



US 20130122053A1

(19) **United States**

(12) **Patent Application Publication**
SPORN et al.

(10) **Pub. No.: US 2013/0122053 A1**

(43) **Pub. Date: May 16, 2013**

(54) **SYNTHETIC TRITERPENOIDS AND TRICYCLIC-BIS-ENONES FOR USE IN STIMULATING BONE AND CARTILAGE GROWTH**

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(21) Appl. No.: **13/625,527**

(22) Filed: **Sep. 24, 2012**

Related U.S. Application Data

(63) Continuation of application No. 11/941,723, filed on Nov. 16, 2007, now Pat. No. 8,299,046.

(60) Provisional application No. 60/866,344, filed on Nov. 17, 2006.

Publication Classification

(51) **Int. Cl.**
A61K 31/4164 (2006.01)
A61K 38/18 (2006.01)
A61K 35/32 (2006.01)
A61K 31/277 (2006.01)
A61K 9/00 (2006.01)

(52) **U.S. Cl.**
CPC *A61K 31/4164* (2013.01); *A61K 31/277* (2013.01); *A61K 9/00* (2013.01); *A61K 35/32* (2013.01); *A61K 38/1841* (2013.01)
USPC **424/400**; 514/510; 514/399; 424/93.7; 514/8.9; 435/377

(57) **ABSTRACT**

The present invention concerns methods for stimulating the growth and repair of bone and cartilage using synthetic triterpenoids and tricyclic-bis-enones. Examples of suitable triterpenoids include CDDO, CDDO-Me, CDDO-Im, and CDDO-Ethylamide. Examples of tricyclic-bis-enones include TBE-31 and TBE-34.

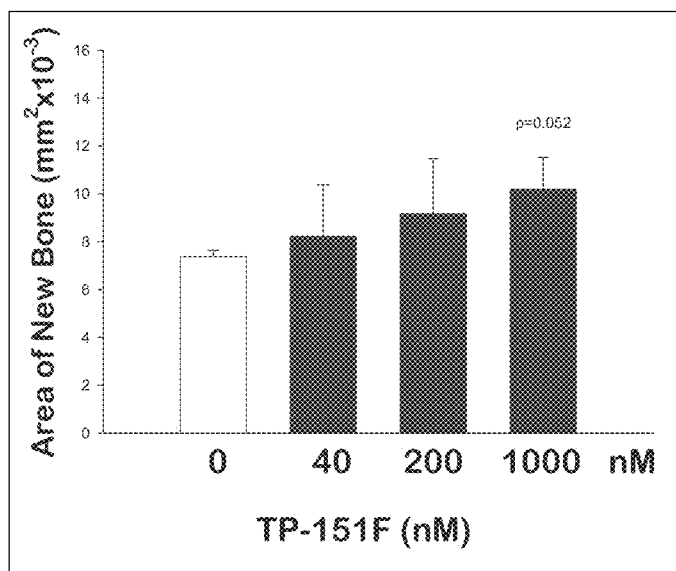


FIG. 1

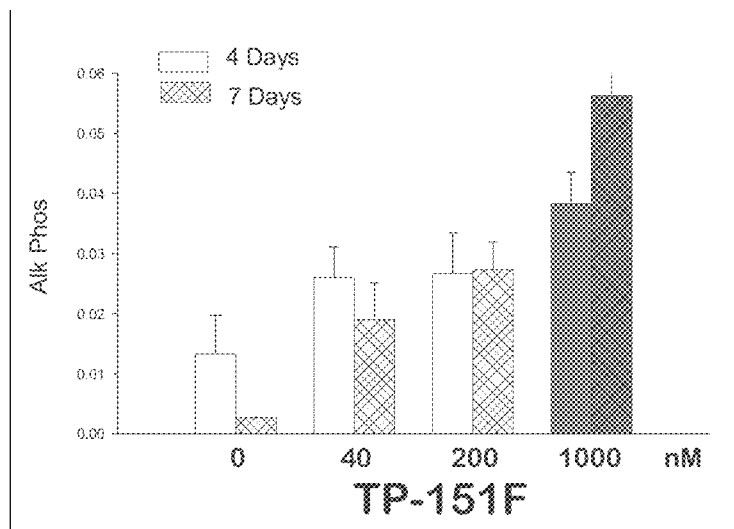


FIG. 2

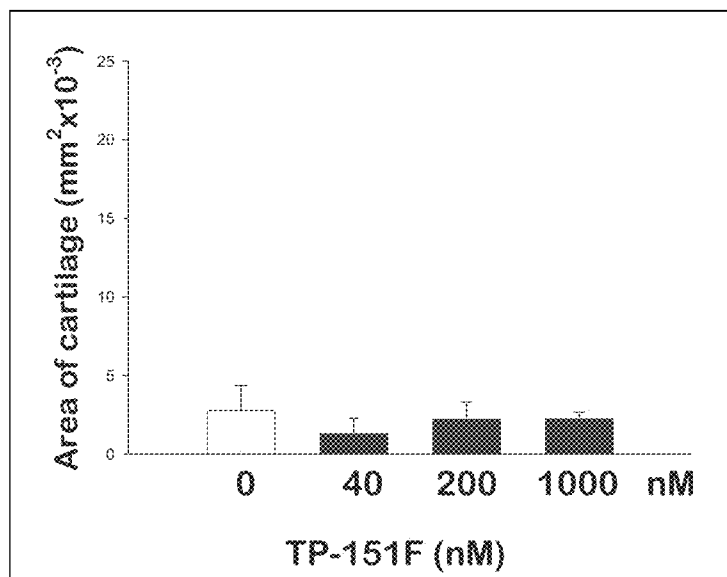


FIG. 3

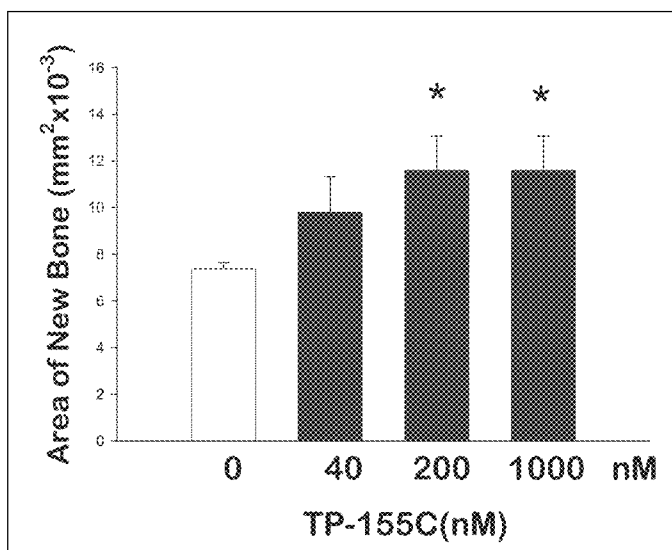


FIG. 4

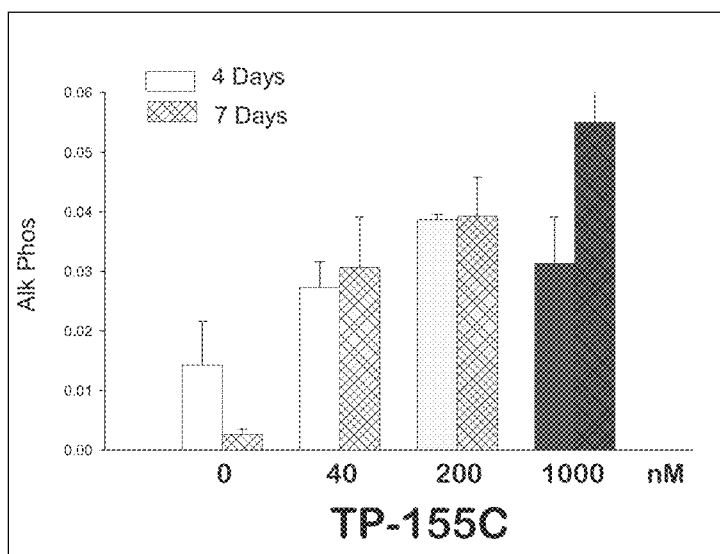


FIG. 5

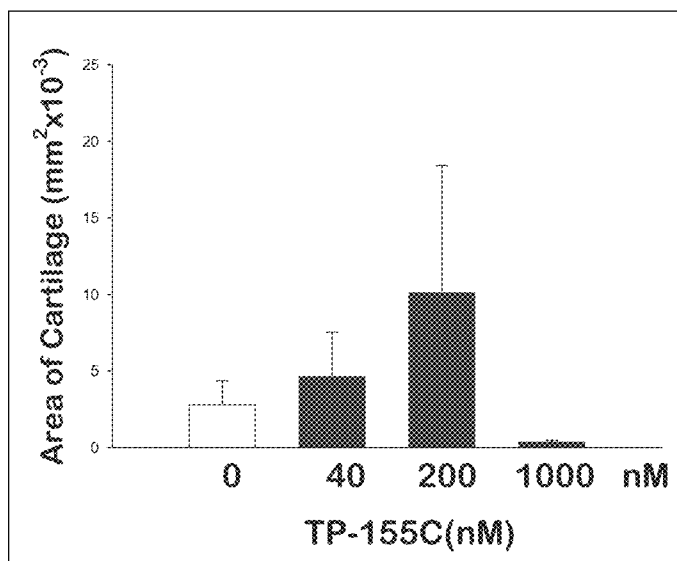


FIG. 6

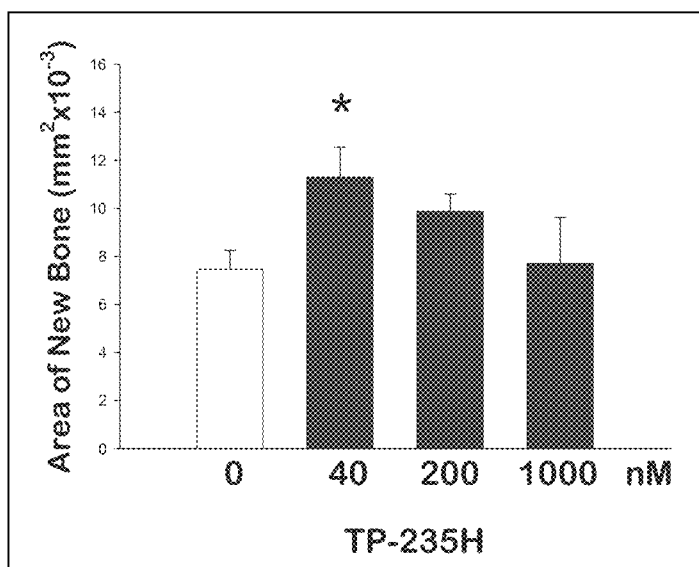


FIG. 7

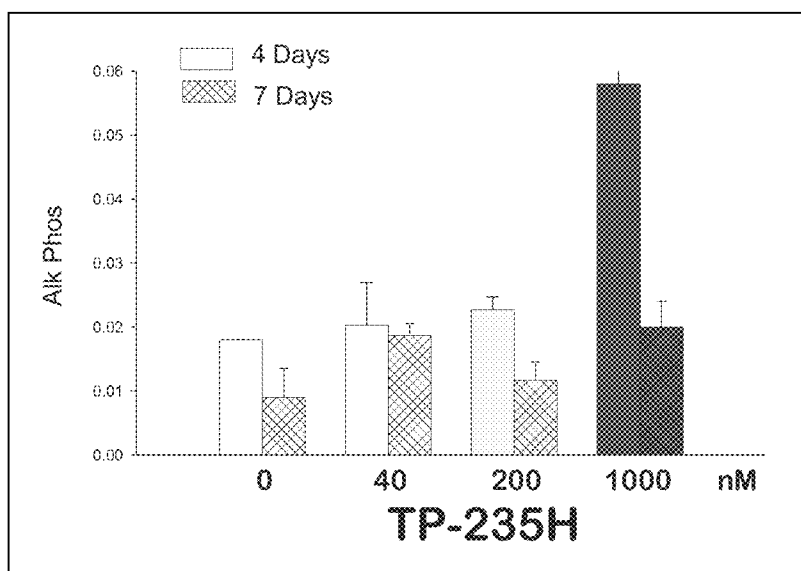


FIG. 8

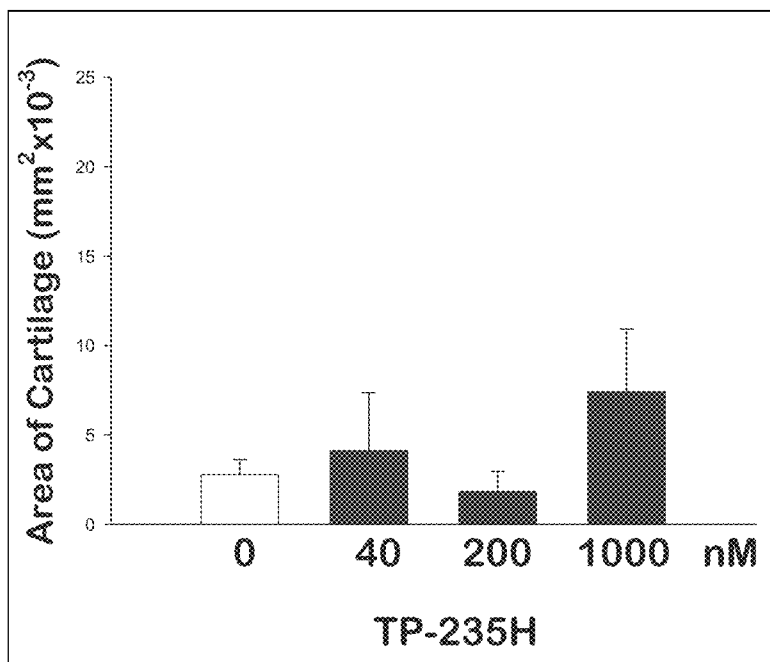


FIG. 9

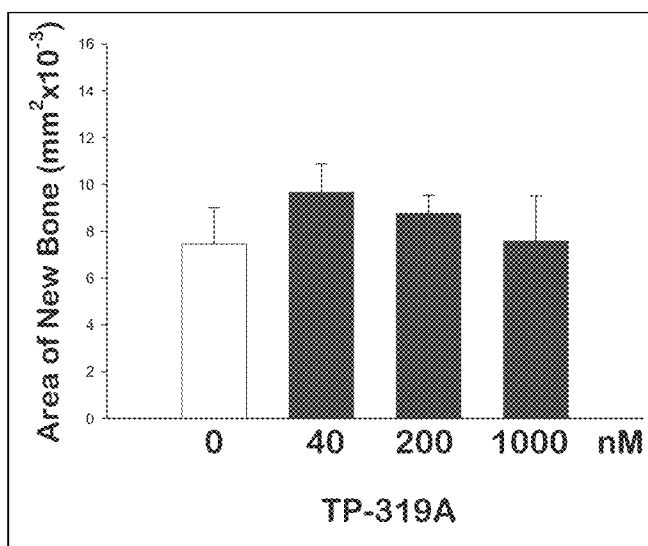


FIG. 10

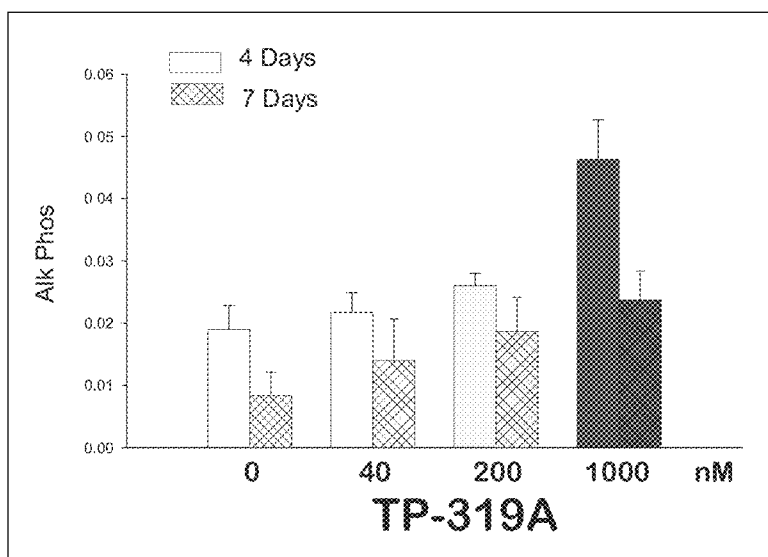


FIG. 11

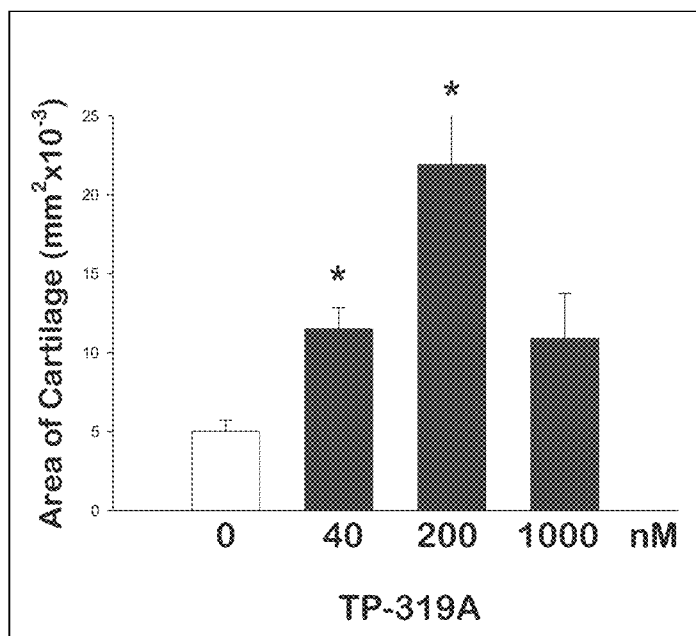


FIG. 12

**SYNTHETIC TRITERPENOIDS AND
TRICYCLIC-BIS-ENONES FOR USE IN
STIMULATING BONE AND CARTILAGE
GROWTH**

[0001] The present application claims the benefit of priority to U.S. Provisional Application No. 60/866,344, filed Nov. 17, 2006, the entire contents of this application being incorporated by reference.

