mammals, and birds orally, rectally, parenterally, intracervically, intravaginally, intraperitoneally, topically (as by powders, ointments or drops), bucally or as an oral or nasal spray. The term "parenterally" as used herein, refers to modes of administration which include intravenous, intramuscular, intraperitoneal, intrasternal, subcutaneous and intraarticular injection and infusion.

[0098] The pharmaceutical compositions can further be administered to humans, other mammals, and birds locally to the desired site of action; for example, into a bone void such as a tooth socket defect, adjacent to an alveolar bone, or a bone defect caused by surgery, trauma, or disease.

[0099] The term "pharmaceutically acceptable carrier" as used herein, means a non-toxic, inert solid, semi-solid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type. Some examples of materials which can serve as pharmaceutically acceptable carriers are sugars such as, but not limited to, lactose, glucose and sucrose; starches such as, but not limited to, corn starch and potato starch; cellulose and its derivatives such as, but not limited to, sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; powdered tragacanth; malt; gelatin; talc; excipients such as, but not limited to, cocoa butter and suppository waxes; oils such as, but not limited to, peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil and soybean oil; glycols; such a propylene glycol; esters such as, but not limited to, ethyl oleate and ethyl laurate; agar; buffering agents such as, but not limited to, magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer’s solution; ethyl alcohol, and phosphate buffer solutions, as well as other non-toxic compatible lubricants such as, but not limited to, sodium lauryl sulfate and magnesium stearate, as well as coloring agents, releasing agents, coating agents, sweetening, flavoring
Pharmaceutical compositions for parenteral injection comprise pharmaceutically acceptable sterile aqueous or nonaqueous solutions, dispersions, suspensions or emulsions as well as sterile powders for reconstitution into sterile injectable solutions or dispersions just prior to use. Examples of suitable aqueous and nonaqueous carriers, diluents, solvents or vehicles include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol and the like), vegetable oils (such as olive oil), injectable organic esters (such as ethyl oleate) and suitable mixtures thereof. Proper fluidity can be maintained, for example, by the use of coating materials such as lecithin, by the maintenance of the required particle size in the case of dispersions and by the use of surfactants.

These compositions can also contain adjuvants such as preservatives, wetting agents, emulsifying agents and dispersing agents. Prevention of the action of microorganisms can be ensured by the inclusion of various antibacterial and antifungal agents, for example, paraben, chlorobutanol, phenol sorbic acid and the like. It can also be desirable to include isotonic agents such as sugars, sodium chloride and the like. Prolonged absorption of the injectable pharmaceutical form can be brought about by the inclusion of agents which delay absorption such as aluminum monostearate and gelatin.

In some cases, in order to prolong the effect of the drug, it is desirable to slow the absorption of the drug from subcutaneous or intramuscular injection. This can be accomplished by the use of a liquid suspension of crystalline or amorphous material with poor water solubility. The rate of absorption of the drug then depends upon its rate of dissolution which, in turn, can depend upon crystal size and crystalline form. Alternatively, delayed absorption of a parenterally administered drug form is accomplished by dissolving or suspending the drug in an oil vehicle.

Injectable depot forms are made by forming microencapsule matrices of the drug in biodegradable polymers such as poly lactide-poly glycolide. Depending upon the ratio of drug to polymer and the nature of the particular polymer employed, the rate of drug release can be controlled. Examples of other biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations are also prepared by entrapping the drug in liposomes or microemulsions which are compatible with body tissues.

Solid dosage forms for oral administration include capsules, tablets, pills, powders, cement, putty, and granules. In such solid dosage forms, the active compound can be mixed with at least one inert, pharmaceutically acceptable excipient or carrier, such as sodium citrate or dicalcium phosphate and/or a) fillers or extenders such as starches, lactose, sucrose, glucose, mannitol and silicic acid; b) binders such as carboxymethylcellulose, alginates, gelatin, polyvinylpyrrolidone, sucrose and acacia; c) humectants such as glycerol; d) disintegrating agents such as agar-agar, calcium carbonate, potato or tapioca starch, alginic acid, certain silicates and sodium carbonate; e) solution retarding agents such as paraffin; f) absorption accelerators such as quaternary ammonium compounds; g) wetting agents such as cetyl alcohol and glycerol monostearate; h) absorbents such as kaolin and bentonite clay and i) lubricants such as talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate and mixtures thereof. In the case of capsules, tablets and pills, the dosage form can also comprise buffering agents.

Solid compositions of a similar type can also be employed as fillers in soft and hard-filled gelatin capsules using such carriers as lactose or milk sugar as well as high molecular weight polyethylene glycols and the like.

The solid dosage forms of tablets, dragees, capsules, pills and granules can be prepared with coatings and shells such as enteric coatings and other coatings well-known in the pharmaceutical formulating art. They can optionally contain opacifying agents and can also be of a composition such that they release the active ingredient(s) only, or preferentially, in a certain part of the intestinal tract, optionally, in a delayed manner. Examples of embedding compositions which can be used include polymeric substances and waxes.

The active compounds can also be in micro-encapsulated form, if appropriate, with one or more of the above-mentioned carriers.

Liquid dosage forms for oral administration include pharmaceutically acceptable emulsions, solutions, suspensions, syrups and elixirs. In addition to the active compounds, the liquid dosage forms can contain inert diluents commonly used in the art such as, for example, water or other solvents, solubilizing agents and emulsiﬁers such as ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butanediol glycol, dimethyl formamide, oils (in particular, cottonseed, groundnut, corn, germ, olive, castor and sesame oils), glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols and fatty acid esters of sorbitan and mixtures thereof.

Besides inert diluents, the oral compositions can also include adjuvants such as wetting agents, emulsiﬁers and suspending agents, sweetening, flavoring and perfuming agents.

Suspensions, in addition to the active compounds, can contain suspending agents as, for example, ethoxylated isostearyl alcohols, polyoxyethylene sorbitol and sorbitan esters, poly(lactic-co-glycolic acid), microcrystalline cellulose, aluminum metahydroxide, bentonite, agar-agar, tragacanth, collagen sponge, demineralized bone matrix, and mixtures thereof.

The compounds can also be administered in the form of liposomes. As is known in the art, liposomes are generally derived from phospholipids or other lipid substances. Liposomes are formed by mono- or multi-lamellar hydrated
liquid crystals which are dispersed in an aqueous medium. Any non-toxic, physiologically acceptable and metabolizable lipid capable of forming liposomes can be used. The present compositions in liposome form can contain, in addition to compounds described herein, stabilizers, preservatives, excipients and the like. The preferred lipids are natural and synthetic phospholipids and phosphatidyl cholines (lecithins) used separately or together. Methods to form liposomes are known in the art, See, for example, Prescott, Ed., Methods in Cell Biology, Volume XIV, Academic Press, New York, N.Y. (1976), p. 33 et seq.

[0112] Dosage forms for topical administration of compounds described herein include powders, sprays, ointments and inhalants. The active compounds can be mixed under sterile conditions with a pharmaceutically acceptable carrier and any needed preservatives, buffers or propellants which can be required. Ophthalmic formulations, eye ointments, powders and solutions are also contemplated as being within the scope.

[0113] The compounds can be used in the form of pharmaceutically acceptable salts derived from inorganic or organic acids. The phrase "pharmaceutically acceptable salt" means those salts which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of humans and lower animals without undue toxicity, irritation, allergic response and the like and are commensurate with a reasonable benefit/risk ratio.

[0114] Pharmaceutically acceptable salts are well known in the art. For example, S. M. Berge et al. describe pharmaceutically acceptable salts in detail in (J. Pharmaceutical Sciences, 1977, 66: 1 et seq). The salts can be prepared in situ during the final isolation and purification of the compounds or separately by reacting a free base function with a suitable organic acid. Representative acid addition salts include, but are not limited to acetate, adipate, algin ate, citrate, aspartate, benzoate, benzenesulfonate, bisulfate, butyrate, camphorate, camphorsulfonate, digluconate, glycerophosphate, hemisulfate, heptanoate, hexanoate, fumarate, hydrochloride, hydrobromide, hydroiodide, 2-hydroxyethanesulfonate (isothionate), lactate, malate, maleate, methanesulfonate, nicotinate, 2-naphthalenesulfonate, oxalate, palmitoate, pectinate, persulfate, 3-phenylpropionate, picate, pivalate, propionate, succinate, tartrate, thiocyanate, phosphate, glutamate, bicarbonate, p-toluensulfonate and undecanoate. Also, the basic nitrogen-containing groups can be quaternized with such agents as lower alkyl halides such as, but not limited to, methyl, ethyl, propyl, and butyl chlorides, bromides and iodides; dialkyl sulfates like dimethyl, diethyl, dibutyl and diamyl sulfates; long chain halides such as, but not limited to, decyl, lauryl, myristyl and stearyl chlorides, bromides and iodides; arylalkyl halides like benzyl and phenethyl bromides and others. Water or oil-soluble or dispersible products are thereby obtained. Examples of acids which can be employed to form pharmaceutically acceptable acid addition salts include such inorganic acids as hydrochloric acid, hydrobromic acid, sulfuric acid, and phosphoric acid and such organic acids as acetic acid, fumaric acid, maleic acid, 4-methylbenzenesulfonic acid, succinic acid and citric acid.

[0115] Basic addition salts can be prepared in situ during the final isolation and purification of compounds by reacting a carboxylic acid-containing moiety with a suitable base such as, but not limited to, the hydroxide, carbonate or bicarbonate of a pharmaceutically acceptable metal cation or with ammonia or an organic primary, secondary or tertiary amine. Pharmaceutically acceptable salts include, but are not limited to, cations based on alkali metals or alkaline earth metals such as, but not limited to, lithium, sodium, potassium, calcium, magnesium and aluminum salts and the like and nontoxic quaternary ammonia and amine cations including ammonium, tetramethylammonium, tetraethylammonium, methylamine, dimethylamine, trimethylamine, triethylamine, diethylamine, ethylamine and the like. Other representative organic amines useful for the formation of base addition salts include ethylenediamine, ethanolamine, diethanolamine, piperidine, piperazine and the like.

[0116] Compounds described herein can exist in unsolvated as well as solvated forms, including hydrated forms, such as hemi-hydrates. In general, the solvated forms, with pharmaceutically acceptable solvents such as water and ethanol, among others, are equivalent to the unsolvated forms.

Chemistry and Examples

[0117] Unless otherwise defined herein, scientific and technical terms used in connection with the exemplary embodiments shall have the meanings that are commonly understood by those of ordinary skill in the art.

[0118] Further, unless otherwise required by context, singular terms shall include pluralities and plural terms shall include the singular. Generally, nomenclature used in connection with, and techniques of chemistry and molecular biology described herein are those well-known and commonly used in the art.

[0119] It will be appreciated that the synthetic schemes and specific examples are illustrative and are not to be read as limiting the scope of the invention. Optimum reaction conditions and reaction times for each individual step may vary depending on the particular reactants employed and substituents present in the reactants used. Unless otherwise specified, solvents, temperatures and other reaction conditions may be readily selected by one of ordinary skill in the art. The skilled artisan will also appreciate that not all of the substituents in the compounds of formula (I) or (la) will tolerate certain reaction conditions employed to synthesize the compounds. Routine experimentation, including appropriate manipulation of the reaction conditions, reagents and sequence of the synthetic route, protection and deprotection may be required in the case of particular compounds. Suitable protecting groups and the methods for protecting and depro-
tecting different substituents using such suitable protecting groups are well known to those skilled in the art; examples of which may be found in T. Greene and P. Wuts, Protecting Groups in Chemical Synthesis (3rd ed.), John Wiley & Sons, NY (1999), which is incorporated herein by reference in its entirety.

Furthermore, the skilled artisan will appreciate that in some cases, the order in which moieties are introduced may vary. The particular order of steps required to produce the compounds of formula (I) or (Ia) is dependent upon the particular compounds being synthesized, the starting compound, and the relative stability of the substituted moieties. Thus, synthesis of the present compounds may be accomplished by methods analogous to those described in the synthetic schemes described herein and in the specific examples, with routine experimentation (e.g., manipulation of the reaction conditions, reagents, and sequence of the synthetic steps).

Starting materials, if not commercially available, may be prepared by procedures selected from standard organic chemical techniques, techniques that are analogous to the synthesis of known, structurally similar compounds, or techniques that are analogous to the above described schemes or the procedures described in the synthetic examples section.

When an optically active form of a compound is required, it may be obtained by carrying out one of the procedures described herein using an optically active starting material (prepared, for example, by asymmetric induction of a suitable reaction step), or by resolution of a mixture of the stereoisomers of the compound or intermediates using a standard procedure (such as chromatographic separation, recrystallization or enzymatic resolution).

Similarly, when a pure geometric isomer of a compound is required, it may be obtained by carrying out one of the above procedures using a pure geometric isomer as a starting material, or by resolution of a mixture of the geometric isomers of the compound or intermediates using a standard procedure such as chromatographic separation.

Systematic names of compound structures have been generated by the Convert-Structure-to-Name function of Chem & Bio Draw 12.0 Ultra by CambridgeSoft®, which uses the Cahn-Ingold-Prelog rules for stereochemistry. When discussing individual atomic positions of compound structures, an alternative continuous numbering scheme for the lactams as described below may be used.

Liquid chromatography - mass spectra (LC/MS) were obtained using an Agilent LC/MSD G1946D or an Agilent 1100 Series LC/MSD Trap G2435A. Quantifications were obtained on a Cary 50 Bio UV-visible spectrophotometer.

1H, 13C, and 19F Nuclear magnetic resonance (NMR) spectra were obtained using a Varian INOVA nuclear
magnetic resonance spectrometer at 400, 100, and 376 MHz, respectively.

[0127] High performance liquid chromatography (HPLC) analytical separations were performed on an Agilent 1100 or Agilent 1200 HPLC analytical system and followed by an Agilent Technologies G1315B Diode Array Detector set at or near the UV $\text{max}_{260}$ nm.

[0128] High performance liquid chromatography (HPLC) preparatory separations were performed on a Gilson preparative HPLC system or an Agilent 1100 preparative HPLC system and followed by an Agilent Technologies G1315B Diode Array Detector set at or near the UV $\text{max}_{260}$ nm.

[0129] Analytical chiral HPLC separations were performed on an Agilent 1100 analytical system and followed by an Agilent Technologies G1315B Diode Array Detector set at or near the UV $\text{max}_{260}$ nm.

[0130] Thin layer chromatography (TLC) analyses were performed on Uniplate™ 250 silica gel plates (Analtech, Inc. Catalog No. 02521) and were typically developed for visualization using a diluted sulfuric acid spray like 50 volume% in water or 10 volume% in methanol.

[0131] When used in the present application, the following abbreviations have the meaning set out below:

- Ac is acetyl;
- ACN is acetonitrile;
- BB$\text{Br}_3$ is boron tribromide;
- Bn is benzyl;
- BnNH$_2$ is benzylamine;
- BSA is bovine serum albumin;
- CH$_2$Cl$_2$ is dichloromethane;
- CHCl$_3$ is chloroform;
- CDC$_3$ is deuterocloroform;
- CSA is camphorsulfonic acid;
- DCC is $N,N'$-dicyclohexylcarbodiimide;
- DME is 1,2-dimethoxyethane;
- DMF is $N,N$-dimethylformamide;
- DMSO is dimethyl sulfoxide;
- DBU is 1,8-diazabicyclo[5.4.0]undec-7-ene;
- DIA is diisopropylamine;
- DMAP is 4-dimethylaminopyridine;
- EDTA is ethylenediaminetetraacetic acid;
- EE is ethoxyeth-1-yl;
- ee is enantiomeric excess;
- EIA is enzyme immunoassay;
- Et is ethyl;
- EtOAc is ethyl acetate;
- EtOH is ethanol;
- Et$_3$N is triethylamine;
- HCl is hydrogen chloride;
- HOBt is 1-hydroxybenzotriazole;
- Me is methyl;
- MeOH is methanol;
- MTBE is methyl tert-butyl ether;
- NaOMe is sodium methoxide;
- nBuLi or n-BuLi is $n$-butyllithium;
- NHS is $N$-hydroxysuccinimide;
- NMP is 1-methyl-2-pyrrolidinone;
- PG is a protecting group;
- Ph is phenyl;
- Pd($\text{Ph}_3$)$_2$ is tetrakis(triphenylphosphine)palladium;
- PhMe is toluene;
- rt is room temperature;
- TBAF is tetrabutylammonium fluoride;
- TBS or TBDMS is tert-butyldimethylsilyl;
- tBu or t-Bu is tert-butyl;
- TEA is triethylamine;
TFA is trifluoroacetic acid;
THF is tetrahydrofuran;
TMS is trimethylsilyl; and
Tris-HCl is 2-amino-2-(hydroxymethyl)-1,3-propanediol hydrochloride.

[0132] Compounds of the present invention may be prepared from commercially available 5-(hydroxymethyl)pyrrolidin-2-one (pyroglutaminol) (1) by general routes illustrated in Scheme 1.

Scheme 1

Compounds of the present invention, (I), may be prepared from 1, for example, by a process that comprises first installing the upper chain with a nitrogen-carbon bond forming reaction, wherein the nitrogen atom of the γ-lactam ring of 1 forms a covalent bond with the appropriate upper chain carbon atom to provide the corresponding 1 + upper chain intermediate shown in Scheme 1. In some aspects of the present invention, the nitrogen-carbon forming reaction comprises an alkylation reaction between 1 or an oxygen-protected analog of 1 and an alkylating agent comprising the upper chain moiety and a leaving group as illustrated in Scheme 1A. In some aspects of the present invention, the alkylating agent is an alkyl halide such as an alkyl iodide, alkyl bromide, or alkyl triflate. In other aspects of the present invention, the alkylating agent is an allyl bromide. In other aspects of the present invention, the alkylating agent is a propargyl halide such as a propargyl bromide.

R^{13} is hydrogen or an oxygen protecting group.
R^{14} is hydrogen or a nitrogen protecting group.
The installation of the upper chain may be followed by a process that comprises installation of the lower chain by way of a carbon-carbon bond forming reaction, wherein the hydroxymethyl group carbon atom attached to the γ-position of the lactam ring of intermediate 1 + upper chain forms a covalent bond (carbon-carbon single, double, or triple bond) with the appropriate lower chain carbon atom to provide the corresponding compound (I). In some aspects of the present invention, the intermediate 1 + upper chain (directly from the alkylation reaction or its O-protected analog having undergone subsequent deprotection) is oxidized to the corresponding aldehyde intermediate, which may be subsequently subjected to Horner-Wadsworth-Emmons reaction conditions in the presence as a phosphonate ester coupling partner to provide compounds (I) of the present invention, wherein L^4 is a carbon-carbon double bond, as illustrated in Scheme 1B.

Alternatively, compounds of the present invention, (I), may be prepared from 1, for example, by a process that comprises first installing the lower chain with a carbon-carbon bond forming reaction, wherein the hydroxymethyl group carbon atom attached to the γ-position of the lactam ring of starting material 1 forms a covalent bond (carbon-carbon single, double, or triple bond) with the appropriate lower chain carbon atom to provide the corresponding 1 + lower chain intermediate shown in Scheme 1. The installation of the lower chain may be followed by a process that comprises installation of the upper chain by way of nitrogen-carbon bond forming reaction, wherein the nitrogen atom of the γ-lactam ring of 1 + lower chain forms a covalent bond with the appropriate upper chain carbon atom to provide the corresponding compound (I).

In some aspects of the present invention, the synthetic route to a compound (I) comprises a process wherein certain intermediates 1 + upper chain may undergo chemical reaction or a series of chemical reactions, which are known in the art or disclosed herein, that chemically modify the upper chain such that chemical installation and/or modification of the lower chain is facilitated.

In further aspects of the present invention, the synthetic route to a compound (I) comprises a process wherein a certain intermediate 1 + upper chain may undergo chemical reaction or a series of chemical reactions, which are known in the art or disclosed herein, that chemically modify the upper chain such that at least one particular functional group or other structural feature not incorporated into said intermediate is incorporated into the structure of invention compound (I).

In some aspects of the present invention, the synthetic route to a compound (I) comprises a process wherein certain intermediates 1 + lower chain may undergo chemical reaction or a series of chemical reactions, which are known in the art or disclosed herein, that chemically modify the lower chain such that chemical installation and/or modification
of the upper chain is facilitated.

In further aspects of the present invention, the synthetic route to a compound (I) comprises a process wherein a certain intermediate 1 + lower chain may undergo chemical reaction or a series of chemical reactions, which are known in the art or disclosed herein, that chemically modify the lower chain such that at least one particular functional group or other structural feature not incorporated into said intermediate is incorporated into the structure of invention compound (I). For some embodiments of compound (I) wherein L4 is a carbon-carbon single bond, the synthesis may comprise a sequence of steps as shown in Scheme 1C.

**Scheme 1C**

![Chemical diagram](attachment:image.png)

Omission of the hydrogenation step of Scheme 1C may provide compounds of Formula (I) wherein L4 is a carbon-carbon double bond and wherein various R4 and R5 may be incorporated. In some aspects, R4 and R5 are determined by the starting ketone used in the chemical route sequence. Some ketones that may be utilized for this purpose and are commercially available include butan-2-one, pentan-2-one, 3-methyl-2-butane (Aldrich), cyclopropyl methyl ketone (Aldrich), cyclobutyl methyl ketone (Aldrich), and 1-cyclopentyl-ethanone (Aldrich). Starting ketones and
substituted acetylenes may also be available according to published procedures or methods well known to those skilled in the art.

[0141] Synthetic routes utilized to prepare compounds of the present invention typically proceed through a carbon-carbon double bond formation (olefination) step to install the compound’s lower chain. The olefination may be accomplished by the interaction of an appropriate aldehyde intermediate with an appropriate nucleophilic carbanion species. Such methods may include Wittig reactions, wherein the nucleophilic carbanion species is an appropriate organic phosphonium ylide. Another carbon-carbon bond forming reaction that may be employed is a Horner-Wadsworth-Emmons reaction, wherein the coupling partner with the aldehyde is an appropriate organic phosphonate carbanion. Published reviews describing the general scope and mechanism along with various protocols for these types of olefination reactions include the following:


[0142] Another carbon-carbon bond forming reaction that may be used to install the lower chain is the Peterson olefination reaction, which is reviewed by Ager, D. J. Organic Reactions, 1990, 38, 1-223.

[0143] Aldehydes that may be used in the olefination step involved in preparation of compounds of the present invention include, but are not limited to, intermediates 6a-f, which can be generally prepared from (R)-(+)5-oxopyrrolidine-2-carboxylic acid (D-pyroglutamic acid) as shown in Scheme 2.
D-pyroglutamic acid may be esterified (Step A) and subsequently reduced (Step B) by known methods, including those described herein, to provide the resulting alcohol intermediate (R)-1. The hydroxyl moiety of intermediate (R)-1 may be protected (Step C) by reacting with ethyl vinyl ether (EVE) in the presence of TFA or tert-butylimethylsilyl chloride (TBDMSCI or TBSCI) in the presence of a base, such as imidazole, to provide the EE-protected or TBS-protected species (2), respectively. N-alkylation of one of the protected pyrrolidone intermediates (2) with an alkylating agent, such as one of 3a-f, affords the corresponding intermediate 4a-f (Step D). Alcohol deprotection (Step E) and subsequent controlled alcohol oxidation (Step F) provides the corresponding aldehyde intermediates 6a-f that may be employed in the subsequent olefination step.

The aldehydes 6a-f may also be prepared from commercially available (R)-di-tert-butyl 2-aminopentanedioate 7 according to the route illustrated in Scheme 3. Condensation of 7 with bromides 3a-f provides 8a-f, respectively (Step A). Subsequent ring closure provides pyrrolidinone intermediates 9a-f (Step B). Removal of the tert-butyl group with TFA (Step C) unmasks the carboxylic acid moiety of intermediates 10a-f. Mixed anhydride formation by reacting these carboxylic acids with isobutyl chloroformate and subsequent reduction of the mixed anhydride with sodium borohydride (Step D) provides alcohol intermediates 5a-f. Controlled oxidation of the alcohol group of each of the compounds 5a-f provides aldehydes 6a-f as illustrated in Scheme 2, Step F.
The aldehyde \((R)\)-methyl 4-[(2-formyl-5-oxopyrrolidin-1-yl)ethyl]benzoate (6b) may be prepared from commercially available \((R)\)-di-tert-butyl 2-aminopentanedioate (7) and aldehyde 11 according to the method described by Yufang X. et al. in Bioorganic and Medicinal Chemistry Letter, 2008, 18, 821-824, where the key reductive alkylation step is shown below in Scheme 4. Condensation of 7 with methyl 4-(2-oxoethyl)benzoate (11) accompanied with subsequent ring closure provides pyrrolidinone intermediate 9b (Step A and B). Deesterification of 9b, as shown generally in Scheme 3, Step C, followed by reduction (Scheme 3, Step D) and subsequent controlled oxidation as generally shown in Scheme 2, Step F produces aldehyde 6b.

Aldehyde intermediate 6f may alternatively be acquired by the hydrogenation of protected alcohol intermediates 4d or 4e to 4f or the unprotected alcohol intermediates 5d or 5e to 5f, followed by the subsequent deprotection (for 4f) and controlled oxidation to 6f. One hydrogenation reaction example is illustrated in Scheme 5. Palladium-catalyzed reduction of the internal carbon-carbon double bond of intermediate 5e (Scheme 5) to provide alcohol intermediate 5f followed by the controlled oxidation of the alcohol affords aldehyde intermediate 6f as illustrated in Scheme 2, Step F.
Detailed procedures for preparing the aldehyde intermediates is described below.

Preparation of (R)-methyl 7-(3,3-difluoro-5-fonnyl-2-oxopyrrolidin-1-yl)heptanoate (6a)

To a solution consisting of (R)-5-oxopyrrolidine-2-carboxylic acid (D-pyroglutamic acid) from Chem-Impex International, 12.6 g, 97.4 mmol) in methanol (100 mL) was added sulfuric acid (1 mL) and the mixture was stirred at room temperature for 24 hours. The solvent was evaporated from the mixture, and the residue was purified by silica gel chromatography. Elution with acetone-dichloromethane (3:7 v/v) afforded the title intermediate (13.3 g, 95%) as a clear oil; TLC R_f 0.42 (solvent system: 3:7 v/v acetone-dichloromethane); 1H-NMR (CDCl_3) δ 4.25 (t, 1H), 3.73 (s, 3H), 2.5-2.2 (m, 4H).

