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Use of Parthenolide Derivatives as Antileukemic and Cytotoxic Agents

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USE OF PARTHENOLIDE DERIVATIVES AS ANTILEUKEMIC AND CYTOTOXIC AGENTS

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ABSTRACT

The present invention provides compounds of the formula (I)

wherein:

- \( X_1, X_2, \) and \( X_3 \) are heteroatoms;
- \( R_4, R_5, R_6, R_7, R_8, R_9, \) and \( R_{10} \) are independently selected from \( \text{H}, \text{halo}, -\text{OH}, -\text{NO}_2, -\text{CN} \) and optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl; and
- \( Z \) is optionally substituted \( \text{C}_1 \text{C}_6 \) straight-chained or branched aliphatic, optionally containing 1 or more double or triple bonds, wherein one or more carbons are optionally replaced by \( R^* \) where \( R^* \) is optionally substituted cycloalkyl, heterocycloalkyl, aryl or heteroaryl; an amino acid residue, \( \text{H}, -\text{CN}, -\text{C(O)} -, -\text{C(O)} \text{(O)} -, -\text{C(O)} \text{NR}^2 -, -\text{C(O)} \text{NR}^3 -, -\text{C(O)} \text{O} -, -\text{OC(O)} -, -\text{NR}^1 \text{CO} -, -\text{O} -, -\text{NR}^1 \text{C(O)} \text{NR}^2 -, -\text{OC(O)} \text{NR}^2 -, -\text{NR}^1 \text{NR}^2 -, -\text{NR}^1 \text{C(O)} -, -\text{S} -, -\text{SO} -, -\text{SO}_2 -, -\text{NR}^1 -, -\text{SO}_2 \text{NR}^1 -, -\text{NR}^1 \text{SO}^2 -, \) wherein \( R^1 \) and \( R^2 \) are independently selected from \( \text{H} \) or optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl; or where \( R^* \) is \( \text{NR}^2 \text{R}^3, \text{R}^2 \text{R}^3 \) or \( \text{R}^* \) optionally together with the nitrogen atom form an optionally substituted 5-12 membered ring, said ring optionally comprising 1 or more heteroatoms or a group selected from \( -\text{CO} -, -\text{SO} -, -\text{SO}_2 -, \) and \( -\text{PO} -; \) or a pharmaceutically acceptable salt, ester or prodrug thereof.

15 Claims, 12 Drawing Sheets
REFERENCES CITED


Hwang et al. (1996) STN Accession No. 1996:592356, Abstract of Biochemical and Biophysical Research Communications 226(3):810-818 “Inhibition of the expression of inducible cyclooxygenase lactones in macrophages correlates with the inhibition of MAP kinases”.


Ross, JJ et al. (1999) PMID. 10193202 “Low concentration of the feverfew component parthenolide inhibit in vitro growth of tumor lines in a cytostatic fashion.”


* cited by examiner
USE OF PARTHENOLIDE DERIVATIVES AS ANTILEUKEMIC AND CYTOTOXIC AGENTS


FIELD OF THE INVENTION

The present invention relates to methods for the structural modification of the sesquiterpene lactone, parthenolide, and the use of these parthenolide derivatives in the treatment of cancer. More specifically, the invention relates to the methods to prepare structural analogs of the parent compound, parthenolide, in order to obtain new, pharmacologically active chemical entities with improved water solubility characteristics, and to use them in the treatment of leukemias and other parental and multi-drug resistant cancers.

BACKGROUND OF THE INVENTION

Sesquiterpene lactones are a group of secondary plant metabolites consisting of a 15-carbon structure containing an a-methylene-γ-butyrolactone moiety and other additional functional groups. Over the last two to three decades, these terpenoids have received considerable attention due to the broad spectrum of their biological activities, to the plants which produce them, and most importantly, because of their pharmacological effects in humans. About 4000 of these terpenoids have been isolated and identified, mostly of them in Asteraceae (Compositae, sunflower family) (Schmidt, Curr. Org. Chem. 1999, 3, 577-608). Some of these plants have been used for centuries in indigenous medical practices in various cultures worldwide.

Parthenolide (1) is a Geraniaceae sesquiterpene lactone with a unique structure. It has been isolated from several different species in Asteraceae (Compositae) family, feverfew (Tanacetum parthenium) being one of them.

Feverfew has been used to reduce fever and pain and in the treatment of migraine and rheumatoid arthritis (Heptinstall et al., ACS Symposium Series (1998), 691 (Phytochemicals of Europe), 158-175). The active component is parthenolide (1). Recently, it has been revealed that parthenolide (1) can induce tumor apoptosis by the inhibition of NF-κB activities (Cory et al., Anticancer Research 2002, 22, 3805-9; Cory et al., Anticancer Research 2001, 21, 3807-11; Gellman et al., Blood, 2000, 98, 2508-17; Kang et al., Brit. J. Pharmacol. 2002, 135, 1235-44; Song et al., J. Asian. Nat. Prod. Res. 2001, 3, 285-91).

Parthenolide (1) is a lipophilic, neutral lactone with low polarity, and has a low water-solubility, limiting its development as a therapeutic agent. Thus, a need exists for the development of soluble parthenolide derivatives that retain their anti-cancer activity.

SUMMARY OF THE INVENTION

In accordance with the present invention, a novel class of compounds with antileukemic activity is presented. Accordingly, the present invention provides compounds of formula (I):

wherein:

X1, X2 and X3 are heteroatoms;
R4, R5, R6, R7, R8, R9 and R10 are independently selected from H, halo, —OH, —NO2, —CN and optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl;
Z is optionally substituted C1–8 straight-chained or branched aliphatic, optionally containing 1 or more double or triple bonds, wherein one or more carbons are optionally replaced by R* wherein R* is optionally substituted cycloalkyl, heterocycloalkyl, ary1 or heteroaryl; and
a pharmaceutically acceptable salt, ester or prodrug thereof.

The invention also provides a pharmaceutical composition comprising an effective amount of a compound of formula (I), or a pharmaceutically acceptable salt, ester or prodrug thereof, in combination with a pharmaceutically acceptable diluent or carrier.

The invention also provides a method of inhibiting cancer cell growth and metastasis of cancer cells, comprising administering to a mammal afflicted with cancer, an amount of a compound of formula (I), effective to inhibit the growth of said cancer cells.

The invention also provides a method comprising inhibiting cancer cell growth by contacting said cancer cell in vitro or in vivo with an amount of a compound of formula (I), to effectively inhibit the growth of said cancer cell.
The invention also provides a compound of formula (I) for use in medical therapy (preferably for use in treating cancer, e.g., solid tumors), as well as the use of such compound for the manufacture of a medicament useful for the treatment of cancer and other diseases/disorders described herein.

The invention further provides methods of treating inflammatory diseases and disorders, including, for example, rheumatoid arthritis, osteoarthritis, allergies (such as asthma), and other inflammatory conditions, such as pain (such as migraine), swelling, fever, psoriasis, inflammatory bowel disease, gastrointestinal ulcers, cardiovascular conditions, including ischemic heart disease and atherosclerosis, partial brain damage caused by stroke, skin conditions (eczema, sunburn, acne), leukotriene-mediated inflammatory diseases of lungs, kidneys, gastrointestinal tract, skin, prostatic and parodontosis.

The invention further provides methods of treating immune response disorders, whereby the immune response is inappropriate, excessive or lacking. Such disorders include allergic responses, transplant rejection, blood transfusion reaction, and autoimmune disorders such as systemic lupus erythematosus and rheumatoid arthritis.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 shows the effectiveness of parthenolide and derivatives of the present invention against prostate cancer cell line CWR22 in a clonogenic assay.

FIG. 2 shows the effectiveness of parthenolide and derivatives of the present invention against lung cancer cell line A549 in a cellular proliferation MTS-PMS assay.

FIG. 3 shows the effectiveness of parthenolide and derivatives of the present invention against lung cancer cell line H-522 in a cellular proliferation MTS-PMS assay.

FIG. 4 shows the effectiveness of parthenolide and derivatives of the present invention against lung cancer cell line H-23 in a cellular proliferation MTS-PMS assay.

FIG. 5 shows the effectiveness of parthenolide and derivatives of the present invention against lung cancer cell line H-460 in a cellular proliferation MTS-PMS assay.

FIG. 6 shows the effectiveness of parthenolide and derivatives of the present invention against breast cancer cell line HBL-100 in a clonogenic assay.

FIG. 7 shows the effectiveness of parthenolide and derivatives of the present invention against breast cancer cell line MD-231 in a clonogenic assay.

FIG. 8 shows the effectiveness of parthenolide and derivatives of the present invention against breast cancer cell line MD-436 in a clonogenic assay.

FIG. 9 shows parthenolide and DMAPl plasma concentrations at one hour following oral gavage in mice.

FIG. 10 shows DMAPl dose-dependent inhibition of NF-kB DNA binding in two transitional cell carcinomas cell lines HT-1376 and UMUC-3 in electrophoretic mobility gel shift assay (EMSA).

FIG. 11 shows FACS analysis of TRAIL induced apoptosis assay using MDA-MB-231 breast cancer cells treated first with DMAPl, then TRAIL-R1I-activating antibodies.

FIG. 12 shows FACS analysis of TRAIL induced apoptosis assay using MDA-MB-231 breast cancer cells treated first with DMAPl, then TRAIL.

**DETAILED DESCRIPTION OF THE INVENTION**

As used herein, the following definitions shall apply unless otherwise indicated.

The phrase “optionally substituted” is used interchangeably with the phrase “substituted or unsubstituted.” Unless otherwise indicated, an optionally substituted group may have a substituent at each substitutable position of the group, and each substitution is independent of any other. Also, combinations of substituents or variables are permissible only if such combinations result in stable compounds. In addition, unless otherwise indicated, functional group radicals are independently selected. Where “optionally substituted” modifies a series of groups separated by commas (e.g., “optionally substituted A, B or C”, or “A, B or C optionally substituted with”), it is intended that each of the groups (e.g., A, B and C) is optionally substituted.

The term “aliphatic” or “aliphatic group” as used herein means a straight-chain or branched C_{1-12} hydrocarbon chain that is completely saturated or that contains one or more units of unsaturation, or a monocyclic C_{3-12} hydrocarbon or bicyclic C_{8-12} hydrocarbon that is completely saturated or that contains one or more units of unsaturation, but which is not aromatic (also referred to herein as “carbocyclic” or “cycloalkyl”), that has a single point of attachment to the rest of the molecule wherein any individual ring in said bicyclic ring system has 3-7 members. For example, suitable aliphatic groups include, but are not limited to, linear or branched or alkyl, alkenyl, alkynyl groups and hybrids thereof such as (cycloalkyl)alkyl, (cycloalkenyl)alkyl or (cycloalkyl)alkynyl.