[0002] The government owns rights in the present invention pursuant to grant numbers CA-078814 and CA-105294 from the National Institutes of Health.

BACKGROUND OF THE INVENTION

[0003] I. Field of the Invention

[0004] The present invention relates generally to the fields of biology and medicine. More particularly, it concerns compositions and methods for promoting bone and cartilage growth and repair.

[0005] II. Description of Related Art

[0006] The development of a functional tissue such as bone requires the concerted action of a number of microenvironmental signals: cytokines/growth factors, extracellular matrix (ECM) molecules, and cell:cell interactions. Moreover, these regulatory signals must be queued in the appropriate temporal and spatial order, resulting in a developmental microenvironment that facilitates three-dimensional growth. The skeletal system is no exception to such requirements. It is well understood that a number of cytokines/growth factors, such as TGF- β 1 family members, modulate bone formation, and that ECM molecules like osteonectin, osteocalcin, and Type I and II collagen, etc., are important in both osteogenesis and chondrogenesis.

[0007] Current methods for the repair of bone defects include grafts of organic and synthetic construction. Three types of organic grafts are commonly used: autografts, allografts, and xenografts. An autograft is tissue transplanted from one site to another in the patient, and thus benefits from the absence of an immune response. However, using an autograft requires a second surgical site, increasing the risk of infection. Further, bone for grafting comes from a limited number of sites, e.g., the fibula, ribs and iliac crest. An allograft is tissue taken from a different organism of the same species, and a xenograft from an organism of a different species. These tissues are readily available in larger quantities than autografts, but genetic differences between the donor and recipient may lead to rejection of the graft. All have advantages and disadvantages, yet none provides an ideal replacement for missing bone. Thus, there exists a need for improved to repair and/or replace bone in subjects suffering from bone disease or trauma.

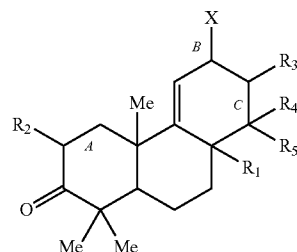
[0008] Articular cartilage is also recalcitrant to regeneration. Articular cartilage has discrete zone of cells including superficial zone, middle zone, and deep zone. The superficial zone chondrocytes secrete superficial protein (SZP) which is encoded by the gene PRG4, homologous to lubricin, and functions as a lubricant in articular joints. In contrast, the chondrocytes in the middle or deep zones of cartilage exhibit little capacity for SZP synthesis. Moreover, camptodactyly-arthropathy-coxa-vara-pericarditis syndrome (CACPS) is known to be caused by mutations in the PRG4 gene which encodes SZP. Understanding of the regulators of SZP synthesis is important for investigating disease, homeostasis of articular joint, and tissue engineering of functional superficial

zone articular cartilage. Transforming growth factor- β (TGF- β) is known to possess a capacity to up-regulate SZP synthesis in articular chondrocytes (Palcy et al., 1999). Methods are needed to modulate TGF- β /Smad signaling in articular chondrocytes in order to provide improved treatments for the repair and/or regeneration of articular cartilage.

SUMMARY OF THE INVENTION

[0009] The present invention provides improved methods of treatment for bone or cartilage disease or trauma. These methods include the repair or replacement bone or cartilage. The methods are provide treatment for diseases resulting in bone or cartilage degeneration or decay.

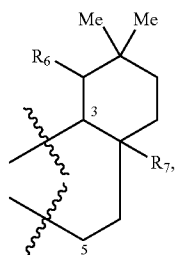
[0010] Thus in some embodiments of the invention, there is provided a method for stimulating a bone- and/or cartilage-forming cell comprising: (a) providing a bone- or cartilage-producing cell or precursor thereof; (b) contacting said cell with a compound having the structure Q:



Q

wherein either R_1 is cyano or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_7 - C_{15} -aralkyl, C_2 - C_{15} -heteroaralkyl, or C_1 - C_{15} -acyl, and R_2 , R_3 , R_4 , and R_5 are each independently —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_6 - C_{15} -aryl, C_7 - C_{15} -aralkyl, C_1 - C_{15} -heteroaryl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -hetaryloxy, C_2 - C_{15} -hetaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynylamino, C_6 - C_{15} -arylamino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -hetarylamin, C_2 - C_{15} -hetaralkylamino, or C_2 - C_{15} -amido, or

R_1 and R_4 are methyl, R_2 is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_6 - C_{15} -aryl, C_7 - C_{15} -aralkyl, C_1 - C_{15} -heteroaryl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynylamino, C_6 - C_{15} -arylamino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroarylamin, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido, R_3 and R_5 are both replaced by a group having the structure shown below, with the bond to R_3 , in the structure above, attached to the carbon atom labeled “3” in the structure below, and, with the bond to R_5 , in the structure above, attached to the carbon atom labeled “5” in the structure:



and

R_6 is hydrogen, R_7 is H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_7 - C_{15} -aralkyl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynylamino, C_6 - C_{15} -arylamino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroarylamino, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido; further wherein X is selected from the group consisting of —H and —O; A, B, and C each independently signifies a single- or double-bond, provided that (1) when C is a double-bond, R_4 is absent, (2) when B is a double bond, X is —O, (3) when B is a single bond, X is —H; any ketone group shown in the above structure may be replaced by its enol tautomer, and pharmaceutically acceptable salts, hydrates, and optical isomers thereof; and (c) culturing the cell. In some embodiments, one or more of steps (a), (b) and (c) occur in one discrete step. In other embodiments, one or more of steps (a), (b) and (c) occurs in 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more discrete steps. Those of skill in the art will recognize that the cell may also be cultured prior to contacting. In certain of these embodiments, the cartilage-producing cell is a chondrocyte.

[0011] In some embodiments, the method for stimulating a bone- and/or cartilage-forming cell further comprises incubating the cell with a growth factor. In some of these embodiments, the growth factor is TGF- β 1, TGF- β 2, TGF- β 1.2, VEGF, insulin-like growth factor I or II, BMP2, BMP4, or BMP7. In other of these embodiments, the growth factor is parathyroid hormone, calcitonin, interleukin-6, or interleukin-11. In certain embodiments, this incubation step can occur either before, after, or at the same time as steps a and b. Those of skill in the art will recognize that the incubation step may occur before, after or simultaneously with any, or all of, steps (a), (b), (c), or any additional step employed. For example, in some of these embodiments, the incubation step occurs after steps (a), (b), and (c). In other embodiments it occurs before either steps (a), (b) or (c). In other embodiments, the incubation step occurs simultaneously with step (b). In some embodiments, steps (a), (b), (c) and the incubation occurs in one discrete step. In other embodiments, steps (a), (b), (c) and/or the incubation occur in 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more discrete steps.

[0012] In certain embodiments, the method for stimulating a bone- and/or cartilage-forming cell further comprises purifying the cell or precursor. For example, in some of these embodiments, the purifying step occurs after steps (a), (b), and (c). In other embodiments it occurs before either steps (a), (b) or (c). In other embodiments, the purifying step occurs simultaneously with step (b). In some embodiments, steps (a), (b), (c) and the purifying occurs in one discrete step. In other embodiments, steps (a), (b), (c) and/or the purifying occur in 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more discrete steps.

(b), (c) and the purifying occurs in one discrete step. In other embodiments, steps (a), (b), (c) and/or the purifying occur in 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more discrete steps.

[0013] In some embodiments, the method for stimulating a bone- and/or cartilage-forming cell further comprises implanting said cell in vivo after step (b) and/or step (c). In certain embodiments, the method for stimulating a bone- and/or cartilage-forming cell results in the formation of bone by said cell. In some embodiments, the method for stimulating a bone- and/or cartilage-forming cell results in the formation of cartilage by said cell.

[0014] In other embodiments of the invention, there is provided a method of providing bone tissue to a mammal comprising: (a) providing a bone- or cartilage-producing cell or precursor thereof; (b) contacting said cell with a compound having the structure Q; (c) culturing the cell to form bone and/or cartilage; and (d) implanting said bone and/or cartilage to said subject. In some embodiments, one or more of steps (a), (b), (c) and (d) occur in one discrete step. In other embodiments, one or more of steps (a), (b), (c) and (d) occurs in 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more discrete steps. Those of skill in the art will recognize that the cell may also be cultured prior to contacting.

[0015] In certain embodiments, the bone and/or cartilage formed may be part of a three-dimensional matrix. In certain of these embodiments, the three-dimensional matrix is one or more of alginate gels, collagen gels, or fibrin gels. In other of these embodiments, the three-dimensional matrix comprises one or more of polylactic acid, polyglycolic acid or PGLA. In some embodiments, the three-dimensional matrix comprises one or more of hydroxyapatite or other apatitic compounds, devitalized animal bone, devitalized human bone, or porous ceramic structures.

[0016] In some embodiments, the implantation is made in conjunction with orthopedic surgery and/or orthopedic devices, such as hip implants, knee implants, or spinal fusions. In other embodiments, the implantation may be made in conjunction with oral surgery and/or dental implants. In still other embodiments, the implantation may be made in conjunction with plastic surgery. In some embodiments, the implantation may be in conjunction with periodontal repairs.

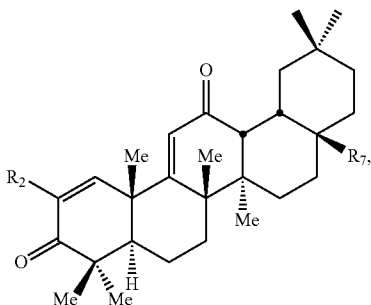
[0017] In certain embodiments, the implantation may be into bone-forming tissue or a bone-repair site. In some embodiments, the implantation is into a wound. In other embodiments, the mammal has a bone disease such as cancer bone disease, localized osteolysis due to cancer and to myeloma, degenerative cartilage conditions, osteoarthritis, osteoporosis, Vitamin D deficiency, Osteitis deformans, or Von Recklinghausen's Disease.

[0018] In other embodiments of the invention, there is provided a method for producing bone ex vivo comprising: (a) providing bone- or cartilage-producing cell or precursor thereof; (b) contacting said cell with a compound having the structure Q; (c) culturing the cell to form bone and/or cartilage. In some embodiments, one or more of steps (a), (b) and (c) occur in one discrete step. In other embodiments, one or more of steps (a), (b) and (c) occurs in 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more discrete steps. Those of skill in the art will recognize that the cell may also be cultured prior to contacting. In some embodiments, the bone and/or cartilage formed may be part of a three-dimensional matrix.

[0019] In other embodiments of the invention, there is provided a method of repairing bone or cartilage damage in a subject comprising administering to said subject a compound

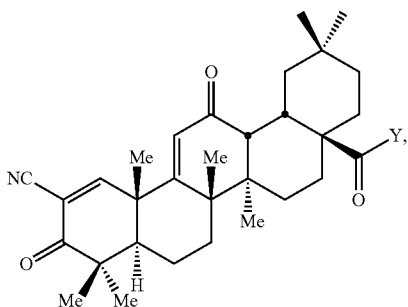
having the structure Q. In some of these embodiments, the compound is administered to a wound or bone disease site. In certain embodiments, the bone disease may be cancer bone disease, localized osteolysis due to cancer and to myeloma, degenerative cartilage conditions, osteoarthritis, osteoporosis, Vitamin D deficiency, Osteotitis deformans, or Von Recklinghausen's Disease. In other of these embodiments, the wound may be a fracture. In some embodiments, bone is formed as part of the method. In certain embodiments, cartilage is formed as part of the method.

[0020] In some embodiments of any of the methods described above, the compound is a synthetic triterpenoid. In some of these embodiments, the synthetic triterpenoid has the structure:



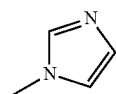
wherein R_2 is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_6 - C_{15} -aryl, C_7 - C_{15} -aralkyl, C_1 - C_{15} -heteroaryl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynylamino, C_6 - C_{15} -arylamino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroaryl amino, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido; R_7 is H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_7 - C_{15} -aralkyl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynylamino, C_6 - C_{15} -arylamino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroaryl amino, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido; further wherein any ketone group shown in the above structure may be replaced by its enol tautomer, and pharmaceutically acceptable salts, and hydrates thereof.

[0021] In some specific embodiments, the synthetic triterpenoid may be defined as

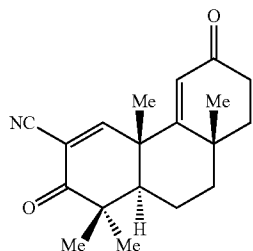


wherein Y is —H, hydroxy, amino, halo, or a substituted or unsubstituted version of C_1 - C_{14} -alkoxy, C_2 - C_{14} -alkenyloxy, C_2 - C_{14} -alkynyloxy, C_6 - C_{14} -aryloxy, C_7 - C_{14} -aralkoxy, C_1 - C_{14} -heteroaryloxy, C_2 - C_{14} -heteroaralkoxy, C_1 - C_{14} -acyloxy, C_1 - C_{14} -alkylamino, C_2 - C_{14} -alkenylamino, C_2 - C_{14} -alkynylamino, C_6 - C_{14} -arylamino, C_7 - C_{14} -aralkylamino, C_1 - C_{14} -heteroaryl amino, C_2 - C_{14} -heteroaralkylamino, C_1 - C_{14} -alkylthio, C_6 - C_{14} -arylthio, C_7 - C_{14} -aralkylthio, C_1 - C_{14} -heteroarylthio, C_2 - C_{14} -heteroaralkylthio, or C_0 - C_{14} -silyl, and substantially free pharmaceutically acceptable salts and hydrates thereof.

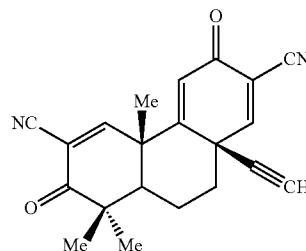
[0022] In certain of these embodiments, Y is hydroxy, methoxy, ethyl-amino, or



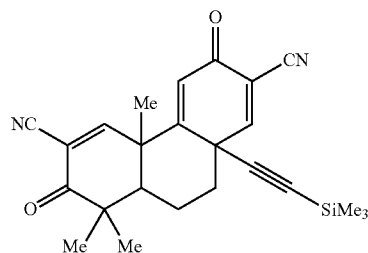
[0023] In some embodiments of any of the methods described above, the compound is a tricyclic bis-enone (TBE). In some of these embodiments, the TBE is further defined as



substantially free from other optical isomers. In other of these embodiments, the TBE is further defined as



substantially free from other optical isomers. In still other of these embodiments, the TBE has the structure:



[0024] In some embodiments of any of the methods described above, the cell or precursor is of human origin. In other embodiments, the cell or precursor is of bovine, equine, canine, feline, murine, rat or chick origin.

[0025] It is contemplated that any method or composition described herein can be implemented with respect to any other method or composition described herein.

[0026] These, and other, embodiments of the invention will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following description, while indicating various embodiments of the invention and numerous specific details thereof, is given by way of illustration and not of limitation. Many substitutions, modifications, additions and/or rearrangements may be made within the scope of the invention without departing from the spirit thereof, and the invention includes all such substitutions, modifications, additions and/or rearrangements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

[0028] FIGS. 1, 4, 7 and 10—New bone growth following treatment with varying concentrations of drug. Bone formation was measured in vitro at 7 days at concentrations of 0, 40, 200 and 100 nM for each of TP-151F (FIG. 1), TP-155C (FIG. 4), TP-235H (FIG. 7) and TP-319A (FIG. 10). (The alphabet at the end of each compound number denotes the synthesis batch of each one.)

[0029] FIGS. 2, 5, 8 and 11—Alkaline phosphatase activity in cultures following treatment with varying concentrations of drug. AkPh activity was measured in vitro at 4 and 7 days at concentrations of 0, 40, 200 and 100 nM for each of TP-151F (FIG. 2), TP-155C (FIG. 5), TP-235H (FIG. 8) and TP-319A (FIG. 11). (The alphabet at the end of each compound number denotes the synthesis batch of each one.)

[0030] FIGS. 3, 6, 9 and 12—New cartilage growth following treatment with varying concentrations of drug. Cartilage formation was measured in vitro at 7 days at concentrations of 0, 40, 200 and 100 nM for each of TP-151F (FIG. 3), TP-155C (FIG. 6), TP-235H (FIG. 9) and TP-319A (FIG. 12). (The alphabet at the end of each compound number denotes the synthesis batch of each one.)