Scheme 2, Step A: Preparation of (R)-methyl 5-oxopyrrolidine-2-carboxylate (D-pyroglutamic acid methyl ester) from (R)-5-oxopyrrolidine-2-carboxylic acid (D-pyroglutamic acid)

To a solution consisting of (R)-methyl 5-oxopyrrolidine-2-carboxylate (D-pyroglutamic acid methyl ester, 13.2 g, 115 mmol) in methanol (100 mL) at 0 °C was added sodium borohydride (10.5 g, 278 mmol) in portions. The reaction mixture was stirred at 0°C until completion, at which time, acetic acid (3 mL) was added. The reaction mixture was

Scheme 2, Step B: Preparation of (R)-5-(hydroxymethyl)pyrrolidin-2-one ((R)-1)
concentrated and the residue was purified on silica gel, eluting with methanol-chloroform (1:9 v/v) to afford the title intermediate (12.9 g, 97%) as a colorless solid; TLC R<sub>f</sub> 0.33 (solvent system: 1:9 v/v methanol-chloroform); <sup>1</sup>H-NMR (CDCl<sub>3</sub>) δ 7.17 (s, 1H), 3.92 (s, 1H), 3.85-3.75 (m, 1H), 3.64-3.40 (m, 2H), 2.42-2.35 (m, 2H), 2.2-2.05 (m, 1H), 1.88-1.7 (m, 1H).

**Scheme 2, Step C: Preparation of (5R)-5-((1-ethoxyethoxy)methyl)pyrrolidin-2-one (2/EE)**

**[0154]**

![Chemical Structure](image)

**[0155]** To a solution consisting of (R)-5-((hydroxymethyl)pyrrolidin-2-one (intermediate (R)-1, 21.7 g, 188 mmol) in dichloromethane (250 mL) was added ethyl vinyl ether (36.2 mL, 376 mmol) followed by trichloroacetic acid (0.878 g, 5.37 mmol). The reaction mixture was stirred at room temperature for 16 hours. To the reaction mixture was added a saturated solution of sodium bicarbonate (400 mL) and the organic phase was separated. The organic phase was subsequently washed with water (200 mL) and brine (200 mL), dried over anhydrous sodium sulfate, filtered, and concentrated. The residue was purified by silica gel chromatography eluting with methanol-chloroform (1:9 v/v) to afford the title intermediate (13.0 g, 37%) as a clear oil; TLC R<sub>f</sub> 0.56 (solvent system: 1:9 v/v methanol-chloroform); <sup>1</sup>H-NMR (CDCl<sub>3</sub>) δ 4.69 (quartet, 1H), 3.83-3.2 (m, 5H), 2.35 (t, 2H), 2.25-2.19 (m, 1H), 1.8-1.7 (m, 1H), 1.38 (d, 3H), 1.21 (t, 3H).

**Scheme 2, Step C: Preparation of (R)-5-(((tert-butyldimethylsilyl)oxy)methyl)-pyrrolidin-2-one (2/TBS)**

**[0156]**

![Chemical Structure](image)

**[0157]** To a solution consisting of (R)-5-((hydroxymethyl)pyrrolidin-2-one (intermediate (R)-1, 5.7 g, 50 mmol) in dimethylsulfoxide (50 mL) was added tert-butyldimethylchlorosilane (9.71 g, 64.5 mmol) followed by imidazole (4.39 g, 64.5 mmol). The reaction mixture was stirred at room temperature overnight. The reaction mixture was quenched with water (50 mL) and extracted with ethyl acetate (3 x 100 mL). The combined organic phase was dried over anhydrous sodium sulfate, filtered, and concentrated. The residue was purified by silica gel chromatography eluting with methanol-chloroform (5:95 v/v) to afford the title intermediate (10.0 g, 85%) as a clear oil; TLC R<sub>f</sub> 0.37 (solvent system: 5:95 v/v methanol-chloroform).

**Scheme 2, Step D: Preparation of methyl 7-(((2R)-2-((1-ethoxyethoxy)methyl)-5-oxopyrrolidin-1-yl)heptanoate (4a)**

**[0158]**

![Chemical Structure](image)

**[0159]** To an ice-chilled suspension consisting of sodium hydride (60% in mineral oil, 1.07 g, 26.7 mmol) and sodium iodide (4.40 g, 29.4 mmol) in hexamethylphosphoramide (30 mL) was added dropwise a solution consisting of (5R)-5-((1-ethoxyethoxy)methyl)-pyrrolidin-2-one (intermediate 2/EE, 5.00 g, 26.7 mmol) in hexamethylphosphoramide (20
mL). The mixture was stirred at room temperature for two hours followed by 50 °C for 20 minutes. To the reaction mixture was added dropwise methyl 7-bromoheptanoate (commercially available from Alfa Aesar, 7.15 g, 32.0 mmol) and stirred overnight at 50 °C. The mixture was diluted with ethyl acetate (300 mL). Concentrated aqueous hydrochloric acid (10 mL) was subsequently added followed by water (50 mL). The aqueous phase was separated and the organic layer was washed with 5% aqueous sodium thiosulfate (100 mL), water (200 mL), and brine (300 mL), and was dried over anhydrous sodium sulfate, filtered and evaporated to provide the crude title intermediate, which was carried on to the next step without further purification or characterization.

**Scheme 2, Step E: Preparation of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate (5a)**

To a solution consisting of the crude methyl 7-((2R)-2-((1-ethoxyethoxy)methyl)-5-oxopyrrolidin-1-yl)heptanoate (4a) in methanol (50 mL) was added p-toluenesulfonic acid monohydrate (10 mg) and the mixture was stirred at room temperature for 18 hours. To the reaction mixture was added a saturated aqueous solution of sodium bicarbonate and the organic material was extracted with ethyl acetate. The organic phase was separated and washed with brine, dried over anhydrous sodium sulfate, filtered, and concentrated. The residue was purified by silica gel chromatography eluting with methanol-ethyl acetate (3:97 v/v) to afford the title intermediate (1.24 g, 18% over two steps) as a pale yellow oil; TLC Rf 0.24 (solvent system: 3:97 v/v methanol-ethyl acetate); MS (APCI+) m/z 258 (M+1).

**Scheme 2, Step F: Preparation of (R)-methyl 7-(2-formyl-5-oxopyrrolidin-1-yl)heptanoate (6a)**

To a solution consisting of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate (intermediate 5a, 1.24 g, 4.82 mmol) in dichloromethane (25 mL) was added Dess-Martin periodinane (2.04 g, 4.82 mmol) in portions and the mixture was stirred at room temperature until completion as monitored by TLC. The volatiles were evaporated, and to the residual mixture was added diethyl ether (50 mL). The solid material was filtered through a thin pad of Celite and the filtrate was concentrated. The residue was purified on silica gel eluting with methanol-ethyl acetate (3:97 v/v) to afford the title intermediate (1.1 g, 89%) as a pale yellow oil; TLC Rf 0.33 (solvent system: 3:97 v/v methanol-ethyl acetate).

**Preparation of (R)-methyl 4-(2-(2-formyl-5-oxopyrrolidin-1-yl)ethyl)benzoate (6b)**

To a solution consisting of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate (intermediate 5a, 1.24 g, 4.82 mmol) in dichloromethane (25 mL) was added Dess-Martin periodinane (2.04 g, 4.82 mmol) in portions and the mixture was stirred at room temperature until completion as monitored by TLC. The volatiles were evaporated, and to the residual mixture was added diethyl ether (50 mL). The solid material was filtered through a thin pad of Celite and the filtrate was concentrated. The residue was purified on silica gel eluting with methanol-ethyl acetate (3:97 v/v) to afford the title intermediate (1.1 g, 89%) as a pale yellow oil; TLC Rf 0.33 (solvent system: 3:97 v/v methanol-ethyl acetate).
Scheme 4, Steps A and B: Preparation of (R)-tert-butyl 1-(4-(methoxycarbonyl)-phenethyl)-5-oxopyrrolidine-2-carboxylate (9b)

Step A: To a solution consisting of (R)-di-tert-butyl 2-aminopentanedioate (reagent 7, H-D-Glu(OtBu)-OtBu, commercially available from Life ProTein (3.50 g, 15.6 mmol) in methanol (100 mL) was added methyl 4-(2-oxoethyl)benzoate (synonym: 4-carbomethoxyphenylacetaldehyde, reagent 11; obtained from methyl 4-formyl benzoate as described in Nair et al., J. Med. Chem., 1989, 32, 1277-1283; 2.80 g, 15.6 mmol), acetic acid (1.05 mL, 2.67 mmol), and sodium cyanoborohydride (1.45 g, 23.1 mmol), and the mixture was stirred at room temperature for three hours. The reaction mixture was diluted with ethyl acetate and washed with water and brine, dried over sodium sulfate, filtered, and concentrated under reduced pressure.

Step B: The residue (crude intermediate 8b) was diluted with xylene and the solution refluxed for 5 hours and concentrated. The residue was purified by silica gel chromatography eluting with ethyl acetate-heptane (1:1) to afford the title compound (2.0 g, 37%) as a white solid; TLC Rf 0.45 (solvent system 1:1 v/v ethyl acetate-heptane).

Scheme 3, Step C: Preparation of (R)-1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylic acid (10b)

A mixture consisting of (R)-tert-butyl 1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylate (intermediate 9b, 2.0 g, 5.7 mmol), trifluoroacetic acid (25 mL), and water (0.125 mL) was stirred for three hours at room temperature and was subsequently concentrated in vacuo to afford the crude title intermediate (2.26 g) as a yellow oil, which was used in the next step without purification.

Scheme 3, Step D: Preparation of (R)-methyl 4-(2-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (5b)

To a stirring mixture consisting of crude (R)-1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylic acid (intermediate 10b, 2.26 g, 8.14 mmol) in THF (40 mL) at -10 °C was added N-methylmorpholine (0.9 mL, 8 mmol). After stirring for five minutes, isobutyl chloroformate (1.08 mL, 8.25 mmol) was added dropwise and the reaction mixture was stirred for an additional thirty minutes and was subsequently filtered through a pad of Celite. The filtrate was cooled to -10 °C, and a solution consisting of sodium borohydride (0.434 g, 11.5 mmol) predissolved in water (15 mL) was added. The resulting mixture was stirred at 0 °C for one hour and then at room temperature for one hour. The mixture was poured into a separatory funnel and diluted with ethyl acetate (200 mL). The organic layer was washed sequentially.
with 1N hydrochloric acid solution, saturated sodium bicarbonate solution, and brine, was dried over sodium sulfate, filtered, and concentrated. The residue was purified by silica gel chromatography eluting with methanol-ethyl acetate (3:97 v/v) to afford the title compound as an off white solid; TLC Rf 0.19 (solvent system 3:97 v/v methanol-ethyl acetate); MS (APCI+) m/z 278 (M+1).

Scheme 2, Step F: Preparation of (R)-methyl 4-(2-(2-formyl-5-oxopyrrolidin-1-yl)ethyl)benzoate (6b)

![Image](image.png)

(R)-Methyl 4-(2-(2-formyl-5-oxopyrrolidin-1-yl)ethyl)benzoate (0.246 g, 62.5% yield from 5b, a colorless oil) was prepared by the method described in Scheme 2, Step F for the preparation of aldehyde intermediate 6a except that (R)-methyl 4-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (5b) was used instead of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate; TLC Rf 0.29 (solvent system 3:97 v/v methanol-ethyl acetate).

Preparation of (R)-methyl 2-(4-((2-formyl-5-oxopyrrolidin-1-yl)methyl)phenyl)-acetate (6c)

![Image](image.png)

Scheme 3, Step A: Preparation of (R)-di-tert-butyl 2-((4-(2-methoxy-2-oxoethyl)benzyl)amino)pentanedioate (8c)

![Image](image.png)

A stirring mixture consisting of (R)-di-tert-butyl 2-aminopentanedioate (reagent 7, H-D-Glu(OtBu)-OtBu, 5.0 g, 16.9 mmol), methyl 2-(4-(bromomethyl)phenyl)acetate (reagent 3c, 4.52 g, 18.6 mmol; prepared in 99% yield from the corresponding carboxylic acid and trimethylsilyldiazomethane according to known methods such as those described in Leggio, A. et al., Chemical Biology & Drug Design, 2009, 73(3), 287-291), diisopropylethylamine (8.83 mL, 50.7 mmol), and sodium iodide (2.53 g, 16.9 mmol) in dry hexamethylphosphoramide (50 mL) was heated at 55 °C for 15 hours. The reaction mixture was cooled, diluted with ethyl acetate (1.5 L), and washed sequentially with an aqueous solution of ammonium chloride and a saturated aqueous solution of sodium chloride. The organic phase was dried over sodium sulfate and concentrated in vacuo. The residue was purified by silica gel chromatography eluting with a gradient of ethyl acetate-heptane (1:20 to 1:5 v/v) to afford the title intermediate (5.78 g, 81%) as a colorless oil; TLC Rf 0.45 (solvent system 1:3 v/v ethyl acetate-heptane); MS (APCI+) m/z 422 (M+1).
Scheme 3, Step B: Preparation of (R)-tert-butyl 1-(4-(2-methoxy-2-oxoethyl)benzyl)-5-oxopyrrolidine-2-carboxylate (9c)

A stirring mixture consisting of (R)-di-tert-butyl 2-((4-(2-methoxy-2-oxoethyl)benzyl)amino)pentanedioate (intermediate 8c, 5.75 g, 13.6 mmol) in o-xylene (40 mL) was heated at 100 °C for three days. The solvent was evaporated under reduced pressure and the residue was purified by silica gel chromatography eluting with a gradient of ethyl acetate-heptane (1:20 to 1:1 v/v) to afford the title intermediate (3.09 g, 65.2%) as a colorless oil; TLC Rf 0.6 (solvent system 4:6 v/v ethyl acetate-heptane); MS (APCI+) m/z 370 (M+23, Na+).

Scheme 3, Step C: Preparation of (R)-1-(4-(2-methoxy-2-oxoethyl)benzyl)-5-oxopyrrolidine-2-carboxylic acid (10c)

A stirring mixture consisting of (R)-tert-butyl 1-(4-(2-methoxy-2-oxoethyl)benzyl)-5-oxopyrrolidine-2-carboxylate (intermediate 9c, 2.93 g, 8.43 mmol) and trifluoroacetic acid (4.55 mL, 59.0 mmol) in dichloromethane (30 mL) was heated at 45 °C for seven hours with subsequent stirring at room temperature overnight. The reaction mixture was diluted with ethanol and evaporated under reduced pressure. The crude residue (2.44 g) was carried onto the next step (Step D) without purification.

Scheme 3, Step D: Preparation of (R)-methyl 2-(4-((2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)methyl)phenyl)acetate (5c)

(R)-Methyl 2-(4-((2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)methyl)phenyl)acetate (1.6 g, 65%, as a colorless oil) was prepared in the same manner as compound 5b in Scheme 3, Step D except that (R)-1-(4-(2-methoxy-2-oxoethyl)benzyl)-5-oxopyrrolidine-2-carboxylic acid (10c) was used instead of (R)-1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylic acid; TLC Rf 0.5 (solvent system 5:95 v/v methanol-dichloromethane); 1H-NMR (CDCl3) δ 7.3-7.2 (m, 4H), 4.9 (d, 1H), 4.2 (d, 1H), 3.8-3.7 (m, 1H), 3.7 (s, 3H), 3.6 (s, 2H), 3.6-3.4 (m, 2H), 2.6-2.4 (m, 2H), 2.1-1.9 (m, 2H).

Scheme 2, Step F: Preparation of (R)-methyl 2-(4-((2-formyl-5-oxopyrrolidin-1-yl)methyl)phenyl)acetate (6c)

(R)-Methyl 2-(4-((2-formyl-5-oxopyrrolidin-1-yl)methyl)phenyl)acetate (1.6 g, 65%, as a colorless oil) was prepared in the same manner as compound 5b in Scheme 3, Step D except that (R)-1-(4-(2-methoxy-2-oxoethyl)benzyl)-5-oxopyrrolidine-2-carboxylic acid (10c) was used instead of (R)-1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylic acid; TLC Rf 0.5 (solvent system 5:95 v/v methanol-dichloromethane); 1H-NMR (CDCl3) δ 7.3-7.2 (m, 4H), 4.9 (d, 1H), 4.2 (d, 1H), 3.8-3.7 (m, 1H), 3.7 (s, 3H), 3.6 (s, 2H), 3.6-3.4 (m, 2H), 2.6-2.4 (m, 2H), 2.1-1.9 (m, 2H).
(R)-Methyl 2-((2-formyl-5-oxopyrrolidin-1-yl)methyl)phenylacetate (0.2 g, 90%) was prepared in the same manner as compound 6a in Scheme 2, Step F except that (R)-methyl 2-{(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)methyl}phenylacetate (5c) was used instead of (R)-methyl 7-{2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate; MS (ESI⁻) m/z 274 (M-1); ¹H-NMR (CDCl₃) δ 9.4 (d, 1H), 7.3-7.1 (m, 4H), 5.0-4.8 (m, 2H), 4.2-4.0 (m, 1H), 3.7 (s, 3H), 3.6 (s, 2H), 2.6-1.9 (m, 4H).

Preparation of (R)-methyl 5-((2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)ethynyl)thiophene-2-carboxylate (6d)

Step 1: Preparation of methyl 5-bromo-2-thiophene carboxylate

To an ice-cooled mixture consisting of 5-bromo-2-thiophene carboxylic acid (5.25 g, 25.4 mmol) in ethyl acetate (200 mL) and methanol (20 mL) was added trimethylsilyldiazomethane (2 M in diethyl ether, 20 mL, 40 mmol) over 20 minutes. The reaction mixture was stirred for 24 hours. The solvent was removed and the residue was purified by silica gel chromatography eluting with ethyl acetate-heptanes (1:50 v/v) to afford the title intermediate (5.5 g, 98%) as a white solid; TLC Rᵉ 0.60 (solvent system 1:9 v/v ethyl acetate-heptanes); ¹H-NMR (CDCl₃) δ 7.5 (d, 1H), 7.1 (d, 1H), 4.9 (s, 3H).

Step 2: Preparation of methyl 5-((3-hydroxyprop-1-yn-1-yl)thiophene-2-carboxylate

To a covered mixture consisting of methyl 5-bromo-2-thiophene carboxylate (5.6 g, 25 mmol) in benzene (60 mL) was added a suspension consisting of tetrakis(triphenylphosphine)palladium (0) (1.4 g, 1.3 mmol) in benzene (10 mL), and the reaction mixture was stirred for 30 minutes. To the reaction mixture was then added copper(I) iodide (480 mg, 2.52 mmol) and n-butylamine (5 mL, 50 mmol) in one portion each, followed by propargyl alcohol (2.2 mL, 38 mmol) in benzene (30 mL) over 15 minutes, and the reaction was stirred for 24 hours. To the reaction mixture was added a saturated solution of ammonium chloride (200 mL) and the organic material was extracted with ethyl acetate. The organic phase was washed with water, then brine, dried over sodium sulfate, filtered, and concentrated. The residue was purified by silica gel chromatography eluting with ethyl acetate-heptanes (1:10 v/v) to afford the title intermediate (3.8 g, 78%).
Step 3: Preparation of methyl 5-(3-bromoprop-1-yn-1-yl)thiophene-2-carboxylate (3d)

To an ice cooled solution of methyl 5-(3-hydroxyprop-1-yn-1-yl)thiophene-2-carboxylate (1.32 g, 6.73 mmol) in dichloromethane (25 ml) was added carbon tetrabromide (3.1 g, 9.42 mmol) and triphenylphosphine (2.5 g, 9.42 mmol) and the mixture stirred for 4 hours. The solvent was removed and the residue was purified by silica gel chromatography eluting with ethyl acetate:heptanes (1:25 v:v) to afford the title compound (1.5 g). TLC Rf 0.65 (solvent system 80:20 v/v heptanes:ethyl acetate); 1H-NMR (CDCl3) δ 7.6 (d, 1H), 7.1 (d, 1H), 4.1 (s, 2H), 3.9 (s, 3H).

Scheme 3, Step A: Preparation of (R)-di-tert-butyl 2-((3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)amino)pentanedioate (8d)

(R)-Di-tert-butyl 2-((3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)amino)pentanedioate was prepared in the same manner as compound 8c in Scheme 3, Step A except that methyl 5-(3-bromoprop-1-yn-1-yl)thiophene-2-carboxylate (3d) was used instead of methyl 2-(4-(bromomethyl)phenyl)acetate; TLC Rf 0.45 (solvent system 80:20 v/v heptanes:ethyl acetate); 1H-NMR (CDCl3) δ 7.7 (d, 1H), 6.9 (d, 1H), 3.9 (s, 3H), 3.3-3.2 (m, 1H), 3.2 (s, 2H), 2.4 (t, 2H), 2.0-1.8 (m, 2H), 1.45 (d, 9H).

Scheme 3, Step B: Preparation of (R)-tert-butyl 1-(3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)-5-oxopyrrolidine-2-carboxylate (9d)

(R)-Tert-butyl 1-(3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)-5-oxopyrrolidine-2-carboxylate was prepared in the same manner as compound 9c in Scheme 3, Step B except that (R)-di-tert-butyl 2-((3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)amino)pentanedioate (8d) was used instead of (R)-di-tert-butyl 2-((4-(2-methoxy-2-oxoethyl)benzyl)amino)pentanedioate; TLC Rf 0.25 (solvent system 60:40 v/v heptanes:ethyl acetate); 1H-NMR (CDCl3) δ 7.7 (d, 1H), 6.9 (d, 1H), 4.5-4.4 (m, 1H), 4.2-4.0 (m, 2H), 3.85 (s, 3H), 2.6-2.5 (m, 1H), 2.4-2.2 (m, 2H), 2.1-2.0 (m, 1H), 1.4 (s, 9H).
Scheme 3, Step C: Preparation of (R)-1-(3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)-5-oxopyrrolidine-2-carboxylic acid (10d)

A solution of (R)-tert-butyl 1-(3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)-5-oxopyrrolidine-2-carboxylate (1.1 g, 3.03 mmol) and trifluoroacetic acid (4 mL, 51.9 mmol) in dichloromethane (45 mL) was heated at 50 °C overnight. The reaction mixture was diluted with ethanol and toluene and evaporated under reduced pressure to produce a residue that was used in the next step (Step D) with no further purification; TLC R<sub>f</sub> 0.10 (solvent system 60:40 v/v heptanes:ethyl acetate).

Scheme 3, Step D: Preparation of (R)-methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (5d)

(R)-Methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate was prepared in the same manner as compound 5b in Scheme 3, Step D except that (R)-1-(3-(5-(methoxycarbonyl)thiophen-2-yl)prop-2-yn-1-yl)-5-oxopyrrolidine-2-carboxylic acid (10d) was used instead of (R)-1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylic acid and triethylamine was used instead of N-methylmorpholine; TLC R<sub>f</sub> 0.30 (solvent system 95:5 v/v dichloromethane:methanol); <sup>1</sup>H-NMR (CDCl<sub>3</sub>): δ 7.6 (d, 1H), 6.9 (d, 1H), 4.1-4.0 (m, 1H), 3.85 (s, 3H), 3.8 (s, 2H) 3.6-3.5 (s, 1H), 3.2-3.0 (br s, 1H), 2.6-2.4 (m, 1H), 2.4-2.3 (m, 1H), 2.2-2.0 (m, 1H), 2.0-1.9 (m, 1H); MS (ESI<sup>+</sup>) m/z 294.0 (M+1), (ESI<sup>−</sup>) m/z 292.0 (M-1).

Scheme 2, Step F: Preparation of (R)-methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (6d)

(R)-Methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate was prepared in the same manner as compound 6a in Scheme 2, Step F except that (R)-methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (5d) was used instead of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate; TLC R<sub>f</sub> 0.30 (solvent system 95:5 v/v dichloromethane:methanol).

Preparation of (R,Z)-methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (6e)
Step 1: Preparation of (Z)-methyl 5-(3-hydroxyprop-1-en-1-yl)thiophene-2-carboxylate

To a mixture consisting of methyl 5-(3-hydroxyprop-1-yn-1-yl)thiophene-2-carboxylate (1.9 g, 9.7 mmol) in ethyl acetate (50 mL) and methanol (5 mL) was added palladium on calcium carbonate (5%, 1.5 g). The reaction flask was evacuated and backfilled with hydrogen gas and the reaction mixture was subsequently stirred for 2 hours while maintaining a hydrogen atmosphere. The mixture was then filtered through Celite and the solvent removed. The residue was purified by silica gel chromatography eluting with ethyl acetate-heptanes (1:10 v/v) to afford the title intermediate (1.5 g); TLC \( R_f \) 0.65 (solvent system 1:1 v/v ethyl acetate-heptanes); MS (ESI+) m/z 221 (M+Na+); \(^1\)H-NMR (CDCl\(_3\)) \( \delta \) 7.7 (d, 1H), 6.9 (d, 1H), 6.6 (d, 1H), 6.0-5.9 (m, 1H), 4.6 (d, 2H), 3.9 (s, 3H), 1.9 (br s, 1H)

Step 2: Preparation of (Z)-methyl 5-(3-bromoprop-1-en-1-yl)thiophene-2-carboxylate (3e)

(Z)-Methyl 5-(3-bromoprop-1-en-1-yl)thiophene-2-carboxylate (2.56 g) was prepared in the same manner as compound 3d except that (Z)-methyl 5-(3-hydroxyprop-1-en-1-yl)thiophene-2-carboxylate was used instead of 5-(3-hydroxyprop-1-yn-1-yl)thiophene-2-carboxylate; TLC \( R_f \) 0.60 (solvent system 20:80 v/v ethyl acetate-heptanes); MS (ESI+) m/z 261 (M+1); \(^1\)H-NMR (CDCl\(_3\)) \( \delta \) 7.7 (d, 1H), 7.2 (d, 1H), 6.6 (d, 1H), 6.2-6.0 (m, 1H), 4.3 (d, 2H), 3.9 (s, 3H).