The terms “alkyl,” “alkoxy,” “hydroxyalkyl,” “alkoxyalkyl” and “alkoxyalkenyl,” used alone or as part of a larger moiety include both straight and branched chains containing one to twelve carbon atoms. The terms “alkenyl” and “alkynyl” used alone or as part of a larger moiety shall include both straight and branched chains containing two to twelve carbon atoms.

The terms “haloalkyl,” “haloalkeny1” and “haloalkoxyl” means alkyl, alkenyl or alkoxy, as the case may be, substituted with one or more halogen atoms. The term “halogen” or “halo” means F, Cl, Br or I.

The term “heteroatom” means nitrogen, oxygen, or sulfur and includes any oxidized form of nitrogen and sulfur, and the quaternized form of any basic nitrogen. Heteroatom further includes Se, S or P.

The term “aryl” used alone or in combination with other terms, refers to monocyclic, bicyclic or tricyclic carbocyclic ring systems having a total of five to fourteen ring members, wherein at least one ring in the system is aromatic and wherein each ring in the system contains 3 to 8 ring members. The term “aryl” may be used interchangeably with the term “aryl ring.” The term “aralkyl” refers to an aryl group substituted by an aryl. The term “aralkoxy” refers to an aralkyl group substituted by an aryl.

The term “heterocycloalkyl,” “heterocyclic,” “heterocyclenyl” or “heterocyclic” as used herein means monocyclic, bicyclic or tricyclic ring systems having five to fourteen ring members in which one or more ring members is a heteroatom, wherein each ring in the system contains 3 to 7 ring members and is non-aromatic.

The term “heteroaryl,” used alone or in combination with other terms, refers to monocyclic, bicyclic and tricyclic ring systems having a total of five to fourteen ring members, and wherein: 1) at least one ring in the system is aromatic; 2) at least one ring in the system contains one or more heteroatoms; and 3) each ring in the system contains 3 to 7 ring members. The term “heteroaryl” may be used interchangeably with the term “heteroaryl ring” or the term “heteroaromatic.” Examples of heteroaryl rings include 2-furanyl, 3-furanyl, N-imidazoyl, 2-imidazoyl, 4-imidazoyl, 5-imidazoyl,
 optionally substituted —CH₂CH₂(Ph), or an unsubstituted 5-6 membered heteroaryl or heterocyclic ring. When R is a C₁₋₆ aliphatic group or a phenyl ring, it may be substituted with one or more substituents selected from —NH₂, —NH(Ph), —(C₁₋₆ aliphatic), —NC(C₁₋₆ aliphatic), —N(C₁₋₆ aliphatic)₂, halogen, —(C₁₋₆ aliphatic), —OH, —O—(C₁₋₆ aliphatic), —NO₂, —CN, —CO₂H, —CO₂(C₁₋₆ aliphatic), —O(halo C₁₋₆ aliphatic) or -halo(C₁₋₆ aliphatic); wherein each C₁₋₆ aliphatic is optionally substituted.

The term “linker group” or “linker” means an organic moiety that connects two parts of a compound. Linkers include alkyldiene chain that is a saturated or unsaturated, straight or branched, C₁₋₈ carbon chain which is optionally substituted, and wherein up to two non-adjacent saturated carbons of the chain are optionally replaced by R’ wherein R’ is —O—, —(O)₂—, —(O)₃—, —(O)₄—, or —(O)₅—; wherein R’ is selected from hydrogen or optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl, and preferably H or optionally substituted C₁₋₆ aliphatic. Optional substituents on the aliphatic chain are as described above for an aliphatic group. Alternatively, the linker group is R’.

The term “treatment” refers to any treatment of a pathologic condition in a mammal, particularly a human, and includes: (i) preventing the pathologic condition from occurring in a subject which may be predisposed to the condition but has not yet been diagnosed with the condition and, accordingly, the treatment constitutes prophylactic treatment for the disease condition; (ii) inhibiting the pathologic condition, i.e., arresting its development; (iii) relieving the pathologic condition, i.e., causing regression of the pathologic condition; or (iv) relieving the conditions mediated by the pathologic condition.

The term “therapeutically effective amount” refers to that amount of a compound of the invention that is sufficient to effect treatment, as defined above, when administered to a mammal in need of such treatment. The therapeutically effective amount will vary depending upon the subject and disease condition being treated, the weight and age of the subject, the severity of the disease condition, the manner of administration and the like, which can readily be determined by one of ordinary skill in the art.

The term “pharmacologically acceptable salts” includes, but is not limited to, salts well known to those skilled in the art, for example, mono-salts (e.g. alkali metal and ammonium salts) and poly salts (e.g. di- or tri-salts) of the compounds of the invention. Pharmacologically acceptable salts of compounds of formulas (I), (II), (III), or (IV) are where, for example, an exchangeable group, such as hydrogen in —OH, —NH—, or —P(=O)(OH) —, is replaced with a pharmacologically acceptable cation (e.g. a sodium, potassium, ammonium ion) and can be conveniently prepared from a corresponding compound of formula (I) by, for example, reaction with a suitable base. In cases where compounds are sufficiently basic or acid to form stable nontoxic acid or base salts, administration of the compounds as salts may be appropriate. Examples of pharmacologically acceptable salts are organic acid addition salts formed with acids that form a physiologically acceptable anion, for example, tosylate, methane-sulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycero-phosphate.

Suitable inorganic salts may also be formed, including hydrochloride, sulfate, nitrate, bicarbonate, and carbonate salts.
Pharmaceutically acceptable salts include quaternary ammonium salts formed with WY; where Y is selected from halogen, tosylate, methanesulfonate, benzenesulfonate, trifluoromethanesulfonate and the like; and R' is selected from an optionally substituted cycloalkyl, heterocycloalkyl, aryl or heteroaryl.

Suitable acids include hydrofluoric acid, hydrochloric acid, hydrobromic acid, hydroiodic acid, sulfuric acid, nitric acid, phosphoric acid, carbonic acid, boric acid, selenious acid, hydrogen sulfide, phosphomolybdic acid, phosphorous acid, sulfuric acid, citric acid, maleic acid, D-malic acid, L-lactic acid, D-lactic acid, DL-lactic acid, oxalic acid, methanesulfonic acid, valeric acid, oleic acid, lauric acid, paratoluensulfonic acid, 1-naphthalensulfonic acid, 2-naphthalensulfonic acid, phthalic acid, tartaric acid, L-malic acid, DL-malic acid, malonic acid, succinic acid, fumaric acid, glycolic acid, thiglycolic acid, glycine, sarcosine, sulfonic acid, nicotinic acid, picolinic acid, isonicotinic acid, benzoic acid and substituted benzoic acid where benzene ring bears one or more substituents.

Pharmaceutically acceptable salts may be obtained using standard procedures well known in the art, for example, by reacting a sufficiently basic compound such as an amine with a suitable acid affording a physiologically acceptable anion. Alkali metal (for example, sodium, potassium or lithium) or alkaline earth metal (for example, calcium) salts of carboxylic acids can also be made.

The term “prodrug” or “prodrugs” is used in its ordinary meaning in the art and means a compound of the invention that has its charged moieties masked or protected by another moiety that is designed to be cleaved under particular physiological conditions, leaving the deprotected or unmasked compound of the invention. The use of masking agents is common and well-known in the art and, in particular, masking phosphate or phosphonate groups. All such masking agents are suitable and can be used with the compounds of the invention. Various agents such as acyloxy alkyl esters are described by Srivasta et al., (1984 Bioorganic Chemistry 12, 118-12) and by Freeman et al. (1997 Progress in Medicinal Chemistry 34:112-147) which are each incorporated in their entirety herein by reference; and 3-phenylthiolphosphate esters are described by Dang Q., et al., (1999 Bioorganic & Med. Chem. Letters, 9:1505-1510), which is incorporated in its entirety herein by reference. For example, and not by way of limitation, Srivasta et al. also describe acetoxyethyl, isobutryloxyethyl, and pivaloyloxymethyl as masking agents. Other suitable masking groups comprising pivaloxalkyl, e.g., pivaloxymethyl, or a pivaloyloxymethyl group as described by Farquhar D. et al., (1995 J. Med. Chem., 38:488-495) which is incorporated in its entirety herein by reference. Still other masking or protecting agents are described in U.S. Pat. Nos. 4,816,570 and 4,968,788 both of which are incorporated in their entirety herein by reference. Lipid prodrugs are also suitable for use with the compounds of the invention. By non-limiting example, certain lipid prodrugs are described in Hostetler et al., (1997 Biochem. Pharm. 53:1815-1822), and Hostetler et al., 1996 Antiviral Research 31:59-67), both of which are incorporated in their entirety herein by reference. Additional examples of suitable prodrug technology is described in WO 90/00555; WO 96/39831; WO 03/095665 A2; U.S. Pat. Nos. 5,411.947; 5,463.092; 6,312, 662; 6,716,828; and U.S. Published Patent Application Nos. 2003/229225 and 2003/222577 each of which is incorporated in their entirety herein by reference. Such prodrugs may also possess the ability to target the drug compound to a particular tissue within the patient, e.g., liver, as described by Erion et al., (2004 J. Am. Chem. Soc. 126:5154-5163; Erion et al., Am. Soc. Pharm. & Exper. Ther. DOI:10.1124/jpet.104.75903 (2004); WO 01/18013 A1; U.S. Pat. No. 6,752,981), each of which is incorporated in their entirety herein by reference. By way of non-limiting example, other prodrugs suitable for use with the compounds of the invention are described in WO 03/090690; and by Harris et al., (2002 Antiviral Chem & Chemo. 12: 293-300; Knaggs et al., 2000 Bioorganic & Med. Chem. Letters 10: 2075-2078) each of which is incorporated in their entirety herein by reference.

The invention relates to the ability of the C-methylene-γ-butyrolactone moiety in sesquiterpene lactones to be structurally modified by, for example, Michael addition with amines or thioles. Modification of the parthenolide (I) molecule by this methodology using primary and/or secondary amines to form water-soluble amino derivatives, affords amine adducts that can easily be obtained as different inorganic or organic salts to further increase water solubility. Thus, a novel class of more water-soluble parthenolide analogs is described. When compounds in this class were evaluated for antileukemic activity, it was found that these compounds were either equipotent as, or more potent than the parent compound, parthenolide. More importantly, these novel analogs showed greater cytotoxicity towards leukemia cells than towards normal cells. Thus, the present invention provides a new class of parthenolide derivatives with potent and selective anticancer activities.