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

I. The Present Invention

[0031] The rate of bone fractures in the United States is estimated at 6,000,000 individuals per year. When a bone is completely fractured, a significant number of fractures require medical intervention beyond simple immobilization (casting), particularly those involving trauma. A major problem in such instances is the lack of proximity of the two bone ends (referred to as non-union). This results in an inappropriate and prolonged repair process, which may prevent recovery. The average length of time for the body to repair a fracture is 25-100 days, for moderate load-bearing, and one

year for complete repair. Thus, both simple fractures and medically complicated breaks would benefit from novel therapeutic modalities which accelerate and/or complete the repair process. The same is true for those bone diseases (referred to as osteopenias) which result in a thinning of the bone the primary symptom of which is an often-debilitating fracture, and other diseases in which bone strength or elasticity is compromised.

[0032] There is no curative treatment for lost bone mass. Likewise, there is no effective replacement or implant for non-union fractures or crush injuries of the bone. Currently, these latter types of injury utilize bovine (cow), or human cadaver bone which is chemically treated (to remove proteins) in order to prevent rejection. However, such bone implants, while mechanically important, are biologically dead (they do not contain bone-forming cells, growth factors, or other regulatory proteins). Thus, they do not greatly modulate the repair process.

[0033] Numerous new synthetic triterpenoids have been studied looking at their effects on transforming growth factor (TGF)- β /Smad signaling. These agents, at nanomolar concentrations, increase the expression of TGF- β -dependent genes, such as those for plasminogen activator inhibitor I and the type II TGF- β receptor, and they synergize with TGF- β in this regard. They prolong the activation of Smad2 induced by TGF- β and markedly enhance the ability of Smad3 to activate a Smad binding element, CAGA-luciferase. In transfection assays, they reverse the inhibitory effects of Smad7. They also enhance Smad signaling in the pathways of two other members of the TGF- β superfamily, namely, activin and bone morphogenetic protein. Finally, these triterpenoids induce expression of the transcriptional coactivator p300-CBP-associated factor and synergize with TGF- β in this regard. Because of these findings, the present inventors sought to determine if these agents had any effect on bone and cartilage formation.

[0034] As shown below in the Examples, the results revealed that all the triterpenoid compounds tested induced new bone formation, some more so than others. Some of the compounds tested also induced cartilage formation. The results also showed that the triterpenoid compounds induced elevated levels of alkaline phosphatase, which is consistent with rapid bone growth.

II. Definitions

[0035] As used herein, the term “amino” means $-\text{NH}_2$; the term “nitro” means $-\text{NO}_2$; the term “halo” designates $-\text{F}$, $-\text{Cl}$, $-\text{Br}$ or $-\text{I}$; the term “mercapto” means $-\text{SH}$; the term “cyano” means $-\text{CN}$; the term “silyl” means $-\text{SiH}_3$, and the term “hydroxy” means $-\text{OH}$.

[0036] The term “substituted,” when used to modify a class of organic radicals (e.g. alkyl, aryl, acyl, etc.), means that one or more than one hydrogen atom of that radical has been replaced by a heteroatom, or a heteroatom containing group. Specific substituted organic radicals are defined more fully below.

[0037] The term “unsubstituted,” when used to modify a class of organic radicals (e.g. alkyl, aryl, acyl, etc.) means that none of the hydrogen atoms of that radical have been replaced with a heteroatom or a heteroatom containing group. Substitution of a hydrogen atom with a carbon atom, or a group consisting of only carbon and hydrogen atoms, is not sufficient to make a group substituted. For example, the group $-\text{C}_6\text{H}_4\text{C}\equiv\text{CH}$ is an example of an unsubstituted aryl group,

while $-C_6H_4F$ is an example of a substituted aryl group. Specific unsubstituted organic radicals are defined more fully below.

[0038] The term “unsubstituted C_n -alkyl” refers to a radical, having a linear or branched, cyclic or acyclic structure, further having no carbon-carbon double or triple bonds, further having a total of n carbon atoms, all of which are nonaromatic, 3 or more hydrogen atoms, and no heteroatoms. For example, an unsubstituted C_1 - C_{10} -alkyl has 1 to 10 carbon atoms. The term “alkyl” includes straight-chain alkyl groups, branched-chain alkyl groups, cycloalkyl (alicyclic) groups, alkyl substituted cycloalkyl groups, and cycloalkyl substituted alkyl groups. The groups, $-CH_3$, $-CH_2CH_3$, $-CH_2CH_2CH_3$, $-CH(CH_3)_2$, $-CH(CH_2)_2$, $-CH_2CH_2CH_2CH_3$, $-CH(CH_3)CH_2CH_3$, $-CH_2CH(CH_3)_2$, $-C(CH_3)_3$, and $-CH_2C(CH_3)_3$, are all examples of unsubstituted alkyl groups.

[0039] The term “substituted C_n -alkyl” refers to a radical, having a single saturated carbon atom as the point of attachment, no carbon-carbon double or triple bonds, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, all of which are nonaromatic, 0, 1, or more than one hydrogen atom, at least one heteroatom, wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_1 - C_{10} -alkyl has 1 to 10 carbon atoms. The following groups are all examples of substituted alkyl groups: trifluoromethyl, $-CH_2F$, $-CH_2Cl$, $-CH_2Br$, $-CH_2OH$, $-CH_2OCH_3$, $-CH_2OCH_2CH_3$, $-CH_2OCH_2CH_2CH_3$, $-CH_2OCH(CH_3)_2$, $-CH_2OCH(CH_2)_2$, $-CH_2OCH_2CF_3$, $-CH_2OCOCH_3$, $-CH_2NH_2$, $-CH_2NHCH_3$, $-CH_2N(CH_3)_2$, $-CH_2NHCH_2CH_3$, $-CH_2N(CH_3)CH_2CH_3$, $-CH_2NHCH_2CH_2CH_3$, $-CH_2NHCH(CH_3)_2$, $-CH_2NHCH(CH_2)_2$, $-CH_2N(CH_2CH_3)_2$, $-CH_2CH_2F$, $-CH_2CH_2Cl$, $-CH_2CH_2Br$, $-CH_2CH_2I$, $-CH_2CH_2OH$, $-CH_2CH_2OCOCH_3$, $-CH_2CH_2NH_2$, $-CH_2CH_2N(CH_3)_2$, $-CH_2CH_2NHCH_2CH_3$, $-CH_2CH_2N(CH_3)CH_2CH_3$, $-CH_2CH_2NHCH_2CH_2CH_3$, $-CH_2CH_2NHCH(CH_3)_2$, $-CH_2CH_2NHCH(CH_2)_2$, $-CH_2CH_2N(CH_2CH_3)_2$, $-CH_2CH_2NHCO_2C(CH_3)_3$, and $-CH_2Si(CH_3)_3$.

[0040] The term “unsubstituted C_n -alkenyl” refers to a radical, having a linear or branched, cyclic or acyclic structure, further having at least one carbon-carbon double bond, at total of n carbon atoms, all of which are nonaromatic, 3 or more hydrogen atoms, and no heteroatoms. For example, an unsubstituted C_2 - C_{10} -alkenyl has 2 to 10 carbon atoms. Unsubstituted alkenyl groups include: $-CH=CH_2$, $-CH=CHCH_3$, $-CH=CHCH_2CH_3$, $-CH=CHCH_2CH_2CH_3$, $-CH=CHCH(CH_3)_2$, $-CH=CHCH(CH_2)_2$, $-CH_2CH=CH_2$, $-CH_2CH=CHCH_3$, $-CH_2CH=CHCH_2CH_3$, $-CH_2CH=CHCH_2CH_2CH_3$, $-CH_2CH=CHCH(CH_3)_2$, and $-CH_2CH=CHCH(CH_2)_2$.

[0041] The term “substituted C_n -alkenyl” refers to a radical, having a single nonaromatic carbon atom as the point of attachment and at least one nonaromatic carbon-carbon double bond, but no carbon-carbon triple bonds, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, and at least one heteroatom, wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_2 - C_{10} -alkenyl has 2 to 10 carbon atoms. The groups,

$-CH=CHF$, $-CH=CHCl$ and $-CH=CHBr$, are examples of substituted alkenyl groups.

[0042] The term “unsubstituted C_n -alkynyl” refers to a radical, having a linear or branched, cyclic or acyclic structure, further having at least one carbon-carbon triple bond, a total of n carbon atoms, all of which are nonaromatic, at least one hydrogen atom, and no heteroatoms. For example, an unsubstituted C_2 - C_{10} -alkynyl has 2 to 10 carbon atoms. The groups, $-C\equiv CH$ and $-C\equiv CCH_3$, are examples of unsubstituted alkynyl groups.

[0043] The term “substituted C_n -alkynyl” refers to a radical, having a single nonaromatic carbon atom as the point of attachment and at least one nonaromatic carbon-carbon triple bond, further having a linear or branched, cyclic or acyclic structure, and having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, and at least one heteroatom, wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_2 - C_{10} -alkynyl has 2 to 10 carbon atoms. The group, $-C\equiv CSi(CH_3)_3$, is an example of a substituted alkynyl group.

[0044] The term “unsubstituted C_n -aryl” refers to a radical, having a single carbon atom as a point of attachment, wherein the carbon atom is part of an aromatic ring structure containing only carbon atoms, further having a total of n carbon atoms, 5 or more hydrogen atoms, and no heteroatoms. For example, an unsubstituted C_6 - C_{10} -aryl has 6 to 10 carbon atoms. Examples of unsubstituted aryl groups include phenyl, methylphenyl, di(methyl)phenyl, $-C_6H_4CH_2CH_3$, $-C_6H_4CH_2CH_2CH_3$, $-C_6H_4CH(CH_3)_2$, $-C_6H_4CH(CH_2)_2$, $-C_6H_3(CH_3)CH_2CH_3$, $-C_6H_4CH=CH_2$, $-C_6H_4CH=CHCH_3$, $-C_6H_4C\equiv CH$, and $-C_6H_4C\equiv CCH_3$. Aryl groups also include polycyclic fused aromatic groups such as naphthyl, quinolyl, indolyl, and the like.

[0045] The term “substituted C_n -aryl” refers to a radical, having a single carbon atom as point of attachment, wherein the carbon atom is part of an aromatic ring structure containing only carbon atoms, further having a total of n aromatic or non-aromatic carbon atoms, 0, 1, or more than one hydrogen atom, and at least one nonaromatic heteroatom, wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_6 - C_{10} -aryl has 6 to 10 carbon atoms. The groups, $-C_6H_4F$, $-C_6H_4Cl$, $-C_6H_4Br$, $-C_6H_4I$, $-C_6H_4OH$, $-C_6H_4OCH_3$, $-C_6H_4OCH_2CH_3$, $-C_6H_4OCOCH_3$, $-C_6H_4OC_6H_5$, $-C_6H_4NH_2$, $-C_6H_4NHCH_3$, $-C_6H_4NHCH_2CH_3$, $-C_6H_4CH_2Cl$, $-C_6H_4CH_2Br$, $-C_6H_4CH_2OH$, $-C_6H_4CH_2OCOCH_3$, $-C_6H_4CH_2NH_2$, $-C_6H_4N(CH_3)_2$, $-C_6H_4CH_2CH_2Cl$, $-C_6H_4CH_2CH_2OH$, $-C_6H_4CH_2CH_2OCOCH_3$, $-C_6H_4CH_2CH_2NH_2$, $-C_6H_4CH_2CH=CH_2$, $-C_6H_4CF_3$, $-C_6H_4CN$, $-C_6H_4C\equiv Si(CH_3)_3$, $-C_6H_4COH$, $-C_6H_4COCH_3$, $-C_6H_4COCH_2CH_3$, $-C_6H_4COCH_2CF_3$, $-C_6H_4COC_6H_5$, $-C_6H_4CO_2H$, $-C_6H_4CO_2CH_3$, $-C_6H_4CONH_2$, $-C_6H_4CONHCH_3$, and $-C_6H_4CON(CH_3)_2$ are examples of substituted aryl groups.

[0046] The term “unsubstituted C_n -aralkyl” refers to a radical, having a single saturated carbon atom as the point of attachment, further having a total of n carbon atoms, wherein at least 6 of the carbon atoms form an aromatic ring structure containing only carbon atoms, 7 or more hydrogen atoms, and no heteroatoms. For example, an unsubstituted C_7 - C_{10} -aralkyl has 7 to 10 carbon atoms. An “aralkyl” includes an

alkyl substituted with an aryl group. Examples of unsubstituted aralkyls include phenylmethyl (benzyl) and phenylethyl.

[0047] The term “substituted C_n -aralkyl” refers to a radical, having a single saturated carbon atom as the point of attachment, further having a total of n carbon atoms, wherein at least 6 of the carbon atoms form an aromatic ring structure containing only carbon atoms, 0, 1, or more than one hydrogen atom, and at least one heteroatom, wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_7 - C_{10} -aralkyl has 7 to 10 carbon atoms.

[0048] The term “unsubstituted C_n -heteroaryl” refers to a radical, having either a single aromatic carbon atom or a single aromatic heteroatom as the point of attachment, further having a total of n carbon atoms, at least one hydrogen atom, and at least one heteroatom, wherein at least one of the carbon atoms and all of the heteroatoms are incorporated into one or more aromatic ring structures, further wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, an unsubstituted C_1 - C_{10} -heteroaryl has 1 to 10 carbon atoms. For example, the term “heteroaryl” includes those groups derived from the compounds: pyrrole, furan, thiophene, imidazole, oxazole, isoxazole, thiazole, isothiazole, triazole, pyrazole, pyridine, pyrazine, pyridazine, pyrimidine, and the like.

[0049] The term “substituted C_n -heteroaryl” refers to a radical, having either a single aromatic carbon atom or a single aromatic heteroatom as the point of attachment, further having a total of n carbon atoms, at least one hydrogen atom, and at least two heteroatoms, wherein at least one of the carbon atoms and at least one of the heteroatoms are incorporated into one or more aromatic ring structures, further wherein at least one of the heteroatoms is not part of the one or more aromatic ring structures, further wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, an substituted C_1 - C_{10} -heteroaryl has 1 to 10 carbon atoms.

[0050] The term “unsubstituted C_n -heteroaralkyl” refers to a radical, having a single saturated carbon atom as the point of attachment, further having a total of n carbon atoms, at least three hydrogen atoms, and at least one heteroatom, wherein at least one of the carbon atoms and all of the heteroatoms form an aromatic ring structure, further wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, an unsubstituted C_2 - C_{10} -heteroaralkyl has 2 to 10 carbon atoms.

[0051] The term “substituted C_n -heteroaralkyl” refers to a radical having a single saturated carbon atom as the point of attachment, further having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, and at least two heteroatoms, wherein at least one of the carbon atoms and at least one of the heteroatoms are incorporated into one or more aromatic ring structures, further wherein at least one of the heteroatoms is not part of an aromatic ring structure, further wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_2 - C_{10} -heteroaralkyl has 2 to 10 carbon atoms.

[0052] The term “unsubstituted C_n -acyl” refers to a radical, having a single carbon atom of a carbonyl group as the point of attachment, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, 1 or more hydrogen atoms, a total of one oxygen atom, and no additional heteroatoms. For example, an unsubstituted

C_1 - C_{10} -acyl has 1 to 10 carbon atoms. The groups, $-\text{COH}$, $-\text{COCH}_3$, $-\text{COCH}_2\text{CH}_3$, $-\text{COCH}_2\text{CH}_2\text{CH}_3$, $-\text{COCH}(\text{CH}_3)_2$, $-\text{COCH}(\text{CH}_2)_2$, $-\text{COC}_6\text{H}_5$, $-\text{COC}_6\text{H}_4\text{CH}_3$, $-\text{COC}_6\text{H}_4\text{CH}_2\text{CH}_3$, $-\text{COC}_6\text{H}_4\text{CH}_2\text{CH}_2\text{CH}_3$, $-\text{COC}_6\text{H}_4\text{CH}(\text{CH}_3)_2$, $-\text{COC}_6\text{H}_4\text{CH}(\text{CH}_2)_2$, and $-\text{COC}_6\text{H}_3(\text{CH}_3)_2$, are examples of unsubstituted acyl groups.

[0053] The term “substituted C_n -acyl” refers to a radical, having a single carbon atom as the point of attachment, the carbon atom being part of a carbonyl group, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, at least one additional heteroatom in addition to the oxygen of the carbonyl group, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_1 - C_{10} -acyl has 1 to 10 carbon atoms. The term substituted acyl includes carbamoyl, thiocarboxylate, and thiocarboxylic acid groups. The groups, $-\text{COCH}_2\text{CF}_3$, $-\text{CO}_2\text{H}$, $-\text{CO}_2\text{CH}_3$, $-\text{CO}_2\text{CH}_2\text{CH}_3$, $-\text{CO}_2\text{CH}_2\text{CH}_2\text{CH}_3$, $-\text{CO}_2\text{CH}(\text{CH}_3)_2$, $-\text{CO}_2\text{CH}(\text{CH}_2)_2$, $-\text{CONH}_2$, $-\text{CONHCH}_3$, $-\text{CONHCH}_2\text{CH}_3$, $-\text{CONHCH}_2\text{CH}_2\text{CH}_3$, $-\text{CONHCH}(\text{CH}_3)_2$, $-\text{CONHCH}(\text{CH}_2)_2$, $-\text{CON}(\text{CH}_3)_2$, $-\text{CON}(\text{CH}_2\text{CH}_3)_2$, $-\text{CON}(\text{CH}_2\text{CH}_3)_2$ and $-\text{CONHCH}_2\text{CF}_3$, are examples substituted acyl groups.