Scheme 3, Step A: Preparation of (R,Z)-di-tert-butyl 2-((3-(5-(methoxycarbonyl)thiophen-2-yl)allyl)amino)pentanedioate (8e)

(R,Z)-Di-tert-butyl 2-((3-(5-(methoxycarbonyl)thiophen-2-yl)allyl)amino)pentanedioate was prepared in the same manner as compound 8c in Scheme 3, Step A, except that (Z)-methyl 5-(3-bromoprop-1-en-1-yl)thiophene-2-carboxylate (3e) was used instead of methyl 2-(4-(bromomethyl)phenyl)acetate; TLC \( R_f \) 0.30 (solvent system 1:4 v/v ethyl acetate-heptanes); MS (ESI+) m/z 440 (M+1); \(^1\)H-NMR (CDCl\(_3\)) \( \delta \) 7.7 (d, 1H), 6.9 (d, 1H), 6.6 (d, 1H), 5.9-5.8 (m,
Scheme 3, Step B: Preparation of \((R,Z)\)-tert-butyl 1-(3-(5-(methoxycarbonyl)-thiophen-2-yl)allyl)-5-oxopyrrolidine-2-carboxylate (9e)

\[
\text{\((R,Z)\)-tert-Butyl 1-(3-(5-(methoxycarbonyl)thiophen-2-yl)allyl)-5-oxopyrrolidine-2-carboxylate was prepared in the same manner as compound 9c in Scheme 3, Step B except that \((R,Z)\)-di-tert-butyl 2-((3-(5-(methoxycarbonyl)thiophen-2-yl)allyl)amino)pentanedioate (8e) was used instead of \((R)\)-di-tert-butyl 2-((4-(2-methoxy-2-oxoethyl)benzyl)amino)pentanedioate; TLC R_f 0.20 (solvent system 2:3 v/v ethyl acetate-heptanes); MS (ESI+) m/z 366 (M+1), 388 (M+Na+); 1H-NMR (CDCl_3) δ 7.7 (d, 1H), 6.9 (d, 1H), 6.6 (d, 1H), 5.7-5.6 (m, 1H), 4.5-4.4 (m, 1H), 4.2-4.0 (m, 2H), 3.85 (s, 3H), 2.6-2.5 (m, 1H), 2.4-2.2 (m, 2H), 2.1-2.0 (m, 1H), 1.4 (s, 9H).
\]

Scheme 3, Step C: Preparation of \((R,Z)\)-1-(3-(5-(methoxycarbonyl)thiophen-2-yl)allyl)-5-oxopyrrolidine-2-carboxylic acid (10e)

\[
\text{A stirring mixture consisting of \((R,Z)\)-tert-butyl 1-(3-(5-(methoxycarbonyl)-thiophen-2-yl)allyl)-5-oxopyrrolidine-2-carboxylate (intermediate 9e, 2.05 g, 5.61 mmol) and trifluoroacetic acid (5.0 mL, 65 mmol) in dichloromethane (40 mL) was heated at 45 °C overnight. The reaction mixture was diluted with ethanol and evaporated under reduced pressure to provide a residue (2.44 g) that was used in the next step (Step D) without further purification; TLC R_f 0.25 (solvent system 50:50:1 v/v ethyl acetate-heptanes-acetic acid).
\]

Scheme 3, Step D: Preparation of \((R,Z)\)-methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (5e)

\[
\text{\((R,Z)\)-Methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate was prepared in the same manner as compound 5b in Scheme 3, Step D except that \((R,Z)\)-1-(3-(5-(methoxycarbonyl)thiophen-2-yl)allyl)-5-oxopyrrolidine-2-carboxylic acid (10e) was used instead of \((R)\)-1-(4-(methoxycarbonyl)phenethyl)-5-oxopyrrolidine-2-carboxylic acid and triethylamine was used instead of N-methylmorpholine; TLC R_f 0.20 (solvent system 50:50:1 v/v ethyl acetate-heptanes-acetic acid); MS (ESI+) m/z 296 (M+1), 318 (M+Na+); 1H-NMR (CDCl_3) δ 7.6 (d, 1H),}
\]
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6.9 (d, 1H), 6.6 (d, 1H), 6.1-5.6 (m, 1H), 4.5-4.3 (m, 1H), 4.1-4.0 (m, 1H), 3.85 (s, 3H), 3.7 (s, 2H) 3.6-3.5 (m, 1H), 3.2-3.0 (br s, 1H), 2.6-2.4 (m, 1H), 2.4-2.3 (m, 1H), 2.2-2.0 (m, 1H), 2.0-1.9 (m, 1H).

Scheme 2, Step F: Preparation of (R,Z)-methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (6e)

[0215]

(R,Z)-Methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate was prepared in the same manner as compound 6a in Scheme 2, Step F except that (R,Z)-methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (5e) was used instead of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate; TLC Rf 0.40 (solvent system 1:1 v/v ethyl acetate-heptanes).

Preparation of (R)-methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (6f)

[0217]

To a solution of (R,Z)-methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (5e, 496 mg,) in ethyl acetate (40 mL) and methanol (4 mL) was added palladium on carbon (10%, 40 mg) and the flask evacuated and exposed to hydrogen for 4 hours. The mixture was then filtered through Celite and the solvent removed to afford the title intermediate in a quantitative yield, which was used without purification; TLC Rf 0.25 (solvent system 95:5 v/v dichloromethane:methanol); 1H-NMR (CDCl3); δ 7.6 (d, 1H), 6.6 (d, 1H), 3.85 (s, 3H), 3.8 (dd, 1H) 3.75-3.65 (m, 2H), 3.6 (dd, 1H), 3.1 (m, 1H), 2.85 (t, 2H), 2.7-2.4 (br s, 1H), 2.5-2.4 (m, 1H), 2.35-2.25 (m, 1H), 2.1-1.8 (m, 4H); MS (ESI+) m/z 298.0 (M+1), 320.0 (M+Na+).

Scheme 2, Step F: Preparation of (R)-methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (6f)

[0220]
(R)-Methyl 5-(3-(2-formyl-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate was prepared in the same manner as compound 6a in Scheme 2, Step F except that (R)-methyl 5-(3-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (5f) was used instead of (R)-methyl 7-(2-(hydroxymethyl)-5-oxopyrrolidin-1-yl)heptanoate; TLC Rf 0.25 (solvent system 95:5 v/v dichloromethane:methanol).

Organic β-keto phosphonate esters such as

\[
C_{1-4} \text{ alkyl}\cdot\text{O-P(O)(O)} B \quad (13)
\]

may be used as reaction coupling partners with aldehydes such as 6a-f in a Horner-Emmons-Wadsworth-type process to install the lactam lower-chain scaffold. Such β-keto phosphonate esters may be prepared by coupling an appropriate carboxylic ester

\[
C_{1-4} \text{ alkyl}\cdot\text{O} B \quad (12)
\]

with lithiated/deprotonated dialkyl methylphosphonate according to the general reaction illustrated in Scheme 6 and variations thereof. Tables A - G/H of Lower Chains (below) describe various lower-chain components B of the exemplary embodiments.

Carboxylic esters 12 may be commercially available or prepared from commercially-available starting materials as shown in Schemes 7a-g. The numbering system, comprising various numerical, lower-case alphabetical, and lower-case Roman numeral descriptors, for intermediates comprising component B, such as carboxylic esters 12, β-keto phosphonate esters 13, NHS esters 16, amides 17, carboxylic acids 18, and (S)-3-(B-carbonyl)-4-benzyloxazolidin-2-ones 19 found in Schemes, Tables, and Examples herein works as follows:
A carboxylic ester, 12(a-f)a or 12(a-f)b/c(i-viii), may be prepared in two steps from commercially available diethyl malonate or an appropriate commercially available diethyl 2-(C1-C4 alkyl) malonate starting material. Reaction of the malonate starting material with an appropriate lithium amide base, such as LDA or LiHMDS, followed by an appropriate alkylating agent R6-L3-X1, as illustrated in Scheme 7a, Step A, affords the corresponding 2-(R6-L3-)-substituted diethyl malonate 14a-f. Subsequent decarboxylation (Step B) provides the corresponding carboxylic ester intermediate 12, wherein both R4 and R5 are hydrogen, or wherein one of R4 and R5 is a C1-C4 alkyl group (alkyl groups (i) through (viii) represent methyl, ethyl, n-propyl, 2-propyl, n-butyl, iso-butyl, sec-butyl, and tert-butyl, respectively) and the other is a hydrogen. Examples of commercially available diethyl (C1-C4 alkyl) malonates include diethyl methyl malonate, diethyl ethyl malonate, diethyl isopropyl malonate, diethyl n-propyl malonate, diethyl isobutyl malonate, and diethyl sec-butyl malonate (all from Sigma-Aldrich, Acros Organics, or Alfa Aesar), diethyl isobutyl malonate, and diethyl sec-butyl malonate (both from Alfa Aesar). Methods for preparing the starting diethyl (C1-C4 alkyl) malonates are known in the art; for example, diethyl malonate may be combined with a base such as potassium carbonate and an appropriate alkylating agent such as methyl iodide, ethyl iodide, n-propyl bromide, or n-butyl bromide under microwave irradiation in the method described by Keglevich et al. in Letters in Organic Chemistry, 2008, 5(3), 224-228 and in Green Chemistry, 2006, 8(12), 1073-1075. Other methods that may be used to prepare the diethyl (C1-C4 alkyl) malonates include the reaction of diethyl malonate with an appropriate alkylating agent such as ethyl iodide, isopropyl bromide, isobutyl bromide, or sec-butyl bromide in the presence of a base such as sodium ethoxide in an organic solvent such as ethanol as described in Patel and Ryono in Bioorganic and Medicinal Chemistry Letters, 1992, 2(9), 1089-1092 and elsewhere.

**Carboxylic ester intermediates 12** possessing a gem-dimethyl substitution at the carbon atom α to the ester

The second lower case letter represents the nature of the R4 and R5 substitutions as follows:

- **a** both R4 and R5 are hydrogen;
- **b** R4 is C1-C4 alkyl, R5 is hydrogen;
- **c** R4 is hydrogen, R5 is C1-C4 alkyl;
- **d** both R4 and R5 are C1-C4 alkyl; and
- **e** R4 and R5 with the carbon to which they are bound form a C3-C5 cycloalkyl.

A designation of "b/c" represents a mixture of the b and c stereoisomers.
carbonyl group (both R^4 and R^5 are methyl), such as 12(a-f)d(i), may be prepared by the methylation of the corresponding mono-α-methyl ester intermediate (stereochemical mixture) 12(a-f)b/c(i) as shown in Scheme 7b and reported in Shibasaki, M. et al, in Chemical and Pharmaceutical Bulletin, 1989, 37(6), 1647-1649.

**0225** Scheme 7c illustrates mono-alkylations of commercially available or prepared carboxylic esters 12(a-f)a with an alkylating agent R^4R^5X^1, wherein the R^4/R^5 group is a C^1-C^3 alkyl group and X^1 is a leaving group such as iodide or bromide to provide the corresponding mono-alkylated analogs 12(a-f)b/c, respectively. The mono-alkylated carboxylic ester analogs may be alkylated a second time; for example, mono-methylated carboxylic acid esters (stereochemical mixture) 12(a-f)b/c(i) may be methylated a second time to provide the corresponding gem-dimethyl substituted esters 12(a-f)d(i), as illustrated in Scheme 7d.

**0226** Scheme 7e illustrates the preparation of 1-(R^6-L^3)-substituted C^2-C^5 cycloalkylcarboxylic acids and their C^1-C^4 alkyl esters 12(a-f)e(ix-xi), Similar transformations are described in Yang, D. et. al. in Journal of Organic Chemistry, 2009, 74(22), 8726-8732; Cowling, S. J. and Goodby, J. W. in Chemical Communications (Cambridge, United Kingdom), 2006, 39, 4107-4709; Araldi, G. L. et. al. in WO 2003/103604; and others.

**0227** Stereopure carboxylic esters 12(a-f)b(i-viii) and their stereoisomers, 12(a-f)c(i-viii) may be prepared according to the route illustrated in Scheme 7f. Alkylation of an appropriately-substituted carboxylic acid starting material, such as propionic acid (R^4/R^5 is a methyl group), at the carbon position alpha to the acid carbonyl group by treatment of the acid with an appropriate base, such as lithium disopropylamide (about two molar equivalents) in the presence of a suitable solvent, such as THF, with an alkylating agent R^4R^5L^3-X^1 (Step A) provides the corresponding carboxylic acid intermediates 18(a-f)b/c(i-viii). Subsequent coupling of the carboxylic acid intermediate with N-hydroxysuccinimide (NHS) forms the corresponding NHS ester (an activated ester) stereoisomeric mixture 16(a-f)b/c(i-viii) (Step B). Treatment of the activated ester stereoisomeric mixture 16(a-f)b/c(i-viii) with (R)-2-amino-2-phenylethanol in THF results in the mixture of two amide diastereomers 17(a-f)b(i-viii) and 17(a-f)c(i-viii) (Step C), which may be separated by chromatography to provide each pure diastereomer (Step D). Amide hydrolysis of each diastereomer to its corresponding carboxylic acid 18(a-f)b(i-viii) and 18(a-f)c(i-viii), respectively (Step E), and subsequent esterification (Step F) provides corresponding individual carboxylic ester stereoisomers 12(a-f)b(i-viii) and 12(a-f)c(i-viii), respectively.

**0228** Scheme 7g shows a synthetic pathway to stereopure carboxylic esters 12(a-f)b(i-vii) (R^5 is hydrogen) employing the use of the chiral auxiliary to generate (S)-3-(B-carbonyl)-4-benzyloxazolidin-2-ones 19(a-f)a (both R^4 and R^5 are hydrogen) for more-efficient (asymmetric) alkylation in Step C to provide the corresponding alkylated (S)-3-(B-carbonyl)-4-benzyloxazolidin-2-ones analogs enriched in the 19(a-f)b(i-vii) stereoisomer over the 19(a-f)c(i-vii) stereoisomer. Removal of the chiral auxiliary (Step D) following alkylation and subsequent chiral amide derivatization (Steps E and F) provides the diastereomers 17(a-f)b(i-vii) separable by chromatography and further purified by crystallization (Step G). Acid-catalyzed amide hydrolysis (Step H) to the corresponding stereopure carboxylic acid 18(a-f)b(i-vii) and subsequent esterification (Step I) provide the desired stereopure carboxylic ester intermediates 12(a-f)b(i-vii), which can be carried onto their corresponding stereopure β-keto phosphonate esters 13(a-f)b(i-vii).

**0229** Scheme 8 particularly illustrates the conversions of acetylenic carboxylic esters 12(a-f)a and 12(a-f)(b-e)(i-xi) to the corresponding β-keto phosphonates by the previously-described general manner.
### Table A of Lower Chains

<table>
<thead>
<tr>
<th></th>
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<th>R⁵</th>
<th>L³,R⁶</th>
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</tr>
<tr>
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<td>Me</td>
<td>H</td>
<td></td>
</tr>
<tr>
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<td>H</td>
<td>Me</td>
<td></td>
</tr>
<tr>
<td>ad(i)</td>
<td>Me</td>
<td>Me</td>
<td></td>
</tr>
<tr>
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<td>Et</td>
<td>H</td>
<td></td>
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<tr>
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<td>H</td>
<td>Et</td>
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<td>Et</td>
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<tr>
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<td>H</td>
<td>sec-Bu</td>
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</tr>
</tbody>
</table>

R⁴ and/or R⁵ = C₁₋₃₅ alkyl

(i) Me
(ii) Et
(iii) n-Pr
(iv) i-Pr
(v) n-Bu
(vi) i-Bu
(vii) sec-Bu
(viii) tert-Bu
(ix) cyclopropyl
(x) cyclobutyl
(xi) cyclopentyl
* R^4 and R^5 may both be C_1-6 alkyl groups that are not the same. Although no examples of these embodiments are represented in these tables, their absence infers no limitation in scope.

<table>
<thead>
<tr>
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ae(ix)  

\[ \text{ae(x)} \]

ae(xi)  

\[ \text{ae(xi)} \]
Table B of Lower Chains

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<td>Me</td>
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R⁴ and/or R⁵ = C₃₋₅ alkyl*
* R₄ and R₅ may both be C₁-C₄ alkyl groups that are not the same. Although no examples of these embodiments are represented in these tables, their absence infers no limitation in scope.
Table C of Lower Chains

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<tr>
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<td>Me</td>
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<tr>
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R^4 and/or R^5 = C_2\text{--}C_4 alkyl

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<tr>
<td>(vi)</td>
<td>i-Bu</td>
<td>cd(iv)</td>
<td>i-Pr</td>
</tr>
<tr>
<td>(vii)</td>
<td>sec-Bu</td>
<td>cb(v)</td>
<td>n-Bu</td>
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<td>(viii)</td>
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* R^4 and R^5 may both be C_1-C_4 alkyl groups that are not the same. Although no examples of these embodiments are represented in these tables, their absence infers no limitation in scope.

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ce(ix) \[ \frac{1}{2} \text{CH}_2 - \text{CH}_2 - \frac{1}{2} \]

ce(x) \[ \frac{1}{2} \text{(CH}_2)_2 - \text{CH}_2 - \frac{1}{2} \]

ce(xi) \[ \frac{1}{2} \text{(CH}_2)_3 - \text{CH}_2 - \frac{1}{2} \]
### Table D of Lower Chains

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R⁴ and/or R⁵ = C₁⁻C₄ alkyl

- (i) Me
- (ii) Et
- (iii) n-Pr
- (iv) i-Pr
- (v) n-Bu
- (vi) i-Bu
- (vii) sec-Bu
- (viii) tert-Bu
- (ix) cyclopropyl
- (x) cyclobutyl
- (xi) cyclopentyl

R⁴⁻ and/or R⁵⁻ = C₃⁻C₅ cycloalkyl

- (x) cyclopentyl
* R⁴ and R⁵ may both be C₁-C₄ alkyl groups that are not the same. Although no examples of these embodiments are represented in these tables, their absence infers no limitation in scope.

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de(ix)

\[ \begin{array}{c}
\text{CH}_2 \\
\text{CH}_2 \\
\end{array} \]

de(x)

\[ \begin{array}{c}
\text{CH}_2 \\
\text{CH}_2 \\
\text{(CH}_2)_2 \\
\end{array} \]

de(xi)

\[ \begin{array}{c}
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\text{CH}_2 \\
\text{(CH}_2)_3 \\
\end{array} \]
Table E of Lower Chains

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<td>Me</td>
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R^4 and/or R^5 = C_2-C_4 alkyl

(i) Me
(ii) Et
(iii) n-Pr
(iv) i-Pr
(v) n-Bu
(vi) i-Bu
(viii) sec-Bu
(ix) tert-Bu

= C_3-C_5 cycloalkyl

(lx) cyclopropyl
(x) cyclobutyl
(xi) cyclopentyl
* R⁴ and R⁵ may both be C₁-C₄ alkyl groups that are not the same. Although no examples of these embodiments are represented in these tables, their absence infers no limitation in scope.

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ee(ix)  
\[
\begin{array}{c}
\text{CH}_2 & \text{CH}_2 \\
\end{array}
\]

ee(x)  
\[
\begin{array}{c}
\text{CH}_2 & \text{CH}_2 \\
\end{array}
\]

ee(xii)  
\[
\begin{array}{c}
\text{(CH}_2)_3 & \text{CH}_2 \\
\end{array}
\]
Carboxylic Esters 12
β-Keto Phosphonate Esters 13
Carboxylic Acids 18
NHS Esters 16
Amides 17
(S)-3-(B-Carbonyl)-4-benzylazolidin-2-ones 19
**Table F of Lower Chains**

<p>| | | | |</p>
<table>
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<tr>
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<td>fc(i)</td>
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<tr>
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<td>(viii)</td>
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<td>(xi)</td>
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* R⁴ and R⁵ may both be C₁-C₄ alkyl groups that are not the same. Although no examples of these embodiments are represented in these tables, their absence infers no limitation in scope.

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<th>fc(vii)</th>
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fe(ix) \[ \begin{array}{c}
\text{CH}_2 \text{CH}_2 \\
\end{array} \]

fe(x) \[ \begin{array}{c}
(\text{CH}_2)_2 \text{CH}_2 \\
\end{array} \]

fe(xi) \[ \begin{array}{c}
(\text{CH}_2)_3 \text{CH}_2 \\
\end{array} \]
Table G/H of Lower Chains

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Table P/Q of Lower Chains

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<td>q</td>
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</table>
Scheme 7a

**Step A**
- 1.1 base (e.g. NaH, LDA or LiHMDS), solvent (e.g. THF)
- 1.2 \( R^4, R^5, R^6, L^3, X^1 \)

**Step B**
- LiCl
- DMSO 80 °C
- \( R^4, R^5, R^6, L^3, X^1 \)
- 12(a-f)a
- or 12(a-f)b/c(i-viii)

\( X^1 = \text{leaving group (e.g. iodide, bromide, or triflate)} \)

Scheme 7b

**12(a-f)b/c(i)**

**1.1 base (e.g. n-BuLi, LDA or LiHMDS), solvent (e.g. THF)**

**1.2 MeI**

**12(a-f)d(i)**

Scheme 7c

**12(a-f)a**

**1.1 base (e.g. n-BuLi, LDA or LiHMDS), solvent (e.g. THF)**

**1.2 \( R^4, R^5, X^1 \)**

\( X^1 = \text{leaving group (e.g. bromide, iodide, or triflate)} \)

**12(a-f)b/c(i-vii)**

Scheme 7d

**12(a-f)b/c(i-vii)**

**1.1 base (e.g. n-BuLi, LDA or LiHMDS), solvent (e.g. THF)**

**1.2 MeI**

**12(a-f)d(i, etc.)**
Scheme 7g

Step A

\[ \text{HO}_2\text{C} - \text{L}^3 - \text{R}^6 \xrightarrow{\text{(COCl)}_2, \text{DMF}_{\text{cat}}} \text{Cl} - \text{C} - \text{O} \xrightarrow{\text{THF}, -78 \degree \text{C}} \]

18(a-f)a

Step B

\[ \text{LiHMDS, THF, -78 \degree \text{C}} \]

\[ 1.1 \text{ LiHMDS, THF, -78 \degree \text{C}} \]

\[ 1.2 \text{ R}^4 - \text{X}^1 \]

\[ \text{19(a-f)a} \]

Step C

\[ X^1 = \text{leaving group (e.g. bromide, iodide, or triflate)} \]

Step D

\[ \text{H}_2\text{O} \xrightarrow{\text{H}_2\text{O}_2, \text{LiOH, 0 \degree \text{C}}} \text{HO} \xrightarrow{\text{EDC, DMAP, solvent}} \text{16(a-f)b(i-vii)} \]

Step E

\[ \text{16(a-f)b(i-vii)} \xrightarrow{\text{(R)-2-amino-2-phenylethanol}} \text{17(a-f)b(i-vii)} \]

Step F

\[ \text{17(a-f)b(i-vii)} \xrightarrow{1. \text{ chromatography} 2. \text{ crystallization}} \]

Step H

\[ \text{highly enantiopure 17(a-f)b(i-vii)} \]

\[ 3 \text{ H}_2\text{SO}_4, 1,4\text{-dioxane, 80 \degree \text{C}} \]

Step I

\[ \text{12(a-f)b(i-vii)} \xrightarrow{\text{EIOH, } \text{H}_2\text{SO}_4} \]

Scheme 8
Scheme 7a, Step A: Preparation of diethyl 2-(but-2-yn-1-yl)-2-methylmalonate (14a)

To a stirring mixture consisting of diethyl 2-methylmalonate (Sigma-Aldrich, 34.8 g, 200 mmol) in THF (50 mL) at -78 °C was added lithium bis-(trimethylsilyl)amide (1M in THF, 200 mL, 200 mmol) and the resulting reaction mixture was stirred at -78 °C for 30 minutes. To the reaction mixture was added a mixture consisting of 1-bromobut-2-yne (GFS, 25 g, 190 mmol) in THF (50 mL), and the mixture was stirred for another hour at -78 °C, and was then allowed to warm to room temperature. The mixture was treated with 10% aqueous sodium hydrogen sulfate, diluted with brine (800 mL), and extracted with ethyl acetate (300 mL). The organic phase was washed with brine (2 x 250 mL), dried over sodium sulfate, filtered, and concentrated. The residue (brown oil) was purified by silica gel chromatography eluting with ethyl acetate-hexane (1:9 v/v) to afford the title intermediate (41.5 g, 97.6%); TLC Rf 0.52 (solvent system: 1:9 v/v ethyl acetate-hexane).

Scheme 7a, Step B: Preparation of (±)-ethyl 2-methylhex-4-ynoate (12ab(i)/12ac(i))

To a mixture consisting of diethyl-2-(but-2-yn-1-yl)-methylmalonate (intermediate 14a, 41.5 g, 184 mmol) in DMSO (150 mL) was added lithium chloride (8.05 g, 190 mmol) and water (6.2 mL), and the stirring mixture was heated at 160 °C overnight. The reaction mixture was cooled and diluted with brine, and the organic material was extracted with ethyl acetate (250 mL). The organic phase was washed with brine (2 x 250 mL), dried over sodium sulfate, filtered, and concentrated. The residue (brown oil) was purified by silica gel chromatography eluting with ethyl acetate-hexane (1:9 v/v) to afford the title intermediate (41.5 g, 97.6%); TLC Rf 0.52 (solvent system: 1:9 v/v ethyl acetate-hexane).

Scheme 8: Preparation of (±)-dimethyl (3-methyl-2-oxohept-5-yn-1-yl)phosphonate (13ab(i)/13ac(i))

To a mixture consisting of diethyl-2-(but-2-yn-1-yl)-methylmalonate (intermediate 14a, 41.5 g, 184 mmol) in DMSO (150 mL) was added lithium chloride (8.05 g, 190 mmol) and water (6.2 mL), and the stirring mixture was heated at 160 °C overnight. The reaction mixture was cooled and diluted with brine, and the organic material was extracted with ethyl acetate (250 mL). The organic phase was washed with brine (2 x 250 mL), dried over sodium sulfate, filtered, and concentrated. The residue (dark brown oil) was filtered through a pad of silica gel, using ethyl acetate-hexane (1:4 v/v) to flush the column. The filtrate was concentrated to give the title intermediate (22.3 g, 78.9%) as a colorless oil; TLC Rf 0.37 (solvent system: 1:4 v/v ethyl acetate-hexane).
To a stirring mixture consisting of dimethyl methylphosphonate (21.7 g, 175 mmol) in THF (200 mL) at -78°C was added n-butyllithium (1.6M in hexanes, 106.2 mL, 169.9 mmol) and the mixture was allowed to continue stirring at -78°C for one hour. To the reaction mixture was added dropwise (±)-ethyl 2-methylhex-4-ynoate (intermediate 15, 22.3 g, 145 mmol) and the resulting mixture was stirred at -78 °C for three hours. The reaction mixture was treated with 10% sodium hydrogen sulfate to achieve pH 4, diluted with brine (800 mL), and extracted with ethyl acetate (250 mL). The organic phase was washed with brine (2 x 150 mL), dried over sodium sulfate, filtered, and concentrated. The residue was purified by silica gel chromatography eluting with ethyl acetate to afford the title intermediate (24.12 g, 71.6%) as a colorless oil; TLC Rf 0.31 (solvent system: ethyl acetate); MS (ESI+) m/z 233 (M+1).