In accordance with the present invention, there are provided compounds of formula (I):

![Diagram of compound (I)]

wherein:
- \( R_1 \), \( R_2 \), and \( R_3 \) are heteroatoms;
- \( R_4 \), \( R_5 \), \( R_6 \), \( R_7 \), \( R_8 \), \( R_9 \), and \( R_{10} \) are independently selected from \( H \), halogen, \( -OH \), \( -NO_2 \), \( -CN \) and optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl; and
- \( Z \) is optionally substituted \( C_{1-3} \) straight-chained or branched aliphatic, optionally containing 1 or more double or triple bonds, wherein one or more carbons are optionally replaced by \( R^* \) wherein \( R^* \) is optionally substituted cycloalkyl, heterocycloalkyl, aryl or heteroaryl; an amino acid residue, \( H \), \( -CN \), \( -CO(OH) \), \( -CO(CO)(O) \), \( -C(O)NR_1^2 \), \( -C(O)NR_1^2 \), \( -C(O)O \), \( -OC(OH) \), \( -NR_1^2 CO_2 \), \( -O \), \( -NR_1^2 CO \), \( NR_2 \), \( -OC(O)NR_1^2 \), \( -NR_1^2 NR_2 \), \( -NR_1^2 C \), \( -S \), \( -SO \), \( -SO_2 \), \( -SO_3 \), \( -SO_2 NR_1 \), \( -NR_1^2 R_2 \), or \( -NR_1^2 SO_2 \), wherein \( R^* \) and \( R^* \) are independently selected from \( H \) and optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl; or where \( R^* \) is \( NR_1^2 R_2 \), \( R^* \) and \( R^* \) optionally together with the nitrogen atom form an optionally substituted 5-12 membered ring, said ring optionally comprising 1 or more heteroatoms and/or a group selected from \(-COOC\), \(-SO_2\), \(-SO_3\) and/or \(-PO_3\); or
a pharmaceutically acceptable salt, ester or prodrug thereof.

Presently preferred compounds include compounds of formula (I) wherein R₁, R₂, R₇, R₈ and R₁₀ are independently selected from H, halo, —OH, —NO₂, —CN, —F₃C, —CH₃CH₂, —CH₂CF₃, —CH₂Cl, —CH₂OH, —CH₂CH₂OH and —CH₂NH₂. Further preferred embodiments include compounds where R₆, R₄, R₃, R₅ and R₁₀ are each H.

Other preferred embodiments of the present invention include compounds where R₄ and R₅ are independently selected from optionally substituted C₁-C₄ alkyl. In one preferred embodiment, R₄ is —CH₃, and in another, R₄ and R₅ are each —CH₃.

In one embodiment, X₁, X₂ and X₃ are heteroatoms independently selected from O, N and S, and in one particular embodiment, X₁, X₂ and X₃ are each O.

According to one embodiment, it is preferred that where R₄, R₅, R₆, R₇ and R₈ are H, R₉ and R₁₀ are each —CH₃, and X₁, X₂ and X₃ are each O; Z is not —CH₂.

According to a further embodiment of the invention, Z is —(CH₂)ₙ—NR₁R₂ where n is an integer from 0 to 4, where preferably, R₁, R₂, R₃ and R₁₀ are H; and R₄ and R₅ are each —CH₃. In one particular embodiment, n is 1.

In other embodiments, R¹ and R² are independently selected from hydrogen, —CN or optionally substituted C₁-C₄ alkyl. In particular embodiments, R¹ and R² are independently selected from —NO₂, —CN, —F₃C, —CH₂CH₃, —CH₂CF₃, —CH₂Cl, —CH₂OH, —CH₂CH₂OH and —CH₂NH₂.

In yet a further embodiment, R¹ and R² together with N form an optionally substituted ring. The ring is a monocyclic, bicyclic or tricyclic aliphatic or aryl ring system, where the ring system is optionally substituted and optionally comprises one or more heteroatoms or a group selected from —CO—, —SO—, —SO₂— and —PO—. In one particular embodiment, R¹ and R² are —CH₂(CH₃)₂CH₂Y, where Y is a heteroatom or a group selected from —CO—, —SO—, —SO₂— and —PO—; n is an integer 0 to 5; and together with —CN or optionally substituted C₁-C₄ alkyl, where the ring system is optionally substituted and optionally comprises one or more heteroatoms.

Alternatively, R₇ and R₈ are —(CH₂)ₙ—Y—(CH₂)ₙ—Y, where Y is a heteroatom or a group selected from —CO—, —SO—, —SO₂— and —PO—; a is an integer 0 to 5; b is an integer 0 to 5; the sum of a and b is 0 to 5; and together with —CN or optionally substituted C₁-C₄ alkyl, where the ring system is optionally substituted and optionally comprises one or more heteroatoms.

Examples of ring systems include an optionally substituted uracil ring or a derivative thereof. Other examples include optionally substituted pyrrole, imidazole, purine and pyrazole and derivative thereof. Examples of fused ring systems include optionally substituted aziridin-1-yl, azetidin-1-yl, pyrrolidin-1-yl, piperidin-1-yl, homopiperidin-1-yl and heptamethyleneimino-1-yl.

According to a further embodiment of the invention, Z is —(CH₂)ₙ—S(OR₁)R₂ where m is an integer from 0 to 4, n is an integer from 0 to 2, where preferably, R₆, R₇, R₈ and R₁₀ are H; and R₄ and R₅ are each —CH₃. In one particular embodiment, m is 1. In another embodiment, n is 0. In other embodiments, R₁ is independently selected from hydrogen, —CH₃, —CH₃CH(CO₂H)(NH₂) and —CH₂CO₂H.

Exemplary compounds of the present invention include: 1S,13-Dihydro,13-dimethylaminoparthenolidine (DMAPT); 1S,13,14-Dihydro,13-diethylaminoparthenolidine; 1S,13-Dihydro,13-(tert-butylamino)parthenolidine; 1S,13-Dihydro,13-(pyrrolidin-1-yl)parthenolidine; 1S,13-Dihydro,13-piperidin-1-yl)parthenolidine (PIPT); 1S,13-Dihydro,13-(morpholin-1-yl)parthenolidine; 1S,13-Dihydro,13-(4-methylpiperidin-1-yl)parthenolidine (4MEPT); 1S,13-Dihydro,13-(4-methylpiperazin-1-yl)parthenolidine; 1S,11,13-Dihydro,13-(homopiperidin-1-yl)parthenolidine; 1S,13-Dihydro,13-(heptamethyleneimino-1-yl)parthenolidine; 1S,11,13-Dihydro,13-(azetidin-1-yl)parthenolidine; 1S,11,13-Dihydro,13-methylbutylaminoparthenolidine; 1S,11,13-Dihydro,13-methylpentylaminoparthenolidine; 1S,11,13-Dihydro,13-ethylaminoparthenolidine; 1S,11,13-Dihydro,13-methylnitroaminoparthenolidine; 1S,11,13-Dihydro,13-cyclopropylaminoparthenolidine; 1S,11,13-Dihydro,13-propargylaminoparthenolidine; 1S,11,13-Dihydro,13-(N-benzyl-N-ethylamino)parthenolidine; 1S,11,13-Dihydro,13-(N-propyl)parthenolidine; 1S,11,13-Dihydro,13-(S-thiophenyl)parthenolidine; 1S,11,13-Dihydro,13-(N,N-diethanolamino)parthenolidine; 1S,11,13-Dihydro,13-(thiormorpholin-4-yl)parthenolidine; 1S,11,13-Dihydro,13-(4-hydroxyazepin-1-yl)parthenolidine; 1S,11,13-Dihydro,13-(1-methylhomopiperidin-4-yl)parthenolidine; 1S,11,13-Dihydro,13-(3-mercaptoacetyl)parthenolidine; 1S,11,13-Dihydro,13-(4-(2′-hydroxyethyl)piperdin-1-yl)parthenolidine; 1S,11,13-Dihydro,13-(piperazin-1-yl)-4-carboxaldehyde parthenolidine; 1S,11,13-Dihydro,13-(4-benzylpiperazin-1-yl)parthenolidine; 1S,11,13-Dihydro,13-(piperidin-1-yl)-4-carboxylic acid parthenolidine; 1S,11,13-Dihydro,13-(azetidin-1-yl)-3-carboxylic acid parthenolidine; 1S,11,13-Dihydro,13-(S-cysteiny1)parthenolidine; 1S,11,13-Dihydro,13-(4-(piperidin-1-yl)piperidin-1-yl) parthenolidine; and 1S,11,13-Dihydro,13-diallylamionoparthenolidine.

Those of skill in the art will recognize that the invention comprises compounds that may contain one or more chiral centers on, for example, the parthenolidine C-11 and thus can exist as racemic mixtures as pure diastereomers, or as pure enantiomers. For many applications, it is preferred to carry out stereoselective synthesis and/or to subject the reaction product to appropriate purification steps so as to produce substantially stereochecmically pure or optically pure materials. Suitable stereoselective synthetic procedures for producing stereochecmically pure or optically pure materials are well known in the art, as are procedures for resolving racemic mixtures into their optically pure enantiomers.

The present invention further provides for compounds having formula (I), or a pharmaceutically acceptable salt thereof, wherein Z is a group that is converted to —CH₃ under physiological conditions during or after administration to a mammalian patient, thereby yielding a methylene group. In particular embodiments, X₁, X₂ and X₃ are O; R₆, R₇, R₈, R₉ and R₁₀ are H; and R₄ and R₅ are each —CH₃; and Z is optionally substituted C₁-C₈ straight-chained or branched aliphatic, optionally containing 1 or more double or triple bonds, wherein one or
more carbons are optionally replaced by R* wherein R* is optionally substituted cycloalkyl, heterocycloalkyl, aryl or heteroaryl; an amino acid residue, H, −CN, −C(O)−, −C(O)(O)−, −C(O)NR2−, −C(O)NR−NR2−, −C(O)O−, −OC(O)−, −NR′CO−, −O−, −NR′C(O)NR2−, −OC(O)NR2−, −NR′NR2−, −NR′C(O)−, −S−, −SO−, −SO2−, −NR′−, −SO2NR2−, −NR′R2, or −NR′SO2−, wherein R1 and R2 are independently selected from H and optionally substituted aliphatic, cycloalkyl, heterocycloalkyl, aryl or heteroaryl. In preferred embodiments Z is −CH2N(CH3)2, −CH2N(H)(C(CH3)3), −CH2N(CH3)CH2−, −CH2N(CH3)2−, −CH2-N, −CH2-pyrrolidine, −CH2-heptamethyleneimine, −CH2-4-methylpiperidine, −CH2-morpholine, −CH2-pyrrolidine, −CH2-proline, −CH2-thiophenol, −CH2-diethanolamine, −CH2-hydroxypiperidine, −CH2-methylhomopiperazine, −CH2-thiomorpholine, −CH2-mercaptoacetic acid, −CH2-benzypiperidine, −CH2-piperidine-4-carboxylic acid, −CH2-azetidine-3-carboxylic acid, −CH2-piperidinylpiperidine, or −CH2-cysteine.