[0054] The term “unsubstituted C_n -alkoxy” refers to a group, having the structure $-\text{OR}$, in which R is an unsubstituted C_n -alkyl, as that term is defined above. Unsubstituted alkoxy groups include: $-\text{OCH}_3$, $-\text{OCH}_2\text{CH}_3$, $-\text{OCH}_2\text{CH}_2\text{CH}_3$, $-\text{OCH}(\text{CH}_3)_2$, and $-\text{OCH}(\text{CH}_2)_2$.

[0055] The term “substituted C_n -alkoxy” refers to a group, having the structure $-\text{OR}$, in which R is a substituted C_n -alkyl, as that term is defined above. For example, $-\text{OCH}_2\text{CF}_3$ is a substituted alkoxy group.

[0056] The term “unsubstituted C_n -alkenyloxy” refers to a group, having the structure $-\text{OR}$, in which R is an unsubstituted C_n -alkenyl, as that term is defined above.

[0057] The term “substituted C_n -alkenyloxy” refers to a group, having the structure $-\text{OR}$, in which R is a substituted C_n -alkenyl, as that term is defined above.

[0058] The term “unsubstituted C_n -alkynyloxy” refers to a group, having the structure $-\text{OR}$, in which R is an unsubstituted C_n -alkynyl, as that term is defined above.

[0059] The term “substituted C_n -alkenyloxy” refers to a group, having the structure $-\text{OR}$, in which R is a substituted C_n -alkynyl, as that term is defined above.

[0060] The term “unsubstituted C_n -aryloxy” refers to a group, having the structure $-\text{OAr}$, in which Ar is an unsubstituted C_n -aryl, as that term is defined above. An example of an unsubstituted aryloxy group is $-\text{OC}_6\text{H}_5$.

[0061] The term “substituted C_n -aryloxy” refers to a group, having the structure $-\text{OAr}$, in which Ar is a substituted C_n -aryl, as that term is defined above.

[0062] The term “unsubstituted C_n -aralkyloxy” refers to a group, having the structure $-\text{OAr}$, in which Ar is an unsubstituted C_n -aralkyl, as that term is defined above.

[0063] The term “substituted C_n -aralkyloxy” refers to a group, having the structure $-\text{OAr}$, in which Ar is a substituted C_n -aralkyl, as that term is defined above.

[0064] The term “unsubstituted C_n -heteroaryloxy” refers to a group, having the structure $-\text{OAr}$, in which Ar is an unsubstituted C_n -heteroaryl, as that term is defined above.

[0065] The term “substituted C_n -heteroaryloxy” refers to a group, having the structure —OAr, in which Ar is a substituted C_n -heteroaryl, as that term is defined above.

[0066] The term “unsubstituted C_n -heteroalkyloxy” refers to a group, having the structure —OAr, in which Ar is an unsubstituted C_n -heteroalkyl, as that term is defined above.

[0067] The term “substituted C_n -heteroalkyloxy” refers to a group, having the structure —OAr, in which Ar is a substituted C_n -heteroalkyl, as that term is defined above.

[0068] The term “unsubstituted C_n -acyloxy” refers to a group, having the structure —OAc, in which Ac is an unsubstituted C_n -acyl, as that term is defined above. An unsubstituted acyloxy group includes alkylcarbonyloxy and arylcarbonyloxy groups. For example, —OCOCH₃ is an example of an unsubstituted acyloxy group.

[0069] The term “substituted C_n -acyloxy” refers to a group, having the structure —OAc, in which Ac is a substituted C_n -acyl, as that term is defined above. A substituted acyloxy group includes alkoxycarbonyloxy, aryloxy carbonyloxy, carboxylate, alkylcarbonyl, alkoxycarbonyl, aminocarbonyl, and alkylthiocarbonyl groups.

[0070] The term “unsubstituted C_n -alkylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having one or two saturated carbon atoms attached to the nitrogen atom, further having a linear or branched, cyclic or acyclic structure, containing a total of n carbon atoms, all of which are nonaromatic, 4 or more hydrogen atoms, a total of 1 nitrogen atom, and no additional heteroatoms. For example, an unsubstituted C_1 - C_{10} -alkylamino has 1 to 10 carbon atoms. An alkylamino group includes dialkylamino groups. An unsubstituted alkylamino group would include —NHCH₃, —NHCH₂CH₃, —NHCH₂CH₂CH₃, —NHCH(CH₃)₂, —NHCH(CH₂)₂, —NHCH₂CH₂CH₂CH₃, —NHCH(CH₃)CH₂CH₃, —NHCH₂CH(CH₃)₂, —NHC(CH₃)₃, —N(CH₃)₂, —N(CH₃)CH₂CH₃, —N(CH₂CH₃)₂, N-pyrrolidiny, and N-piperidiny.

[0071] The term “substituted C_n -alkylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having one or two saturated carbon atoms attached to the nitrogen atom, no carbon-carbon double or triple bonds, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, all of which are nonaromatic, 0, 1, or more than one hydrogen atom, and at least one additional heteroatom, that is, in addition to the nitrogen atom at the point of attachment, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_1 - C_{10} -alkylamino has 1 to 10 carbon atoms.

[0072] The term “unsubstituted C_n -alkenylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having a linear or branched, cyclic or acyclic structure, containing at least one carbon-carbon double bond, a total of n carbon atoms, all of which are nonaromatic, 4 or more hydrogen atoms, a total of one nitrogen atom, and no additional heteroatoms. For example, an unsubstituted C_2 - C_{10} -alkenylamino has 2 to 10 carbon atoms. An alkenylamino group includes dialkenylamino and alkyl(alkenyl) amino groups.

[0073] The term “substituted C_n -alkenylamino” refers to a radical, having a single nitrogen atom as the point of attachment and at least one nonaromatic carbon-carbon double

bond, but no carbon-carbon triple bonds, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, and at least one additional heteroatom, that is, in addition to the nitrogen atom at the point of attachment, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_2 - C_{10} -alkenylamino has 2 to 10 carbon atoms.

[0074] The term “unsubstituted C_n -alkynylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having a linear or branched, cyclic or acyclic structure, containing at least one carbon-carbon triple bond, a total of n carbon atoms, all of which are nonaromatic, at least one hydrogen atoms, a total of one nitrogen atom, and no additional heteroatoms. For example, an unsubstituted C_2 - C_{10} -alkynylamino has 2 to 10 carbon atoms. An alkynylamino group includes dialkynylamino and alkyl(alkynyl) amino groups.

[0075] The term “substituted C_n -alkynylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having at least one nonaromatic carbon-carbon triple bond, further having a linear or branched, cyclic or acyclic structure, and further having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, and at least one additional heteroatom, that is, in addition to the nitrogen atom at the point of attachment, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_2 - C_{10} -alkynylamino has 2 to 10 carbon atoms.

[0076] The term “unsubstituted C_n -arylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having at least one aromatic ring structure attached to the nitrogen atom, wherein the aromatic ring structure contains only carbon atoms, further having a total of n carbon atoms, 6 or more hydrogen atoms, a total of one nitrogen atom, and no additional heteroatoms. For example, an unsubstituted C_6 - C_{10} -arylamino has 6 to 10 carbon atoms. An arylamino group includes diarylamino and alkyl(aryl) amino groups.

[0077] The term “substituted C_n -arylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having at least one aromatic ring structure attached to the nitrogen atom, wherein the aromatic ring structure contains only carbon atoms, further having a total of n carbon atoms, 0, 1, or more hydrogen atom, and at least one additional heteroatom, that is, in addition to the nitrogen atom at the point of attachment, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_6 - C_{10} -arylamino has 6 to 10 carbon atoms.

[0078] The term “unsubstituted C_n -aralkylamino” refers to a radical, having a single nitrogen atom as the point of attachment, further having one or two saturated carbon atoms attached to the nitrogen atom, further having a total of n carbon atoms, wherein at least 6 of the carbon atoms form an aromatic ring structure containing only carbon atoms, 8 or more hydrogen atoms, a total of one nitrogen atom, and no additional heteroatoms. For example, an unsubstituted C_7 - C_{10} -aralkylamino has 7 to 10 carbon atoms. An aralkylamino group includes diaralkylamino, alkyl(aralkyl)amino, and aryl(aralkyl)amino groups.

[0079] The term “substituted C_n -aralkylamino” refers to a radical, having a single nitrogen atom as the point of attach-

ment, further having at least one or two saturated carbon atoms attached to the nitrogen atom, further having a total of n carbon atoms, wherein at least 6 of the carbon atoms form an aromatic ring structure containing only carbon atoms, 0, 1, or more than one hydrogen atom, and at least one additional heteroatom, that is, in addition to the nitrogen atom at the point of attachment, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_7 - C_{10} -aralkylamino has 7 to 10 carbon atoms.

[0080] The term “unsubstituted C_n -heteroaryl-amino” refers to a radical, having a single nitrogen atom as the point of attachment, further having a total of n carbon atoms, at least one hydrogen atom, and at least one additional heteroatom, in addition to the nitrogen atom at the point of attachment, wherein at least one of the carbon atoms and all of the additional heteroatoms are incorporated into one or more aromatic ring structures, further wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, an unsubstituted C_1 - C_{10} -heteroaryl-amino has 1 to 10 carbon atoms. A heteroaryl-amino group includes alkyl(heteroaryl)amino and aryl(heteroaryl)amino groups.

[0081] The term “substituted C_n -heteroaryl-amino” refers to a radical, having a single nitrogen atom as the point of attachment, further having a total of n carbon atoms, at least one hydrogen atom, at least two additional heteroatoms, that is, in addition to the nitrogen atom at the point of attachment, wherein at least one of the carbon atoms and at least one of the additional heteroatoms are incorporated into one or more aromatic ring structures, further wherein at least one of the additional heteroatoms is not part of the one or more aromatic ring structures, further wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_1 - C_{10} -heteroaryl-amino has 1 to 10 carbon atoms.

[0082] The term “unsubstituted C_n -heteroaralkyl-amino” refers to a radical, having a single nitrogen atom as the point of attachment, further having one or two saturated carbon atoms attached to the nitrogen atom, further having a total of n carbon atoms, at least three hydrogen atoms, at least one additional heteroatom, wherein at least one of the carbon atoms and all of the additional heteroatoms form an aromatic ring structure, further wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, an unsubstituted C_2 - C_{10} -heteroaralkyl-amino has 2 to 10 carbon atoms. A heteroaralkyl-amino group includes alkyl(heteroaralkyl)amino and aryl(heteroaralkyl)amino groups.

[0083] The term “substituted C_n -heteroaralkyl-amino” refers to a radical, having a single nitrogen atom as the point of attachment, further having one or two saturated carbon atoms attached to the nitrogen atom, further having a total of n carbon atoms, 0, 1, or more than one hydrogen atom, at least two additional heteroatoms, that is, in addition to the nitrogen atom at the point of attachment, wherein at least one of the carbon atoms and at least one of the additional heteroatoms are incorporated into one or more aromatic ring structures, further wherein at least one of the heteroatoms is not part of an aromatic ring structure, further wherein each heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_2 - C_{10} -heteroaralkyl-amino has 2 to 10 carbon atoms.

[0084] The term “unsubstituted C_n -amido” refers to a radical, having a single nitrogen atom as the point of attachment, further having a carbonyl group attached via its carbon atom to the nitrogen atom, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, 1 or more hydrogen atoms, a total of one oxygen atom, a total of one nitrogen atom, and no additional heteroatoms. For example, an unsubstituted C_1 - C_{10} -amido has 1 to 10 carbon atoms. A amido group includes N-alkyl-amido, N-aryl-amido, N-aralkyl-amido, acylamino, alkylcarbonylamino, arylcarbonylamino, and ureido groups. The group, $-\text{NHCOCH}_3$, is an example of an unsubstituted amido group.

[0085] The term “substituted C_n -amido” refers to a radical, having a single nitrogen atom as the point of attachment, further having a carbonyl group attached via its carbon atom to the nitrogen atom, further having a linear or branched, cyclic or acyclic structure, further having a total of n aromatic or nonaromatic carbon atoms, 0, 1, or more than one hydrogen atom, at least one additional heteroatom in addition to the oxygen of the carbonyl group, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_1 - C_{10} -amido has 1 to 10 carbon atoms. The group, $-\text{NHCO}_2\text{C}(\text{CH}_3)_3$, is an example of a substituted amido group.

[0086] The term “unsubstituted C_n -alkylthio” refers to a group, having the structure $-\text{SR}$, in which R is an unsubstituted C_n -alkyl, as that term is defined above. The group, $-\text{SCH}_3$, is an example of an unsubstituted alkylthio group.

[0087] The term “substituted C_n -alkylthio” refers to a group, having the structure $-\text{SR}$, in which R is a substituted C_n -alkyl, as that term is defined above.

[0088] The term “unsubstituted C_n -alkenylthio” refers to a group, having the structure $-\text{SR}$, in which R is an unsubstituted C_n -alkenyl, as that term is defined above.

[0089] The term “substituted C_n -alkenylthio” refers to a group, having the structure $-\text{SR}$, in which R is a substituted C_n -alkenyl, as that term is defined above.

[0090] The term “unsubstituted C_n -alkynylthio” refers to a group, having the structure $-\text{SR}$, in which R is an unsubstituted C_n -alkynyl, as that term is defined above.

[0091] The term “substituted C_n -alkenylthio” refers to a group, having the structure $-\text{SR}$, in which R is a substituted C_n -alkenyl, as that term is defined above.

[0092] The term “unsubstituted C_n -arylthio” refers to a group, having the structure $-\text{SAr}$, in which Ar is an unsubstituted C_n -aryl, as that term is defined above. The group, $-\text{SC}_6\text{H}_5$, is an example of an unsubstituted arylthio group.

[0093] The term “substituted C_n -arylthio” refers to a group, having the structure $-\text{SAr}$, in which Ar is a substituted C_n -aryl, as that term is defined above.

[0094] The term “unsubstituted C_n -aralkylthio” refers to a group, having the structure $-\text{SAr}$, in which Ar is an unsubstituted C_n -aralkyl, as that term is defined above. The group, $-\text{SCH}_2\text{C}_6\text{H}_5$, is an example of an unsubstituted aralkylthio group.

[0095] The term “substituted C_n -aralkylthio” refers to a group, having the structure $-\text{SAr}$, in which Ar is a substituted C_n -aralkyl, as that term is defined above.

[0096] The term “unsubstituted C_n -heteroarylthio” refers to a group, having the structure $-\text{SAr}$, in which Ar is an unsubstituted C_n -heteroaryl, as that term is defined above.

[0097] The term “substituted C_n -heteroarylthio” refers to a group, having the structure —SAr, in which Ar is a substituted C_n -heteroaryl, as that term is defined above.

[0098] The term “unsubstituted C_n -heteroarylthio” refers to a group, having the structure —SAr, in which Ar is an unsubstituted C_n -heteroaryl, as that term is defined above.

[0099] The term “substituted C_n -heteroalkylthio” refers to a group, having the structure —SAr, in which Ar is a substituted C_n -heteroalkyl, as that term is defined above.

[0100] The term “unsubstituted C_n -acylthio” refers to a group, having the structure —SAc, in which Ac is an unsubstituted C_n -acyl, as that term is defined above. The group, —SCOCH₃, is an example of an unsubstituted acylthio group.

[0101] The term “substituted C_n -acylthio” refers to a group, having the structure —SAc, in which Ac is a substituted C_n -acyl, as that term is defined above.

[0102] The term “unsubstituted C_n -alkylsilyl” refers to a radical, having a single silicon atom as the point of attachment, further having one, two, or three saturated carbon atoms attached to the silicon atom, further having a linear or branched, cyclic or acyclic structure, containing a total of n carbon atoms, all of which are nonaromatic, 5 or more hydrogen atoms, a total of 1 silicon atom, and no additional heteroatoms. For example, an unsubstituted C_1 - C_{10} -alkylsilyl has 1 to 10 carbon atoms. An alkylsilyl group includes dialkylamino groups. The groups, —Si(CH₃)₃ and —Si(CH₃)₂C(CH₃)₃, are examples of unsubstituted alkylsilyl groups.

[0103] The term “substituted C_n -alkylsilyl” refers to a radical, having a single silicon atom as the point of attachment, further having at least one, two, or three saturated carbon atoms attached to the silicon atom, no carbon-carbon double or triple bonds, further having a linear or branched, cyclic or acyclic structure, further having a total of n carbon atoms, all of which are nonaromatic, 0, 1, or more than one hydrogen atom, and at least one additional heteroatom, that is, in addition to the silicon atom at the point of attachment, wherein each additional heteroatom is independently selected from the group consisting of N, O, F, Cl, Br, I, Si, P, and S. For example, a substituted C_1 - C_{10} -alkylsilyl has 1 to 10 carbon atoms.