Preparation of (±)-dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate (13bb(i)/13bc(i))

(±)-Dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate was prepared in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Schemes 7a and 8 except that 2-yne was used instead of 1-bromobut-2-yne in Scheme 7a, Step A; MS (ESI+) m/z 247.1 (M+1).

Preparation of (±)-dimethyl (3-methyl-2-oxonon-5-yn-1-yl)phosphonate (13cb(i)/13cc(i))

(±)-Dimethyl (3-methyl-2-oxonon-5-yn-1-yl)phosphonate was prepared in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Schemes 7a and 8 except that 1-bromohex-2-yne (prepared from the corresponding commercially available alcohol using PBr₃/pyridine) was used instead of 1-bromobut-2-yne in Scheme 7a, Step A; MS (ESI+) m/z 261 (M+1).

Preparation of (±)-dimethyl (3-methyl-2-oxo-6-phenylhex-5-yn-1-yl)phosphonate (13db(i)/13dc(i))

(±)-Dimethyl (3-methyl-2-oxo-6-phenylhex-5-yn-1-yl)phosphonate was prepared in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Schemes 7a and 8 except that (3-bromoprop-1-yn-1-yl)benzene (prepared from the corresponding commercially available alcohol using PBr₃/pyridine) was used instead of 1-bromobut-2-yne in Scheme 7a, Step A to afford 2.4 g of a clear oil; ¹H-NMR (CDCl₃) δ 7.35-7.45
Dimethyl (2-oxohept-5-yn-1-yl)phosphonate (13aa)

Scheme 7a, Step A: Preparation of diethyl 2-(but-2-yn-1-yl)malonate (14a)

Dimethyl (2-oxohept-5-yn-1-yl)phosphonate was prepared in two steps from diethyl 2-(but-2-yn-1-yl)malonate (14a), above, in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Scheme 7a, Step B and Scheme 8, to afford 2.5 g as a clear oil; \(^1\)H-NMR (CDCl\(_3\)) \(\delta\) 3.78 (d, 6H, J=11.1 Hz), 3.11 (d, 2H, J=22.8 Hz), 2.81 (t, 2H), 2.45-2.38 (m, 2H), 2.28-2.36 (m, 2H), 1.08 (t, 3H).

Preparation of dimethyl (2-oxooct-5-yn-1-yl)phosphonate (13ba)

Dimethyl (2-oxooct-5-yn-1-yl)phosphonate was prepared in the same manner as that of compound intermediate 13aa as described above and illustrated in Scheme 7a and 8, except that 1-bromopent-2-yne (GFS, 6.9 g, 47 mmol) was used instead of 1-bromobut-2-yne to afford 2.5 g as a clear oil; \(^1\)H-NMR (CDCl\(_3\)) \(\delta\) 3.78 (d, 6H, J=11.1 Hz), 3.11 (d, 2H, J=22.8 Hz), 2.81 (t, 2H), 2.45-2.38 (m, 2H), 2.28-2.36 (m, 2H), 1.08 (t, 3H).
Preparation of dimethyl (2-oxonon-5-yn-1-yl)phosphonate (13ca)

[0250]

Dimethyl (2-oxonon-5-yn-1-yl)phosphonate is prepared in the same manner as that of compound intermediate 13aa as described above and illustrated in Scheme 7a and 8, except that 1-bromohex-2-yn is used instead of 1-bromobut-2-yn.

Preparation of dimethyl (2-oxo-6-phenylhex-5-yn-1-yl)phosphonate (13da)

[0252]

Scheme 7a, Step A: Preparation of diethyl 2-(hex-2-yn-1-yl)malonate (14d)

[0253]

To a 0 °C stirring suspension consisting of sodium hydride (1.22 g, 51.3 mmol) in THF (100 mL) was added dropwise a solution of diethyl malonate (12.3 g, 76.9 mmol) in THF (20 mL) and the reaction mixture was stirred for 30 minutes. To the 0 °C reaction mixture was added a solution of (4-bromobut-1-yn-1-yl)benzene (5.0 g, 25.6 mmol, prepared from the corresponding commercially available alcohol using PBr3/pyridine) in THF (30 mL) and the mixture was allowed to warm to room temperature for one hour. The reaction mixture was quenched with an aqueous solution of sodium chloride (500 mL) and extracted with diethyl ether (500 mL). The organic phase was washed with brine (300 mL), dried over sodium sulfate, filtered, and concentrated to afford the title intermediate (10.6 g) which was used as is in the following reaction; TLC Rf 0.47 (solvent system: 1:5 v/v ethyl acetate-heptane).

Preparation of dimethyl (2-oxo-6-phenylhex-5-yn-1-yl)phosphonate (13da)

[0255]

Dimethyl (2-oxo-6-phenylhex-5-yn-1-yl)phosphonate was prepared in two steps from diethyl 2-(hex-2-yn-1-yl)malonate, above, in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Scheme 7a, Step B and Scheme 8 to afford 2.12 g; TLC Rf 0.20 (solvent system: 4:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 281 (M+1).
Preparation of dimethyl (2-oxohex-3-yn-1-yl)phosphonate (13g)

Dimethyl (2-oxohex-3-yn-1-yl)phosphonate was prepared in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Scheme 8 except that ethyl pent-2-ynoate was used instead of (±)-ethyl 2-methylhex-4-ynoate; MS (ESI+) m/z 205 (M+1).

Preparation of dimethyl (2-oxo-4-phenylbut-3-yn-1-yl)phosphonate (13h)

Dimethyl (2-oxo-4-phenylbut-3-yn-1-yl)phosphonate was prepared in the same manner as that of compound intermediate 13ab(i)/13ac(i) as described above and illustrated in Scheme 8 except that ethyl 3-phenylpropiolate was used instead of (±)-ethyl 2-methylhex-4-ynoate; MS (ESI+) m/z 253 (M+1).

Preparation of (S)-(+)dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate (13bb(i))

(S)-(+)Dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate (13bb(i)) was prepared by following the sequence of reaction steps described in Scheme 7b and Scheme 8. The intermediate 2-methylhept-4-ynoic acid was prepared according to a method described in WO 2011/003058 A1. (S)-(+)Dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate was prepared according to the method described in the Journal of Medicinal Chemistry, 1986, 29(3), 313-315, except that 2,5-dioxopyrrolidin-1-yl 2-methylhept-4-ynoate (N-hydroxysuccinimide 2-methylhept-4-ynoate) was prepared as an activated acyl species (activated ester) instead of 2-methylhept-4-ynoyl chloride to make the diastereomeric pair (S)-N-((R)-2-hydroxy-1-phenylethyl)-2-methylhept-4-ynamide (17bb(i)) and (R)-N-((R)-2-hydroxy-1-phenylethyl)-2-methylhept-4-ynamide (17bc(i)) described in general terms in Scheme 7f. The diastereomers were separated by silica gel chromatography and 17bb(i) was subsequently manipulated as described to afford the title intermediate as a clear oil. The absolute stereochemistry of the title intermediate was proven by determination of its specific rotation: [α]T 20D = +45.92° (c = 2.5, CHCl3); literature-reported specific rotation for (S)-(+)diethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate from Liebig's Annalen der Chemie, 1989, 11, 1081-1083; [α]21.9D = +45.92° (c = 1, CHCl3); chiral analytical HPLC (stationary phase: Chiralcel OJ-H normal phase 250x4.6mm; mobile phase: 85:15 hexane/1-propanol; flow rate: 1 mL/min) retention time 6.4 min, 100% purity; TLC Rf 0.32 (solvent system: 4:1 v/v ethyl acetate-hexane); 1H-NMR (CDCl3) δ 3.76-3.80 (m, 6H), 3.11-3.29 (m, 2H), 2.86-2.95 (m, 1H), 2.36-2.44 (m, 1H), 2.26-2.33 (m, 1H), 2.09-2.16 (m, 2H), 1.16-1.20 (m, 3H), 1.06-1.11 (m, 3H); MS (ESI+) m/z 247 (M+H)+.

A second preparation of the title intermediate by the same process described above afforded the title intermediate wherein the specific rotation (c=1, CHCl3) is +49°.
Preparation of (R)-(−)-dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate (13bc(i))

(R)-(−)-Dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate (13bc(i)) was prepared by the same method described for the preparation of 13fbb(i) above, except that the (R)-N-(1R)-2-hydroxy-1-phenylethyl)-2-methylhept-4-ynamide (17bc(i)) diastereomer collected from the silica gel chromatography was taken on to afford the title phosphonate intermediate; [α]T = α/cl, [α]21.9D = -0.306/(0.01925 g/1.5 mL)(0.5) = -47.69° (c = 1.28, CHCl3); TLC Rf 0.347 (solvent system: 85:15 v/v ethyl acetate-heptane); MS (ESI+) m/z 247 (M+H)+.

Exemplary embodiments may be prepared utilizing a Horner-Emmons-Wadsworth-type procedure, according to the route described below in Schemes 9 and 10 by the coupling of an aldehyde intermediate, such as those for which their preparations are described and illustrated above (6a-f), with an organic β-keto phosphonate ester, such as those that are commercially available or for which their preparations are described and illustrated above (13), to provide an α,β-unsaturated ketone compound intermediate (20a-f). In some applications, the Horner-Emmons-Wadsworth reaction comprises contacting the aldehyde with the β-keto phosphonate in the presence of lithium chloride, a trialkylamine base, such as triethylamine or diisopropylethylamine, and a suitable solvent such as THF. A reduction of the C15-oxo group to the corresponding C15-hydroxyl group may be carried out with a reducing agent to provide stereoisomeric mixtures of the corresponding C15-alcohol 21a-f (Scheme 9, Step B). In some applications, the reducing agent comprises sodium borohydride. In some applications, the reduction is a stereoselective reduction such as a Corey-Bakshi-Shibata (CBS) reduction. These mixtures may be separated into their C15-stereoisomer components 22a-f and 23a-f by HPLC (Step C) to provide the C15α-hydroxy (22a-f) and C15β-hydroxy (23a-f) diastereomers. The ester intermediates 22a-f and 23a-f may subsequently be hydrolyzed to carboxylic acid embodiments 24a-f (Step D1) and 25a-f (Step D2), respectively. Organic β-keto phosphonate esters 13 bearing a single chiral center, such as 13(a-f)b(i-viii), where R4 is a C1-C4 alkyl group and R5 is hydrogen, or such as 13(a-f)c(i-viii), where R4 is a hydrogen and R5 is a C1-C4 alkyl group, when coupled with aldehydes like 6a-f in Scheme 9, Step A and subsequently reduced as in Step B, form a mixture (26a-f) comprising four diastereomers. The mixture may be separated into its isolated diastereomers 27-30a-f using preparatory HPLC as illustrated in Scheme 10, Step A. The corresponding carboxylic acids 31-34a-f may be obtained by basic aqueous hydrolysis of the esters using equimolar or excess (about 1-10 molar equivalents) hydroxide base, such as lithium hydroxide, potassium hydroxide, or sodium hydroxide, at about 1-3 M in hydroxide base. The basic aqueous hydrolysis reaction mixture may further comprise at least one solvent that is miscible with water, such as methanol, ethanol, THF, 1,4-dioxane, or DMF. Detailed procedures for preparing these compounds are described below.
Scheme 9

\[
\text{Step A} \quad \text{LiCl, TEA, THF} \quad 6a-f + 13 \rightarrow 20a-f
\]

\[
\text{Step B} \quad \text{NaBH}_4, \text{CeCl}_3-7\text{H}_2\text{O, MeOH} \quad 6a-f \rightarrow 21a-f
\]

\[
\text{Step C} \quad \text{HPLC separation} \quad 21a-f \rightarrow 22a-f + 23a-f
\]

\[
\text{Step D1} \quad \text{hydrolysis} \quad 22a-f \rightarrow 24a-f
\]

\[
\text{Step D2} \quad \text{hydrolysis} \quad 23a-f \rightarrow 25a-f
\]

\[
L = \begin{cases} 
\text{a} & \text{b} & \text{c} & \text{d} & \text{e} & \text{f}
\end{cases}
\]

75
EXAMPLES

Examples 1A - 1F

Scheme 9, Step A: Preparation of methyl 7-((2R)-2-((4R/S,E)-4-methyl-3-oxooct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate

[0267]

[0268] To a stirring mixture consisting of (R)-methyl 7-((2R)-2-((4R/S,E)-4-methyl-3-oxooct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (6a, 0.500 g, 1.96 mmol) and (±)-dimethyl (3-methyl-2-oxohept-5-yn-1-yl)phosphonate (13ab(i)/13ac(ii)), 0.438 g, 1.89 mmol) in THF (40
mL) at 0 °C was added lithium chloride (280 mg, 6.61 mmol) and triethylamine (0.30 g, 3.0 mmol). The reaction mixture was stirred at room temperature overnight. To the reaction mixture was added a saturated solution of ammonium chloride (30 mL) and organic material was extracted with ethyl acetate (100 mL). The organic layer was separated, washed with brine (50 mL), dried over sodium sulfate, filtered, and concentrated in vacuo. The residue was purified by silica gel chromatography eluting with ethyl acetate-heptane (7:3 v/v) to afford the title compound (360 mg, 51%); TLC Rf 0.44 (solvent system: ethyl acetate); MS (APCI+) m/z 362 (M+1).

Scheme 9, Step B: Preparation of four-diastereomer mixture methyl 7-{(2R)-2-{[((E)-3-hydroxy-4-methyloct-1-en-6-yn-1-y1)-5-oxopyrrolidin-1-yl]heptanoate

[0269]

To a mixture consisting of methyl 7-{((2R)-2-{((4R/S,E)-4-methyl-3-oxooct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (0.36 g, 1.0 mmol) in methanol (10 mL) at -40 °C was added cerium (III) chloride heptahydrate (0.373 g, 1.00 mmol). The reaction mixture was cooled to -78 °C and stirred for one hour. To the reaction mixture was added sodium borohydride (0.076 g, 2.0 mmol), and the reaction mixture stirred for two hours. Acetone was added and the mixture was stirred for 15 minutes at -78 °C, after which time the mixture was elevated to room temperature. To the room temperature reaction mixture was added a saturated aqueous solution of ammonium chloride (30 mL) and the organic material was extracted with ethyl acetate (100 mL). The organic layer was separated and washed with brine (50 mL), dried over sodium sulfate, filtered, and concentrated in vacuo. The residue was purified by silica gel chromatography eluting with ethyl acetate-heptane (7:3 v/v) to afford the title compound (450 mg) as a stereoisomeric mixture of four diastereomeric components with regard to the configurations of the C15-OH and C16-Me positions.

Scheme 9, Step C: Preparation of methyl 7-{((2R)-2-{((3R,S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 1A) and methyl 7-{((2R)-2-{((3R,S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 1B)

[0271]

From the stereoisomeric mixture comprising the four methyl 7-{((2R)-2-{((3R,S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate diastereomers (450 mg, prepared in Step B of this Example above) were separated the methyl 7-{((2R)-2-{((3R,S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate diastereomeric pair from the methyl 7-{((2R)-2-{((3R,S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate diastereomeric pair by prep HPLC. The separations were performed on an Agilent Semi-Prep instrument equipped with an ultraviolet detector at 210 nm and using a Chiralpak IA 250 mm X 20 mm column eluting with a mobile phase of heptanes-ethanol (90:10 v/v) at a flow rate of 18 mL/min. Each of the two diastereomeric mixtures, Examples 1A and 1B, was isolated as a clear oil.

Example 1A (89 mg); prep HPLC retention time 22-25 minutes; TLC Rf 0.20 (solvent system: ethyl acetate); MS (APCI+) m/z 364 (M+1).

Example 1B (191 mg); prep HPLC retention time 16-19 minutes; TLC Rf 0.27 (solvent system: ethyl acetate); MS (APCI+) m/z 364 (M+1).
Scheme 9, Step D1: Preparation of 7-((2R)-2-(((3S,4R,S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1C)

[0275]

Scheme 9, Step D2: Preparation of 7-((2R)-2-(((3R,4R,S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1D)

[0277]

Scheme 9, Step E: Preparation of 7-((R)-2-(((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1E) and 7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1F)

[0279]

[0280] From the stereoisomer mixture comprising 7-((2R)-2-(((3S,4R,S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1C, 35mg) were separated the pure stereoisomers 7-((R)-2-(((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1E) and 7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1F)
droxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 1F) by prep HPLC. Each pure stereoisomer was isolated as a colorless solid. The separation was performed on a Gilson Semi-Prep instrument equipped with an ultraviolet detector at 205 nm and using a Luna Silica 5µ 250 mm X 10 mm column eluting with a mobile phase of heptane-ethanol (92:8 v/v).

[0281] Example 1E (5 mg); a colorless solid; HPLC retention time 52 minutes; TLC Rf 0.31 (solvent system: 80:20:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI-) m/z 348 (M-1); melting point 113-114°C.

[0282] Example 1F (9 mg); a colorless solid; HPLC retention time 49 minutes; TLC Rf 0.31 (solvent system: 80:20:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI-) m/z 348 (M-1); melting point 100-101°C.

Examples 2A - 2F

Scheme 9, Step A: Preparation of methyl 7-((2R)-2-((4R,S,E)-4-methyl-3-oxonon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate

[0283]

Methyl 7-((2R)-2-((4R,S,E)-4-methyl-3-oxonon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (648 mg) was prepared by the method described in Examples 1A - 1F section, Step A above except that (±)-dimethyl (3-methyl-2-oxooct-5-yn-1-yl)phosphonate (13bb(i)/13bc(i)) was used instead of dimethyl (3-methyl-2-o xohept-5-yn-1-yl)phosphonate; TLC Rf 0.33 (solvent system: 4:1 v/v ethyl acetate-heptane).

Scheme 9, Steps Band C: Preparation of methyl 7-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 2A) and methyl 7-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 2B)

[0285]

[0286] Mixture methyl 7-((2R)-2-((E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (570 mg), consisting of the four diastereomers, was prepared by the method described in Examples 1A - 1F, Steps B and C. Both diastereomeric pairs methyl 7-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 2A) and methyl 7-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 2B) were isolated following separation by prep HPLC. The separation was performed on a Gilson Prep instrument equipped with an ultraviolet detector at 210 nm and using a Luna Silica 250 X 42.5 mm column eluting with a mobile phase of 9:1 v/v heptane - n-propanol.

[0287] Example 2A (70 mg); a clear oil; HPLC retention time of 7 min; TLC Rf 0.35 (solvent system: ethyl acetate); MS (ESI+) m/z 378 (M+1).

[0288] Example 2B (240 mg); a clear oil; HPLC retention time of 6 min; TLC Rf 0.44 (solvent system: ethyl acetate); MS (ESI+) m/z 378 (M+1).
Scheme 9, Step D1: Preparation of 7-((2R)-2-((3S,4R,S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2C)

[0289]

![Chemical Structure](image)

[0290] 7-((2R)-2-((3S,4R,S,E)-3-Hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2C) was prepared from methyl 7-((2R)-2-((3S,4R,S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoate (Example 2A) by the method described in Step D1 for the preparation of Example 1C, to obtain the title compound (58 mg, 91%) as a nearly colorless solid; melting point 123-124 °C; MS (ESI -) m/z 362 (M-1); 1HNMR (CDCl3) δ 5.76 (dd, 1H), 5.64 (dd, 1H), 4.25 (t, 1H), 4.2-4.0 (m, 1H), 3.6-3.4 (m, 1H), 3.0-2.9 (m, 1H), 2.5-1.15 (m, 19H), 1.15 (t, 3H), 0.9 (dd, 3H).

Scheme 9, Step D2: Preparation of 7-((2R)-2-((3R,4R,S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2D)

[0291]

![Chemical Structure](image)

[0292] 7-((2R)-2-((3R,4R,S,E)-3-Hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2D) was prepared from methyl 7-((2R)-2-((3R,4R,S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoate (Example 2B) by the method described in Step D1 for the preparation of Example 1C, to obtain the title compound (223 mg) as a nearly colorless solid; MS (ESI- ) m/z 362 (M-1); melting point 56-57 °C.

Step E: Preparation of 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2E) and 7-((R)-2-((3S,4R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2F)

[0293]

![Chemical Structures](image)

[0294] From the stereoisomer mixture comprising 7-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2C, 143 mg) were separated the pure stereoisomers 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2E) and 7-((R)-2-((3S,4R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxypyrrolidin-1-yl)heptanoic acid (Example 2F) by prep HPLC. Each pure stereoi-
somer was isolated as a colorless solid. The separation was performed on an Agilent 1200 Prep instrument equipped with an ultraviolet detector at 210 nm and using a Luna Silica 21.2 X 250 mm column eluting with a mobile phase of heptanes-ethanol (95:5 v/v).

**[0295]** Example 2E (24 mg); white solid; prep HPLC retention time 67 minutes; MS (ESI⁻) m/z 362 (M-1); melting point 138-139 °C.

**[0296]** Example 2F (30 mg); white solid; prep HPLC retention time 62 minutes; MS (ESI⁻) m/z 362 (M-1); melting point 112-113 °C.

Example 2E, alternate route

**Step A:** Preparation of methyl 7-((2R)-2-((S,E)-4-methyl-3-oxonon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate

**[0297]**

[Diagram of molecular structure]

**[0298]** Methyl 7-((2R)-2-((S,E)-4-methyl-3-oxonon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate was prepared by the method described for Examples 1A - 1F, Step A, except that (S)-(+)dimethyl (3-methyl-2-o xoct-5-yn-1-yl)phosphonate (13bb(i); prepared above) was used instead of (±)-dimethyl (3-methyl-2-oxohept-5-yn-1-yl)phosphonate (13bb(i)/13bc(i)); TLC Rf 0.33 (solvent system: 4:1 v/v ethyl acetate-heptane).

**Steps Band C:** Preparation of diastereomeric mixture methyl 7-((2R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate (Example 2G) and methyl 7-((2R)-2-((3R,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate (Example 2G-15-epi)

**[0299]**

[Diagram of molecular structures]

**[0300]** To a room temperature solution consisting of methyl 7-((2R)-2-((S,E)-4-methyl-3-oxonon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate (695 mg, 1.85 mmol) was treated with (R)-(+)2-methyl-CBS-oxazaborolidine (1.85 mL, 1.85 mmol, 1M solution in toluene). The reaction mixture was cooled to -40 °C and to the mixture was added catecholborane (6.1 mL, 6.1 mmol, 1M solution in THF). The reaction mixture was allowed to warm to room temperature and stirred for one hour followed by the addition of 1 mL of 1N HCl and stirring over night. To the reaction mixture was added methanol and the organic material was extracted with ethyl acetate. The organic phase was washed with brine, dried over sodium sulfate and concentrated. The residue was chromatographed on a silica gel column eluted with 80:20 ethyl acetate-heptane to afford (280 mg) the diastereomeric mixture of alcohols; TLC Rf 0.17 (solvent system: 4:1 v/v ethyl acetate-heptane).

**[0301]** From the diastereomeric mixture of methyl 7-((2R)-2-((4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate (approximately 95:5 ratio of Example 2G to Example 2G-15-epi) were separated the pure stereoisomers methyl 7-((2R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate (Example 2G) and methyl 7-((2R)-2-((3R,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl))-5-oxopyrrolidin-1-yl)heptanoate (Example 2G-15-epi) by prep HPLC. The separation was performed on an Agilent 1200 Prep instrument equipped with an ultraviolet detector at 210 nm and using a CN 5µ 250 x 21.2 mm column eluting with a mobile phase of heptanes-ethanol (92:8 v/v).
Example 2G (57 mg); a clear oil; prep HPLC retention time 19 minutes; TLC \( R_f \) 0.35 (solvent system: ethyl acetate); MS (ESI\(^+\)) \( m/z \) 378 (M+1).

Scheme 9, Step D1: Preparation of 7-\((\text{R})\)-2-\(((3\text{S},4\text{S},\text{E})\)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl\))-5-oxopyrrolidin-1-yl\)heptanoic acid (Example 2E)

[0303] 7-\((\text{R})\)-2-\(((3\text{S},4\text{S},\text{E})\)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl\))-5-oxopyrrolidin-1-yl\)heptanoic acid (Example 2E) was prepared from methyl 7-\((\text{R})\)-2-\(((3\text{S},4\text{S},\text{E})\)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl\))-5-oxopyrrolidin-1-yl\)heptanoate (Example 2G) by the method described in Step D1 for the preparation of Example 1C, to obtain the title compound MS (ESI\(^+\)) \( m/z \) 362 (M-1); \(^1\)H-NMR (MeOD-\(d_4\)) \( \delta \) 5.76 (dd, 1H), 5.55 (dd, 1H), 4.17-4.23 (m, 1H), 4.02 (t, 1H), 3.43-3.51 (m, 1H), 2.95 (dd, 1H), 2.21-2.41 (m, 2H), 2.08-2.18 (m, 2H), 1.68-1.82 (m, 2H), 1.43-1.64 (m, 4H), 1.25-1.4 (m, 5H), 1.1 (t, 3H), 0.96 (d, 3H).

Example 2F, alternate route

[0304]

Scheme 9, Steps A, B and C: Preparation of methyl 7-\((\text{R})\)-2-\(((3\text{S},4\text{R},\text{E})\)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl\))-5-oxopyrrolidin-1-yl\)heptanoate (Example 3A) and methyl 7-\((\text{R})\)-2-\(((3\text{R},4\text{R},\text{S})\)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl\))-5-oxopyrrolidin-1-yl\)heptanoate (Example 3B)

[0307] The diastereomeric mixtures of Example 3A and Example 3B were isolated following separation by prep HPLC.