The present invention further provides for compounds having formula (I), or a pharmaceutically acceptable salt thereof, wherein Z is CH2N(CH3)2, which under physiological conditions during or after administration to a mammalian patient, undergoes mono- or di-demethylation; conversion to −CH2, or cysteine or protein conjugation. In particular embodiments, X1, X2 and X3 are O; R6, R8, R9, R7, and R10 are H; R4 and R5 are −CH2;

The present invention further provides compounds wherein the parthenolide based derivatives of formula (I) form dimers or duplexes with another molecule of formula (I) or with basic nitrogen-containing synergistic anticancer drug molecules such as 5-fluorouracil, cycloamine, mytomycin C, Doxorubicin and Daunorubicin. Accordingly, the present invention provides compounds of the general formula (II):

where L is a linker, as defined above, and W is a molecule with anti-cancer growth activity. Where W is another parthenolide derivative of formula (I), the present invention provides compounds of formula (III):

In accordance with another embodiment of the invention, the methods for the preparation of the amino analogs described in this invention are disclosed in Schemes I and II.
In the above scheme, the solvent is selected from a low alkyl alcohol, such as methanol, ethanol, propanol, isopropanol, n-butanol, tert-butanol, and chloroform, methylene chloride, benzene, toluene, tetrahydrofuran, dioxane, 1,2-dimethoxyethane, pyridine, carbon tetrachloride, diethyl ether, tert-butyl methyl ether and/or the mixture of two or more of the solvents listed above. The base is selected from a low trialkylamine, such as trimethylamine, triethylamine, tripropylamine, and tributylamine, and pyridine, 2-, 3-, and 4-picoline, 2-, 3-, and 4-dimethylaminopyridines. The temperature is selected from -20°C to 130°C. The reaction time required to effect the desired coupling reaction can vary widely, typically falling in the range of 30 min to 24 hours. Purification can be achieved by a variety of techniques, such as, liquid chromatography through neutral or basic silica gel, bonded silica gel phases such as octadecylsilica, octylsilica and the like, cellulose or alumina with the solvent such as, for example, the mixture of chloroform and methanol or ethanol, the mixture of methylene chloride and methanol or ethanol, the mixture of hexane and acetone or acetonitrile or methanol or ethanol or isopropanol, the mixture of diethyl ether and acetone or acetonitrile or methanol or ethanol or isopropanol; and recrystallization using normal organic solvent or solvent mixture, such as methanol, ethanol, propanol, isopropanol, tert-butanol, acetonitrile, diethyl ether, chloroform, methylene chloride and the mixture of two or more solvents listed above. The purity of the invention compounds prepared is assessed by mass spectrometry, nuclear magnetic resonance spectrometry (NMR) and elemental combustion analysis.

Furthermore, in accordance with still another embodiment of the present invention, the methods for the preparation of the invention salts are disclosed in Schemes III and IV.

In these schemes, HX is selected from hydrochloride, hydrobromide, hydroiodide, perchlorate, sulfate, hemisulfate, mesylate, toluenesulfonate, benzenesulfonate, succinate, hemisuccinate, fumarate, tartarate, ascorbate, acetate, hemifumarate, malate, citrate, oxalate, malonate, malic, propionate and benzoate; Y0 is selected from halide (fluoride, chloride, bromide, iodide), methylsulfonate, toluenesulfonate, benzenesulfonate and sulfate; and the solvent is selected from a low alkyl alcohol, such as diethyl ether, methanol, ethanol, propanol, isopropanol, n-butanol, tert-butanol, and chloroform, methylene chloride, benzene, toluene, tetrahydrofuran, dioxane, 1,2-dimethoxyethane, pyridine, carbon tetrachloride, tert-butyl methyl ether, acetone and/or the mixture of two or more of the solvents listed above. The temperature is selected from -20°C to 50°C. Purification can be achieved by recrystallization using normal organic solvent or solvent mixture, such as methanol, ethanol, acetone, propanol, iso-propanol, t-butanol, acetonitrile, diethyl ether, chloroform, methylene chloride and the mixture of two or more solvents listed above.
The present invention further provides analogues of compounds of formula (I). Examples are described below and include costunolide, dehydrocostus lactone, alantolactone, isoalantolactone, amino-3-oxo-isovalantolactone, helenalin, 11,13-dihydrohelenalin, aminocyanaranopicrin, aminodesacglycyanaranopicrin, (+)-aminoreyynosin, aminosantamarin, aminosoulanganilide and aminoisotelekin. In addition, the present invention provides compounds of the analogues below, amino-3-oxo-isovalantolactone, aminocyanaranopicrin, aminodesacglycyanaranopicrin, (+)-aminoreyynosin, aminosantamarin, aminosoulanganilide and aminoisotelekin wherein (—CH₂—NR₁R₂) is replaced by Z, where Z is as defined herein.
The invention relates to the ability of the α-methylene-γ-butyrolactone moiety in all the above-mentioned sesquiterpene lactones to be structurally modified by, for example, Michael addition with the following chemical entities to form more water-soluble derivatives than the corresponding parent sesquiterpene, and with improved properties conducive for drug development, such as, chemical stability, reduced toxicity and oral bioavailability.

The present invention further provides compounds of the parthenolide-analog dehydrocostus lactone based derivatives of formula (IV):

Presently preferred compounds include compounds of formula (IV) wherein R₃, R₄, R₅, R₆ and R₁₀ are independently selected from H, halo, —OH, —NO₂, —CN, —CH₃, —CF₃, —CH₂CH₃, —CH₂CF₃, —CH₂Cl, —CH₂OH, —CH₂NH₂, and —CH₃NH₂. Furthermore preferred embodiments include compounds where R₃, R₅, R₆, R₉, and R₁₀ are each H.

Other preferred embodiments of the present invention include compounds where R₃ and R₄ are independently selected from optionally substituted C₁-C₄ alkyl. In one preferred embodiment, R₃ and R₄ are each —CH₃.

In one embodiment, X₁ and X₂ are heteroatoms independently selected from O, N and S, and in one particular embodiment, X₁ and X₂ are each O.

According to a further embodiment, Z is —(CH₂)ₙ—NR₁R₂ where m is an integer from 0 to 4, where preferably, R₁, R₆, R₇, R₉, and R₁₀ are H; and R₄ and R₅ are each —CH₃. In one particular embodiment, m is 1. In other embodiments, R¹ and R² are independently selected from hydrogen, —CN or optionally substituted C₁-C₄ alkyl. In particular embodiments, R¹ and R² are independently selected from —NO₂, —CN, —CH₃, —CF₃, —CH₂CH₃, —CH₂CF₃, —CH₂Cl, —CH₂OH, —CH₂CH₂OH and —CH₃NH₂.

In yet a further embodiment, R¹ and R² together with N form an optionally substituted ring. The ring is a monocyclic, bicyclic or tricyclic aliphatic or aryl ring system, where the ring system is optionally substituted and optionally comprises one or more heteroatoms or a group selected from —CO—, —SO—, —SO₂— and —PO—. In one particular embodiment, R¹ and R² are —CH₂(CH₃)₂CH₂Y, where Y is a heteroatom or a group selected from —CO—, —SO—, —SO₂— and —PO—; n is an integer 0 to 5; and together with N form an optionally substituted ring, which may be additionally fused to a cycloalkyl or aryl group to form a bicyclic or tricyclic ring system, where the system is optionally substituted and optionally comprises one or more heteroatoms. Alternatively, R₁ and R₂ are —(CH₂)ₙ—Y—(CH₂)ₙ—, where Y is a heteroatom or a group selected from —CO—, —SO—, —SO₂— and —PO—; a is an integer 0 to 5; b is an integer 0 to 5; where the sum of a and b is 0 to 5; and together with N form an optionally substituted ring, the ring being optionally fused to a cycloalkyl or aryl group to form a bicyclic or tricyclic ring system, where the system is optionally substituted and optionally comprises one or more heteroatoms.

Examples of ring systems include an optionally substituted uracil ring or a derivative thereof. Other examples include optionally substitute pyrrole, imidazole, purine and pyrazole and derivative thereof. Examples of fused ring systems include optionally substituted aziridin-1-yl, azetidin-1-yl, pyrroolidin-1-yl, piperidin-1-yl, homopiperidin-1-yl and heptamethylenimine-1-yl.

With respect to formulas (I) and (IV), in other embodiments, Z is hydroxylamine, a hydroxalkyloximino compound, a thioalkylximino compound, a diaminoalkane. Examples include ethylenediamine, piperazine, triaalkylamines, polyamines, polylysine, putrescine, spermine, spermidine, aminoguanidines and agmatine. In other embodiments, Z is an amino acid. For example glycine, serine, hydroxyproline, β-alanine, cysteine, homocysteine, arginine, lysine, glutamic acid, ornithine, aspartic acid, γ-aminobutyric acid, or taurine. In other embodiments, Z is an amino sugar; for example glucosamine. In other embodiments, Z is a polyoxyethylene glycol of various molecular weights, each of which terminate in an amino functionality that will form a adduct with the appropriate sesquiterpene.

Modification of the sesquiterpene molecules by these methodologies, affords adducts that can easily be obtained as different inorganic or organic salts to further increase water solubility.