[0104] The term “pharmaceutically acceptable salts,” as used herein, refers to salts of compounds of this invention that are substantially non-toxic to living organisms. Typical pharmaceutically acceptable salts include those salts prepared by reaction of a compound of this invention with an inorganic or organic acid, or an organic base, depending on the substituents present on the compounds of the invention.

[0105] Examples of inorganic acids which may be used to prepare pharmaceutically acceptable salts include: hydrochloric acid, phosphoric acid, sulfuric acid, hydrobromic acid, hydroiodic acid, phosphorous acid and the like. Examples of organic acids which may be used to prepare pharmaceutically acceptable salts include: aliphatic mono- and dicarboxylic acids, such as oxalic acid, carbonic acid, citric acid, succinic acid, phenyl-substituted alkanolic acids, aliphatic and aromatic sulfuric acids and the like. Pharmaceutically acceptable salts prepared from inorganic or organic acids thus include hydrochloride, hydrobromide, nitrate, sulfate, pyrosulfate, bisulfate, sulfite, bisulfate, phosphate, monohydrogenphosphate, dihydrogenphosphate, metaphosphate, pyrophosphate, hydroiodide, hydrofluoride, acetate, propionate, formate, oxalate, citrate, lactate, p-toluene-

sulfonate, methanesulfonate, maleate, and the like. Other suitable salts are known to one of ordinary skill in the art.

[0106] Suitable pharmaceutically acceptable salts may also be formed by reacting the agents of the invention with an organic base such as methylamine, ethylamine, ethanolamine, lysine, ornithine and the like. Other suitable salts are known to one of ordinary skill in the art.

[0107] Pharmaceutically acceptable salts include the salts formed between carboxylate or sulfonate groups found on some of the compounds of this invention and inorganic cations, such as sodium, potassium, ammonium, or calcium, or such organic cations as isopropylammonium, trimethylammonium, tetramethylammonium, and imidazolium.

[0108] It should be recognized that the particular anion or cation forming a part of any salt of this invention is not critical, so long as the salt, as a whole, is pharmacologically acceptable and as long as the anion or cation does not contribute undesired qualities or effects. Further, additional pharmaceutically acceptable salts are known to those skilled in the art, and may be used within the scope of the invention. Additional examples of pharmaceutically acceptable salts and their methods of preparation and use are presented in *Pharmaceutical Salts: Properties, Selection and Use—A Handbook*, by C. G. Wermuth and P. H. Stahl, Verlag Helvetica Chimica Acta, 2002, which is incorporated herein by reference.

[0109] As used herein, the term “patient” is intended to include living organisms in which certain conditions as described herein can occur. Examples include humans, monkeys, cows, sheep, goats, dogs, cats, mice, rats, and transgenic species thereof. In a preferred embodiment, the patient is a primate. In an even more preferred embodiment, the primate is a human. Other examples of subjects include experimental animals such as mice, rats, dogs, cats, goats, sheep, pigs, and cows. The experimental animal can be an animal model for a disorder, e.g., a transgenic mouse with an Alzheimer’s-type neuropathology. A patient can be a human suffering from a neurodegenerative disease, such as Alzheimer’s disease, or Parkinson’s disease.

[0110] As used herein, the term “IC₅₀” refers to an inhibitory dose which is 50% of the maximum response obtained.

[0111] As used herein, the term “water soluble” means that the compound dissolves in water at least to the extent of 0.010 mole/liter or is classified as soluble according to literature precedence.

[0112] As used herein, predominantly one enantiomer means that the compound contains at least 95% of one enantiomer, or more preferably at least 98% of one enantiomer, or most preferably at least 99% of one enantiomer. For example, a compound may contain 99% (+) TBE-31 and 1% (–) TBE-31.

[0113] Other abbreviations used herein are as follows: DMSO, dimethyl sulfoxide; iNOS, inducible nitric oxide synthase; COX-2, cyclooxygenase-2; NGF, nerve growth factor; IBMX, isobutylmethylxanthine; FBS, fetal bovine serum; GPDH, glycerol 3-phosphate dehydrogenase; RXR, retinoid X receptor; TGF- β , transforming growth factor- β ; IFN- γ , interferon- γ ; LPS, bacterial endotoxic lipopolysaccharide; TNF- α , tumor necrosis factor- α ; IL-1 β , interleukin-1 β ; GAPDH, glyceraldehyde-3-phosphate dehydrogenase; MTT, 3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide; TCA, trichloroacetic acid.

[0114] The use of the word “a” or “an” when used in conjunction with the term “comprising” or “having” in the claims

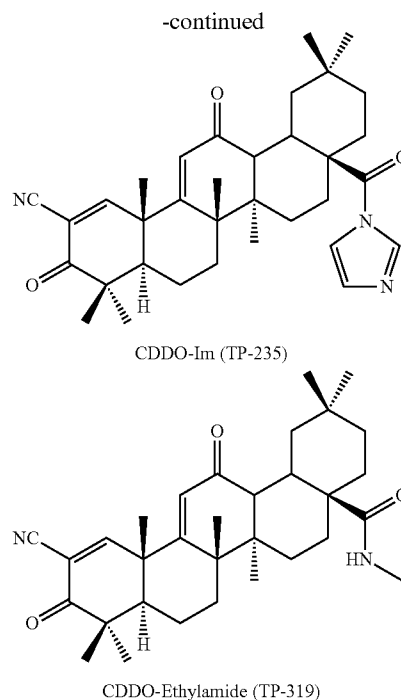
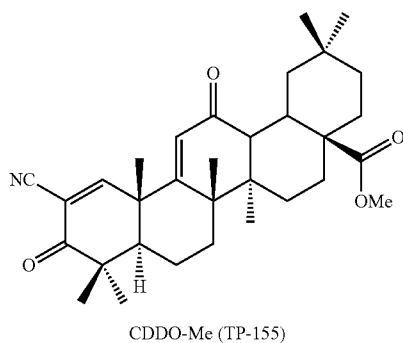
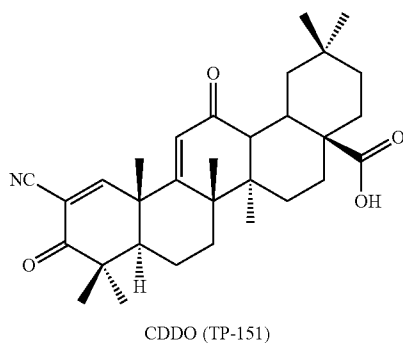
and/or the specification may mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.” As used herein “another” may mean at least a second or more.

III. Synthetic Triterpenoids and TBEs

[0115] Triterpenoids, biosynthesized in plants by the cyclization of squalene, are used for medicinal purposes in many Asian countries; and some, like ursolic and oleanolic acids, are known to be anti-inflammatory and anti-carcinogenic (Huang et al., 1994; Nishino et al., 1988). However, the biological activity of these naturally-occurring molecules is relatively weak, and therefore the synthesis of new analogs to enhance their potency was undertaken (Honda et al., 1997; Honda et al., 1998). Subsequent research by the inventors has identified a number of synthetic compounds that have improved activity as compared to the naturally-occurring triterpenoids.

[0116] A. CDDO Family Compounds

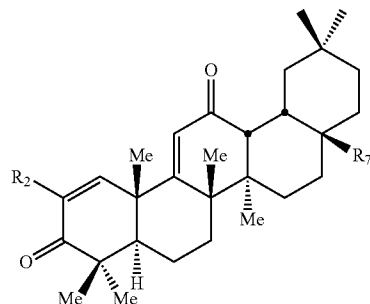
[0117] The ongoing efforts for the improvement of anti-inflammatory and antiproliferative activity of oleanolic and ursolic acid analogs led to the discovery of 2-cyano-3,12-dioxooleane-1,9(11)-dien-28-oic acid (CDDO) and related compounds (e.g., CDDO-Me, TP-225, CDDO-Im) (Honda et al., 1997, 1998, 1999, 2000a, 2000b, 2002; Suh et al., 1998; 1999; 2003; Place et al., 2003; Liby et al., 2005). Clinical trials of CDDO (TP-151) and CDDO-Me (TP-155) as anti-cancer drugs started in 2005.



CDDO is the prototype for a large number of compounds in a family of agents that have been shown useful in a variety of contexts, including cancer treatment and chemoprevention. CDDO-Me (TP-155), CDDO-Im (TP-235), and CDDO-Ethylamide (TP-319) are CDDO derivatives that are modified at the C-28 position.

[0118] CDDO-Me and CDDO-Im are also reported to possess capacities to modulate transforming growth factor- β (TGF- β)/Smad signaling in several types of cells (Suh et al., 2003; Minns et al., 2004; Mix et al., 2004)

[0119] The following formula provides CDDO family compounds that may be used in accordance with the present invention:



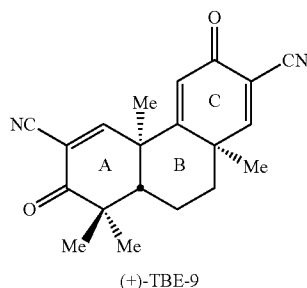
wherein R₂, is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C₁-C₁₅-alkyl, C₂-C₁₅-alkenyl, C₂-C₁₅-alkynyl, C₆-C₁₅-aryl, C₇-C₁₅-aralkyl, C₁-C₁₅-heteroaryl, C₂-C₁₅-heteroalkyl, C₁-C₁₅-acyl, C₁-C₁₅-alkoxy, C₂-C₁₅-alkenyloxy, C₂-C₁₅-alkynyloxy, C₆-C₁₅-aryloxy, C₇-C₁₅-aralkoxy, C₁-C₁₅-heteroaryloxy, C₂-C₁₅-heteroalkoxy, C₁-C₁₅-acyloxy, C₁-C₁₅-alkylamino, C₂-C₁₅-alkenylamino, C₂-C₁₅-alkynylamino, C₆-C₁₅-ary-

lamino, C₇-C₁₅-aralkylamino, C₁-C₁₅-heteroarylamino, C₂-C₁₅-heteroaralkylamino, or C₂-C₁₅-amido; R₇ is H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C₁-C₁₅-alkyl, C₂-C₁₅-alkenyl, C₂-C₁₅-alkynyl, C₇-C₁₅-aralkyl, C₂-C₁₅-heteroaralkyl, C₁-C₁₅-acyl, C₁-C₁₅-alkoxy, C₂-C₁₅-alkenyloxy, C₂-C₁₅-alkynyloxy, C₆-C₁₅-aryloxy, C₇-C₁₅-aralkoxy, C₁-C₁₅-heteroaryloxy, C₂-C₁₅-heteroaralkoxy, C₁-C₁₅-acyloxy, C₁-C₁₅-alkylamino, C₂-C₁₅-alkenylamino, C₂-C₁₅-alkynylamino, C₆-C₁₅-arylamino, C₇-C₁₅-aralkylamino, C₁-C₁₅-heteroarylamino, C₂-C₁₅-heteroaralkylamino, or C₂-C₁₅-amido; further wherein any ketone group shown in the above structure may be replaced by its enol tautomer, and pharmaceutically acceptable salts, and hydrates thereof.

[0120] CDDO compounds corresponding to this formula can be prepared according to the methods taught by Honda et al., 2000b and Honda et al., 2002, which are both incorporated herein by reference.

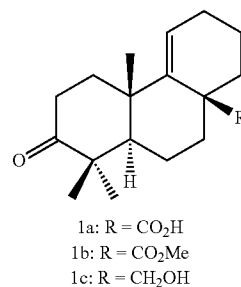
[0121] B. TBE Compounds

[0122] It has been shown that tricyclic-bis-enone compounds (TBEs) with similar enone functionalities in rings A and C also inhibit NO production in mouse macrophages (Favaloro et al., 2002) and RAW cells. In particular, bis-cyano enone (±)-TBE-9 is orally active in a preliminary in vivo inflammation model (Favaloro et al., 2002).



[0123] In addition, it has been found that (+)-TBE-9 having the opposite configuration to that of CDDO shows 10-times higher inhibitory activity than (-)-TBE-9 on NO production in mouse macrophages. To the contrary, (-)-TBE-9 is active against MCF-7 mouse breast cancer cell lines, whilst (+)-TBE-9 is inactive (Honda et al., 2003; U.S. Patent Publication No. US2003/0232786).

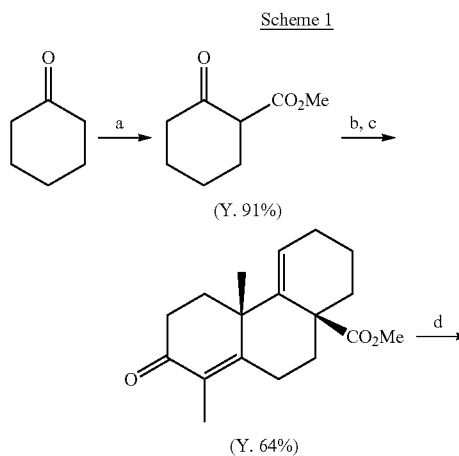
[0124] Therefore, additional TBE compounds were designed. Initial attention was focused on modifying the C-8a position because insertion of functionalities at C-8a would be expected to improve the potency and pharmacokinetics because the balance between hydrophilicity and hydrophobicity is shifted. Also, water-soluble compounds could be obtained by the insertion of appropriate functionalities. In addition, although some biologically active natural products have functionalities at the same position (e.g., anti-tumor quassinoids (Cassady et al., 1980)), CDDO analogs with functionalities at the same position cannot be synthesized from oleanolic acid. Various C-8a functionalized (including typical electron-withdrawing and releasing groups) TBE compounds were synthesized using the simple tricycles 1a-1c, shown below, as starting materials, whose efficient synthesis has been established in Honda et al., 2005, which is incorporated herein by reference.

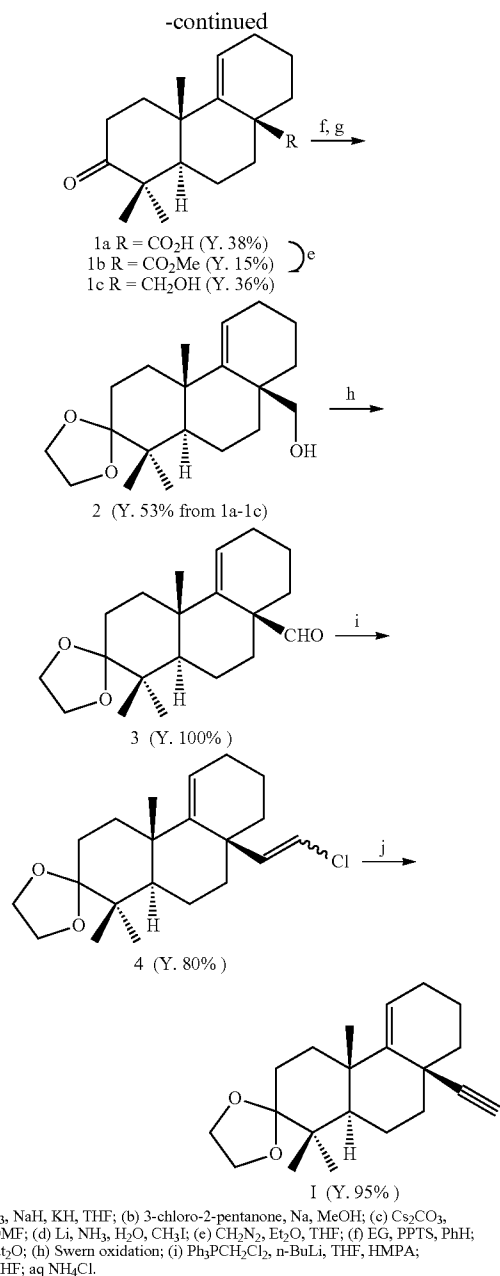


[0125] The potency of the new TBEs for inhibition of NO production in RAW cells has been evaluated. Amongst the compounds studied, it was found that (±)-TBE-31, having a C_{1-8a} alkyne group is extremely potent at one nanomolar concentrations. The potency is much higher than CDDO and equal to TP-225, which has the highest potency amongst semi-synthetic triterpenoids in the same assay (Honda et al., 2002). In addition, TBE-31 shows extremely high potency in various in vitro and in vivo assays. For example, TBE-31 inhibits proliferation of RPMI 8226 human myeloma cells and U937 human leukemia cells. TBE-31 is a potent inducer of heme oxygenase-1 in U937 cells. TBE-31 is orally active in the in vivo assay of heme oxygenase-1 induction. This potency is much higher than CDDO and equal to CDDO-Im, which has the highest potency amongst semi-synthetic triterpenoids in the same assay (Liby et al., 2005). TBE-31 induces CD11b expression in U937 cells. This potency is much higher than CDDO and CDDO-Im. TBE-31 inhibits iNOS in RAW cells stimulated with interferon-γ.

[0126] Given the structural similarities between TBEs and CDDO compounds, especially the presence of the two enone groups, which are believed to function as Michael addition acceptors, the inventors contemplate that the TBEs will promote the growth of bone and/or cartilage. The TBEs, which are described in the present invention, may have the capacity to modulate transforming growth factor-β (TGF-β)/Smad signaling in several types of cells.

[0127] i. Synthesis of (±)-TBE-31 and 34 in Racemic Form
[0128] Intermediate I is a key intermediate for the synthesis of various TBE-31 analogs. Scheme 1 shows the synthesis of Common Intermediate I.