[0309] Gilson Prep instrument; ultraviolet detector at 210 nm; Luna 5\(\mu\) Silica 250 X 21.2 mm column; mobile phase of heptane-ethanol (9:1 v/v) with a flow rate of 21 mL/min.

[0310] Example 3A (80 mg); a clear oil; HPLC retention time 19 min; TLC \( R_f \) 0.69 (solvent system: ethyl acetate); MS (ESI\(^+\)) \( m/z \) 392 (M+1).

[0311] Example 3B (180 mg); a colorless solid; HPLC retention time 14.5 min; TLC \( R_f \) 0.74 (solvent system: ethyl acetate); MS (ESI\(^+\)) \( m/z \) 392 (M+1).
Scheme 9, Step D1: Preparation of 7-((2R)-2-((3S,4R,S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 3C)

[0312]

\[
\text{Scheme 9, Step D2: Preparation of 7-((2R)-2-((3R,4R,S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 3D)}
\]

[0314]

Examples 4A - 4D

Scheme 9, Steps A, B, and C: Preparation of methyl 7-((2R)-2-((3S,4R,S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 4A) and methyl 7-((2R)-2-((3R,4R,S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 4B)

[0316]

The diastereomeric mixtures of Example 4A and Example 4B were isolated following separation by prep HPLC.

[0317] Agilent Prep 1100 instrument; ultraviolet detector at 233 nm; Chiralpak IA 250 X 20 mm column; mobile phase of heptane-ethanol (88:12 v/v) with a flow rate of 18 mL/min.

[0318] Example 4A (100 mg); a clear oil; HPLC retention time 28 min; TLC Rf 0.30 (solvent system: 9:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 426 (M+).

[0319] Example 4B (195 mg); a clear oil; HPLC retention time 20 min; TLC Rf 0.36 (solvent system: 9:1 v/v ethyl acetate-heptane).
heptane); MS (ESI+) m/z 426 (M+1).

Scheme 9, Step D1: Preparation of 7-((2R)-2-((3S,4R,S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 4C)

[0321]

95 mg (100%) as a pale yellow oil; TLC R<sub>f</sub> 0.28 (solvent system: 50:50:1 v/v acetone-heptane-acetic acid); MS (ESI+) m/z 412 (M+1).

Scheme 9, Step D2: Preparation of 7-((2R)-2-((3R,4R,S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 4D)

[0323]

175 mg (93%) as a pale yellow oil; TLC R<sub>f</sub> 0.32 (solvent system: 50:50:1 v/v acetone-heptane-acetic acid); MS (ESI+) m/z 412 (M+1).

Examples 5A - 5D

Scheme 9, Steps A, B, and C: Preparation of methyl 7-((2R)-2-((3S,E)-3-hydroxy-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 5A) and methyl 7-((2R)-2-((3R,E)-3-hydroxy-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 5B)

[0325]

The single diastereomers of Example 5A and Example 5B were isolated following separation by prep HPLC.

[0326] Gilson Prep instrument; ultraviolet detector at 210 nm; Luna 5μ. Silica 250 X 21.2 mm column; mobile phase of heptanes-ethanol (90:10 v/v) with a flow rate of 21.2 mL/min.
Example 5A (47 mg): a clear oil; HPLC retention time 27 min; TLC R_f 0.36 (solvent system: 8:2 v/v ethyl acetate-heptane); MS (ESI^+) m/z 412 (M+1).

Example 5B (67 mg); a clear oil; HPLC retention time 21 min; TLC R_f 0.41 (solvent system: 8:2 v/v ethyl acetate-heptane); MS (ESI^+) m/z 412 (M+1).

Scheme 9, Step D1: Preparation of 7-((R)-2-((3S, E)-3-hydroxy-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 5C)

37 mg (100%); clear oil; TLC R_f 0.25 (solvent system: 80:20:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI^-) m/z 397 (M-1); ^1H-NMR (MeOH-d4, δ: 7.26-7.36 (m, 5H), 5.81 (dd, 1H), 5.6 (dd, 1H), 4.3 (q, 1H), 2.34 (td, 1H), 2.31-2.33 (m, 3H), 1.71-1.84 (m, 3H), 1.51-1.62 (m, 3H), 1.21-1.38 (m, 5H)

Scheme 9, Step D2: Preparation of 7-((R)-2-((3R, E)-3-hydroxy-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 5D)

55 mg (100%); clear oil; TLC R_f 0.33 (solvent system: 80:20:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI^-) m/z 397 (M-1).

Examples 6A - 6D

Steps A and B: Preparation of methyl 7-((R)-2-((R, E)-3-hydroxymethyl-1-en-4-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 6A) and methyl 7-((R)-2-((S, E)-3-hydroxymethyl-1-en-4-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 6B)
From the diastereomeric mixture (404 mg), the single diastereomers Example 6A and Example 6B were isolated following separation by prep HPLC.

Agilent 1100 Prep instrument; ultraviolet detector at 210 nm; Luna 5µ Silica 250 X 21.2 mm column; mobile phase of heptanes-ethanol (92:8 v/v) with a flow rate of 21.2 mL/min.

Example 6A (40 mg); a clear oil; HPLC retention time 26 min; TLC Rf 0.34 (solvent system 4:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 336 (M+1);

Example 6B (90 mg); a clear oil; HPLC retention time 24 min; TLC Rf 0.39 (solvent system 4:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 336 (M+1).

Example 6C (27 mg, 70%) as a clear oil; TLC Rf 0.22 (solvent system 85:15:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI+) m/z 322 (M+1); 1H-NMR (CDCl3) δ 5.8 (dd, 2H), 4.90 (d, 1H), 4.12 (t, 1H), 1.2-2.58 (m, 18H), 1.08 (t, 3H).

Example 6D (40 mg, 46%) as a clear oil; TLC Rf 0.25 (solvent system 85:15:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI+) m/z 322 (M+1).

Examples 7A - 7D

Scheme 9, Steps A, B, and C: Preparation of methyl 7-((R)-2-((R,E)-3-hydroxy-5-phenylpent-1-en-4-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 7A) and methyl 7-((R)-2-((S,E)-3-hydroxy-5-phenylpent-1-en-4-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate (Example 7B)
The single diastereomers Example 7A and Example 7B were isolated following separation by prep HPLC.

Example 7A (40 mg); a clear oil; HPLC retention time 20.9 min;
Example 7B (90 mg); a yellow oil; HPLC retention time 19.4 min.

Scheme 9, Step D1: Preparation of 7-((R)-2-((R,E)-3-hydroxy-5-phenylpent-1-en-4-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 7C)

27 mg (71%) as a yellow solid; MS (ESI\(^{-}\)) \textit{m/z} 368 (M-1); \(^1\)H-NMR (CDCl\(_3\)) \(\delta\) 7.5-7.2 (m, 5H), 5.9 (dd, 1H), 5.8 (dd, 1H), 5.19 (d, 1H), 4.1-4.0 (m, 1H), 3.6-3.4 (m, 1H), 3.0-2.9 (m, 1H), 2.45-1.2 (m, 14H).

Step D2: Preparation of 7-((R)-2-((S,E)-3-hydroxy-5-phenylpent-1-en-4-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid (Example 7D)

40 mg (47%) as a yellow oil; TLC \(R_f\) 0.22 (solvent system 90:10:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI\(^{-}\)) \textit{m/z} 368 (M-1).

Examples 8A - 8D

Scheme 9, Steps A, B, and C: Preparation of methyl 4-(2-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 8A) and methyl 4-(2-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 8B)

The diastereomeric mixtures of Example 8A and Example 8B were isolated following separation by prep HPLC.
Agilent Semi-Prep instrument; ultraviolet detector at 210 nm; Chiralpak IA 250 mm X 10 mm column; mobile phase of heptanes-ethanol (9:1 v/v) with a flow rate of 5 mL/min.

Example 8A (30 mg of a clear oil); prep HPLC retention time 19.3-21.1 minutes; TLC Rf 0.69 (solvent system: ethyl acetate); MS (ESI\(^+\)) m/z 406 (M+23);

Example 8B (40 mg of a colorless solid); prep HPLC retention time 14.9-16.1 minutes; TLC Rf 0.72 (solvent system: ethyl acetate); MS (ESI\(^+\)) m/z 406 (M+23).

Scheme 9, Step D1: Preparation of 4-(2-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methylhex-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid (Example 8C)

16.5 mg (59%) as a colorless solid; TLC Rf 0.28 (solvent system 90:10:1 v/v ethyl acetate-heptane-acetic acid); melting point 183-185 °C; MS (ESI\(^-\)) m/z 368 (M-1); \(^1\)H-MNR (CDCl\(_3\)) δ 8.0 (d, 2H), 7.2 (d, 2H), 5.6 (dd, 2H), 5.4 (dd, 2H) 4.2 (t, 1H), 4.1-4.0 (m, 1H), 3.85-3.75 (m, 1H), 3.2-3.1 (m, 1H), 2.4-1.2 (m, 12H), 0.9 (dd, 3H).

Scheme 9, Step D2: Preparation of 4-(2-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methylhex-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid (Example 8D)

10 mg (26%) as an off-white solid; TLC Rf 0.29 (solvent system 90:10:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI\(^-\)) m/z 368 (M-1).

Examples 9A - 9D

Scheme 9, Steps A, B, and C: Preparation of ethyl 4-(2-((1S,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 9A) and ethyl 4-(2-((3R,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 9B)
Mixture ethyl 4-((2R)-2-(((3S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (217 mg), consisting of the two diastereomers, was prepared by the method described in Example 2E, Steps A, and B (Scheme 9) utilizing the appropriate aldehyde (6b) and β-keto phosphonate ester (13bb(i)). Both C15-hydroxy diastereomers ethyl 4-(2-((2R)-2-(((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 9A) and ethyl 4-(2-((2R)-2-(((3R,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 9B) were isolated following separation by prep HPLC. The separation was performed on an Agilent Semi-Prep instrument; ultraviolet detector at 210 nm; Luna Silica 250 mm X 10 mm column; mobile phase of heptane-ethanol-acetic acid (93:7:0.1 v/v) with a flow rate of 5 mL/min.

Example 9A; a clear oil, HPLC retention time 26 minutes; TLC Rf 0.39 (solvent system: 3:1 v/v ethyl acetate-heptane); MS (ESI+): m/z 434 (M+23(Na+));

Example 9B; a clear oil, HPLC retention time 18 minutes; TLC Rf 0.45 (solvent system: 3:1 v/v ethyl acetate-heptane); MS (ESI+): m/z 434 (M+23(Na+)).
111 mg (100%) as a colorless solid; TLC Rf 0.42 (solvent system 100:1 v/v ethyl acetate-acetic acid); MS (ESI- ) m/z 382 (M-1).

Examples 10A - 10D

Scheme 9, Steps A, B, and C: Preparation of ethyl 4-(2-((R))-2-((3S,4R/S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 10A) and ethyl 4-(2-((R))-2-((3R,4R/S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 10B)

The diastereomeric mixtures of Example 10A and Example 10B were isolated following separation by prep HPLC.

Gilson Semi-Prep instrument; ultraviolet detector at 210 nm; Luna Silica 250 mm X 21.2 mm column; mobile phase of heptane-ethanol (94:6 v/v) with a flow rate of 21.2 mL/min.

Example 10A (161 mg); a clear oil; HPLC retention time 24 minutes; TLC Rf 0.36 (solvent system: 3:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 448 (M+23(Na+));

Example 10B (97 mg); a clear oil; HPLC retention time 39 minutes; TLC Rf 0.43 (solvent system: 3:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 448 (M+23(Na+)).

Scheme 9, Step D1: 4-(2-((2R))-2-((3S,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid (Example 10C)

61 mg (96%) as a colorless solid; TLC Rf 0.47 (solvent system 80:20:1 v/v ethyl acetate-heptane-acetic acid); melting point 109-111 °C; MS (ESI+) m/z 396 (M-1); 1H-NMR (MeOH-d4) δ 7.94-7.96 (d, 2H), 7.32-7.34 (dd, 2H), 5.66-5.73 (m, 1H), 5.45-5.54 (m, 1H), 4.4-4.09 (m, 2H), 3.71-3.79 (m, 1H), 3.14-3.29 (m, 1H), 2.8-2.98 (m, 2H), 2.09-2.38 (m, 7H), 1.66-1.79 (m, 2H), 1.48 (m, 2H), 0.93-1.04 (m, 6H).

Scheme 9, Step D2: 4-(2-((2R))-2-((3R,E)-3-hydroxy-4-methyldec-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid (Example 10D)

61 mg (96%) as a colorless solid; TLC Rf 0.47 (solvent system 80:20:1 v/v ethyl acetate-heptane-acetic acid); melting point 109-111 °C; MS (ESI+) m/z 396 (M-1); 1H-NMR (MeOH-d4) δ 7.94-7.96 (d, 2H), 7.32-7.34 (dd, 2H), 5.66-5.73 (m, 1H), 5.45-5.54 (m, 1H), 4.4-4.09 (m, 2H), 3.71-3.79 (m, 1H), 3.14-3.29 (m, 1H), 2.8-2.98 (m, 2H), 2.09-2.38 (m, 7H), 1.66-1.79 (m, 2H), 1.48 (m, 2H), 0.93-1.04 (m, 6H).
113 mg (75%) as a colorless solid; TLC Rf 0.51 (solvent system 80:20:1 v/v ethyl acetate-heptane-acetic acid); MS (ESI-) m/z 396 (M-1).

Examples 11A - 11D

Scheme 9, Step A, B, and C: Preparation of methyl 4-(2-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 11A) and methyl 4-(2-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 11B)

The diastereomeric mixtures of Example 11A and Example 11B were isolated following separation by prep HPLC.

Scheme 9, Step A, B, and C: Preparation of methyl 4-(2-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 11A) and methyl 4-(2-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate (Example 11B)

Example 11A (64 mg); HPLC retention time 18 minutes; TLC Rf 0.15 (solvent system: 4:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 446 (M+1);

Example 11B (90 mg); HPLC retention time 15.5 minutes; TLC Rf 0.18 (solvent system: 4:1 v/v ethyl acetate-heptane); MS (ESI+) m/z 446 (M+1).

Scheme 9, Step D1: Preparation of 4-(2-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid (Example 11C)

[0384] 60 mg (100%) as a clear oil; TLC Rf 0.31 (solvent system 50:50:1 v/v acetone-heptane-acetic acid); MS (ESI-) m/z 430 (M-1); 1H-NMR (400 MHz, CDCl3) δ 8.0 (d, 2H), 7.35-7.45 (m, 2H), 7.25-7.32 (m, 5H), 5.6 (dd, 2H), 4.3 (t, 1H), 4.15-4.2 (m, 2H), 3.2-3.1 (m, 2H) 2.6-1.3 (m, 9H) 1.1 (dd, 3H); 13CNMR (100 MHz, CDCl3) δ 175.18, 170.16, 145.05,
Scheme 9, Step D2: Preparation of 4-(2-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoic acid (Example 11D)

\[0385\]

45 mg (51%) as a clear oil; TLC \(R_f\) 0.36 (solvent system: 50:50:1 v/v acetone-heptane-acetic acid); MS (ESI⁻) \(m/z\) 430 (M-1).

Examples 12A - 12D

Scheme 9, Step A, B, and C: Preparation of methyl 2-(4-(((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)methyl)phenyl)acetate (Example 12A) and methyl 2-(4-(((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)methyl)phenyl)acetate (Example 12B)

\[0387\]

Example 12A

Example 12B

\[0388\] The diastereomeric mixtures of Example 12A and Example 12B were isolated following separation by prep HPLC.

\[0389\] Agilent Semi-Prep instrument; ultraviolet detector at 210 nm; Chiralpak IA 250 mm X 10 mm column; mobile phase of heptane-ethanol (9:1 v/v).

\[0390\] Example 12A (11.2 mg); prep HPLC retention time 18.1-19.5 minutes; TLC \(R_f\) 0.5 (solvent system 5:95:1 v/v methanol-dichloromethane-acetic acid);

\[0391\] Example 12B (7.3 mg); prep HPLC retention time 15.0-16.0 minutes; TLC \(R_f\) 0.45 (solvent system 5:95:1 v/v methanol-dichloromethane-acetic acid).

Scheme 9, Step D1: Preparation of 2-(4-(((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)methyl)phenyl)acetic acid (Example 12C)

\[0392\]
**Scheme 9, Step D2: Preparation of 2-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)methyl)phenyl)acetic acid (Example 12D)**

3.5 mg as an oil; TLC R$_f$0.25 (solvent system: 5:95:1 v/v methanol-dichloromethane-acetic acid); MS (ESI$^-$) m/z 368 (M-1); $^1$H-NMR (400 MHz, CDCl$_3$) δ 7.2 (quartet, 4H), 5.6-5.4 (m, 2H), 4.8 (t, 1H), 4.2 (t, 1H), 4.0-3.9 (m, 2H), 3.7 (s, 2H), 2.6-2.3 (m, 2H), 2.3-2.1 (m, 2H), 2.1-2.0 (m, 2H), 1.8-1.7 (m, 5H), 0.9 (t, 3H).

**Scheme 9, Steps A, B, and C: Preparation of methyl 5-((2R)-2-((3S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (Example 13A) and methyl 5-((2R)-2-((3R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (Example 13B)**

8.4 mg as an oil; TLC R$_f$0.2 (solvent system: 5:95:1 v/v methanol-dichloromethane-acetic acid); $^1$H-NMR (400 MHz, CDCl$_3$) δ 7.2 (quartet, 4H), 5.6-5.4 (m, 2H), 4.8 (t, 1H), 4.2 (t, 1H), 4.0-3.9 (m, 2H), 3.7 (s, 2H), 2.6-2.3 (m, 2H), 2.3-2.1 (m, 2H), 2.1-2.0 (m, 2H), 1.8-1.7 (m, 5H), 0.9 (t, 3H).

From the diastereomeric mixture of four isomers (76 mg), the diastereomeric mixtures of Example 13A and Example 13B were isolated following separation by prep HPLC.

Agilent Semi-Prep instrument; ultraviolet detector at 205 nm; Luna Silica 5μ 250 mm X 10 mm column; mobile phase of 9:1 v/v heptane: ethanol.

Example 13A (18.7 mg); as a clear oil; HPLC retention time of 16.1-18.1 minutes; MS (APCI$^+$) m/z 436.1 (M+23(Na$^+$))

Example 13B (46.6 mg); as a clear oil; HPLC retention time of 13.4-15.1 minutes; MS (APCI$^+$) m/z 436.1 (M+23(Na$^+$))
Scheme 9, Step D1: Preparation of 5-(3-((2R)-2-((3S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylic acid (Example 13C)

10.7 mg as an oil; TLC \( R_f \) 0.35 (solvent system 96:4:1 v/v dichloromethane-methanol-acetic acid); MS (ESI⁺) \( m/z \) 400.1 (M+1) (ESI⁻) \( m/z \) 398.0 (M-1)

Scheme 9, Step D2: Preparation of 5-(3-((2R)-2-((3R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylic acid (Example 13D)

35.6 mg as an oil; TLC \( R_f \) 0.35 (solvent system 96:4:1 v/v dichloromethane-methanol-acetic acid); MS (ESI⁺) \( m/z \) 400.1 (M+1) (ESI⁻) \( m/z \) 398.1 (M-1)

Example 14A - 14D

Scheme 9, Steps A, B, and C: Preparation of methyl 5-(3-((2R)-2-((3S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (14A) and methyl 5-(3-((2R)-2-((3R,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophene-2-carboxylate (14B)

The diastereomeric mixtures of Example 14A and Example 14B were isolated following separation by prep HPLC.

Agilent Semi-Prep instrument; ultraviolet detector at 205 nm; Luna Silica 5μm, 250 mm X 10 mm column; mobile phase of 9:1 v/v heptane: ethanol.

Example 14A (18.7 mg); as a clear oil; HPLC retention time of 16.1-18.1 minutes; MS (APCI⁺) \( m/z \) 436.1
Example 14B (50.1 mg); as a clear oil; HPLC retention time of 13.4-15.1 minutes; MS (APCI+) m/z 436.1 (M+23(Na+))

Scheme 9, Step D1: Preparation of 5-((Z)-3-((2R)-2-((3S, E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid (Example 14C)

14.4 mg as an oil; TLC Rf 0.35 (solvent system 96:4:1 v/v dichloromethane-methanol-acetic acid); MS (ESI+) m/z 400.1 (M+1) (ESI-) m/z 398.0 (M-1)

Scheme 9, Step D2: Preparation of 5-((Z)-3-((2R)-2-((3R, E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid (Example 14D)

36.1 mg as an oil; TLC Rf 0.35 (solvent system 96:4:1 v/v dichloromethane-methanol-acetic acid); MS (ESI+) m/z 400.1 (M+1) (ESI-) m/z 398.1 (M-1)

Examples 15A - 15D

Scheme 9, Step A, B, and C: Preparation of methyl 5-((Z)-3-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-non-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (Example 15A) and methyl 5-((Z)-3-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyl-non-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (Example 15B)
The diastereomeric mixtures of Example 15A and Example 15B were isolated following separation by prep HPLC.

Agilent Semi-Prep instrument; ultraviolet detector at 205 nm; Luna Silica 5μm, 250 mm X 10 mm column; mobile phase of heptane-ethanol (93:7 v/v).

Example 15A (6.3 mg); a clear oil; prep HPLC retention time 27-29.8 minutes; MS (APCI⁺) m/z 438 (M+23(Na⁺));

Example 15B (2.7 mg); a clear oil; prep HPLC retention time 23.5-24.8 minutes; MS (APCI⁺) m/z 438 (M+23(Na⁺)).

Scheme 9, Step D1: Preparation of 5-((Z)-3-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrroloidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid (Example 15C)

Scheme 9, Step D2: Preparation of 5-((Z)-3-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrroloidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylic acid (Example 15D)

Examples 16A - 16D

Scheme 9, Step A, B, and C: Preparation of methyl 5-((Z)-3-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrroloidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (Example 16A) and methyl 5-((Z)-3-((2R)-2-((3R,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrroloidin-1-yl)prop-1-en-1-yl)thiophene-2-carboxylate (Example 16B)
The diastereomeric mixtures of Example 16A and Example 16B were isolated following separation by prep HPLC.

Agilent Semi-Prep instrument; ultraviolet detector at 205 nm; Luna Silica 5 μ 250 mm X 10 mm column; mobile phase of heptane-ethanol (93:7 v/v).

Example 16A (23 mg); a clear oil; prep HPLC retention time 26.5-28.2 minutes; MS (APCI+) m/z 464 (M+1);

Example 16B (7.5 mg); a clear oil; prep HPLC retention time 23-24.8 minutes; MS (APCI+) m/z 464 (M+1).

Scheme 9, Step D1: Preparation of 5-((Z)-3-((2R)-2-((3S,4R/S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-y)prop-1-en-1-yl)thiophene-2-carboxylic acid (Example 16C)

3.0 mg as a colorless oil; TLC R_{f} 0.35 (solvent system: 95: 5:1 v/v dichloromethane-methanol-acetic acid); MS (ESI+) m/z 472 (M+23(Na+)).

Scheme 9, Step D2: Preparation of 5-((Z)-3-((2R)-2-((3R,S)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-y)prop-1-en-1-yl)thiophene-2-carboxylic acid (Example 16D)

2.5 mg as a colorless oil; TLC R_{f} 0.35 (solvent system: 95:5:1 v/v dichloromethane-methanol-acetic acid); MS (ESI-) m/z 448 (M-1).
Examples 17A - 17E

Scheme 9, Step A, B, and C: Preparation of methyl 5-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 17A) and methyl 5-((R)-2-((3S,4R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 17B) and methyl 5-((2R)-2-((3R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 17C)

The stereoisomeric mixtures of Examples 17A, 17B, and 17C were isolated from the diastereomeric mixture of methyl 5-((2R)-2-((3R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate following separation by prep HPLC.

Agilent Semi-Prep instrument; ultraviolet detector at 205 nm; Luna Silica 5 μm 250 mm X 10 mm column; mobile phase of heptane-ethanol (95:5 v/v).

Example 17A (4.9 mg); a clear oil; HPLC retention time 48.8-51.8 minutes; 1H-NMR (CDCl3) δ 7.6 (d, 1H), 6.8 (d, 1H), 5.7-5.6 (m, 1H), 5.6-5.5 (m, 1H), 4.2-4.1 (m, 2H), 3.85 (s, 3H), 3.7-3.5 (m, 1H), 3.0-2.9 (m, 1H), 2.9-2.8 (t, 2H), 2.5-2.1 (m, 6H), 2.0-1.7 (m, 5H), 1.1 (t, 3H), 0.95 (d, 3H); MS (ESI+) m/z 418.1 (M+1), 440.1 (M+23(Na+)).

Example 17B (7.2 mg); a clear oil; HPLC retention time 45.9-48.4 minutes; 1H-NMR (CDCl3) δ 7.6 (d, 1H), 6.8 (d, 1H), 5.7-5.6 (m, 1H), 5.6-5.5 (m, 1H), 4.3-4.2 (m, 1H), 4.1-4.2 (m, 1H), 3.85 (s, 3H), 3.7-3.5 (m, 1H), 3.0-2.9 (m, 1H), 2.9-2.8 (t, 2H), 2.5-2.1 (m, 6H), 2.0-1.7 (m, 5H), 1.1 (t, 3H), 0.95 (d, 3H); MS (ESI+) m/z 418.1 (M+1), 440.1 (M+23(Na+)).

Example 17C (26.7 mg); a clear oil; HPLC retention time 34.1-36.9 minutes; 1H-NMR (CDCl3) δ 7.6 (d, 1H), 6.8 (d, 1H), 5.7-5.6 (m, 1H), 5.6-5.5 (m, 1H), 4.3-4.2 (m, 0.5H), 4.1-4.2 (m, 1.5H), 3.85 (s, 3H), 3.7-3.5 (m, 1H), 3.0-2.9 (m, 1H), 2.9-2.8 (t, 2H), 2.5-2.1 (m, 6H), 2.0-1.7 (m, 5H), 1.1 (t, 3H), 0.95 (d, 3H); MS (ESI+) m/z 418.1 (M+1), 440.1 (M+23(Na+)).