The compounds described herein are useful for treating cancer. Cancers treatable by the present therapy include the solid and hematomal tumors, such as prostate cancer, ovarian cancer, breast cancer, brain cancer and hepatic cancer, comprising administering to a mammal afflicted with said cancer an amount of parthenolide derivative effective to inhibit the viability of cancer cells of said mammal. The parthenolide derivative may be administered as primary therapy, or as adjunct therapy, either following local intervention (surgery, radiation, local chemotherapy) or in conjunc-
tion with at least one other chemotherapeutic agent discussed hereinafter, as well as the solid tumors disclosed in U.S. Pat. No. 5,514,555. Hematological cancers, such as the leukemias are disclosed in the Mayo Clinic Family Health Book, D. E. Larson, ed., William Morrow, N. Y. (1990) and include C.L.L., A.L.L., CML, and the like. Compounds of the present invention may be used in bone marrow transplant procedure to treat bone marrow prior to reintroduction to the patient. In addition, the compounds of the present invention may be used as chemotherapy sensitizers or radiation therapy sensitizers. Accordingly, a patient, or cells, or tissues, derived from a cancer patient, are pre-treated with the compounds prior to standard chemotherapy or radiation therapy. The present invention contemplates that parthenolidine may also be used in such methods.

Within another aspect of the present invention, methods are provided for inhibiting angiogenesis in patients with non-tumorigenic, angiogenesis-dependent diseases, comprising administering a therapeutically effective amount of a composition comprising parthenolidine derivative to a patient with a non-tumorigenic angiogenesis-dependent disease, such that the formation of new blood vessels is inhibited. Within other aspects, methods are provided for inhibit reactive proliferation of endothelial cells or capillary formation in non-tumorigenic, angiogenesis-dependent diseases, such that the blood vessel is effectively occluded. Within one embodiment, the anti-angiogenic composition comprising parthenolidine derivative is delivered to a blood vessel which is actively proliferating and nourishing a tumor.

In addition to tumors, numerous other non-tumorigenic angiogenesis-dependent diseases, which are characterized by the abnormal growth of blood vessels, may also be treated with the anti-angiogenic parthenolidine derivative compositions, or anti-angiogenic factors of the present invention. Anti-angiogenic parthenolidine derivative compositions of the present invention can block the stimulatory effects of angiogenesis promoters, reducing endothelial cell division, decreasing endothelial cell migration, and impairing the activity of the proteolytic enzymes secreted by the endothelium. Representative examples of such non-tumorigenic angiogenesis-dependent diseases include corneal neovascularization, hypertrophic scars and keloids, proliferative diabetic retinopathy, arteriovenous malformations, atherosclerotic plaques, delayed wound healing, hemophilic joints, nonunion fractures, Osler-Weber syndrome, psoriasis, pyogenic granuloma, scleroderma, trachoma, meningioma, retinal fibroplasia and vascular adhesions. The pathology and treatment of these conditions is disclosed in detail in published PCT application PCT/CA94/00373 (WO 95/03036), at pages 26-36. Topical or directed local administration of the present compositions is often the preferred mode of administration of therapeutically effective amounts of parthenolidine derivative, i.e., in depot or other controlled release forms.

Anti-angiogenic compositions of the present invention may also be utilized in a variety of other manners. For example, they may be incorporated into surgical sutures in order to prevent stitch granulomas, implanted in the uterus (in the same manner as an IUD) for the treatment of menorrhagia or as a form of female birth control, administered as either a peritoneal lavage fluid or for peritoneal implantation in the treatment of endometriosis, attached to a monocular antibody directed against activated endothelial cells as a form of systemic chemotherapy, or utilized in diagnostic imaging when attached to a radioactively labelled monoclonal antibody which recognizes active endothelial cells. The magnitude of a prophylactic or therapeutic dose of parthenolidine derivative, an analog thereof or a combination thereof, in the acute or chronic management of cancer, i.e., prostate or breast cancer, will vary with the stage of the cancer, such as the solid tumor to be treated, the chemotherapeutic agent(s) or other anti-cancer therapy used, and the route of administration. The dose, and perhaps the dose frequency, will also vary according to the age, body weight, and response of the individual patient. In general, the total daily dose range for parthenolidine derivative and its analogs, for the conditions described herein, is from about 0.5 mg to about 2500 mg, in single or divided doses. Preferably, a daily dose range should be about 1 mg to about 100 mg, in single or divided doses, most preferably about 5-50 mg per day. In managing the patient, the therapy should be initiated at a lower dose and increased depending on the patient’s global response. It is further recommended that infants, children, patients over 65 years, and those with impaired renal or hepatic function initially receive lower doses, and that they be titrated based on global response and blood level. It may be necessary to use dosages outside these ranges in some cases. Further, it is noted that the clinician or treating physician will know how and when to interrupt, adjust or terminate therapy in conjunction with individual patient response. The terms “effective amount” or “an effective sensitizing amount” are encompassed by the above-described dosage amounts and dose frequency schedule.

Any suitable route of administration may be employed for providing the patient with an effective dosage of parthenolidine derivative (e.g., oral, sublingual, rectal, intravenous, epidural, intrathecal, subcutaneous, transcutaneous, intramuscular, intraperitoneal, intracutaneous, inhalation, transdermal, nasal spray, nasal gel or drop, and the like). While it is possible that, for use in therapy, parthenolidine derivative or its analogs may be administered as the pure chemicals, as by inhalation of a fine powder via an insufflator, it is preferable to present the active ingredient as a pharmaceutical formulation. The invention this further provides a pharmaceutical formulation comprising parthenolidine derivative or an analog thereof, together with one or more pharmaceutically acceptable carriers therefor and, optionally, other therapeutic and/or prophylactic ingredients. The carrier(s) must be ‘acceptable’ in the sense of being compatible with the other ingredients of the formulation and not deleterious to the recipient thereof, such as a human patient or domestic animal.

Pharmaceutical formulations include those suitable for oral or parenteral (including intramuscular, subcutaneous and intravenous) administration. Forms suitable for parenteral administration also include forms suitable for administration by inhalation or insufflation or for nasal, or topical (including buccal, rectal, vaginal and sublingual) administration. The formulations may, where appropriate, be conveniently presented in discrete unit dosage forms and may be prepared by any of the methods well known in the art of pharmacy. Such methods include the step of bringing into association the active compound with liquid carriers, solid matrices, semi-solid carriers, finely divided solid carriers or combinations thereof, and then, if necessary, shaping the product into the desired delivery system. Pharmaceutical formulations suitable for oral administration may be presented as discrete unit dosage forms such as hard or soft gelatin capsules, cachets or tablets each containing a predetermined amount of the active ingredient; as a powder or as granules; as a solution, a suspension or an emulsion; or in a chewable base such as a synthetic resin or chicle for ingestion of the agent from a chewing gum. The active ingredient may also be presented as a bolus, electuary or paste. Tablets and capsules for oral administration may contain conventional excipients such as binding agents, fill-
ers, lubricants, disintegrants, or wetting agents. The tablets may be coated according to methods well known in the art, i.e., with enteric coatings.

Oral liquid preparations may be in the form of, for example, aqueous or oily suspensions, solutions, emulsions, syrups or elixirs, or may be presented as a dry product for constitution with water or other suitable vehicle before use. Such liquid preparations may contain conventional additives such as suspending agents, emulsifying agents, non-aqueous vehicles (which may include edible oils), or preservatives.

The compounds according to the invention may also be formulated for parenteral administration (e.g., by injection, for example, bolus injection or continuous infusion) and may be presented in unit dose form in ampules, pre-filled syringes, small volume infusion containers or in multi-dose containers with an added preservative. The compositions may take such forms as suspensions, solutions, or emulsions in oily or aqueous vehicles, and may contain formulatory agents such as suspending, stabilizing and/or dispersing agents. Alternatively, the active ingredient may be in powder form, obtained by aseptic isolation of sterile solid or by lyophilization from solution, for constitution with a suitable vehicle, e.g., sterile, pyrogen-free water, before use.

For topical administration to the epidermis, the compounds may be formulated as ointments, creams or lotions, or as the active ingredient of a transdermal patch. Suitable transdermal delivery systems are disclosed, for example, in A. Fisher et al. (U.S. Pat. No. 4,788,603), or R. Bawa et al. (U.S. Pat. Nos. 4,931,279; 4,668,506 and 4,713,224). Ointments and creams may, for example, be formulated with an aqueous or oily base with the addition of suitable thickening and/or gelling agents. Lotions may be formulated with an aqueous or oily base and will in general also contain one or more emulsifying agents, stabilizing agents, dispersing agents, suspending agents, thickening agents, or coloring agents.

Formulations suitable for topical administration in the mouth include unit dosage forms such as lozenges comprising active ingredient in a flavored base, usually sucrose and acacia or tragacanth; pastilles comprising the active ingredient in an inert base such as gelatin and glycerin or sucrose and acacia; mucoadhesive gels, and mouthwashes comprising the active ingredient in a suitable liquid carrier.

When desired, the above-described formulations can be adapted to give sustained release of the active ingredient employed, e.g., by combination with certain hydrophilic polymer matrices, e.g., comprising natural gels, synthetic polymer gels or mixtures thereof. The polymer matrix can be coated onto, or used to form, a medical prosthesis, such as a stent, valve, shunt, graft, or the like.

Pharmaceutical formulations suitable for rectal administration wherein the carrier is a solid are most preferably presented as unit dose suppositories. Suitable carriers include cocoa butter and other materials commonly used in the art, and the suppositories may be conveniently formed by admixture of the active compound with the softened or melted carrier(s) followed by chilling and shaping in molds.

Formulations suitable for vaginal administration may be presented as pessaries, tampons, creams, gels, pastes, foams or sprays containing, in addition to the active ingredient, such carriers as are known in the art to be appropriate.

For administration by inhalation, the compounds according to the invention are conveniently delivered from an insufflator, nebulizer or a pressurized pack or other convenient means of delivering an aerosol spray. Pressurized packs may comprise a suitable propellant such as dichlorodifluoromethane, trichlorofluoromethane, dichlorotetrafluoroethane, carbon dioxide or other suitable gas. In the case of a pressurized aerosol, the dosage unit may be determined by providing a valve to deliver a metered amount.

Alternatively, for administration by inhalation or insufflation, the compounds according to the invention may take the form of a dry powder composition, for example, a powder mix of the compound and a suitable powder base such as lactose or starch. The powder composition may be presented in unit dosage form in, for example, capsules or cartridges or, e.g., gelatin or blister packs from which the powder may be administered with the aid of an inhalator or insufflator.

For intra-nasal administration, the compounds of the invention may be administered via a liquid spray, such as via a plastic bottle atomizer. Typical of these are the Mistrumeter® (Wintrop) and the Medihafer® (Riker). For topical administration to the eye, the compounds can be administered as drops, gels (U.S. Pat. No. 4,255,415), ointments (see U.S. Pat. No. 4,136,177) or via a prolonged-release ocular insert.