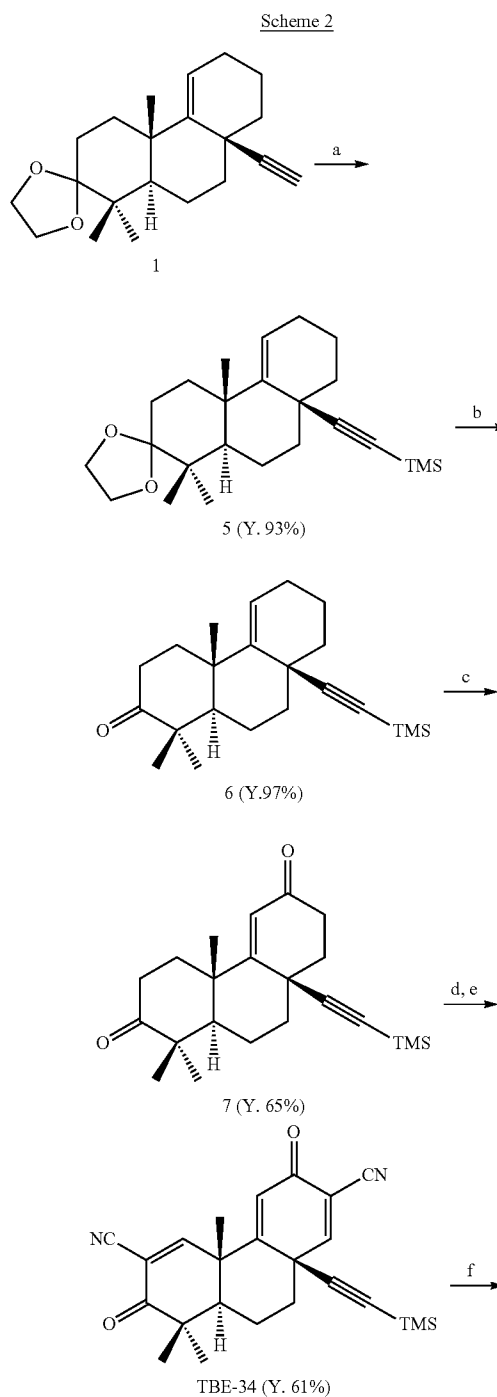


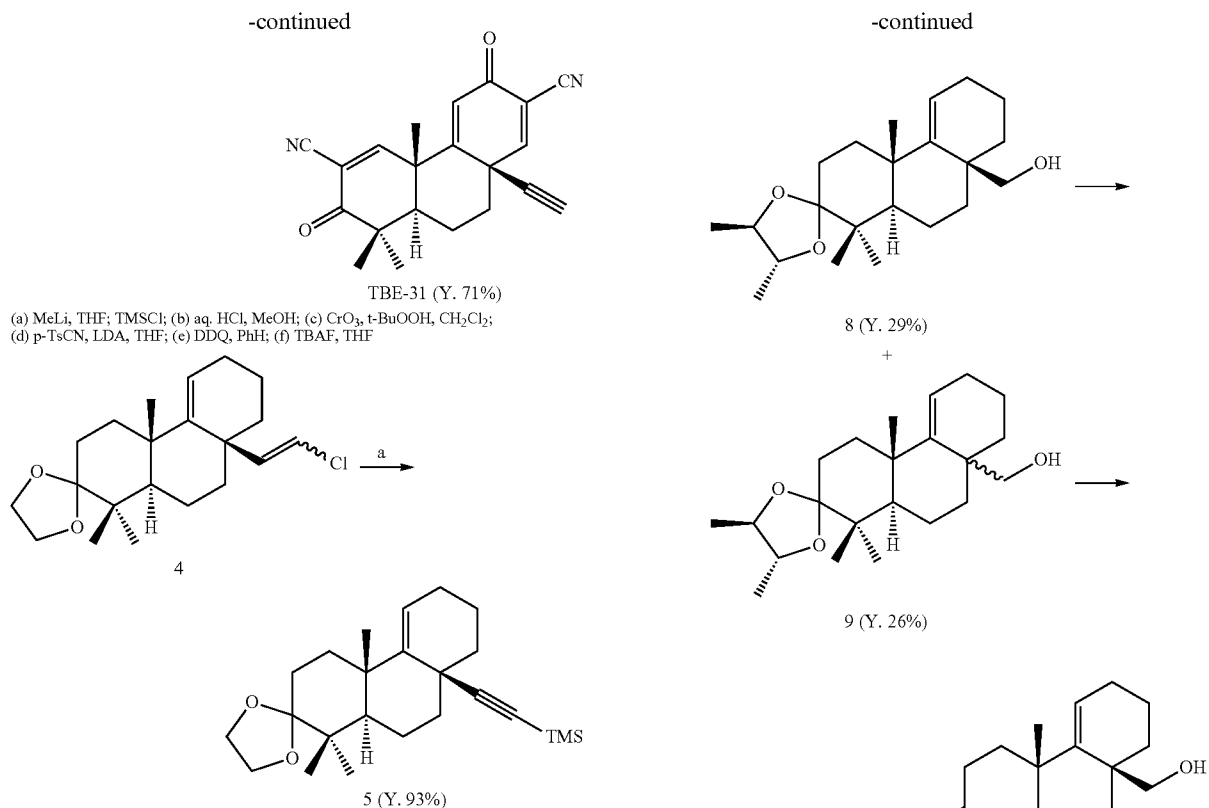


[0129] Compounds 1a-1c were obtained from cyclohexanone according to the method of Honda et al. 2005, which is incorporated herein by reference. Without separation, a mixture of 1a-1c was converted to a mixture of 1b and 1c with ethereal diazomethane. Compound 2 was obtained from the mixture of 1b and 1c by protection of their carbonyl groups with ethylene glycol (EG) in the presence of pyridinium p-toluenesulfonate (PPTS) in benzene (PhH) (Sterzycki, 1979), followed by LiAlH₄ reduction (53% yield from the mixture of 1a-1c). Swern oxidation (DMSO and oxalyl chloride, Omura and Swern, 1978) of 2 gave 3 in quantitative yield. Compound 4 was prepared in 80% yield as a mixture of E/Z chlorovinyl isomers by Wittig reaction on 3 with (chloromethyl)triphenylphosphonium chloride (Mella et al., 1988). Dehydrochlorination of 4 with methyl lithium, fol-

lowed by quenching the acetylide with aqueous NH₄Cl solution afforded the common intermediate I in 95% yield (21% overall yield from cyclohexanone) (Mella et al., 1988). Noteworthy is that 100 g of I can be made from 160 g of cyclohexanone by this sequence.

[0130] TBE-31 and 34 in racemic form were synthesized from I by the sequence shown in Scheme 2.

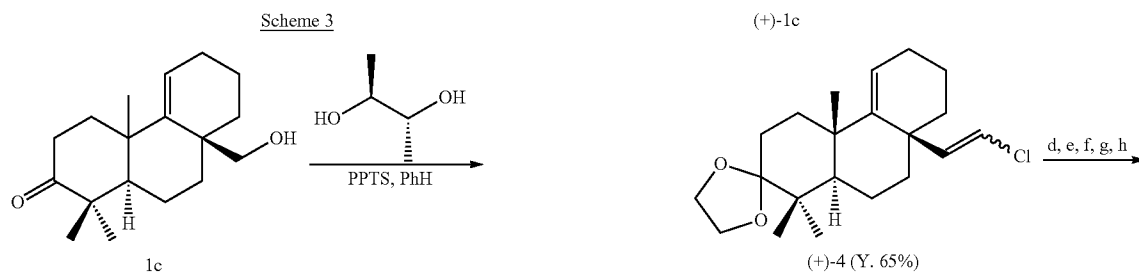


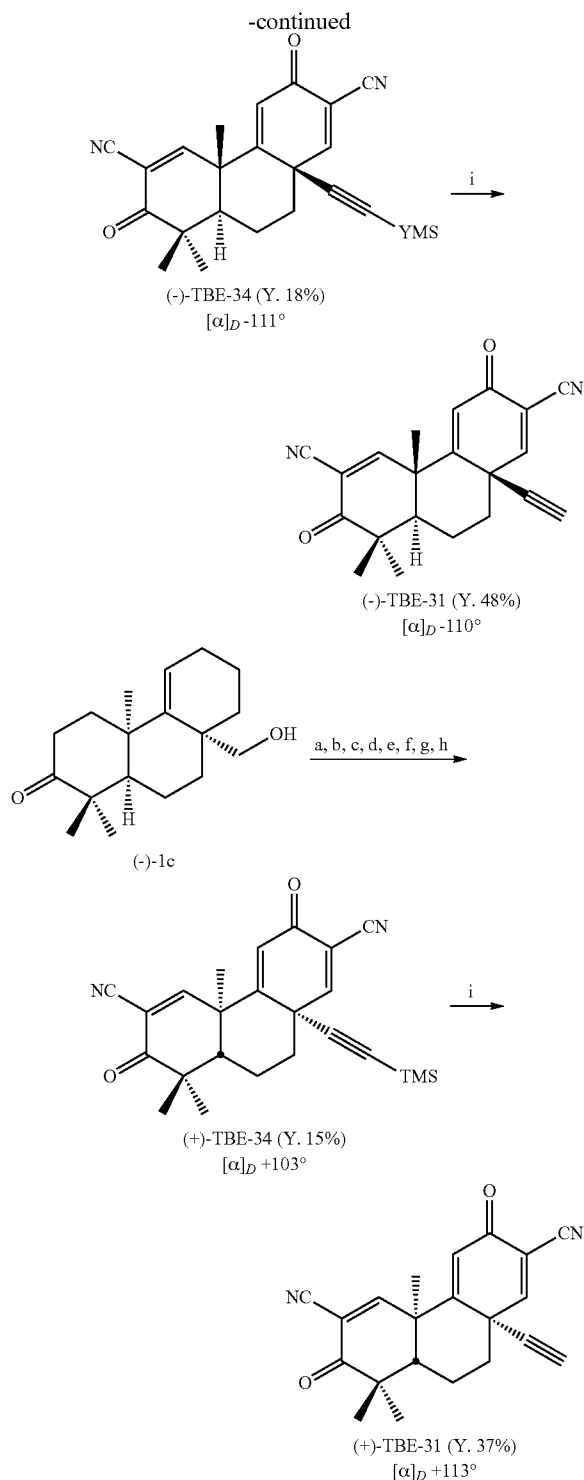


[0131] Treatment of lithium acetylide of I with chlorotrimethylsilane (TMSCl) gave 5 in 93% yield. Deketalization of 5 afforded 6 in 97% yield. Enone 7 was prepared in 65% yield by a chromium-mediated allylic oxidation of 6 (Muzart, 1987). TBE-34 was obtained in 61% yield by double cyanoation of 7 with lithium diisopropylamide (LDA) and p-toluenesulfonyl cyanide (p-TsCN) (Kahne et al., 1981), followed by 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) oxidation (36% overall yield from I). The TMS group was removed by tetra(n-butyl)ammonium fluoride (TBAF) (Cai et al., 1995) to give TBE-31 in 71% yield (25% overall yield from I). Also, intermediate 5 was directly made in 93% yield from 4 using Corey's method (Corey et al., 1973) without going through intermediate I.

[0132] ii. Synthesis of Optically Active (-)- and (+)-TBE-31 and 34

[0133] Optically active (-)- and (+)-TBE-31 and 34 were synthesized by the sequence shown in Scheme 3.





(a) EG, PPTS, PhH; (b) Swern oxidation; (c) Ph₃PCH₂Cl₂, n-BuLi, THF, HMPA; (d) MeLi, THF; TMSCl; (e) aq. HCl, MeOH; (f) CrO₃, t-BuOOH, CH₂Cl₂; (g) p-TsCN, LDA, THF; (h) DDQ, PhH; (i) TBAF, THF

[0134] The resolution of alcohol 1c was carried out in the manner described by Grieco (Grieco and Speake, 1998). Treatment of 1c with the chiral diol, (-)-(R,R)-2,3-butanediol afforded the pair of diastereomers 8 and 9. Separation of the

two diastereomers was achieved by iterative flash column chromatography to give diastereomer 8 (including 8% of 9) in 29% yield and diastereomer 9 (including 10% of 8) in 26% yield. The diastereomeric purity was determined by ¹H NMR (300 MHz, CDCl₃) using the integration values of the methyl signals (δ 0.92 and 0.88 of 8, and 0.96 and 0.86 of 9) for the two diastereomers.

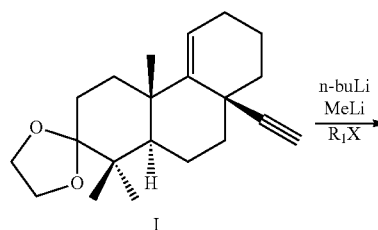
[0135] Diastereomer 8 was then treated with acidic methanol and the resulting ketone (+)-1c was obtained in 91% yield. Similarly, the other diastereomer 9 gave (-)-1c in 88% yield under the same conditions. Based on the diastereomeric purity, we concluded that (+)-1c includes 8% of (-)-1c (enantiomeric excess (ee), 84%) and (-)-1c includes 10% of (+)-1c (ee, 80%). The CD values for the two enantiomers (+)-1c and (-)-1c are $\Delta_{288} = +0.22$, and $\Delta_{288} = -0.22$ respectively. Based on these CD values and application of the octant rule (Charney, 1979), we have determined that (+)-1c has the same configuration as that of CDDO and (-)-1c has the opposite configuration.

[0136] Enantiomer (+)-1c was treated with ethylene glycol and PPTS to give the protected ketone, which was subjected to Swern oxidation with oxalyl chloride and dimethyl sulfoxide. A Wittig reaction of the resulting aldehyde with (chloromethyl) triphenylphosphonium chloride afforded the alkenyl chloride (+)-4 in 65% yield. Treatment of (+)-4 with methyl lithium and quenching of the resulting anion by TMSCl gave the TMS protected acetylene. Deprotection of the ketal group was followed by a chromium mediated allylic oxidation with t-butyl hydroperoxide which afforded the enone. Double cyanation of the enone with LDA and p-TsCN gave the dinitrile intermediate, which was oxidized by DDQ in benzene to give the desired compound (-)-TBE-34 in 18% yield. Removal of the TMS group was achieved by treatment of (-)-TBE-34 with TBAF to give (-)-TBE-31 in 48% yield.

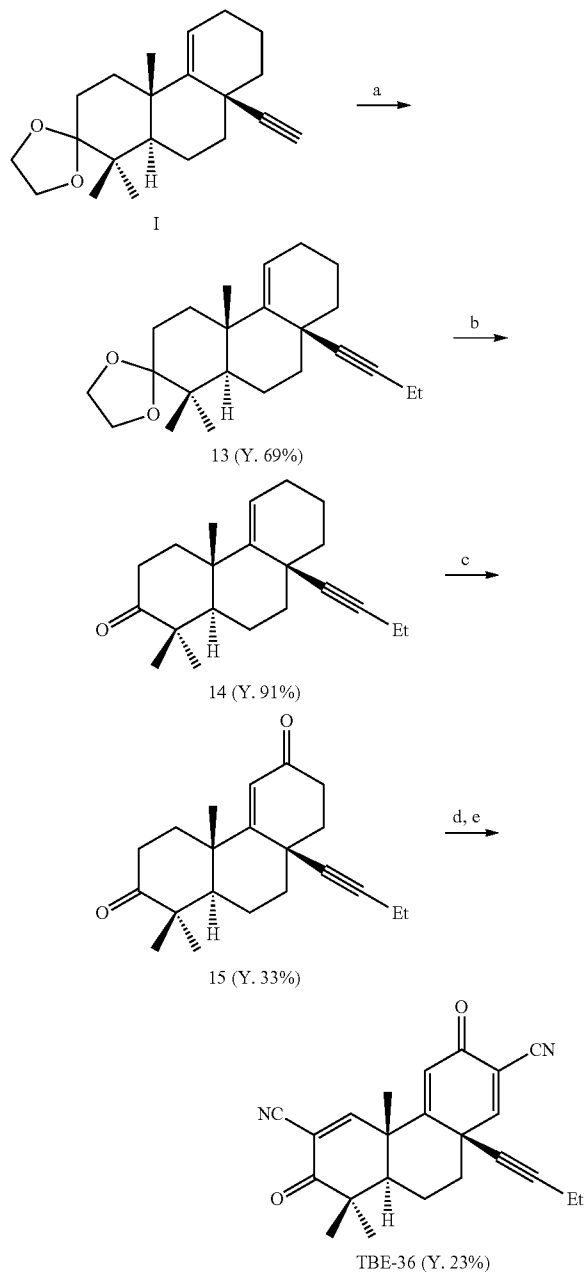
[0137] (+)-TBE-34 was obtained from (-)-1c in 15% yield by the same procedure used to obtain (-)-TBE-34 from (+)-1c. Removal of the TMS group from (+)-TBE-34 with TBAF afforded the desired (+)-TBE-31 in 37% yield.

[0138] iii. Design and Synthesis of New TBE-31 Analogs Using Alkyl Lithium

[0139] As shown below, TBE-31 analogs having the structure III, shown below, can be synthesized from compounds having the structure II, also shown below, which is obtained from compound I using alkyl lithium (n-BuLi, MeLi and so on) and R₁X (nucleophilic substitution). TBE-34 (intermediate of TBE-31), TBE-35, 36, 38, and 39 have been prepared in this fashion.