Scheme 9, Step D: Preparation of 5-((3(R))-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17D)

5-((3(R))-2-((3S,4S,E)-3-Hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17D) was prepared from methyl 5-((3(R))-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17A) by the method described in Step D for the preparation of Example 1C, to obtain the title compound (3.7 mg) as a colorless oil; TLC Rf 0.35 (solvent system: 96:4 v/v dichloromethane-methanol-acetic acid); 1H-NMR (CDCl3) δ 7.7 (d, 1H, J=3.6 Hz), 6.8 (d, 1H, J=3.6 Hz), 5.8-5.7 (m, 1H),...
Scheme 9, Step D1: Preparation of 5-(3-((R)-2-((3S,4R, E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17E)

5.6-5.5 (m, 1H), 4.3-4.2 (m, 0.5H), 4.2-4.0 (m, 1.5H), 3.7-3.5 (m, 1H), 3.1-3.0 (m, 1H), 2.9-2.8 (m, 2H), 2.6-2.3 (m, 2H), 2.3-2.1 (m, 5H), 2.0-1.7 (m, 4H), 1.2-1.0 (m, 3H), 1.0-0.9 (m, 3H); MS (ESI\(^+\)) \(m/z\) 404.1 (M+1), (ESI\(^-\)) \(m/z\) 402.1 (M-1).

Scheme 9, Step D1: Preparation of 5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17E) is prepared from methyl 5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 17B) by the method described in Step D1 for the preparation of Example 1C.

Scheme 9, Step D1: Preparation of 5-(3-((R)-2-((3S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17F)

5-(3-(\((R)\)-2-\((3S,4R,E)\))-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 17B) by the method described in Step D1 for the preparation of Example 1C, to obtain the title compound as a colorless oil; \(^1\)H-NMR (CDCl\(_3\)) \(\delta\) 7.7 (d, 1H, \(J=3.6\) Hz), 6.8 (d, 1H, \(J=3.6\) Hz), 5.6-5.5 (m, 1H), 5.6-5.5 (m, 1H), 4.3-4.2 (m, 0.5H), 4.2-4.0 (m, 1.5H), 3.7-3.5 (m, 1H), 3.1-3.0 (m, 1H), 2.9-2.8 (m, 2H), 2.6-2.3 (m, 2H), 2.3-2.1 (m, 5H), 2.0-1.7 (m, 4H), 1.2-1.0 (m, 3H), 1.0-0.9 (m, 3H); MS (ESI\(^-\)) \(m/z\) 402.1 (M-1).

Scheme 9, Step D2: Preparation of 5-(3-((R)-2-((3R,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17G)

5-(3-(\((R)\)-2-\((3R,E)\))-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 17G)
ic acid (Example 17G) was prepared from methyl 5-((R)-2-((3R,E)-3-Hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 17C) by the method described in Step D1 for the preparation of Example 1C, to obtain the title compound as a colorless oil; $^1$H-NMR (CDCl$_3$) $\delta$ 7.7 (d, 1H, J=3.6 Hz), 6.8 (d, 1H, J=3.6 Hz), 5.8-5.7 (m, 1H), 5.6-5.5 (m, 1H), 4.2-4.0 (m, 2H), 3.7-3.5 (m, 1H), 3.1-3.0 (m, 1H), 2.9-2.8 (m, 2H), 2.6-2.3 (m, 2H), 2.3-2.1 (m, 5H), 2.0-1.7 (m, 4H), 1.2-1.0 (m, 3H), 1.0-0.9 (m, 3H); MS (ESI$^+$) m/z 402.1 (M-1).

Examples 18A - 18D

Scheme 9, Steps A, B, and C: Preparation of methyl 5-((2R)-2-((3S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 18A) and methyl 5-((2R)-2-((3R,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate (Example 18B)

[0446]

Example 18A

Example 18B

[0447] The diastereomeric mixtures of Example 18A and Example 18B were isolated following separation by prep HPLC.

[0448] Agilent Semi-Prep instrument; ultraviolet detector at 205 nm; Luna Silica 5µ 250 mm X 10 mm column; mobile phase of heptane-ethanol (90:10 v/v).

Example 18A (15.4 mg); a clear oil; prep HPLC retention time 21.5-24.5 minutes; MS (ESI$^+$) m/z 466.1 (M+1), 488.1 (M+23(Na$^+$))

Example 18B (38.2 mg); a clear oil; prep HPLC retention time 17.1-20.2 minutes; MS (ESI$^+$) m/z 466.1 (M+1), 488.1 (M+23(Na$^+$))

Scheme 9, Step D1: 5-((2R)-2-((3S,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 18C)

[0449]

[0450] 9.8 mg as a colorless oil; TLC R$_{f}$0.35 (solvent system: 96:4:1 v/v dichloromethane-methanol-acetic acid); MS (ESI$^-$) m/z 450.1 (M-1).

Scheme 9, Step D2: 5-((2R)-2-((3R,E)-3-hydroxy-4-methyl-7-phenylhept-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid (Example 18D)

[0451]
Example 19

Radioligand binding assay for the evaluation of the affinity of compounds for the agonist site of the human prostanoid EP₄ receptor in transfected HEK-293 cells

Assay volume and format: 200 μl in 96-well plate

[0453] Cell membrane homogenates (20 μg protein) are incubated for 120 min at 22°C with 0.5 nM [³H]PGE₂ in the absence or presence of the test compound in a buffer containing 10 mM MES/KOH (pH 6.0), 10 mM MgCl₂, and 1 mM EDTA.

[0454] Nonspecific binding is determined in the presence of 10 μM PGE₂.

[0455] Following incubation, the samples are filtered rapidly under vacuum through glass fiber filters (GF/B, Packard) presoaked with 0.3% PEI and rinsed several times with ice-cold 50 mM Tris-HCl using a 96-sample cell harvester (Unifilter, Packard). The filters are dried then counted for radioactivity in a scintillation counter (Topcount, Packard) using a scintillation cocktail (Microscint 0, Packard).

[0456] The standard reference compound is PGE₂, which is tested in each experiment at several concentrations to obtain a competition curve from which its IC₅₀ is calculated.

Example 20

Functional Cellular Assays (STEP Plate Format)

[0457] Both SEAP activity assay and cAMP level assay for EP₂ or EP₄ agonist were performed on EP₂/EP₄ STEP (Surface Transfection and Expression Protocol) plates (from Originus®) which are coated with both rat EP₂ or EP₄ receptor and secreted alkaline phosphatase (SEAP) reporter constructs. Cells grown on the STEP complex will express EP₂ or EP₄ at the cell surface. Binding of agonists to EP₂ or EP₄ initiates a signal transduction cascade results in a transient increase in cAMP and an increase in expression of SEAP which is secreted into the cell culture media. cAMP levels were then measured with an ELISA assay and SEAP activity was measured with a luminescence-based alkaline phosphatase substrate.

Procedure of SEAP Activity Assay for EP₂/EP₄ agonist

[0458]

1. Seed cells on an EP₂ or EP₄ STEP plate at a density of 40,000 - 80,000 cells/well in 200 μl of reduced serum medium containing 0.5% FBS. Place the plate in a 37°C incubator with 5% CO₂ and incubate overnight.
2. After 16 - 18 hours of incubation, aspirate the culture media from each well.
3. Add 200 μl of culture medium containing different concentration of test compounds to the assigned wells. For each test compound, at least 8 concentrations starting at highest 10 μM and lowest 0.01 pM were tested. In addition each concentration had triplicates. A PGE₂ curve (concentrations from lowest to highest, 0 pM, 0.384 pM, 1.92 pM, 9.6 pM, 48 pM, 240 pM, 1200 pM, and 6000 pM) was always run in parallel with test compounds.
4. After 6 - 8 hours of stimulation with test compounds and PGE₂, 10 μl of culture media from each well was transferred to a corresponding well of a 96-well solid black plate. Cover the plate with the lid.
5. Inactivate the endogenous alkaline phosphatase by heating the samples at 65°C for 30 minutes.
6. Add 50 μl of luminescence-based alkaline phosphatase substrate (Michigan Diagnostics, LLC, Cat#SAP450101) to each well.
7. Measure the SEAP (secreted alkaline phosphatase) activity by reading the luminescent signal from each well with a Tecan Safire2 microplate detection system (measures fluorescence) to measure activity.
8. The data was analyzed and the EC\textsubscript{50} for PGE\textsubscript{2} and each test compound was calculated using GraphPad Prism 5.

**Procedure of cAMP Assay for EP\textsubscript{2}/EP\textsubscript{4} agonist**

[0459]

1. Seed cells on an EP\textsubscript{2} or EP\textsubscript{4} STEP plate at a density of 40,000 - 80,000 cells/well in 200 \( \mu \text{L} \) of reduced serum medium containing 0.5% FBE. Place the plate in a 37°C incubator with 5% CO\textsubscript{2} and incubate overnight.
2. After 16 - 18 hours of incubation, aspirate the culture media from each well.
3. Add 200 \( \mu \text{L} \) of culture medium containing 500 \( \mu \text{M} \) IBMX (an inhibitor of cAMP phosphodiesterase) and different concentration of test compounds to the assigned wells. For each test compound, at least 8 concentrations starting at highest 10 \( \mu \text{M} \) and lowest 0.01 pM were tested. In addition each concentration had triplicates. A PGE\textsubscript{2} curve (concentrations from lowest to highest, 0 pM, 0.384 pM, 1.92 pM, 9.6 pM, 48 pM, 240 pM, 1200 pM, and 6000 pM) was always run in parallel with test compounds.
4. Incubate the cells in a cell culture incubator for 30 minutes.
5. Centrifuge the plate at 1,000 x rpm for 10 minutes.
6. Aspirate the supernatant.
7. Add 100 \( \mu \text{L} \) of EIA assay buffer to each well and put the plate with the lid in a -80°C freezer. Freeze the sample in the -80°C for at least one hour.
8. Take the plate out from the -80°C freezer and leave it at room temperature to thaw completely.
9. Centrifuge the plate at 1,000 x rpm for 10 minutes.
10. Pick up 50 \( \mu \text{L} \) of supernatant from each well for cAMP level measurement, using an ELISA assay kit from Cayman chemical, Item #581001.

11. The data was analyzed and the EC\textsubscript{50} for PGE\textsubscript{2} and each test compound was calculated using GraphPad Prism 5.

**Specificity of EP\textsubscript{2}/EP\textsubscript{4} agonist on the receptors**

[0460] Compounds demonstrating potency in SEAP or cAMP functional assays were confirmed for receptor agonist specificity by incubation of the cells with the compound together with an EP\textsubscript{2} specific antagonist AH-6809 or an EP\textsubscript{4} specific antagonist L-161,982. Compounds that showed agonist activity for either EP\textsubscript{2} or EP\textsubscript{4} are specific if the stimulation effect was diminished when incubated together with their receptor specific antagonist.
Table 1

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Absolute Configuration

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<th>cAMP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
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*Note: EC₅₀ values are for hEP₄ receptor binding STEP cell functional assay.*
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Table 7

Absolute Configuration

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<th>C-16 Configuration</th>
<th>hEP&lt;sub&gt;4&lt;/sub&gt; receptor binding (nM)</th>
<th>IC&lt;sub&gt;50&lt;/sub&gt; (nM)</th>
<th>K&lt;sub&gt;i&lt;/sub&gt; (nM)</th>
<th>cAMP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
<th>SEAP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
<th>SEAP/EP&lt;sub&gt;2&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>8A</td>
<td>α/β</td>
<td>Me</td>
<td>6.74</td>
<td>364</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>8B</td>
<td>β/α</td>
<td>Me</td>
<td>1,640</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8C</td>
<td>α/β</td>
<td>H</td>
<td>1.3</td>
<td>1.640</td>
<td>0.47</td>
<td>120</td>
<td>13.4</td>
<td>1,130</td>
</tr>
<tr>
<td>8D</td>
<td>β/α</td>
<td>H</td>
<td>13.4</td>
<td>1.640</td>
<td>0.47</td>
<td>120</td>
<td>13.4</td>
<td>1,130</td>
</tr>
</tbody>
</table>
Table 9

<table>
<thead>
<tr>
<th>Example No.</th>
<th>C-15</th>
<th>C-16</th>
<th>R²</th>
<th>IC₅₀ (nM)</th>
<th>Kᵢ (nM)</th>
<th>cAMP/EP₄</th>
<th>SEAP/EP₄</th>
<th>SEAP/EP²</th>
</tr>
</thead>
<tbody>
<tr>
<td>9A</td>
<td>α</td>
<td>β</td>
<td>Et</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9B</td>
<td>β</td>
<td>β</td>
<td>Et</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9C</td>
<td>α</td>
<td>β</td>
<td>H</td>
<td>0.67</td>
<td>0.25</td>
<td>0.31</td>
<td>0.020±0.017 (N=4)</td>
<td>&gt;1,000</td>
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<tr>
<td>9D</td>
<td>β</td>
<td>β</td>
<td>H</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Example No</td>
<td>C-15</td>
<td>C-16</td>
<td>R(^0)</td>
<td>IC(_{50}) (nM)</td>
<td>K(_i) (nM)</td>
<td>cAMP/EP(_4)</td>
<td>SEAP/EP(_4)</td>
<td>SEAP/EP(_2)</td>
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<tr>
<td>------------</td>
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</tr>
<tr>
<td>10A</td>
<td>α</td>
<td>α/β</td>
<td>Et</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10B</td>
<td>β</td>
<td>α/β</td>
<td>Et</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10C</td>
<td>α</td>
<td>α/β</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>10D</td>
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<td>α/β</td>
<td>H</td>
<td></td>
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</table>

Table 10

**Absolute Configuration**

α = \(\alpha\) or \(\alpha\)

β = \(\beta\) or \(\beta\)

hEP\(_4\) receptor binding STEP cell functional assay EC\(_{50}\) (nM)
<table>
<thead>
<tr>
<th>Example No.</th>
<th>C-15</th>
<th>C-16</th>
<th>Absolute Configuration</th>
<th>hEP4 receptor binding STEP cell functional assay EC50s (nM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IC50 (nM)</td>
</tr>
<tr>
<td>11A</td>
<td>α</td>
<td>α/β</td>
<td>α or β</td>
<td>0.054</td>
</tr>
<tr>
<td>11B</td>
<td>β</td>
<td>α/β</td>
<td>β or β</td>
<td>3.51</td>
</tr>
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</table>
### Table 12

<table>
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<tr>
<th>Example No.</th>
<th>C-15</th>
<th>C-16</th>
<th>R&lt;sup&gt;0&lt;/sup&gt;</th>
<th>IC&lt;sub&gt;50&lt;/sub&gt; (nM)</th>
<th>K&lt;sub&gt;i&lt;/sub&gt; (nM)</th>
<th>cAMP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
<th>SEAP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
<th>SEAP/EP&lt;sub&gt;2&lt;/sub&gt;</th>
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</thead>
<tbody>
<tr>
<td>12A</td>
<td>α</td>
<td>α/β</td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12B</td>
<td>β</td>
<td>α/β</td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12C</td>
<td>α</td>
<td>α/β</td>
<td>H</td>
<td>2,290</td>
<td>&gt; 10,000</td>
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<tr>
<td>12D</td>
<td>β</td>
<td>α/β</td>
<td>H</td>
<td>&gt; 10,000</td>
<td>&gt; 10,000</td>
<td></td>
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</tr>
<tr>
<td>Example No</td>
<td>Absolute Configuration</td>
<td>( R^0 )</td>
<td>Me</td>
<td>Me</td>
<td>H</td>
<td>H</td>
<td>cAMP/EP4</td>
<td>SEAP/EP4</td>
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<td>---</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>13A</td>
<td>( \alpha\beta )/( \beta )Me</td>
<td>( \alpha\beta )/( \beta )Me</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>&gt;10,000</td>
<td>18.3</td>
<td>&gt;10,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13B</td>
<td>( \alpha\beta )/( \beta )Me</td>
<td>( \alpha\beta )/( \beta )Me</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>&gt;10,000</td>
<td>18.3</td>
<td>&gt;10,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13C</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>&gt;10,000</td>
<td>18.3</td>
<td>&gt;10,000</td>
<td></td>
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</tr>
<tr>
<td>13D</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>( \alpha\beta )/( \beta )H</td>
<td>&gt;10,000</td>
<td>18.3</td>
<td>&gt;10,000</td>
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Table 14

<table>
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<tr>
<th>Example No.</th>
<th>C-15</th>
<th>C-16</th>
<th>Absolute Configuration</th>
<th>hEP&lt;sub&gt;4&lt;/sub&gt; receptor binding STEP cell functional assay EC&lt;sub&gt;50&lt;/sub&gt;s (nM)</th>
<th>IC&lt;sub&gt;50&lt;/sub&gt; (nM)</th>
<th>K&lt;sub&gt;i&lt;/sub&gt; (nM)</th>
<th>cAMP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
<th>SEAP/EP&lt;sub&gt;4&lt;/sub&gt;</th>
<th>SEAP/EP&lt;sub&gt;2&lt;/sub&gt;</th>
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<tr>
<td>14A</td>
<td>α</td>
<td>α/β</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14B</td>
<td>β</td>
<td>α/β</td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14C</td>
<td>α</td>
<td>α/β</td>
<td>H</td>
<td></td>
<td>&gt;100</td>
<td>&gt;10,000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>14D</td>
<td>β</td>
<td>α/β</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;10,000</td>
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### Table 15

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<th>Example No.</th>
<th>Absolute Configuration</th>
<th>hEP₄ receptor binding</th>
<th>STEP cell functional assay</th>
<th>EC₉₀ s (nM)</th>
<th>IC₉₀ (nM)</th>
<th>Kᵢ (nM)</th>
<th>cAMP/EP₄</th>
<th>SEAP/EP₄</th>
<th>SEAP/EP₂</th>
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<tbody>
<tr>
<td>15A</td>
<td>α</td>
<td>α/β</td>
<td>Me</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15B</td>
<td>β</td>
<td>α/β</td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
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<td>15C</td>
<td>α</td>
<td>α/β</td>
<td>H</td>
<td>200</td>
<td>&gt;1,500</td>
<td>&gt;10,000</td>
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<tr>
<td>15D</td>
<td>β</td>
<td>α/β</td>
<td>H</td>
<td>1,600</td>
<td>&gt;10,000</td>
<td>&gt;10,000</td>
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Table 16  

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<tbody>
<tr>
<td>16A</td>
<td>αα/β</td>
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<td>&gt;10,000</td>
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<tr>
<td>16B</td>
<td>βα/β</td>
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<td></td>
<td>&gt;10,000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>16C</td>
<td>αα/β</td>
<td></td>
<td></td>
<td></td>
<td>H</td>
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<td>H</td>
<td></td>
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<tr>
<td>16D</td>
<td>βα/β</td>
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<td></td>
<td>672</td>
<td>1,200</td>
<td>&gt;10,000</td>
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**Note:** EC50 and IC50 values are given in nanomolar (nM).
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<th></th>
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</thead>
<tbody>
<tr>
<td>17A</td>
<td>α</td>
<td>β</td>
<td></td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17B</td>
<td>α</td>
<td>α</td>
<td></td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17C</td>
<td>β</td>
<td>α/β</td>
<td></td>
<td>Me</td>
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<td></td>
</tr>
<tr>
<td>17D</td>
<td>α</td>
<td>β</td>
<td>H</td>
<td>6.1</td>
<td>2.3</td>
<td>1.54</td>
<td>0.32</td>
<td>5,300</td>
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<tr>
<td>17E</td>
<td>α</td>
<td>α</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>17F</td>
<td>α</td>
<td>α/β</td>
<td>H</td>
<td>0.091</td>
<td>&gt;10,000</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>17G</td>
<td>β</td>
<td>α/β</td>
<td>H</td>
<td>18.4</td>
<td>&gt;10,000</td>
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</tr>
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</table>

**Table 17**

α = or

β = or
**Table 18**

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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18A</td>
<td>α</td>
<td>α/β</td>
<td>Me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18B</td>
<td>β</td>
<td>α/β</td>
<td>Me</td>
<td></td>
<td>&gt;10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18C</td>
<td>α</td>
<td>α/β</td>
<td></td>
<td></td>
<td>&lt;0.01</td>
<td>&gt;10,000</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(75% agonist response vs PGE₂)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>18D</td>
<td>β</td>
<td>α/β</td>
<td></td>
<td></td>
<td>2.03</td>
<td>&gt;10,000</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>α</td>
<td>β</td>
<td>H</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>18F</td>
<td>α</td>
<td>α</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
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</table>

Absolute Configuration:

α = /\(α\)\; β = /\(β\)/\(β\)
Example 21

**Accelerated healing of a calvarial bone defect by Example 2E**


[0462] Bone defects are created by removal of bone from the cranium of female Sprague Dawley rats by a bone trephine (cranial defect). Cranial defects are 2.6 mm in diameter and the cranium approximately 1 mm thick. A matrix of approximately 2 mm thickness is applied to the defect. Thus the dosing volume for each defect is calculated as $\pi \times r^2 \times$ matrix thickness = 3.14 * 1.32 * 2 = 10.61 $\mu$l and rounded to 11 $\mu$l for purposes of dose calculation.

[0463] Example 2E is delivered set inside calcium phosphate cement that, after loading with drug and setting, is ground to a fine powder and suspended in demineralized bone matrix at a ratio of 1:8 (weight/volume). Example 2E is tested at one dose of 3 mg/ml with five rats in the test group. A negative control group treated with dosing matrix containing no drug (Vehicle) is also included in the study.

[0464] Calcium Phosphate cement powders may be combinations of $\alpha$-tri-calcium phosphate, $\beta$-tri-calcium phosphate and hydroxyapatite; combinations of Dicalcium Phosphate and Tetracalcium Phosphate; or a commercially available calcium phosphate cement. Commercially available Human demineralized bone matrix, Puros Demineralized Bone Matrix Bone Putty manufactured by RTI Biologics (Alachua, FL) using the Urist & Dowell method, is used in the studies described. Demineralized bone matrix can also be made by the method described by Urist & Dowell (Inductive Substratum for Osteogenesis in Pellets of Particulate Bone Matrix, Clin. Orthop. Relat. Res., 1968, 61, 61-78.)

[0465] Dosing solutions are made from a 10 mg/ml Example 2E stock which is made by dissolving 2.07 mg of neat Example 2E in 207 $\mu$l of 100% ethanol.

[0466] The dosing volume of a single defect is 11 $\mu$l. Thus for each group of five rats the total treatment volume is 55 $\mu$l. The ratio of calcium phosphate cement to volume is 1:8 thus for each group of five rats 6.8 mg of calcium phosphate cement was used.

[0467] The dosing solution for Example 2E was made by adding 18 $\mu$L of the 5 mg/ml stock to 6.8 mg of calcium phosphate cement powder. The Vehicle dosing solution was made by adding 18 $\mu$L of ethanol containing no Example 2E to 6.8 mg of calcium phosphate cement powder.

[0468] After the ethanol had been vented off, the cement was wetted with a setting solution and mixed thoroughly for 1 minute as the cement begins to set. The cement was allowed to set overnight at room temperature before being ground to a fine powder in a mortar and pestle.

[0469] Following grinding the cement was added to 55 $\mu$L of demineralized bone matrix (DBM) and thoroughly mixed using two spatulas. The cement-DBM mix was rolled into a single length of material of equal thickness and using a ruler as a guide cut into five equal length pieces. The dosing matrix was placed in a test subject within four hours of mixing the cement with the DBM.

[0470] Immediately after creation the bone defect was filled with dosing matrix containing no drug (Vehicle) or 3 mg/ml of Example 2E. The operation area was closed and sutured and the animal was allowed to recover. Eight weeks after the beginning of treatment each rat was anaesthetized with isoflurane and the defect area was imaged using a cone beam dental CT scanner (Vatech Pax-Duo3D).

[0471] The area measured at eight weeks was compared to the area of the original defect and the degree of repair calculated by the following formula:

$\frac{\text{original area} - \text{current area}}{\text{original area}} \times 100$

[0472] The mean repair for each group after eight weeks of treatment is shown in the Figure 1.

**Claims**

1. A compound of formula (Ia)
or a pharmaceutically acceptable salt thereof, wherein:

\[ \text{L}^1 \text{ is} \]

a) \( \text{C}_3^\text{a}-\text{C}_7^\text{a} \text{alkylene}, \text{C}_3^\text{a}-\text{C}_7^\text{a} \text{alkenylene}, \text{or C}_3^\text{a}-\text{C}_7^\text{a} \text{alkynylene, wherein the C}_3^\text{a}-\text{C}_7^\text{a} \text{alkylene, C}_3^\text{a}-\text{C}_7^\text{a} \text{alkenylene, or} \) \\
\( \text{C}_3^\text{a}-\text{C}_7^\text{a} \text{alkynylene are each optionally substituted with 1, 2, 3, or 4 fluoro substituents;} \)

b) \( -(\text{CH}_2)_t-G-(\text{CH}_2)_p-, \) wherein \( t \) is 0, 1, or 2, \( p \) is 0, 1, 2, or 3, and \( t+p = 0, 1, 2, 3, \) or 4; or

c) \( -(\text{CH}_2)_n-G^1-(\text{CH}_2)_p-, -(\text{CH}_2)_n-G^2-(\text{CH}_2)_p-, -(\text{CH}_2)_n-C-G^2-, \) or \( -(\text{CH}_2)_n-C(R^1)^2-C(R^2)^2-, \) wherein \( n \) is 1, 2, 3, 4, or 5, \( p \) is 0, 1, 2, or 3, and \( n+p = 1, 2, 3, 4, 5, \) or 6;

\( \text{G}^1 \) is \( \text{O}, \text{C(O)}, \text{S}, \text{S(O)}, \text{S(O)}_2, \) or \( \text{NR}^7; \) wherein \( \text{R}^7 \) is \( \text{H, C}_1^\text{a}-\text{C}_4^\text{a} \text{ alkyl, or C}_1^\text{a}-\text{C}_4^\text{a} \text{alkylcarbonyl}; \) 

\( \text{G}^2 \) is

\( \text{G}^2 \) is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of \( \text{C}_1^\text{a}-\text{C}_4^\text{a} \text{ alkyl, C}_1^\text{a}-\text{C}_4^\text{a} \text{haloalkyl, cyano, halogen, C}_1^\text{a}-\text{C}_3^\text{a} \text{alkoxy, and C}_1^\text{a}-\text{C}_3^\text{a} \text{haloalkoxy;} \) 

\( \text{R}^1 \) is \( \text{COOR}^9, \text{CONR}^9\text{R}^{10}, \text{CH}_2\text{OR}^9, \text{SO}_2\text{R}^9, \text{SO}_2\text{NR}^9\text{R}^{10}, \text{PO(OR}^9)_2, \) or tetrazol-5-yl; 

\( \text{R}^8 \) is \( \text{H, C}_1^\text{a}-\text{C}_4^\text{a} \text{ alkyl, or aryl;} \)
R^10 is H, C_1-C_4 alkyl, COR^{11}, OR^9, or SO_2R^{11};
R^{11} is C_1-C_4 alkyl;
R^{12}, at each occurrence, is independently H or C_1-C_4 alkyl;
L^4 is -C(R^2)_2-C(R^3)_2-, -C(R^2)=C(R^3)-, -C=C-, or

\[
\begin{array}{c}
\text{\textbullet} \\
\text{\textbullet} \\
\end{array}
\]

wherein R^2 and R^3 are each H, CH_3, fluoro, or chloro;
L^2 is -CH_2- or a bond;
R^4 and R^5 are each independently H, F, CF_3, or C_1-C_4 alkyl; or R^4 and R^5 together with the carbon to which they are attached form a C_3-C_5 cycloalkyl,

\[
\begin{array}{c}
\text{\textbullet} \\
\text{\textbullet} \\
\end{array}
\]

L^3 is C_2-C_6 alkynylene, wherein the C_2-C_6 alkynylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents; R^6 is ary1, heteroaryl, heterocyclyl, C_1-C_10 alkyl, C_2-C_4 cycloalkyl, C_2-C_10 alkenyl, C_2-C_10 alky1, C_1-C_10 haloalkyl, C_2-C_4 haloalkycycloalkyl, C_2-C_10 haloalkenyl, or C_2-C_10 haloalkynyl; wherein the aryl and heteroaryl are optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, cyano, halogen, C_1-C_3 haloalkoxy; and wherein the ary1 and heteroaryl are optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C_1-C_4 alkyl, C_1-C_3 haloalkyl, C_2-C_4 haloalkenyl, C_2-C_4 haloalkycycloalkyl, C_2-C_10 haloalkenyl, and C_2-C_10 haloalkynyl are optionally substituted with a substituent selected from the group consisting of COOR^9, CONR^9R^{10}, CH_3 OR^9, SO_2 NR^9R^{10}, PO(OR^9)_2, and tetrazol-5-yl;
R^8 is H, C_1-C_4 alkyl, or ary1;
R^{10} is H, C_1-C_4 alkyl, COR^{11}, OR^9, or SO_2R^{11};
R^{11} is C_1-C_4 alkyl;
r is 0 or 1; and
s is 0 or 1;
for use in treating osteoporosis, bone fracture, bone loss, bone loss due to periodontal disease, a tooth socket having undergone implantation, a joint that is to undergo or that has undergone orthopedic implantation, or vertebrae that have undergone spinal fusion, or for increasing bone density.