The invention will now be described in greater detail by reference to the following non-limiting examples.

EXAMPLES

Example 1

General Synthetic Procedure for the Preparation of 11S,11,13-Dihydro-13-Substituted Aminoparthenolides

A mixture of parthenolide (Sigma P 0667, 100 mg, 0.4 mmol), the appropriate primary amine or secondary amine (2 mmol), and triethylamine (1 to 2 ml) in 30 ml of anhydrous ethanol was stirred at a specific temperature ranging from ambient temperature to the temperature of the refluxing solvent utilized, or was left to stand in the refrigerator (−20°C to 4°C) overnight for 24 hours. Ethanol, triethylamine and/or the appropriate volatile amine were then evaporated under vacuum in a rotary evaporator. The resulting residue was subjected to silica gel column chromatographic purification using chloroform-methanol or methylene chloride-methanol mixed solvent as the mobile phase. NMR (Varian, 300 MHz and 400 MHz) and GC/MS (Agilent, 6890GC and 5973MSD) analysis methodologies were utilized to assure the identity and purity of the synthetic compounds.

Example 2

11S,11,13-Dihydro,13-dimethylaminoparthenolide (DMAPT)

Parthenolide (100 mg, 0.4 mmol), dimethylamine (2M in methanol, 1 ml), triethylamine (2 ml), ethanol (30 ml) were refluxed overnight. After column purification, 109 mg of pale yellow 11S,11,13-dihydro,13-dimethylaminoparthenolide was obtained (Yield: 93%). Melting point: 143-144°C. 1H-NMR (300 MHz, CDCl3): δ 5.22 (1H, d), 3.85 (1H, t), 2.75 (2H, m), 2.65 (1H, dd), 2.5-2.3 (3H, m), 2.25 (6H, s), 2.5-2.0 (5H, m), 1.7 (3H, s), 1.3 (3H, s), 1.3-1.15 (1H, m).

13C-NMR (300 MHz, CDCl3): δ 176.1, 134.4, 124.8, 81.9, 66.4, 61.3, 57.6, 47.8, 46.4, 46.1, 41.0, 36.6, 29.9, 24.0, 17.2, 16.9. Mass Spec (GC-MS): 293 (M+), Retention time: 12.56 minutes. Ultra-violet (Methanol): λmax at 214 nm. Infra-Red (Nujol): 1757.9, 1460, 1377 cm−1. X-ray crystallographic analysis using a Nonius KappaCCD diffractometer DMAPT (11S,11,13-dihydro, 13-dimethylaminoparthenolide) has the S-configuration at C-11.
Example 3

11S,11,13-Dihydro,13-diethylaminoparthenolide

Parthenolide (100 mg, 0.4 mmol), diethylamine (200 mg, 2.7 mmol), triethylamine (2 mL), ethanol (30 mL) were refluxed overnight. After column purification, 114 mg of yellow 11S,11,13-dihydro,13-diethylaminoparthenolide was obtained (Yield: 88%).

Example 4

Preparation of Salts of 11S,11,13-Dihydro,13-aminoparthenolide Derivatives

The aminoparthenolide derivative was dissolved in anhydrous ether and to this solution was added the corresponding acid in ether or ethanol. The mixture was kept in the refrigerator (4°C) overnight. The crystals formed were filtered and dried under vacuum, or submitted to further recrystallization, if needed.

Example 5

Preparation of 11S,11,13-dihydro,13-(piperidin-1-yl)parthenolide hydrochloride

11S,11,13-dihydro,13-(piperidin-1-yl)parthenolide (5 mg) was dissolved in 2 mL of dry ether. Hydrochloride in ether (1M, 0.015 mL) was added to the ether solution until the solution became cloudy; then more ether was added and the mixture was heated to obtain a clear solution. The mixture was left in refrigerator (4°C) for more than 24 hours. The white crystals that formed were filtered through filter paper, and dried under vacuum overnight (Yield: 18%).

Example 6

Preparation of 11S,11,13-dihydro,13-dimethylaminoparthenolide maleate

To 11S,11,13-dihydro,13-dimethylaminoparthenolide (30 mg, 0.1 mmol) in anhydrous ethanol (5 mL) was added maleic acid (12 mg, 0.1 mmol) in 3 mL of anhydrous ethanol. The solution was shaken well and filtered through a regular filter paper. The clear solution was left in the refrigerator for a week. The white crystals formed were obtained by filtration, dried in a desiccator under vacuum with anhydrous CaCl₂ (Yield: 55%).

Example 7

Preparation of 11S,11,13-dihydro,13-Dimethylaminoparthenolide methiodide

To 11S,11,13-dihydro,13-dimethylaminoparthenolide (30 mg, 0.1 mmol) in anhydrous methanol (5 mL) was added iodomethane (90 mg, 0.6 mmol) in methanol (1 mL). The clear solution was shaken and stored at room temperature. After three days, the methanol was evaporated, the pale yellow residue was dried in a desiccator under vacuum, over anhydrous CaCl₂. Recrystallization from acetone-ether afforded pale yellow crystals (Yield: 86%).

Example 8

11S,11,13-dihydro,13-(4-Methylpiperidin-1-yl)parthenolide methiodide

To 11S,11,13-dihydro,13-(4-methylpiperidin-1-yl)parthenolide (35 mg, 0.1 mmol) in anhydrous methanol (5 mL) was added iodomethane (90 mg, 0.6 mmol) in methanol (1 mL). The clear solution was shaken and stored at room temperature. After three days, the methanol was evaporated, the pale yellow residue was dried in a desiccator under vacuum, over anhydrous CaCl₂. Recrystallization from acetone-ether afforded pale yellow crystals (Yield: 79%).

Example 9

Assay for Antileukemic Activity

For apoptosis analysis, one million primary acute myelogenous leukemia (AML) cells were washed with cold PBS and resuspended in 200 microliters of Annexin binding buffer (10 mM HEPES/NaOH pH 7.4; 140 mM NaCl; 2.5 mM CaCl₂). Annexin V-FITC (Pharmingen) and 0.25 mg/mL 7-AAD (7-aminoactinomycin D, Molecular Probes, CA) were added and the tubes were incubated at room temperature in the dark for 15 minutes. Cells were then diluted with 200 microliters of Annexin binding buffer and analyzed immediately by flow cytometry. Viable cells were identified as failing to label with Annexin V or 7-AAD. Cells beginning to die label with Annexin V, and as membrane integrity is lost, will also label with 7-AAD. For each parthenolide derivative, the percentage of viable cells was determined after 24 hours of culture at a 10 micromolar concentration. Data are normalized to untreated control specimens. The data are in Table 1 for aminoparthenolide derivatives and Table 2 for the salts of some aminoparthenolides.

Healthy human bone marrow cells were used in the above assay to test the cytotoxicity of parthenolide. Eighty-five percent of the normal cells survived 10 μM of parthenolide. All the aminoparthenolides evaluated afforded results similar to parthenolide, i.e. the survival rate of healthy human bone marrow cells was over 85% at a concentration of 10 μM.

**TABLE 1**

<table>
<thead>
<tr>
<th>Aminoparthenolides and their antileukemic activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compound</strong></td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Parthenolide</td>
</tr>
<tr>
<td><strong>(N.A.)</strong></td>
</tr>
<tr>
<td>Compound</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-dimethylaminoparthenolide (DMAPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-dioctylaminoparthenolide (DEAPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(t-tert-butyramino) parthenolide (IBAPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(pyrrolidin-1-yl) parthenolide (PyrPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(piperidin-1-yl)parthenolide (PipPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(morpholin-1-yl)parthenolide (MorPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(4-methylpiperidino-1-yl)parthenolide (4MePipPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(4-methylpiperazino-1-yl)parthenolide (4MePzPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(homo-2-pyrrolidino-1-yl)parthenolide (HomoPyrPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(heptanethylenimin-1-yl)parthenolide (HeptaMePipPT)</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(azetidin-1-yl)parthenolide (AzetPT)</td>
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<tr>
<td>11S,11,13-Dihydro, 13-diallylaminoparthenolide</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-Methylbutyl aminoparthenolide</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-Methyl pentyl amino parthenolide</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-ethylamino parthenolide</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-methylamino parthenolide</td>
</tr>
</tbody>
</table>
### TABLE 1-continued

<table>
<thead>
<tr>
<th>Compound</th>
<th>Reactants and Solvent</th>
<th>Reaction Conditions</th>
<th>Yield (%)</th>
<th>Antileukemic activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>11S,11,13-Dihydro, 13-cyclopropylamino parthenolide</td>
<td>Parthenolide 25 mg Cyclopropylamine 20 mg Methanol, 6 hrs</td>
<td>Room temperature with stirring</td>
<td>90%</td>
<td>10 μM, ~6%</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-propargylamino parthenolide</td>
<td>Parthenolide 25 mg Propargylamine 20 mg Methanol, 6 hrs</td>
<td>Room temperature with stirring</td>
<td>82%</td>
<td>10 μM, 7%</td>
</tr>
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</table>