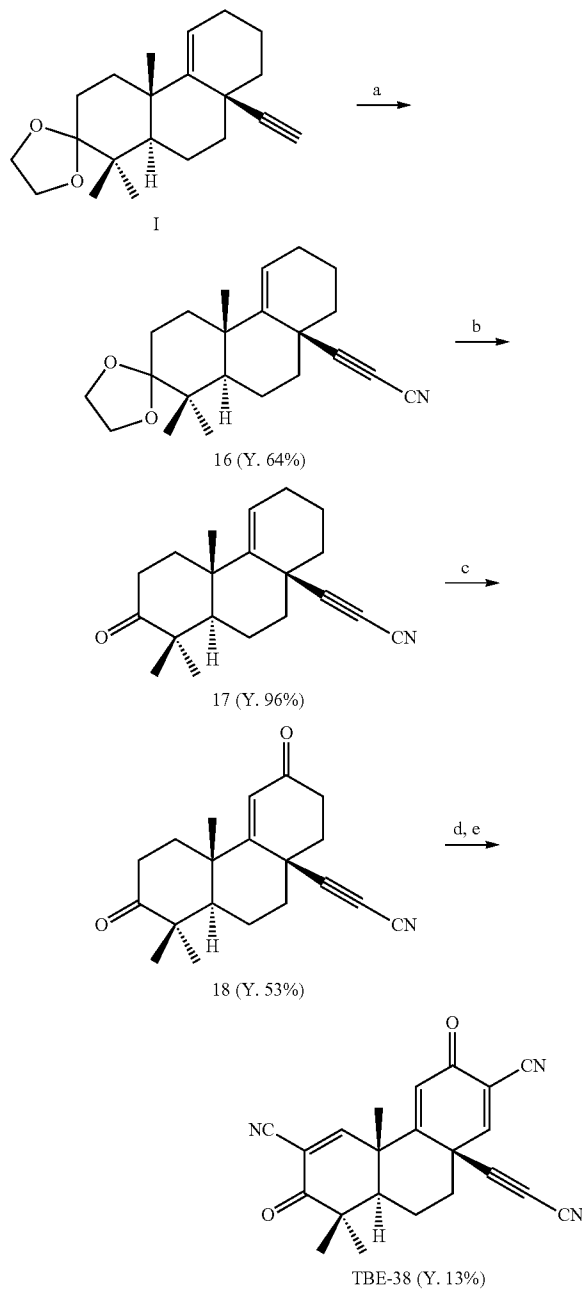
Scheme 5



[0144] Reaction of compound I with MeLi and iodoethane gave the ethyl acetylene 13 in 69% yield. Compound 13 was treated with aqueous HCl solution to give the ketone 14 in 91% yield. Allylic oxidation of 14 afforded the diketone 15 in 33% yield. Treatment of 15 with LDA and p-TsCN gave the dinitrile intermediate, which was subjected to oxidation by DDQ in benzene to give the desired compound TBE-36 in 23% yield (5% overall yield from I).

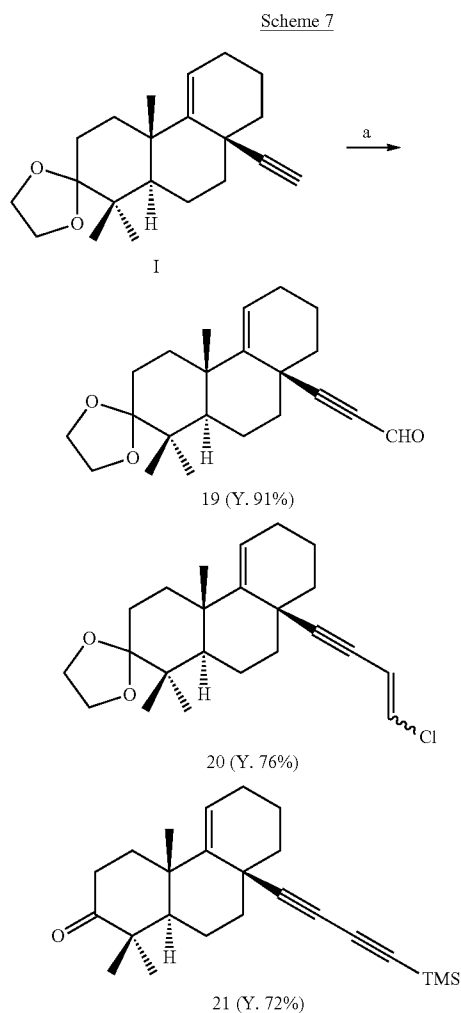
[0145] Scheme 6 shows the synthesis of TBE-38 from I.

Scheme 6

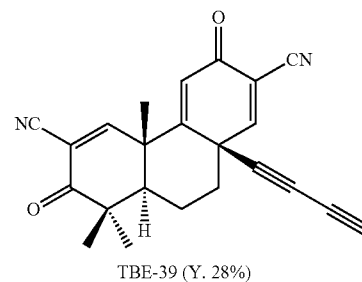


[0146] Treatment of lithium acetylide of I with phenyl cyanate (PhOCN) afforded 16 in 64% yield (Murray et al., 1980). Deketalization of 16 gave 17 in 96% yield. Allylic oxidation of 17 gave 18 in 53% yield. Double cyanation of 18, followed by DDQ oxidation gave TBE-38 in 13% yield (4% overall yield from I).

[0147] Scheme 7 shows the synthesis of TBE-39 from I.



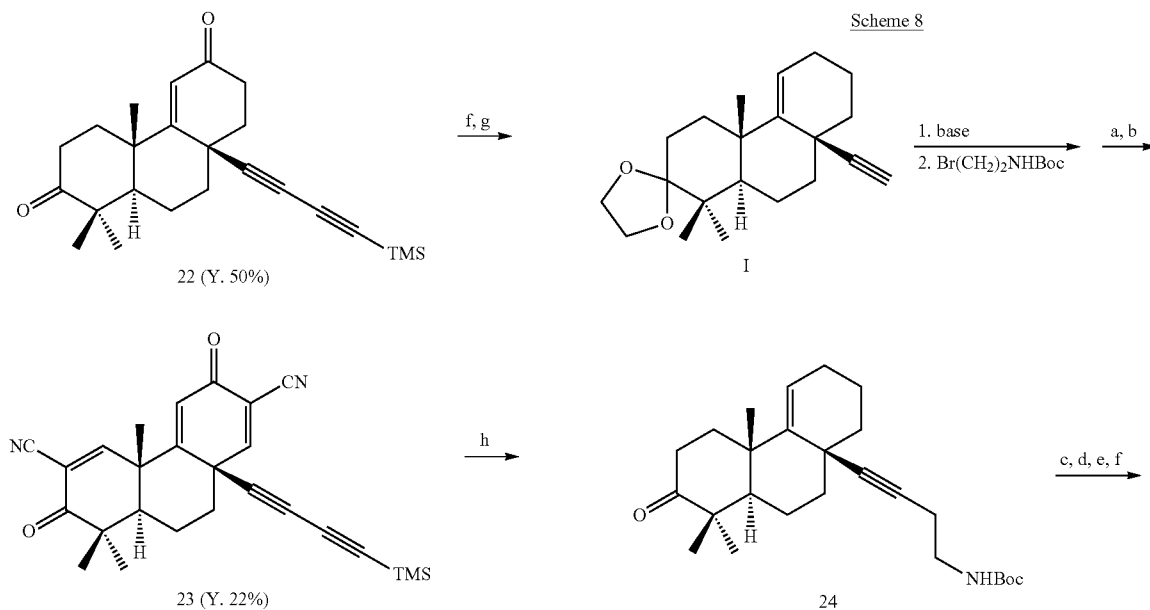
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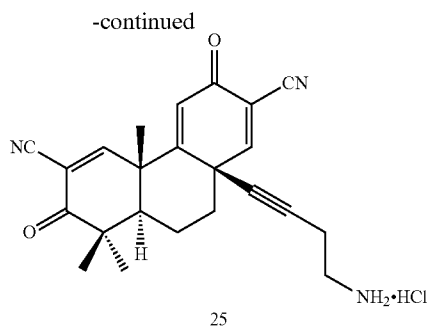


(a) *n*-BuLi, BF₃Et₂O, DMF, THF; (b) Ph₃PCH₂Cl, *n*-BuLi, HMPA, THF; (c) MeLi, THF, TMSCl; (d) aq. HCl, MeOH; (e) CrO₃, *t*-BuOOH, CH₂Cl₂; (f) *p*-TsCN, LDA, THF; (g) DDQ, PhH; (h) TBAF, THF.

[0148] The aldehyde 19 was obtained by the formylation of alkyne I with dimethylformamide and boron trifluoride etherate in 91% yield (Iguchi et al, 1993). The Wittig reaction of aldehyde 19 with (chloromethyl) triphenylphosphonium chloride gave the alkenyl chloride 20 in 76% yield. Treatment of 20 with methyl lithium and quenching of the resulting anion with TMSCl yielded the TMS protected alkyne. Treatment of this alkyne with aqueous HCl solution afforded the ketone 21 in 72% yield. Allylic oxidation of 21 gave the enone 22 in 50% yield. Double cyanation of 22 with *p*-TsCN gave the dinitrile intermediate, which was subsequently oxidized with DDQ to give the bis-enone 23 in 22% yield. Removal of the TMS group with TBAF gave the desired compound TBE-39 in 28% yield (2% overall yield from I).

[0149] As an amine hydrochloride, compound 25, shown below, would be water-soluble, making this compound very interesting. The synthetic plan is shown in Scheme 8.





(a) PPTS, acetone; (b) Boc_2O ; (c) CrO_3 , $t\text{-BuOOH}$, CH_2Cl_2 ; (d) $p\text{-TsCN}$, LDA , THF ; (e) DDQ , PhH ; (f) HCl

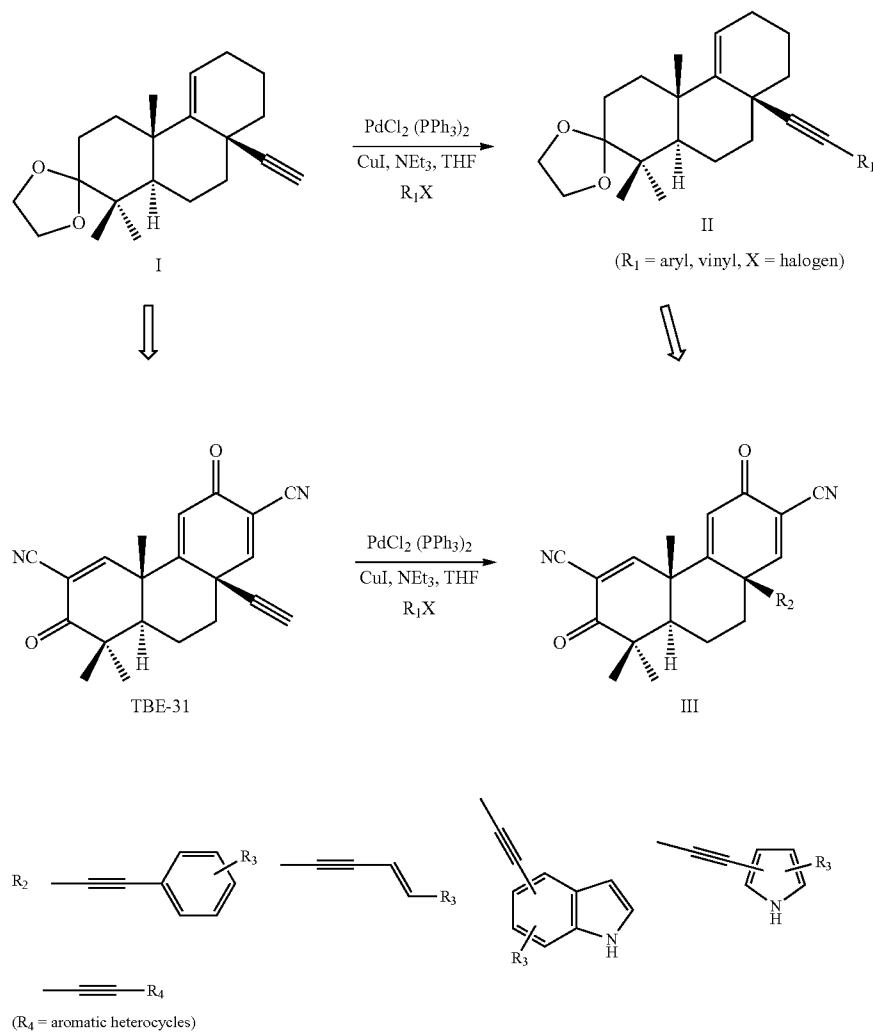
[0150] Compound 24 can be synthesized by treatment of acetylide of I with commercially available $\text{Br}(\text{CH}_2)_2\text{NHBoc}$,

followed by deketalization and subsequent protection with Boc_2O . Compound 25 can be obtained from 24 by the same sequence (allylic oxidation, double cyanation, and DDQ oxidation) as for other TBEs, followed by deprotection with HCl .

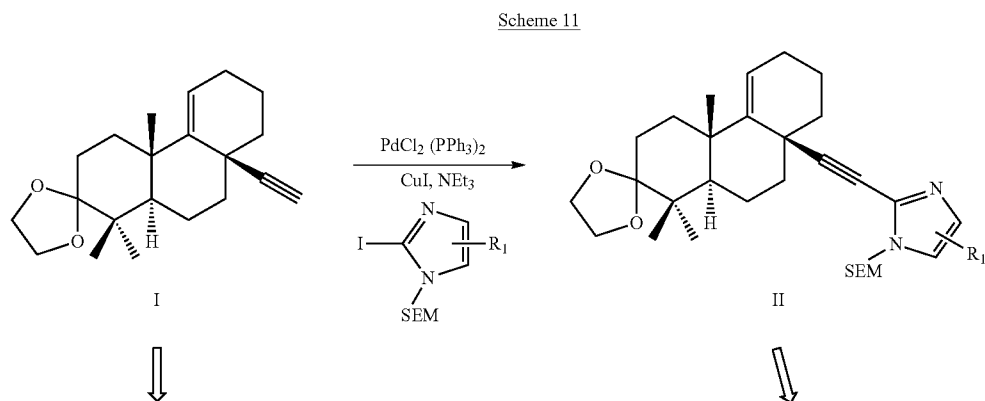
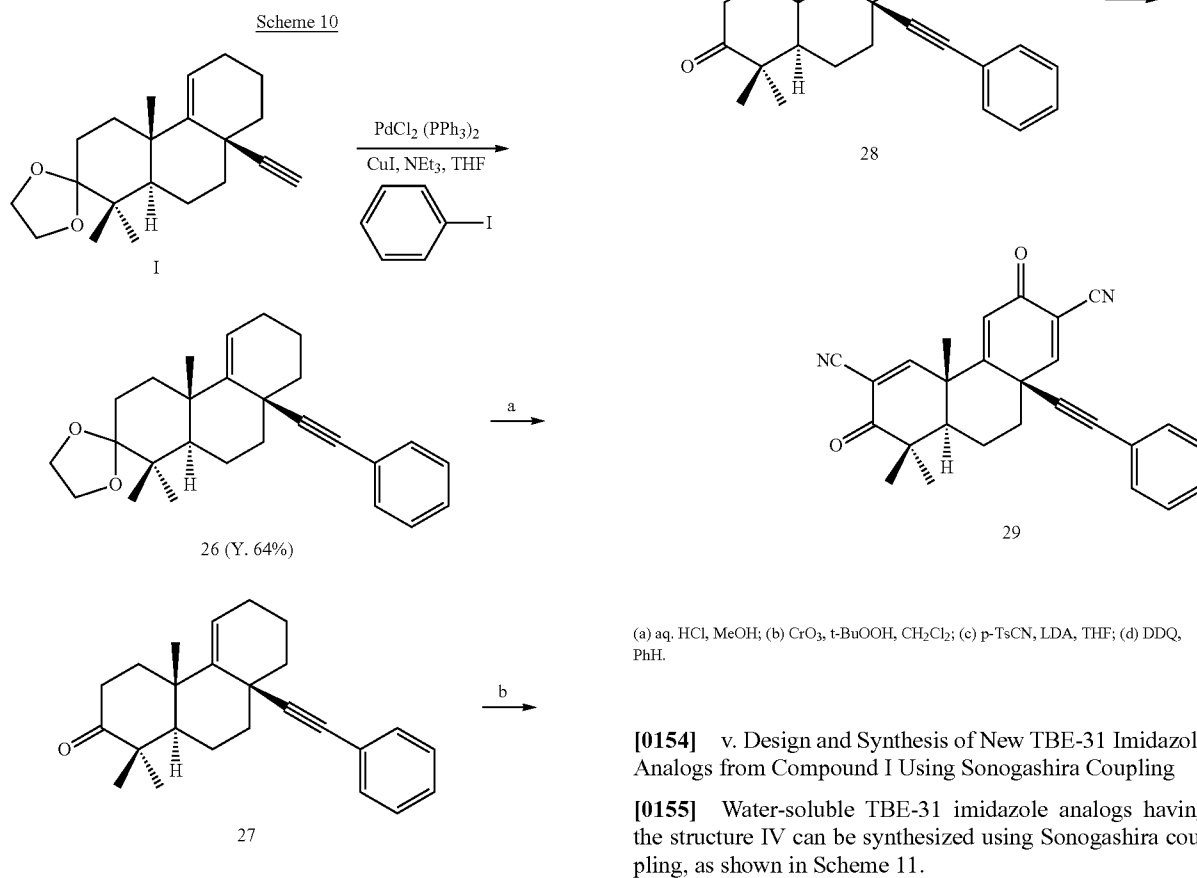
[0151] iv. Design and Synthesis of New TBE-31 Analogs Using Sonogashira Coupling

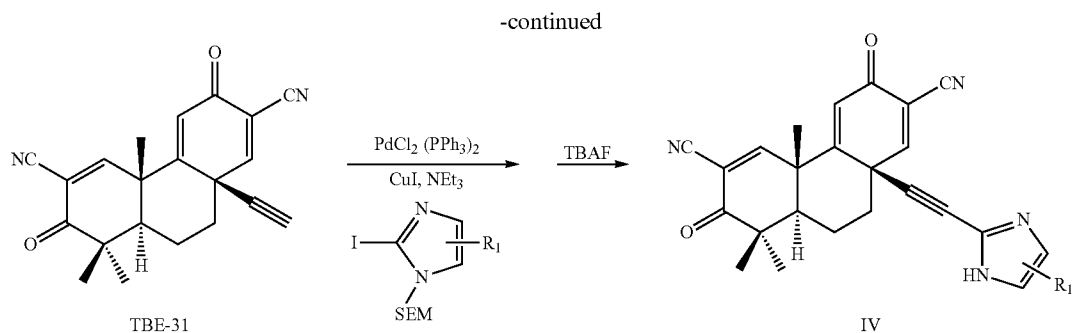
[0152] Sonogashira coupling of acetylene with aryl halide and/or vinyl halide using palladium complex (e.g. $\text{PdCl}_2(\text{PPh}_3)_2$) and CuI is a very useful reaction for the synthesis of various acetylene derivatives (Sonogashira et al., 1975). Compounds having structure III can be synthesized by Sonogashira coupling, as shown in Scheme 9. Also, it is possible to synthesize compounds having the structure III, directly from TBE-31. Sonogashira coupling provides a more convergent synthetic approach, allowing for the exploration of various compounds having the structure III.