2. The compound for use of claim 1, wherein:

L^1 is

\[\begin{array}{c}
\text{\textbullet} \\
\text{\textbullet} \\
\end{array}\]

a) C_3-C_7 alky1, wherein the C_3-C_7 alky1 is optionally substituted with 1, 2, 3, or 4 fluoro substituents; or
c) -(CH_2)_n-G^2-(CH_2)_p-, -(CH_2)_n-C-C-G^2, or -(CH_2)_n-C(H)=C(H)-G^2, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6;

\[
\begin{array}{c}
\text{\textbullet} \\
\text{\textbullet} \\
\end{array}
\]

wherein G^2 is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C_1-C_4 alkyl, C_2-C_4 haloalkyl, cyano, halogen, C_1-C_3 haloalkoxy, and C_1-C_3 haloalkoxy;
R^1 is COOR^9; and
R^8 is H or C\textsubscript{1}-C\textsubscript{4} alkyl.

3. The compound for use of claim 1, wherein:

- L\textsuperscript{2} is a bond;
- L\textsuperscript{4} is -C(R\textsuperscript{2})=C(R\textsuperscript{3})-;
- R\textsuperscript{2} and R\textsuperscript{3} are each hydrogen;
- R\textsuperscript{4} and R\textsuperscript{5} are independently H or C\textsubscript{1}-C\textsubscript{4} alkyl;
- L\textsuperscript{3} is C\textsubscript{2}-C\textsubscript{6} alkynylene; wherein the C\textsubscript{2}-C\textsubscript{6} alkynylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents; and
- R\textsuperscript{6} is aryl or C\textsubscript{1}-C\textsubscript{10} alkyl, wherein the aryl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C\textsubscript{1}-C\textsubscript{4} alkyl, C\textsubscript{1}-C\textsubscript{3} haloalkyl, cyano, halogen, C\textsubscript{1}-C\textsubscript{3} alkoxy, C\textsubscript{1}-C\textsubscript{3} haloalkoxy; and -C\textsubscript{1}-C\textsubscript{3} alkyne-C\textsubscript{1}-C\textsubscript{3} alkoxy.

4. The compound for use of claim 2, wherein:

- L\textsuperscript{2} is a bond;
- L\textsuperscript{4} is -C(R\textsuperscript{2})\textsubscript{2}-C(R\textsuperscript{3})\textsubscript{2}-, -C(R\textsuperscript{2})=C(R\textsuperscript{3})-, -C\equiv C-, or 

\[
\begin{array}{c}
\text{R}^2 \\
\text{R}^3
\end{array}
\]

wherein R\textsuperscript{2} and R\textsuperscript{3} are each H, CH\textsubscript{3}, fluoro, or chloro;
- R\textsuperscript{4} and R\textsuperscript{5} are each independently H, F, CF\textsubscript{3}, or C\textsubscript{1}-C\textsubscript{4} alkyl; or R\textsuperscript{4} and R\textsuperscript{5} together with the carbon to which they are attached form a C\textsubscript{3}-C\textsubscript{5} cycloalkyl; and
- R\textsuperscript{6} is aryl, C\textsubscript{1}-C\textsubscript{10} alkyl, C\textsubscript{3}-C\textsubscript{8} cycloalkyl, C\textsubscript{2}-C\textsubscript{10} alkenyl, C\textsubscript{1}-C\textsubscript{10} haloalkyl, C\textsubscript{3}-C\textsubscript{8} halocycloalkyl, C\textsubscript{2}-C\textsubscript{10} haloalkenyl, or C\textsubscript{2}-C\textsubscript{10} haloalkynyl, wherein the aryl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C\textsubscript{1}-C\textsubscript{4} alkyl, C\textsubscript{1}-C\textsubscript{3} haloalkyl, cyano, halogen, C\textsubscript{1}-C\textsubscript{3} alkoxy, C\textsubscript{1}-C\textsubscript{3} haloalkoxy; and -C\textsubscript{1}-C\textsubscript{3} alkyne-C\textsubscript{1}-C\textsubscript{3} alkoxy.

5. The compound for use of claim 4, wherein:

- L\textsuperscript{4} is

\[
\begin{array}{c}
\text{R}^2 \\
\text{R}^3
\end{array}
\]

- R\textsuperscript{4} and R\textsuperscript{5} are each independently H or C\textsubscript{1}-C\textsubscript{4} alkyl;
- L\textsuperscript{3} is C\textsubscript{2}-C\textsubscript{6} alkynylene; and
- R\textsuperscript{6} is aryl or C\textsubscript{1}-C\textsubscript{10} alkyl, wherein the aryl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C\textsubscript{1}-C\textsubscript{4} alkyl, C\textsubscript{1}-C\textsubscript{3} haloalkyl, cyano, halogen, C\textsubscript{1}-C\textsubscript{3} alkoxy, C\textsubscript{1}-C\textsubscript{3} haloalkoxy; and -C\textsubscript{1}-C\textsubscript{3} alkyne-C\textsubscript{1}-C\textsubscript{3} alkoxy.

6. The compound for use of claim 5, wherein:

- R\textsuperscript{4} and R\textsuperscript{5} are each independently H or CH\textsubscript{3};
- L\textsuperscript{1} is

\begin{itemize}
  \item a) C\textsubscript{3}-C\textsubscript{7} alkyne; or
  \item c) -\text{CH}_{2}\text{H}_n\text{G}^2-(\text{CH}_2)_{p}\text{, -(CH}_2)_n\text{C=}-\text{G}^2-, or -(\text{CH}_2)_n\text{C(H)=C(H)-G}^2-, wherein n is 1, 2 or 3; p is 0, 1, or 2, and n+p = 1, 2, 3, or 4;
\end{itemize}

- G\textsuperscript{2} is
L₃ is ethynylene, propynylene, or butynylene; and
R⁶ is phenyl or C₁-C₆alkyl, wherein the phenyl is optionally substituted with 1, 2, 3, or 4 substituents selected from the group consisting of C₁-C₄alkyl, C₁-C₃haloalkyl, cyano, halogen, C₁-C₃alkoxy, C₁-C₃haloalkoxy; and -C₁-C₃alkylene-C₁-C₃alkoxy.

7. The compound for use of claim 6, wherein:

L¹ is

a) n-hexylene; or
c) -(CH₂)ₙ-G²-(CH₂)ₚ, -CH₂-C≡G²-, or -CH₂C(H)=C(H)-G²-, wherein n is 1, 2 or 3; p is 0 or 1, and n+p = 2 or 3;

G² is

R¹ is COOR⁹;
R⁹ is H or CH₃;
L₃ is -C≡C- or -CH₂-C≡C--; and
R⁶ is phenyl, methyl, ethyl, or propyl.

8. The compound for use of claim 5, wherein:

L³ is -CH₂-C≡C--; and
s is 1.

9. The compound for use of claim 5, wherein:

L³ is -C≡C--; and
s is 0.

10. The compound for use of claim 5, wherein:

L¹ is C₃-C₇alkylene, wherein the C₃-C₇alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents.

11. The compound for use of claim 5, wherein:

L¹ is
c) -(CH₂)ₙ-G²-(CH₂)ₚ, -(CH₂)ₙ-C≡G²-, or -(CH₂)ₙ-C(H)=C(H)-G²-, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; and

G² is

wherein G² is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C₁-C₄alkyl, C₁-C₃haloalkyl, cyano, halogen, C₁-C₃alkoxy, and C₁-C₃haloalkoxy.
12. The compound for use of claim 8, wherein:

L₁ is C₃-C₇alkylene, wherein the C₃-C₇alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents.

13. The compound for use of claim 8, wherein:

L₁ is

c) -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²-, or -(CH₂)ₙ-C(H)=C(H)-G²-, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; and

G² is

wherein G² is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C₁-C₄alkyl, C₁-C₃haloalkyl, cyano, halogen, C₁-C₃alkoxy, and C₁-C₃haloalkoxy.

14. The compound for use of claim 9, wherein:

L₁ is C₃-C₇alkylene, wherein the C₃-C₇alkylene is optionally substituted with 1, 2, 3, or 4 fluoro substituents.

15. The compound for use of claim 9, wherein:

L₁ is

c) -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²-, or -(CH₂)ₙ-C(H)=C(H)-G²-, wherein n is 1, 2, 3, 4, or 5, p is 0, 1, 2, or 3, and n+p = 1, 2, 3, 4, 5, or 6; and

G² is

wherein G² is optionally substituted with 1, 2, or 3 substituents selected from the group consisting of C₁-C₄alkyl, C₁-C₃haloalkyl, cyano, halogen, C₁-C₃alkoxy, and C₁-C₃haloalkoxy.

16. The compound for use of claim 7, wherein:

L₃ is -CH₂-C≡C--; and

s is 1.

17. The compound for use of claim 7, wherein:

L₃ is -C≡C--; and

s is 0.

18. The compound for use of claim 1, wherein the compound of formula (Ia) is selected from the group consisting of:

methyl 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate;
methyl 7-((R)-2-((3S,4R,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate;
(Z)-methyl 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-enoate;
methyl 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)sulfanyl)butanoate;
methyl 5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)sulfanyl)thiophene-2-
methyl 5-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
methyl 4-((2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate;
methyl 3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-enoic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-yn-1-yl thiophene-2-carboxylic acid;
4-((2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoic acid;
methyl 5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-yn-1-yl thiophene-2-carboxylic acid;
methyl 4-((2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)benzoate;
methyl 3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-enoic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
5-3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2
carboxylate;
methyl \((3\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{prop-1-yn-1-yl})\text{thiophene-2-carboxylate;}
\]
methyl \((Z)-3\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldc-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{prop-1-yn-1-yl})\text{thiophene-2-carboxylate;}
\]
methyl \(4\cdot((2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{ethyl} \text{benzoate;}
\]
methyl \(3\cdot((3\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{propyl} \text{benzoate;}
\]
\(7\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{heptanoic acid;}
\]
\(7\cdot((R)-2\cdot((3S,4R,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{heptanoic acid;}
\]
\((Z)-7\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{hept-5-enoic acid;}
\]
\(4\cdot((2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{ethyl} \text{thio} \text{butanoic acid;}
\]
\(5\cdot((3\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{propyl} \text{thiophene-2-carboxylic acid;}
\]
\(5\cdot((3\cdot((R)-2\cdot((3S,4R,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{propyl} \text{thiophene-2-carboxylic acid;}
\]
\((Z)-3\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{thiophene-2-carboxylic acid;}
\]
\((Z)-7\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{heptanoic acid;}
\]
\(4\cdot((2\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{ethyl} \text{thiophene-2-carboxylic acid;}
\]
\((Z)-7\cdot((R)-2\cdot((3S,4S,E)-3\text{-hydroxy-4-methyldec-1-en-6-yn-1-yl})-5\text{-oxopyrrolidin-1-yl})\text{heptanoic acid;}
\]
e 128
methyl 7-((R)-2-(((3R,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3R,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
7-((R)-2-(((3S,4R,E)-3-hydroxy-4-methyl-3-phenyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
methyl 5-(3-((S)-2-((3R,4S)-3-hydroxy-4-methylnon-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
methyl 5-(3-((S)-2-((3R,4R)-3-hydroxy-4-methylnon-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylate;
5-(3-((S)-2-((3R,4S)-3-hydroxy-4-methylnon-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
methyl 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-ynoate; and
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-ynoic acid;
or a pharmaceutically acceptable salt thereof.

19. The compound for use of claim 18, wherein the compound of formula (Ia) is selected from the group consisting of:
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid;
4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoic acid;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methyloct-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid;
4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butanoic acid; or
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophene-2-carboxylic acid;
or a pharmaceutically acceptable salt thereof.

20. The compound for use of claim 1, wherein the compound of formula (Ia), or pharmaceutically acceptable salts thereof, is further combined with a pharmaceutically acceptable carrier.

21. A pharmaceutical composition comprising 7-((R)-2-((3S,4S,E)-3-hydroxy-4-methylnon-1-en-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoic acid at a dose of 3 mg/mL; a calcium phosphate cement; and a demineralized bone matrix; wherein the ratio of calcium phosphate cement to demineralized bone matrix is 1:8 (weight/volume).

Patentansprüche

1. Verbindung der Formel (Ia)

   ![](image)

   (Ia)

   oder pharmazeutisch unbedenkliches Salz davon, mit den folgenden Bedeutungen:

   L¹ bedeutet

   a) C₃-C₇-Alkyle, C₃-C₇-Alkenyle oder C₃-C₇-Alkinylen, wobei das C₃-C₇-Alkyle, C₃-C₇-Alkenyle oder C₃-C₇-Alkinylen jeweils gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten substituiert sind;
b) (CH₂)ₜ-G-(CH₂)ₚ⁻; wobei t 0, 1 oder 2 bedeutet, p 0, 1, 2 oder 3 bedeutet und t+p = 0, 1, 2, 3 oder 4; oder
c) -(CH₂)n-G¹-(CH₂)p-, -(CH₂)n-G²-(CH₂)p-, -(CH₂)n-C≡G²- oder -(CH₂)n-C(R¹²)=C(R¹²)-G²-, wobei n 1, 2, 3, 4 oder 5 bedeutet, p 0, 1, 2 oder 3 bedeutet und n+p=1, 2, 3, 4, 5 oder 6;

G bedeutet

oder

G¹ bedeutet O, C(O), S, S(O), S(O)₂ oder NR⁷; wobei R⁷ H, C₁-C₄-Alkyl oder C₁-C₄-Alkylcarbonyl bedeutet; G² bedeutet

oder

wobei G² gegebenenfalls durch 1, 2 oder 3 Substituenten, ausgewählt aus der Gruppe bestehend aus C₁-C₄-Alkyl, C₁-C₃-Halogenalkyl, Cyano, Halogen, C₁-C₃-Alkoxy und C₁-C₃-Halogenalkoxy, substituiert ist; R¹ bedeutet COOR⁸, CONR⁸R¹⁰, CH₂OR⁸, SO₃R⁶, SO₂NR⁸R¹⁰, PO(OR⁸)₂ oder Tetrazol-5-yl; R⁸ bedeutet H, C₁-C₄-Alkyl oder Aryl; R¹⁰ bedeutet H, C₁-C₄-Alkyl, COR¹¹, OR⁸ oder SO₂R¹¹; R¹¹ bedeutet C₁-C₄-Alkyl; R¹² bedeutet bei jedem Auftreten unabhängig H oder C₁-C₄-Alkyl; L⁴ bedeutet -C(R²)₂-C(R³)₂-, -C(R²)=C(R³)-, -C≡C- oder

wobei R² und R³ jeweils H, CH₃, Fluor oder Chlor bedeuten; L² bedeutet -CH₂ oder eine Bindung; R⁴ und R⁵ bedeuten jeweils unabhängig H, F, CF₃ oder C₁-C₄-Alkyl; oder R⁴ und R⁵ gemeinsam mit dem Kohlenstoff, an den sie gebunden sind, bilden ein C₃-C₅-Cycloalkyl,
L³ bedeutet C₂-C₆-Alkinylen, wobei das C₂-C₆-Alkinylen gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten substituiert ist;
R⁶ bedeutet Aryl, Heteroaryl, Heterocyclen, C₁-C₁₀-Alkyl, C₃-C₈-Cycloalkyl, C₂-C₁₀-Alkenyl, C₂-C₁₀-Alkinyl, C₇-C₁₀-Halogenalkyl, C₂-C₆-Halogenecycloalkyl, C₂-C₁₀-Halogenalkenyl oder C₂-C₁₀-Halogenalkynyl; wobei das Aryl und Heteroaryl gegebenenfalls substituiert sind durch 1, 2, 3 oder 4 Substituenten, ausgewählt aus der Gruppe bestehend aus C₁-C₉-Alkyl, C₇-C₉-Alkenyl, C₇-C₉-Alkinyl, C₇-C₁₀-Halogenalkyl, C₃-C₈-Halogenecycloalkyl, C₂-C₁₀-Halogenalkenyl und C₂-C₁₀-Halogenalkynyl gegebenenfalls durch einen Substituenten, ausgewählt aus der Gruppe bestehend aus COOR⁹, CONR⁹'R¹⁰, CH₂OR⁹, SO₃R⁹, SO₂NR⁹'R¹⁰, PO(OR⁹)₂ und Tetrazol-5-yl, substituiert sind;
R⁹' bedeutet H, C₁-C₄-Alkyl oder Aryl;
R¹⁰' bedeutet H, C₁-C₄-Alkyl, COR¹¹', OR⁹' oder SO₂R¹¹';
R¹¹' bedeutet C₁-C₄-Alkyl;
r bedeutet 0 oder 1; und
s bedeutet 0 oder 1;
zur Verwendung in der Behandlung von Osteoporose, Knochenbruch, Knochenverlust, Knochenverlust aufgrund von Parodontitis, einem Zahnfach, bei dem eine Implantation durchgeführt wurde, einem Gelenk, bei dem eine orthopädische Implantation durchgeführt werden soll oder worden ist, oder von Wirbeln, bei denen eine operative Wirbelsäulenversteifung durchgeführt worden ist, oder zum Erhöhen der Knochendichte.

2. Verbindung zur Verwendung nach Anspruch 1, mit den folgenden Bedeutungen:
L¹ bedeutet
  a) C₃-C₇-Alkylen, wobei das C₃-C₇-Alkylen gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten substituiert ist; oder
  c) -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²- oder -(CH₂)ₙ-C(H)=C(H)-G²-, wobei n 1, 2, 3, 4 oder 5 bedeutet, p 0, 1, 2 oder 3 bedeutet und n+p=1, 2, 3, 4, 5 oder 6;
G² bedeutet
wobei G² gegebenenfalls durch 1, 2 oder 3 Substituenten, ausgewählt aus der Gruppe bestehend aus C₁-C₄-Alkyl, C₁-C₃-Halogenalkyl, Cyano, Halogen, C₁-C₃-Alkoxy und C₁-C₃-Halogenalkoxy substituiert ist;
R¹ bedeutet COOR⁹; und
R⁹ bedeutet H oder C₁-C₄-Alkyl.

3. Verbindung zur Verwendung nach Anspruch 1, mit den folgenden Bedeutungen:
L² bedeutet eine Bindung;
L⁴ bedeutet -C(R²)=C(R³)-;
R² und R³ bedeuten jeweils Wasserstoff;
R⁴ und R⁵ bedeuten unabhängig H oder C₁-C₄-Alkyl;
L³ bedeutet C₂-C₆-Alkinyl; wobei das C₂-C₆-Alkinyl gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten substituiert ist; und
R⁶ bedeutet Aryl oder C₁-C₁₀-Alkyl, wobei das Aryl gegebenenfalls substituiert ist durch 1, 2, 3 oder 4 Substi-
4. Verbindung zur Verwendung nach Anspruch 2, mit den folgenden Bedeutungen:

L² bedeutet eine Bindung;
L⁴ bedeutet -C(R²)₂-C(R³)₂-; -C(R²)=C(R³)- oder

wobei R² und R³ jeweils H, CH₃, Fluor oder Chlor bedeuten;
R⁴ und R⁵ bedeuten unabhängig H, F, CF₃ oder C₁-C₄-Alkyl; oder R⁴ und R⁵ gemeinsam mit dem Kohlenstoff, an den sie gebunden sind, bilden ein C₂-C₅-Cycloalkyl; und

5. Verbindung zur Verwendung nach Anspruch 4, mit den folgenden Bedeutungen:

L⁴ bedeutet

R⁴ und R⁵ bedeuten unabhängig H oder C₁-C₄-Alkyl;
L³ bedeutet C₂-C₆-Alkinylen; und
R⁶ bedeutet Aryl oder C₁-C₁₀-Alkyl, wobei das Aryl gegebenenfalls substituiert ist durch 1, 2, 3 oder 4 Substituenten, ausgewählt aus der Gruppe bestehend aus C₁-C₄-Alkyl, C₁-C₃-Halogenalkyl, Cyan, Halogen, C₁-C₃-Alkoxy, C₁-C₃-Halogenalkoxy und -C₁-C₃-Alkénylen-C₁-C₃-alkoxy.

6. Verbindung zur Verwendung nach Anspruch 5, mit den folgenden Bedeutungen:

R⁴ und R⁵ bedeuten unabhängig H oder CH₃;
L¹ bedeutet

a) C₃-C₇-Alkylen; oder
b) -(CH₂)ₙ-G²-(CH₂)ₚ, -(CH₂)ₙ-C≡C-G²- oder -(CH₂)ₙ-C(H)=C(H)-G²-, wobei n 1, 2 oder 3 bedeutet, p 0, 1 oder 2 bedeutet, und n+p=1, 2, 3 oder 4;
G² bedeutet

L³ bedeutet Ethinylen, Propinylen oder Butinylen; und
R⁶ bedeutet Phenyl oder C₁-C₆-Alkyl, wobei das Phenyl gegebenenfalls substituiert ist durch 1, 2, 3 oder 4 Substituenten, ausgewählt aus der Gruppe bestehend aus C₁-C₄-Alkyl, C₁-C₃-Halogenalkyl, Cyan, Halogen, C₁-C₃-Alkoxy, C₁-C₃-Halogenalkoxy und -C₁-C₃-Alkénylen-C₁-C₃-alkoxy.

7. Verbindung zur Verwendung nach Anspruch 6, mit den folgenden Bedeutungen:
L¹ bedeutet

a) n-Hexylen; oder
c) -(CH₂)n-G²-(CH₂)p, -(CH₂)n-C≡C²- oder -CH₂-C(H)=C(H)-G²-, wobei n 1, 2 oder 3 bedeutet, p 0 oder 1 bedeutet, und n+p=2 oder 3;

G² bedeutet

8. Verbindung zur Verwendung nach Anspruch 5, mit den folgenden Bedeutungen:

L³ bedeutet -CH₂-C≡C⁻; und
s bedeutet 1.

9. Verbindung zur Verwendung nach Anspruch 5, mit den folgenden Bedeutungen:

L³ bedeutet -C≡C⁻; und
s bedeutet 0.

10. Verbindung zur Verwendung nach Anspruch 5, mit den folgenden Bedeutungen:

L¹ bedeutet C₃-C₇-Alkylen, wobei das C₃-C₇-Alkylen gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten substituiert ist.

11. Verbindung zur Verwendung nach Anspruch 5, mit den folgenden Bedeutungen:

L¹ bedeutet

c) -(CH₂)n-G²-(CH₂)p, -(CH₂)n-C≡C²- oder -(CH₂)n-C(H)=C(H)-G²-, wobei n 1, 2, 3 oder 5 bedeutet, p 0, 1, 2 oder 3 bedeutet, und n+p=1, 2, 3, 4 oder 6; und

G² bedeutet

wobei G² gegebenenfalls durch 1, 2 oder 3 Substituenten, ausgewählt aus der Gruppe bestehend aus C₁-C₄-Alkyl, C₇-C₉-Halogenalkyl, Cyano, Halogen, C₁-C₃-Alkoxy und C₁-C₃-Halogenalkoxy substituiert ist.

12. Verbindung zur Verwendung nach Anspruch 8, wobei

L¹ C₃-C₇-Alkylen bedeutet, wobei das C₃-C₇-Alkylen gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten substituiert ist.

13. Verbindung zur Verwendung nach Anspruch 8, wobei

L¹
c) -(CH₂)ₙ-G²-(CH₂)ₚ, -(CH₂)ₙ-C≡C-G²- oder -(CH₂)ₙ-C(H)=C(H)-G²- bedeutet, 
wobei n 1, 2, 3, 4 oder 5 bedeutet, p 0, 1, 2 oder 3 bedeutet und n+p=1, 2, 3, 4, 5 oder 6; und

\[ G² \]

bedeutet, wobei G² gegebenenfalls durch 1, 2 oder 3 Substituenten, ausgewählt aus der Gruppe bestehend aus 

14. Verbindung zur Verwendung nach Anspruch 9, wobei
L¹ C₃⁻C₇-Alkylen bedeutet, wobei das C₃⁻C₇-Alkylen gegebenenfalls durch 1, 2, 3 oder 4 Fluorsubstituenten sub-
stituiert ist.