### TABLE 2

<table>
<thead>
<tr>
<th>Compound</th>
<th>Reactants and Solvent</th>
<th>Reaction Conditions</th>
<th>Yield (%)</th>
<th>Antileukemic activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>11S,11,13-Dihydro, 13-dimethylamino parthenolide hydrochloride</td>
<td>11S,11,13-Dihydro, 13-dimethylamino parthenolide (10 mg), HCl in ether (1M, 0.03 mL)</td>
<td>Refrigerator, 24 hours</td>
<td>72</td>
<td></td>
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<tr>
<td>11S,11,13-Dihydro, 13-(pyrrolidin-1-yl)parthenolide hydrochloride</td>
<td>11S,11,13-Dihydro, 13-(pyrrolidin-1-yl)parthenolide (5 mg), HCl in ether (1M, 0.015 mL)</td>
<td>Refrigerator, 24 hours</td>
<td>10</td>
<td>10 μM, 85%</td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(piperidin-1-yl)parthenolide hydrochloride</td>
<td>11S,11,13-Dihydro, 13-(piperidin-1-yl)parthenolide (5 mg), HCl in ether (1M, 0.015 mL)</td>
<td>Refrigerator, 24 hours</td>
<td>18</td>
<td>10 μM, 88%</td>
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<tr>
<td>11S,11,13-Dihydro, 13-(4-methylpiperidin-1-yl)parthenolide hydrochloride</td>
<td>11S,11,13-Dihydro, 13-(4-methylpiperidin-1-yl)parthenolide (50 mg), HCl in ether (1M, 0.15 mL)</td>
<td>Refrigerator, 4 days</td>
<td>38.3</td>
<td>10 μM, 62%</td>
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<tr>
<td>11S,11,13-Dihydro, 13-dimethylaminoparthenolide maleate</td>
<td>11S,11,13-Dihydro, 13-dimethylaminoparthenolide (30 mg), maleic acid (12 mg), ethanol (8 mL)</td>
<td>Room temperature for 1 week</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-dimethylaminoparthenolide methiodide</td>
<td>11S,11,13-Dihydro, 13-dimethylaminoparthenolide (30 mg), added iodomethane (90 mg), methanol (6 mL)</td>
<td>Room temperature for 3 days</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>11S,11,13-Dihydro, 13-(4-methylpiperidin-1-yl)parthenolide methiodide</td>
<td>11S,11,13-Dihydro, 13-(4-methylpiperidin-1-yl)parthenolide (70 mg), iodomethane (200 mg), methanol (12 mL)</td>
<td>Room temperature for 3 days</td>
<td>79</td>
<td></td>
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<tr>
<td>1H,13-(N,N-Dimethylamino)-dehydrocostus lactone</td>
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<td>10 μM, 12%</td>
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<tr>
<td>1H,13-(N-Piperidin)-dehydrocostus lactone</td>
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<td></td>
<td>10 μM, 14%</td>
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<tr>
<td>1H,13-(N-Butyl-N-methylamino)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 8%</td>
<td></td>
</tr>
<tr>
<td>1H,13-(N-Propylamino)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 24%</td>
<td></td>
</tr>
<tr>
<td>1H,13-(N-Diallyl)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 2%</td>
<td></td>
</tr>
<tr>
<td>1H,13-(N-Morpholine)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 10%</td>
<td></td>
</tr>
<tr>
<td>1H,13-(N-Pyrrolidine)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 20%</td>
<td></td>
</tr>
<tr>
<td>1H,13-(N-Ethyl-N-benzyl)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 13%</td>
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<tr>
<td>1H,13-(N-Methyl-N-propylamino)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM, 1%</td>
<td></td>
</tr>
<tr>
<td>Compound</td>
<td>Reactants and Solvent</td>
<td>Reaction Conditions</td>
<td>Yield</td>
<td>Antileukemic activity (%)</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------</td>
<td>---------------------</td>
<td>-------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>11H,13-(N,N-Diethylamino)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM</td>
<td>5%</td>
</tr>
<tr>
<td>11H,13-(N-Methyl-N-pentylamino)-dehydrocostus lactone</td>
<td></td>
<td></td>
<td>10 μM</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 2-continued

Example 10
Analysis of Parthenolide and Dimethylaminoparthenolide (DMAPT) Using Human-Mouse Xenografts

To assess the effect of parthenolide on primary human stem cell populations, experiments were conducted using transplantation into immune deficient NOD/SCID mice. Successful engraftment of NOD/SCID bone marrow at 6-8 weeks post-transplant has been shown to be a measure of stem cell content for human hematopoietic cell populations (Lapidot et al., J Mol Med. 1997; 75: 664-673; Dick, Curr Opin Hematol. 1996; 3:405-409). For each experiment, cryopreserved mononuclear cell specimens from normal or AML donors were thawed, and treated in vitro with 7.5 micromolar parthenolide for 12-18 hours. Following culture, 5-10 million cells/animal were injected intravenously into sublethally irradiated (300 Rad) NOD/SCID mice. After 6-8 weeks, animals were sacrificed and bone marrow was analyzed for the presence of human cells using flow cytometry as previously described (Guzman et al., Proc Natl Acad Sci USA 2002; 99: 16220-162253). Human specific antibodies for CD45 were used to assess the level of total engraftment.

In three independent experiments, the level of engraftment for parthenolide-treated AML cells was dramatically reduced, which indicates a direct effect on the AML stem cell compartment. In contrast, no reduction in engraftment was detected for parthenolide-treated normal specimens, thus showing the parthenolide does not target normal hematopoietic stem cells. Similarly, treatment of AML cells with 7.5 micromolar DMAPT also yielded a strong reduction in NOD/SCID engraftment while treatment of normal cells showed no significant effects.

Example 11
MTS-PMS Assay

A 96-well U-bottomed plate (Becton Dickinson Labware, Franklin Lakes, N.J.) at a concentration of 5,000 cells per 50 microliters (mL) of media was incubated in 5% CO₂ at 37°C C. for 24 hours. Varying compound concentrations in 50 mL of media were added to the media 24 hours later. Colorimetric readings were obtained using the MTS/PMS system and an ELISA plate reader, after 48 hours of exposure to DMAPT. The readings obtained for each concentration tested were from an average of eight wells. Each experiment was expressed as a percentage of the solvent control and completed at least three times with consistent results. The results presented are an average of three experiments. The hormone refractory prostate cancer cell line CWR22Rv1 was treated with increasing concentrations of parthenolide and DMAPT, for three hours Both parthenolide and DMAPT reduced cellular proliferation by 50% at 5 μm in the CWR22 MTS-PMS assay. Cellular proliferation was also measured in the MTS-PMS assay using four lung cancer cell lines treated with parthenolide and derivatives PIP (m11s,11,13-dihydro, 13-(piperidin-1-yl)parthenolide), 4MEPT (m11s,11,13-dihydro, 13-(4-methylpiperidin-1-yl)parthenolide) and AMP (m11, 11,13-dihydro,13-dimethylaminoparthenolide). Parthenolide and its derivatives inhibited cellular proliferation in a dose dependent manner between 2 and 10 μM with 70% inhibition at 10 μM in A549, 50% in H460, 40% in H123 and 40% in H522 (FIGS. 2-5).

Example 12
Clonogenic Assay

Initially, 100 cells growing in log phase were plated per 3 mL of media in each well of a six well plate. After 24 hrs of plating of the cells the test compound was added at varying concentrations. At 24 and 96 hours after addition of drug, the media was changed. Hence, the cells were only exposed to the drug for 24 hrs. When cell colonies appeared at Day 15 they were stained by Sure Stain Dye and counted. The hormone refractory prostate cancer cell line CWR22Rv1 was treated with increasing concentrations of parthenolide derivatives DMAPT, PIP and 4MEPT for three hours. Cellular proliferation was reduced by up to 80% at 2 μm in the clonogenic assay (FIG 1). The breast cancer cell line clonogenic assay with hbl-100, mdv-231 and 436 cells showed almost complete inhibition of proliferation with DMAPT at 2 μm concentration in the clonogenic assay (FIGS. 6-8). Parthenolide also reduced proliferation with similar dosage ranges.

Example 13
cDNA Array Analysis

Total cellular RNA was extracted from the human monocyte cell line THP-1 under three conditions 2 hours after Time 0:
1) Control was added at Time 0
2) Lipopolysaccharide (10 nM) was added at Time plus one (1) hour
3) At Time 0, 10 micromoles of DMAPT was added and then at Time+1 LPS (10 nM) was added.
RNA was extracted using RNeasy Min Kit (Qiagen, USA) according to the manufacturer’s instructions. The Human Drug Targets for Inflammation and Immunomodulation Q series GE array kit (H1-048-12) was obtained from SuperArray Bioscience Corporation (Frederick, Md.). The kit determines expression of 96 genes that are associated with inflammation. RNA from respective samples was used as a template to generate biotin labeled cDNA probes using GEArray Ampolabelling RT kit (SuperArray, Bioscience Corp., USA).
The cDNA probes corresponding to the mRNA population were then denatured and hybridization was carried out in GEHyb solution on nylon membranes spotted with gene specific fragments. Membranes were then washed in 2×SSC, 1% SDS twice for 15 minutes each, followed by 0.1 SSC, 0.5% SDS twice for 15 minutes each. Chemiluminescence was used to visualize the expression levels of each transcript and the results were quantified with the GEArray Analyzer. The change in a given gene transcript was estimated by normalizing the signal intensities with the signal derived from PPIA and with minimum background subtraction.

As can be seen in Table 3, transcription of 25 genes was increased after pre-treatment with LPS. More importantly pretreatment with DMAPT prevented or blunted the increase in gene transcription induced by LPS. For example, the transcription of tumor necrosis factor (TNF), released in septic shock, is increased by 3 fold (298%) when treated with LPS. Pretreatment with DMAPT however prevents transcription of LPS and in fact decreases its production to 2% of control. Similarly, transcription of cyclo-oxygenase-2, the target of classical non-steroidal anti-inflammatory agents, was increased 1.5 fold (15%). In the presence of DMAPT, the gene expression not only prevented the increase by LPS but decreased it to 30% (0.7) of solvent control. DMAPT therefore may act to decrease inflammation by decreasing cytokines as evidenced by decreased genes in human monocytes.

<table>
<thead>
<tr>
<th>Gene</th>
<th>DMAPT Pre-treatment for 2 hours</th>
<th>% Change of Gene</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD82 antigen (Ig44)</td>
<td>23</td>
<td>0.814</td>
</tr>
<tr>
<td>CD3D antigen, gamma polypeptide (T13 complex)</td>
<td>14</td>
<td>0.6</td>
</tr>
<tr>
<td>Colony stimulating factor 2 (granulocyte-macrophage)</td>
<td>26</td>
<td>0.926</td>
</tr>
<tr>
<td>Interleukin 13</td>
<td>93</td>
<td>0.64</td>
</tr>
<tr>
<td>Interleukin 1 receptor, type I</td>
<td>10</td>
<td>0.33</td>
</tr>
<tr>
<td>Interleukin 1 receptor, type II</td>
<td>326</td>
<td>0.74</td>
</tr>
<tr>
<td>Nitric oxide synthase 2A (inducible)</td>
<td>226</td>
<td>48</td>
</tr>
<tr>
<td>Phosphodiesterase 4A, cAMP-specific</td>
<td>14</td>
<td>0.46</td>
</tr>
<tr>
<td>Phosphodiesterase 4B, cAMP-specific</td>
<td>220</td>
<td>0.59</td>
</tr>
<tr>
<td>Phospholipase A2, group IB (pancreas)</td>
<td>114</td>
<td>0.57</td>
</tr>
<tr>
<td>Phospholipase A2, group IV</td>
<td>350</td>
<td>0.89</td>
</tr>
<tr>
<td>Phospholipase A2, group VII</td>
<td>129</td>
<td>0.05</td>
</tr>
<tr>
<td>Peroxidase proliferative activated receptor, gamma</td>
<td>342</td>
<td>0.24</td>
</tr>
<tr>
<td>Platelet-activating factor receptor</td>
<td>49</td>
<td>0.48</td>
</tr>
<tr>
<td>Prostaglandin D2 receptor (DP)</td>
<td>32</td>
<td>0.002</td>
</tr>
<tr>
<td>Prostaglandin F receptor (FP)</td>
<td>35</td>
<td>0.17</td>
</tr>
<tr>
<td>Cyclooxygenase 1</td>
<td>879</td>
<td>1.46</td>
</tr>
<tr>
<td>Cyclooxygenase 2</td>
<td>176</td>
<td>0.751</td>
</tr>
<tr>
<td>Thromboxane A synthase</td>
<td>152</td>
<td>0.7</td>
</tr>
<tr>
<td>Tumor necrosis factor (TNF superfamily, member 2)</td>
<td>283</td>
<td>0.07</td>
</tr>
<tr>
<td>Tumor necrosis factor (ligand) superfamily, member 13b</td>
<td>298</td>
<td>0.02</td>
</tr>
<tr>
<td>Tumor necrosis factor (ligand) superfamily, member 5</td>
<td>217</td>
<td>0.89</td>
</tr>
<tr>
<td>Vascular cell adhesion molecule 1</td>
<td>692</td>
<td>23</td>
</tr>
</tbody>
</table>

Electrophoretic Mobility Gel Shift Assay

Each cancer cell line in exponential growth phase was treated with solvent control or various concentrations of parthenolide derivatives dissolved in 100% ethanol for 3 hours prior to harvesting. Cells were harvested and whole cell extracts were prepared as described previously (Nakshatri et al., Mol Cell Biol, 17: 3629-3639, 1997; Sweeney et al., Clin Cancer Res, 10: 5501-5507, 2004). Extracts were incubated with a radiolabelled NF-kB probe for 30 minutes at room temperature. The oligonucleotide probe binds to the NF-kB DNA binding site in the promoter region of the immunoglobulin gene. Electrophoresis and autoradiography were performed as described previously (Nakshatri et al., 1997) using NF-kB and SP-1 probes (Promega, Madison, Wis.). The specificity of parthenolide and derivative inhibition of NF-kB DNA binding was verified by the use of the SP-1 probe as a control. Identification of the NF-kB subunits binding to DNA and inhibited by DMAPT were identified by gel supershift. Constitutive NF-kB DNA binding activity was determined in the lung cancer cell lines A-549, H-23, H-522, and H-460. All four non-small lung cancer cells were treated with increasing concentrations of DMAPT for three hours, and NF-kB DNA binding was measured by electrophoretic mobility shift assay (EMSA) as described. NF-kB DNA binding activity was highest in A-549 cells, followed by H-23, H-522 and H-460 cells. DMAPT between 2 and 10 micromolar substantially decreased NF-kB DNA binding activity in all lung cancer cell lines tested.

Cancer cell lines HT-1376 and UMUC-3 were treated with increasing concentrations of DMAPT for three hours. Whole cell extracts were prepared as described and DNA binding by NF-kB was analyzed by EMSA with NF-kB and OCT-1 (internal control) probes. DMAPT decreased NF-kB DNA binding in a dose-dependent manner with HT-1376 and UMUC-3 cell lines (Fig. 10).

The hormone refractory prostate cancer cell line, CWR22Rv1 was treated with increasing concentrations of DMAPT for three hours. Whole cell extracts were prepared as described and DNA binding by NF-kB was analyzed by EMSA with NF-kB and SP-1 (internal control) probes. DMAPT decreased NF-kB DNA binding in a dose dependent manner with substantial decreases of NF-kB DNA binding at 10 μM DMAPT.

EMSA results thus showed DMAPT decreased the constitutive NF-kB DNA binding in several cancer cell lines.
Example 16

Pretreatment of Radiation Sensitive Cell Line A549

The radiation sensitive cell line A549 was pretreated with

parthenolide concentrations ranging from 0 to 2.5 micromolar.

The cells were then subjected to ionizing radiation doses ranging from 0-6Gy and survival fraction of the cells determined. Results demonstrated that parthenolide induced radiation sensitivity to the cells in a dose-dependent manner with survival fraction at 2.5 micromolar ranging from 10% at 2Gy to less than 1% at 6Gy. Cells not receiving pre-treatment with parthenolide had greater than 50% survival fraction at the highest radiation dose of 6Gy and over 90% survival at 2Gy.

Example 17

TRAIL Induced Apoptosis Assay

MDA-MB-231 breast cancer cells (2×105 cells in 60 mm plates) were treated first with 2 or 5 μM of DMAPT (LC-1). After two hours, TRAIL (TNF related apoptosis-inducing-ligand, 5 ng/ml) or TRAIL-RII-activating antibodies (10 ng/ml) were added. After 48 hours of TRAIL or TRAIL-RII antibody treatment, cells were harvested and apoptosis was measured using carboxyfluorescein-FLICA assay. Briefly, both attached and floating cells were collected by trypsinization, incubated with carboxyfluorescein-labeled pan-caspase inhibitor FAM-VAD-FMK for 2 h at 37° C. Labeled cells were rinsed twice in PBS and resuspended in 300 μl of PBS containing 0.3 μg of propidium iodide. Apoptotic cells were identified by FACScan analysis. Live cells do not stain (FigS. 11 and 12) Lower left quadrant). FAM-VAD-FMK stains apoptotic cells (upper left). Apoptotic cells that have lost plasma membrane integrity are stained by both FAM-VAD-FMK and propidium iodide (upper right). Necrotic cells are stained only by propidium iodide (lower right). MDA-MB-231 cells are relatively resistant to TRAIL. However, they become sensitive to TRAIL or TRAIL-RII activating antibody-induced apoptosis and apical apoptosis upon pre-treatment with DMAPT.

We claim:

1. A method of inhibiting cancer cell growth comprising contacting said cancer cell in vitro with an effective amount of a compound of formula (I):

   ![Chemical Structure](image)

   where:
   
   R₁, R₂, and R₃ are O;
   
   R₄, R₅, R₆, and R₁₀ are H, and R₄ and R₅ are methyl; and
   
   Z is CH₂R* wherein R* is an amino acid residue bonded to the Z methylene via a nitrogen or a sulfur atom; or R* is NRⁱCN=O—R⁺;

   —NRᵢCN=O—R⁺; —S—R¹; —NRᵢ¹R²; or —N⁺RᵢR²;

   wherein

   7. The method of claim 6 wherein R₁ and R₂ are

   —CH₃(CH₂)ₙCH₂Y—; where Y is a heteroatom or a group selected from —CO—, —SO—, and —SO₂—; n is an integer 0 to 5; and together with N form an optionally substituted ring, said ring optionally fused to a cycloalkyl or aryl group to form a bicyclic or tricyclic ring system, said system optionally substituted and optionally comprising one or more heteroatoms.

8. The method of claim 6 wherein R₁ and R₂ are

   —CH₃(CH₂)ₙCH₂Y—; where Y is a heteroatom or a group selected from —CO—, —SO—, and —SO₂—; a is an integer 0 to 5; b is an integer 0 to 5; the sum of a and b being 0 to 5; and together with N form an optionally substituted ring, said ring optionally fused to a cycloalkyl or aryl group to form a bicyclic or tricyclic ring system, said system optionally substituted and optionally comprising one or more heteroatoms.

9. The method of claim 6 wherein NRᵢR₂ is selected from optionally substituted aziridin-1-yl, azetidin-1-yl, pyrrolidin-1-yl, piperidin-1-yl, homopiperidin-1-yl and heptamethyl-eneimin-1-yl.

10. The method of claim 1 wherein the compound of formula (I) is selected from:

   (11S,13S)-Dihydro-13-dimethylaminoparthenolide;
   (11S,13S)-Dihydro-13-diethylaminoparthenolide;
   (11S,13S)-Dihydro-13-(tert-butyramino)parthenolide;
   (11S,13S)-Dihydro-13-(pyrrolidin-1-yl)parthenolide;
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11S,11,13-Dihydro,13-dimethylaminoparthenolide; or a pharmaceutically acceptable salt thereof.

11. The method of claim 10 wherein the compound of formula (I) is
11S,11,13-Dihydro,13-dimethylaminoparthenolide; or a pharmaceutically acceptable salt thereof.

12. The method of claim 11 wherein the compound of formula (I) is
11S,11,13-Dihydro,13-dimethylaminoparthenolide hydrochloride; or

13. The method of claim 1 wherein the compound of formula (I) is selected from:
11S,11,13-Dihydro,13-(pyrrolidin-1-yl)parthenolide hydrochloride; 11S,11,13-Dihydro,13-(piperidin-1-yl)parthenolide hydrochloride; 11S,11,13-Dihydro,13-(4-methylpiperidin-1-yl)parthenolide hydrochloride; 11S,11,13-Dihydro,13-dimethylaminoparthenolide methiodide; or
11S,11,13-Dihydro,13-(4-methylpiperidin-1-yl)parthenolide methiodide.

14. The method of claim 1 wherein Z is --CH₂S--R¹; wherein
R¹ is selected from optionally substituted straight-chained or branched aliphatic wherein optional substituents are selected from one or more of --NH₂, --N(C₄H₉)₂, --N(C₆H₅)₂, --OH, --O--(C₄H₅)₂ aliphatic, --NO₂, --CN, --CO₂H, --CO₂(C₆H₅)₂ aliphatic, --O-(halo C₄H₅)₂ aliphatic, or --O-(halo C₆H₅)₂ aliphatic; wherein each C₄H₅ aliphatic is optionally substituted; cycloalkyl, heterocycloalkyl, aryl or heteroaryl.

15. The method of claim 1 wherein Z is --CH₂S--R¹; wherein
R¹ is selected from optionally substituted straight-chained or branched aliphatic wherein optional substituents are selected from one or more of --NH₂, --N(C₄H₉)₂, --N(C₆H₅)₂, --OH, --O--(C₄H₅)₂ aliphatic, --NO₂, --CN, --CO₂H, --CO₂(C₆H₅)₂ aliphatic, --O-(halo C₄H₅)₂ aliphatic, or --O-(halo C₆H₅)₂ aliphatic; wherein each C₄H₅ aliphatic is optionally substituted; cycloalkyl, heterocycloalkyl, aryl or heteroaryl.

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