15. Verbindung zur Verwendung nach Anspruch 9, wobei
L¹ c) -(CH₂)ₙ-G²-(CH₂)ₚ, -(CH₂)ₙ-C≡C-G²- oder -(CH₂)ₙ-C(H)=C(H)-G²- bedeutet, 
wobei n 1, 2, 3, 4 oder 5 bedeutet, p 0, 1, 2 oder 3 bedeutet und n+p=1, 2, 3, 4, 5 oder 6; und

\[ G² \]

bedeutet, wobei G² gegebenenfalls durch 1, 2 oder 3 Substituenten, ausgewählt aus der Gruppe bestehend aus 

16. Verbindung zur Verwendung nach Anspruch 7, mit den folgenden Bedeutungen:

L³ bedeutet -CH₂-C≡C--; und
s bedeutet 1.

17. Verbindung zur Verwendung nach Anspruch 7, mit den folgenden Bedeutungen:

L³ bedeutet -C=C--; und
s bedeutet 0.

18. Verbindung zur Verwendung nach Anspruch 1, wobei die Verbindung der Formel (Ia) aus der Gruppe bestehend 
aus den folgenden ausgewählt ist:

7-((R)-2- ((3S,4S,E)-3-Hydroxy-4-methyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäuremethylester;
7-((R)-2- ((3S,4S,E)-3-Hydroxy-4-methyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl) heptansäuremethylester;
7-((R)-2- ((3S,4S,E)-3-Hydroxy-4-methyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)hept-5-ensäure-(Z)-methyles-
ter;
4-((2-((R)-2- ((3S,4S,E)-3-Hydroxy-4-methyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio) butansäureme-
thylester;
5-((3-((R)-2- ((3S,4S,E)-3-Hydroxy-4-methyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbon-
säuremethylester;
5-((3-((R)-2- ((3S,4S,E)-3-Hydroxy-4-methyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbon-
säuremethylester;
5-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl 1-1-yl)thiophen-2-carbonsäuremethylester;
5-(3-Z)-3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl 1-1-yl)thiophen-3-carbonsäuremethylester;
4-(2-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethylbenzosäuremethylester;
3-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylbenzosäuremethylester;
7-(R)-2-((3S,4R,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäure;
7-(R)-2-((3S,4R,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäure;
(Z)-7-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäure;
4-(2-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethylthiobutansäure;
5-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylthiophen-2-carbonsäure methylester;
5-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl 1-1-yl)thiophen-2-carbonsäure;
5-(3-(Z)-3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl 1-1-yl)thiophen-2-carbonsäure methylester;
4-(2-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethylbenzosäuremethylester;
5-(3-(R)-2-((3S,4R,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylthiophen-2-carbonsäuremethylester;
5-(3-(R)-2-((3S,4R,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylbenzosäuremethylester;
5-(3-(Z)-3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl 1-1-yl)thiophen-2-carbonsäure methylester;
7-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäuremethylester;
7-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäuremethylester;
5-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylthiophen-2-carbonsäure methylester;
5-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylbenzosäuremethylester;
5-(3-(Z)-3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl 1-1-yl)thiophen-2-carbonsäure methylester;
4-(2-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethylbenzosäuremethylester;
3-(3-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propylbenzosäuremethylester;
7-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäuremethylester;
7-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäuremethylester;
4-(2-(R)-2-((3S,4S,E)-3-Hydroxy-4-methylcyclohex-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethylthiobutansäuremethylester;
5-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylthiophen-2-carbonsäuremethylester;
5-[(R)-2-[(3S,4R,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylthiophen-2-carbonsäuremethylester;
5-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]prop-1-en-1-ylthiophen-2-carbonsäuremethylester;
5-[(Z)-3-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]prop-1-en-1-ylthiophen-2-carbonsäuremethylester;
4-[(2-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]ethyl]benzosäuremethylester;
3-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methylecdec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylbenzosäuremethylester;
7-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]heptansaure;
7-[(R)-2-[(3S,4R,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]heptansaure;
(Z)-7-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methylecdec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]hept-5-ensäure;
4-[(2-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]ethyl]thio)butansaure;
5-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methylecdec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylthiophen-2-carbonsäure;
5-[(R)-2-[(3S,4R,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylthiophen-2-carbonsäure;
5-[(Z)-3-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]prop-1-en-1-ylthiophen-2-carbonsäuremethylester;
4-[(2-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]ethyl]benzosäuremethylester;
3-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylbenzosäuremethylester;
5-[(R)-2-[(3S,4R,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylthiophen-2-carbonsäure;
5-[(R)-2-[(3S,4R,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylthiophen-2-carbonsäure;
5-[(Z)-3-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]prop-1-en-1-ylthiophen-2-carbonsäuremethylester;
4-[(2-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]ethyl]thio)butansaure;
5-[(R)-2-[(3S,4S,5)-3-Hydroxy-4-methyldec-1-en-6-in-1-yl]-5-oxopyrrolidin-1-yl]propylbenzosäuremethylester;
7-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-(3-
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5-(3-((R)-2-((3S,4R,E)-3-Hydroxy-4-methyl-8-phenyloct-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäure;
5-(3-((R)-2-((3S,4R,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäuremethylester;
5-(3-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäure;
5-(3-((R)-2-((3S,4R,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäuremethylester;
5-(3-((S)-2-((3R,4S)-3-Hydroxy-4-methyl-9-phenylnon-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäuremethylester;
5-(3-((S)-2-((3R,4R)-3-Hydroxy-4-methyl-4-phenylnon-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carboxylat;
5-(3-((S)-2-((3R,4R)-3-Hydroxy-4-methyl-9-phenylnon-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäuremethylester;
7-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)hept-5-insäuremethylester; und
7-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)hept-5-insäure;
oder einem pharmazeutisch unbedenklichen Salz davon.

**19.** Verbindung zur Verwendung nach Anspruch 18, wobei die Verbindung der Formel (Ia) aus der Gruppe bestehend aus den folgenden ausgewählt ist:

7-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäure;
4-((2-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butansäure;
5-3-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäure;
7-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäure;
4-((2-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)ethyl)thio)butansäure; oder
5-(3-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophen-2-carbonsäure;
oder einem pharmazeutisch unbedenklichen Salz davon.

**20.** Verbindung zur Verwendung nach Anspruch 1, wobei die Verbindung der Formel (Ia) oder pharmazeutisch unbedenkliche Salze davon weiter mit einem pharmazeutisch unbedenklichen Träger zusammengegeben wird/werden.

**21.** Pharmazeutische Zusammensetzung, umfassend 7-((R)-2-((3S,4S,E)-3-Hydroxy-4-methyl-9-phenylnon-1-en-6-in-1-yl)-5-oxopyrrolidin-1-yl)heptansäure in einer Dosis von 3 mg/ml; einen Calciumphosphatzement; und eine demineralisierte Knochenmatrix; wobei das Verhältnis von Calciumphosphatzement zu demineralisierter Knochenmatrix 1:8 (Gewicht/Volumen) beträgt.

**Revidications**

**1.** Composé de formule (Ia)
ou sel pharmaceutiquement acceptable de celui-ci, où :

$L^1$ représente

a) un groupement alkylène en C$_3$-C$_7$, alcénylène en C$_3$-C$_7$ ou alcynylène en C$_3$-C$_7$, où chacun des groupements alkylène en C$_3$-C$_7$, alcénylène en C$_3$-C$_7$ ou alcynylène en C$_3$-C$_7$ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro ;
b) -(CH$_2$)$_t$-G-(CH$_2$)$_p$- ; où t est égal à 0, 1 ou 2, p est égal à 0, 1, 2 ou 3, et t + p = 0, 1, 2, 3 ou 4 ; ou
c) -(CH$_2$)$_n$-G$_1$-(CH$_2$)$_p$-, -(CH$_2$)$_n$-G$_2$-(CH$_2$)$_p$- -(CH$_2$)$_n$-C=C-G$_2$- ou -(CH$_2$)$_n$-C(R$_{12}$)=C(R$_{12}$)-G$_2$-, où n est égal à 1, 2, 3, 4 ou 5, p est égal à 0, 1, 2 ou 3, et n + p = 1, 2, 3, 4, 5 ou 6 ;

G représente

ou

ou

$G^1$ représente O, C(O), S, S(O)$_2$ ou NR$_7$ ; où R$_7$ représente H ou un groupement alkyle en C$_1$-C$_4$ ou (alkyle en C$_1$-C$_4$)-carbonyle ;

$G^2$ représente

ou

ou

où $G^2$ est éventuellement substitué par 1, 2 ou 3 substituants choisis dans le groupe constitué par les groupe-
ments alkyle en C₁-C₄, halogénoalkyle en C₁-C₃, cyano, halogène, alkoxy en C₁-C₃ et halogénoalkoxy en C₁-C₃ ;
R¹ représente un groupement COOR⁹, CONR⁹R¹⁰, CH₂OR⁹, SO₃R⁹, SO₃NR⁹R¹⁰, PO(OR⁹)₂ ou tétrazol-5-yle ;
R⁸ représente H ou un groupement alkyle en C₁-C₄ ou aryle ;
R¹⁰ représente H ou un groupement alkyle en C₁-C₄, COR¹¹, OR⁹ ou SO₂R¹¹ ;
R¹¹ représente un groupement alkyle en C₁-C₄ ;
R¹² représente indépendamment dans chacune de ses occurrences H ou un groupement alkyle en C₁-C₄ ;
L⁴ représente -C(R²)₂-C(R³)₂-, -C(R²)=C(R³)- ou -C=C- ou

où chacun des radicaux R² et R³ représente H ou un groupement CH₃, fluoro ou chloro ;
L² représente -CH₂- ou une liaison ;
chacun des radicaux R⁴ et R⁵ représente indépendamment H, F, ou un groupement CF₃ ou alkyle en C₁-C₄ ;
or R⁴ et R⁵ forment ensemble et avec l’atome de carbone auquel ils sont liés un groupement cycloalkyle en C₃-C₅ ;

L³ représente un groupement alcynylène en C₂-C₆, où le groupement alcynylène en C₂-C₆ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro ;
R⁶ représente un groupement aryle, hétéroaryle, hétérocyclé, alkyle en C₁-C₁₀, cycloalkyle en C₃-C₈, alcényle en C₂-C₄, cloroalkyle en C₁-C₄, halogénocycloalkyle en C₃-C₈, halogénoalcényle en C₂-C₄, halogénoalcynylène en C₂-C₄ ; où les groupements aryle et hétéroaryle sont éventuellement substitués par 1, 2, 3 ou 4 substituants choisis dans le groupe constitué par les groupements alkyle en C₁-C₄, halogénoalkyle en C₁-C₄, cyano, halogène, alkoxy en C₁-C₃, halogénoalkoxy en C₁-C₃ ; et - (alkyle en C₁-C₃)-(alkoxy en C₁-C₃) ; et où chacun des groupements alkyle en C₁-C₁₀, alcényle en C₃-C₈, cloroalkyle en C₁-C₄, halogénoalkyle en C₁-C₄, halogénoalcényle en C₂-C₄, halogénoalcynylène en C₂-C₄, halogénoalcynylène en C₂-C₄ est éventuellement substitué par un substituant choisi dans le groupe constitué par COOR⁹, CONR⁹R¹⁰, CH₂OR⁹, SO₃R⁹, SO₃NR⁹R¹⁰, PO(OR⁹)₂ et tétrazol-5-yle ;
R⁸ représente H ou un groupement alkyle en C₁-C₄ ou aryle ;
R¹₀ représente H ou un groupement alkyme en C₁-C₄, COR¹¹, OR⁹ ou SO₂R¹¹ ;
R¹¹ représente un groupement alkyme en C₁-C₄ ;
r est égal à 0 ou à 1 ; et
s est égal à 0 ou à 1 ;

pour utilisation dans le traitement de l’ostéoporose, des fractures osseuses, des pertes osseuses, des pertes osseuses dues à une maladie parodontale, une alvéole dentaire ayant subi une implantation, une articulation devant subir ou ayant subi une implantation orthopédique, ou des vertèbres ayant subi une fusion spinale, ou dans l’augmentation de la densité osseuse.

2. Composé pour utilisation selon la revendication 1, où :

L¹ représente
a) un groupement alkylène en C₂⁻C₇, où le groupement alkylène en C₂⁻C₇ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro ; ou

c) -(CH₂)ₙ-G²-(CH₂)ₚ- ou -(CH₂)ₙ-C≡C-G²- ou -(CH₂)ₙ-C=CH-G²-, où n est égal à 1, 2, 3, 4 ou 5, p est égal à 0, 1, 2 ou 3, et n + p = 1, 2, 3, 4, 5 ou 6 ;

G² représente

[Diagramme]

où G² est éventuellement substitué par 1, 2 ou 3 substituants choisis dans le groupe constitué par les groupements alkyle en C₁⁻C₄, halogénoalkyle en C₁⁻C₃, cyano, halogène, alkoxy en C₁⁻C₃ et halogénoalkoxy en C₁⁻C₃ ;

R¹ représente COOR⁹ ; et

R⁹ représente H ou un groupement alkyle en C₁⁻C₄.

3. Composé pour utilisation selon la revendication 1, où :

L² représente une liaison ;

L⁹ représente -C(R²)=C(R³)- ;

chacun des radicaux R² et R³ représente un atome d’hydrogène ;

chacun des radicaux R⁴ et R⁵ représente indépendamment H ou un groupement alkyle en C₁⁻C₄ ;

L³ représente un groupement alcynylène en C₃⁻C₆, où le groupement alcynylène en C₃⁻C₆ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro ; et

R⁶ représente un groupement arylique ou alkyle en C₁⁻C₄, où le groupement arylique est éventuellement substitué par 1, 2 ou 3 substituants choisis dans le groupe constitué par les groupements alkyle en C₁⁻C₄, halogénoalkyle en C₁⁻C₃, cyano, halogène, alkoxy en C₁⁻C₃, halogénoalkoxy en C₁⁻C₃ et -(alkylène en C₁⁻C₃)-(alkoxy en C₁⁻C₃).

4. Composé pour utilisation selon la revendication 2, où :

L² représente une liaison ;

L⁴ représente -C(R²)₂-C(R³)₂-, -C(R²)=C(R³)-, -C≡C- ou

[Diagramme]

où chacun des radicaux R² et R³ représente H ou un groupement CH₃, fluoro ou chloro ;

chacun des radicaux R⁴ et R⁵ représente indépendamment H, F, ou un groupement CF₃ ou alkyle en C₁⁻C₄ ;

ou R⁴ et R⁵ forment ensemble et avec l’atome de carbone auquel ils sont liés un groupement cycloalkyle en C₃⁻C₅ ;

R⁶ représente un groupement arylique, alkyle en C₁⁻C₁₀, cycloalkyle en C₃⁻C₆, alcénylique en C₂⁻C₁₀, alcénylique en C₂⁻C₁₀, halogénoalkyle en C₁⁻C₁₀, halogénochycloalkyle en C₃⁻C₆, halogénochalcénylique en C₂⁻C₁₀ ou halogénochalcénylique en C₂⁻C₁₀, où le groupement arylique est éventuellement substitué par 1, 2, 3 ou 4 substituants choisis dans le groupe constitué par les groupements alkyle en C₁⁻C₄, halogénoalkyle en C₁⁻C₃, cyano, halogène, alkoxy en C₁⁻C₃, halogénoalkoxy en C₁⁻C₃ et -(alkylène en C₁⁻C₃)-(alkoxy en C₁⁻C₃).

5. Composé pour utilisation selon la revendication 4, où :

L⁴ représente

[Diagramme]

chacun des radicaux R⁴ et R⁵ représente indépendamment H ou un groupement alkyle en C₁⁻C₄ ;

L³ représente un groupement alcynylène en C₃⁻C₆ ; et
R° représente un groupement aryle ou alkyle en C1-C10, où le groupement aryle est éventuellement substitué par 1, 2, 3 ou 4 substituants choisis dans le groupe constitué par les groupements alkyle en C1-C4, halogénoalkyle en C1-C3, cyano, halogène, alkoxy en C1-C3, halogénoalkoxy en C1-C3 et -(alkyle en C1-C3)-(alkoxy en C1-C3).

6. Composé pour utilisation selon la revendication 5, où :

chacun des radicaux R4 et R5 représente indépendamment H ou CH3 ;
L1 représente

a) un groupement alkylène en C3-C7 ; ou
b) -(CH2)2n-G2-(CH2)p -CH2-(H)=C-(H)-G2- où n est égal à 1, 2 ou 3 ; p est égal à 0, 1 ou 2, et n + p = 1, 2, 3 ou 4 ;
G2 représente

L3 représente un groupement éthynylène, propynylène ou butynylène ; et
R° représente un groupement phényle ou alkyle en C1-C6, où le groupement phényle est éventuellement substitué par 1, 2, 3 ou 4 substituants choisis dans le groupe constitué par les groupements alkyle en C1-C4, halogénoalkyle en C1-C3, cyano, halogène, alkoxy en C1-C3, halogénoalkoxy en C1-C3 et -(alkyle en C1-C3)-(alkoxy en C1-C3).

7. Composé pour utilisation selon la revendication 6, où :

L1 représente

a) un groupement n-hexylène ; ou
b) -(CH2)2n-G2-(CH2)p -CH2-(H)=C-(H)-G2- où n est égal à 1, 2 ou 3 ; p est égal à 0 ou à 1, et n + p = 2 ou 3 ;
G2 représente

R1 représente COOR° ;
R° représente H ou un groupement CH3 ;
L3 représente un groupement -C=O ou -CH2-C=O ; et
R° représente un groupement phényle, méthyle, éthyle ou propyle.

8. Composé pour utilisation selon la revendication 5, où :

L3 représente un groupement -CH2-C=O ; et
s est égal à 1.

9. Composé pour utilisation selon la revendication 5, où :

L3 représente un groupement -C=O ; et
s est égal à 0.

10. Composé pour utilisation selon la revendication 5, où :
L¹ représente un groupement alkylène en C₃-C₇, où le groupement alkylène en C₃-C₇ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro.

11. Composé pour utilisation selon la revendication 5, où :

L¹ représente

c) -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²- ou -(CH₂)ₙ-C(H)=C(H)-G²-, où n est égal à 1, 2, 3, 4 ou 5, p est égal à 0, 1, 2 ou 3, et n + p = 1, 2, 3, 4, 5 ou 6 ; et

G² représente

![Structure](image1.png)

où G² est éventuellement substitué par 1, 2 ou 3 substituants choisis dans le groupe constitué par les groupements alkyle en C₁-C₄, halogénoalkyle en C₁-C₃, cyano, halogène, alkoxy en C₁-C₃ et halogénoalkoxy en C₁-C₃.

12. Composé pour utilisation selon la revendication 8, où :

L¹ représente un groupement alkylène en C₃-C₇, où le groupement alkylène en C₃-C₇ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro.

13. Composé pour utilisation selon la revendication 8, où :

L¹ représente

c) -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²- ou -(CH₂)ₙ-C(H)=C(H)-G²-, où n est égal à 1, 2, 3, 4 ou 5, p est égal à 0, 1, 2 ou 3, et n + p = 1, 2, 3, 4, 5 ou 6 ; et

G² représente

![Structure](image2.png)

où G² est éventuellement substitué par 1, 2 ou 3 substituants choisis dans le groupe constitué par les groupements alkyle en C₁-C₄, halogénoalkyle en C₁-C₃, cyano, halogène, alkoxy en C₁-C₃ et halogénoalkoxy en C₁-C₃.

14. Composé pour utilisation selon la revendication 9, où :

L¹ représente un groupement alkylène en C₃-C₇, où le groupement alkylène en C₃-C₇ est éventuellement substitué par 1, 2, 3 ou 4 substituants fluoro.

15. Composé pour utilisation selon la revendication 9, où :

L¹ représente

c) -(CH₂)ₙ-G²-(CH₂)ₚ-, -(CH₂)ₙ-C≡C-G²- ou -(CH₂)ₙ-C(H)=C(H)-G²-, où n est égal à 1, 2, 3, 4 ou 5, p est égal à 0, 1, 2 ou 3, et n + p = 1, 2, 3, 4, 5 ou 6 ; et

G² représente

![Structure](image3.png)
où G² est éventuellement substitué par 1, 2 ou 3 substituants choisis dans le groupe constitué par les groupements alkyle en C₁-C₄, halogénoalkyle en C₁-C₃, cyano, halogène, alkoxy en C₁-C₃ et halogénoalkoxy en C₁-C₃.

16. Composé pour utilisation selon la revendication 7, où :
L³ représente un groupement -CH₂-C≡C- ; et
s est égal à 1.

17. Composé pour utilisation selon la revendication 7, où :
L³ représente un groupement -C≡C- ; et
s est égal à 0.

18. Composé pour utilisation selon la revendication 1, où le composé de formule (Ia) est choisi dans le groupe constitué par les suivants :

- 7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
- 7-((R)-2-(((3S,4R,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
- (Z)-7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-énoate de méthyle ;
- 4-((2-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoate de méthyle ;
- 5-3-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
- 5-3-((R)-2-(((3S,4R,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
- 5-3-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-ényl)thiophène-2-carboxylate de méthyle ;
- 5-3-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-én-1-yl)thiophène-2-carboxylate de méthyle ;
- 5-3-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate de méthyle ;
- acide 7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
- acide 7-((R)-2-(((3S,4R,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
- acide (Z)-7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-énoïque ;
- acide 4-((2-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoïque ;
- acide 5-3-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
- acide 5-3-((R)-2-(((3S,4R,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
- acide 5-3-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-én-1-yl)thiophène-2-carboxylique ;
- acide 4-((2-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthyloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoïque ;
- acide 7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
- acide 7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
- acide (Z)-7-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-énoïque ;
- acide 4-((2-((R)-2-(((3S,4S,E)-3-hydroxy-4-méthylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoïque.
boxylate de méthyle ;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylate de méthyle ;
5-(Z)-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylate de méthyle ;
4-(2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)benzoate de méthyle ;
3-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate de méthyle ;
acide 7-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
acide (Z)-7-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-énoïque ;
acide 4-(2-(2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thiobutanoïque ;
acide 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
acide 5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)-propyl-1-én-1-yl)thiophène-2-carboxylique ;
acide 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate de méthyle ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;
5-(Z)-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate de méthyle ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;
5-(Z)-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate de méthyle ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;
5-(Z)-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoate de méthyle ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyldec-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl-1-én-1-yl)thiophène-2-carboxylique ;

7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
(Z)-7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)hept-5-énoate de méthyle ;
4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoate de méthyle ;
5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-((3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophène-2-carboxylate de méthyle ;
5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophène-2-carboxylate de méthyle ;
4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoïque ;
acide 5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
acide 5-((3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
acide 5-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophène-2-carboxylique ;
acide 5-((Z)-3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)prop-1-yn-1-yl)thiophène-2-carboxylique ;
acide 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)benzoïque ;
acide 3-((3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)benzoïque ;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate d'éthyle ;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate d'isopropyle ;
N-éthyl-7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanamide ;
7-(1-((1H-tétrazol-5-yl)hexyl)-5-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)pyrrolidin-2-one ;
7-((R)-3-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)N-(méthylsulfonyl)heptanamide ;
(R)-1-((6-((1H-tétrazol-5-yl)hexyl)-5-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)pyrrolidin-2-one ;
(R)-5-((3S,4S,E)-3-hydroxy-4-méthyl-7-phénylhept-1-én-6-yn-1-yl)-1-(7-hydroxyheptyl)pyrrolidin-2-one ;
7-((R)-2-((3S,4S,E)-4-éthyl-3-hydroxynon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((3R,4R,E)-3-hydroxy-4-isopropylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-3-hydroxy-3-(1-(pent-2-yn-1-yl)cyclopropyl)prop-1-én-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-3-hydroxy-3-(1-(pent-2-yn-1-yl)cyclobutyl)prop-1-én-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-4,4-difluoro-3-hydroxynon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((S,E)-3-hydroxynon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-3-hydroxy-4-méthyl-8-phényloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-3-hydroxy-3-hydroxy-4-méthyl-8-phényloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((R,E)-3-hydroxy-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
7-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoate de méthyle ;
5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-(3-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
acide 7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
acide 7-((R)-2-((3S,4R,E)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
5-(3-((S)-2-((3R,4S)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
5-(3-((S)-2-((3R,4R)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
acide 5-((S)-2-((3R,4S)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
acide 5-((S)-2-((3R,4R)-3-hydroxy-4-méthyl-9-phénylnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylate de méthyle ;
ou sel pharmaceutiquement acceptable de celui-ci.
19. Composé pour utilisation selon la revendication 18, où le composé de formule (Ia) est choisi dans le groupe constitué par les suivants :

- acide 7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthiloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
- acide 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthiloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoïque ;
- acide 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthiloct-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;
- acide 7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthilnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque ;
- acide 4-((2-((R)-2-((3S,4S,E)-3-hydroxy-4-méthilnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)éthyl)thio)butanoïque ;
- acide 5-(3-((R)-2-((3S,4S,E)-3-hydroxy-4-méthilnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)propyl)thiophène-2-carboxylique ;

ou sel pharmaceutiquement acceptable de celui-ci.

20. Composé pour utilisation selon la revendication 1, où le composé de formule (Ia), ou les sels pharmaceutiquement acceptables de celui-ci, est combiné plus avant à un vecteur pharmaceutiquement acceptable.

21. Composition pharmaceutique comprenant l’acide 7-((R)-2-((3S,4S,E)-3-hydroxy-4-méthilnon-1-én-6-yn-1-yl)-5-oxopyrrolidin-1-yl)heptanoïque à une dose de 3 mg/mL ;
un ciment de phosphate de calcium ;
et une matrice osseuse déminéralisée ;
ou le rapport du ciment de phosphate de calcium sur la matrice osseuse déminéralisée est de 1:8 (masse/volume).
Calvarial Defect Repair 8 weeks

![Graph showing percent repair between Vehicle and 3 mg/ml EXAMPLE 2E.]

* p < 0.05 vs Vehicle.

Fig. 1
REFERENCES CITED IN THE DESCRIPTION

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