Scheme 9

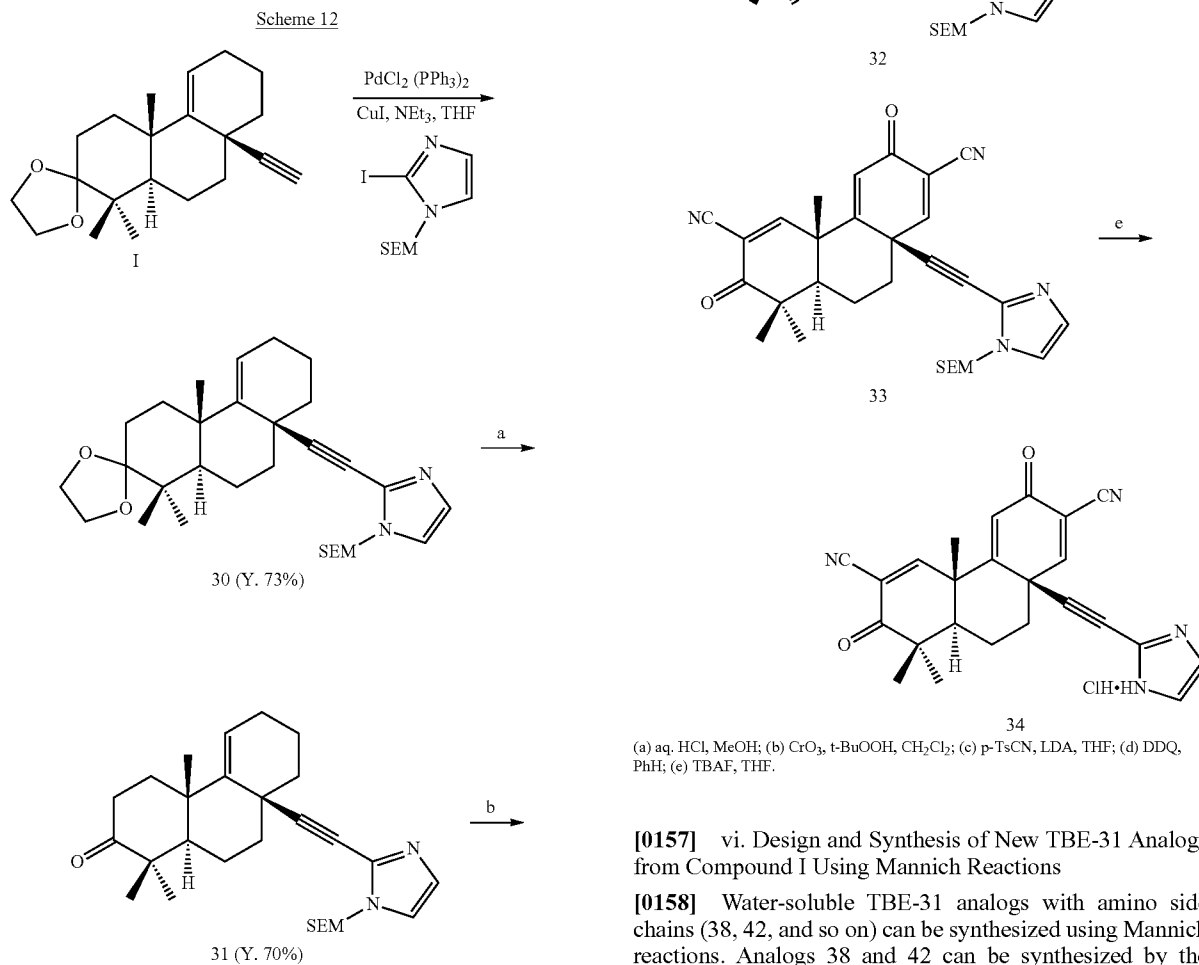


[0153] The synthetic plan of compound 29 is shown in Scheme 10. Compound 26 was successfully synthesized in 64% yield from 1 using Sonogashira coupling. Deketalization of 26 can give 27. Allylic oxidation of 27 can afford enone 28. Double cyanation of 28, followed by DDQ oxidation can give compound 29.





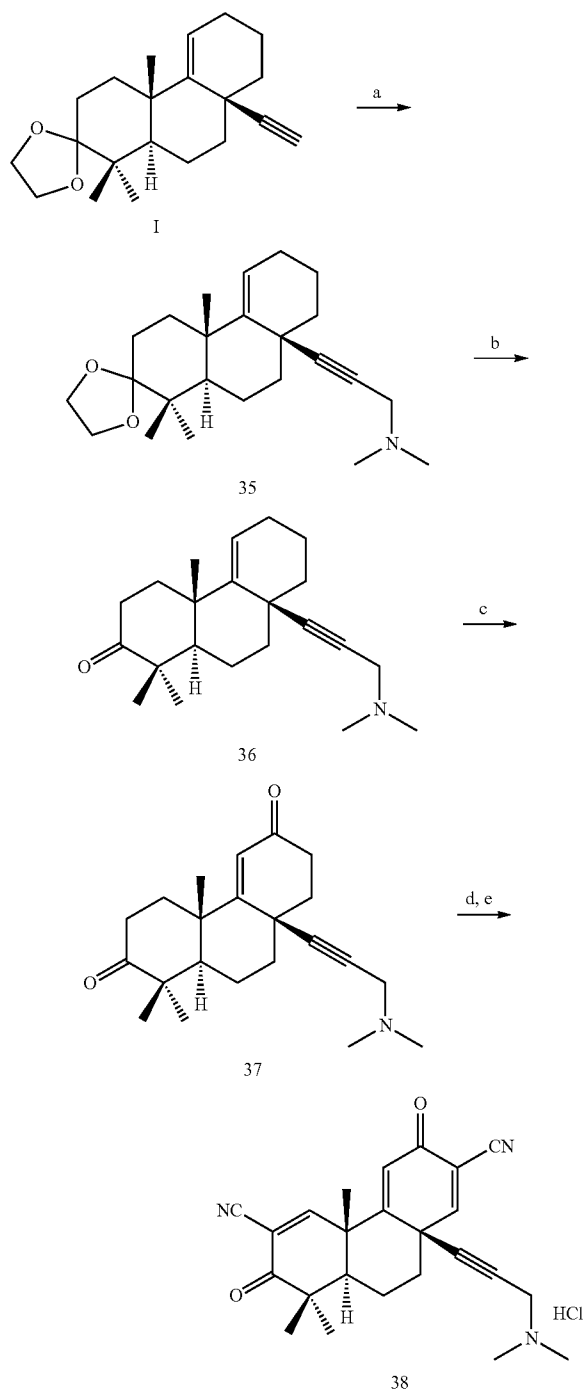
[0156] The synthetic plan of compound 34 is shown in Scheme 12. Imidazole hydrochloride 34 is expected to be water-soluble. Compound 30 was synthesized in 73% yield from I by Sonogashira coupling using iodo-SEM-imidazole (Paul et al. 2002). Deketalization of 30 gave 31 in 70% yield. Allylic oxidation of 31 can give 32. Double cyanation of 32, followed by DDQ oxidation can afford 33. The desired compound 34 can be obtained by removal of SEM group of 33.



[0157] vi. Design and Synthesis of New TBE-31 Analogs from Compound I Using Mannich Reactions

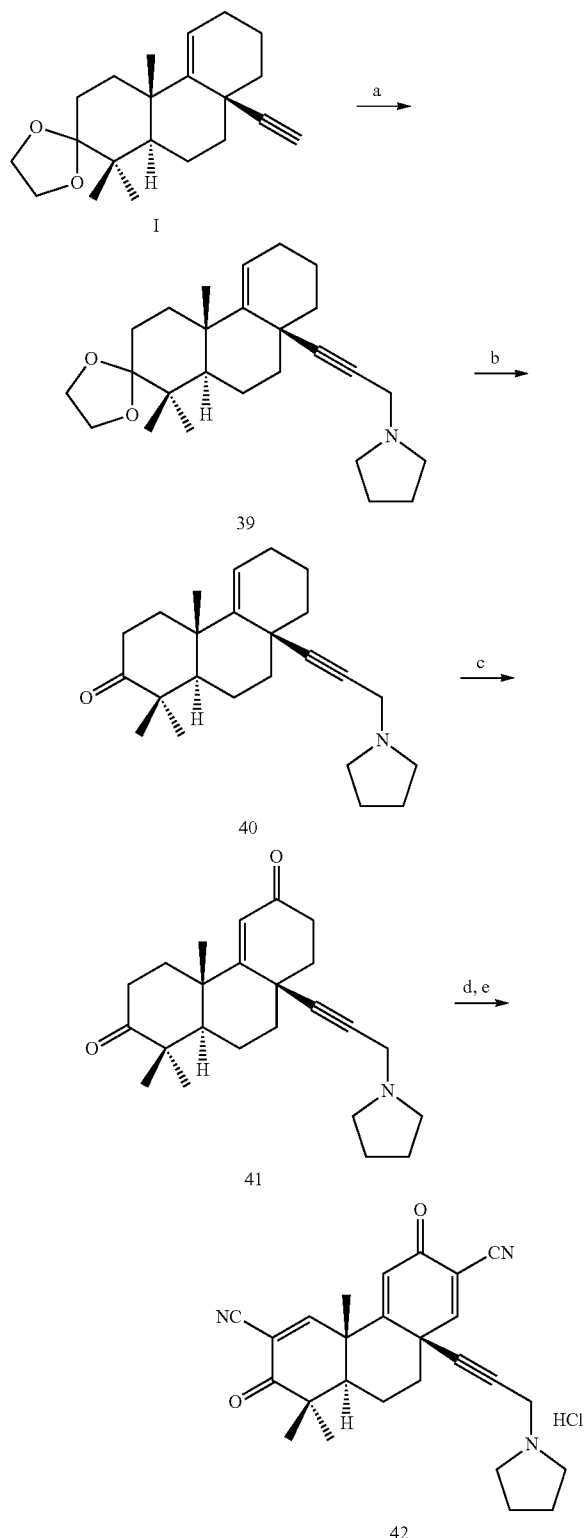
[0158] Water-soluble TBE-31 analogs with amino side chains (38, 42, and so on) can be synthesized using Mannich reactions. Analogs 38 and 42 can be synthesized by the sequence shown in Schemes 13 and 14.

Scheme 13



(a) $(\text{Me}_2\text{N})_2\text{CH}_2$, CuCl, THF; (b) aq. HCl, MeOH; (c) CrO_3 , t-BuOOH, CH_2Cl_2 ; (d) p-TsCN, LDA, THF; (e) DDQ, PhH, HCl, dioxane.

Scheme 14



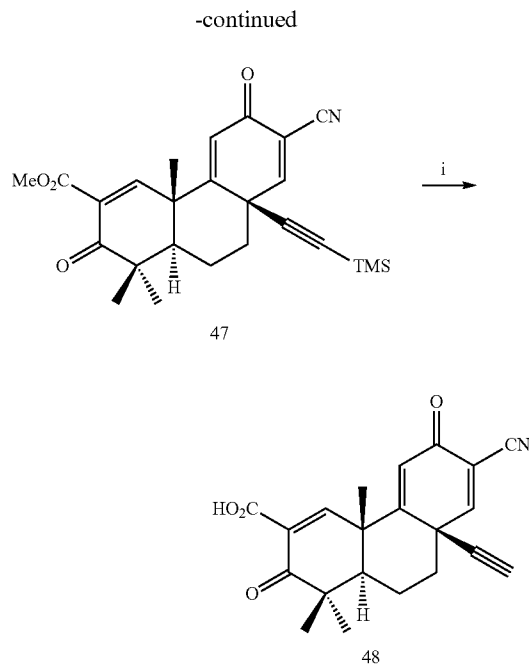
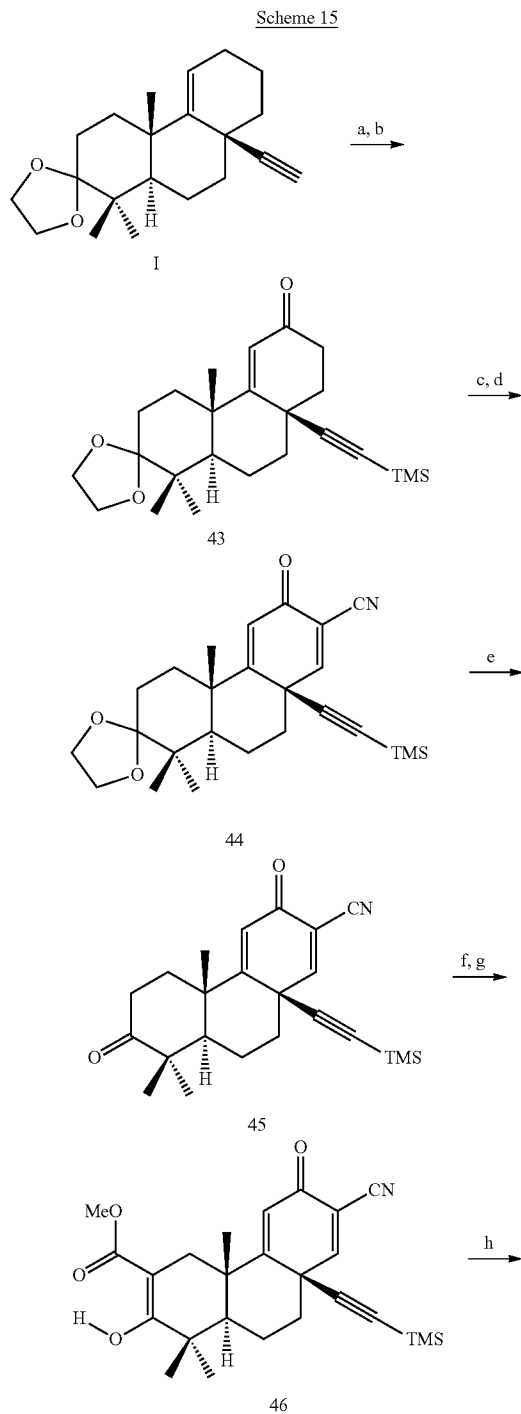
(a) HCHO, pyrrolidine, CuCl, THF; (b) aq. HCl, MeOH; (c) CrO_3 , t-BuOOH, CH_2Cl_2 ; (d) p-TsCN, LDA, THF; (e) DDQ, PhH, HCl, dioxane.

[0159] The Mannich reaction of I with bis(dimethylamino) methane (Amstutz et al., 1987; Chung et al., 1990) under the catalysis of CuCl in refluxing THF can afford 35. Compound 38 can be obtained from 35 by the same sequence as for other TBEs.

[0160] Compound 39 can be synthesized by the Mannich reaction using formaldehyde and pyrrolidine under the catalysis of CuCl. Compound 42 can be obtained from 39 by the same sequence as for other TBEs.

[0161] vii. Design and Synthesis of New TBE-31 Analogs with a Carboxyl Group in Ring A

[0162] Compound 48 can be synthesized by the sequence shown in Scheme 15.



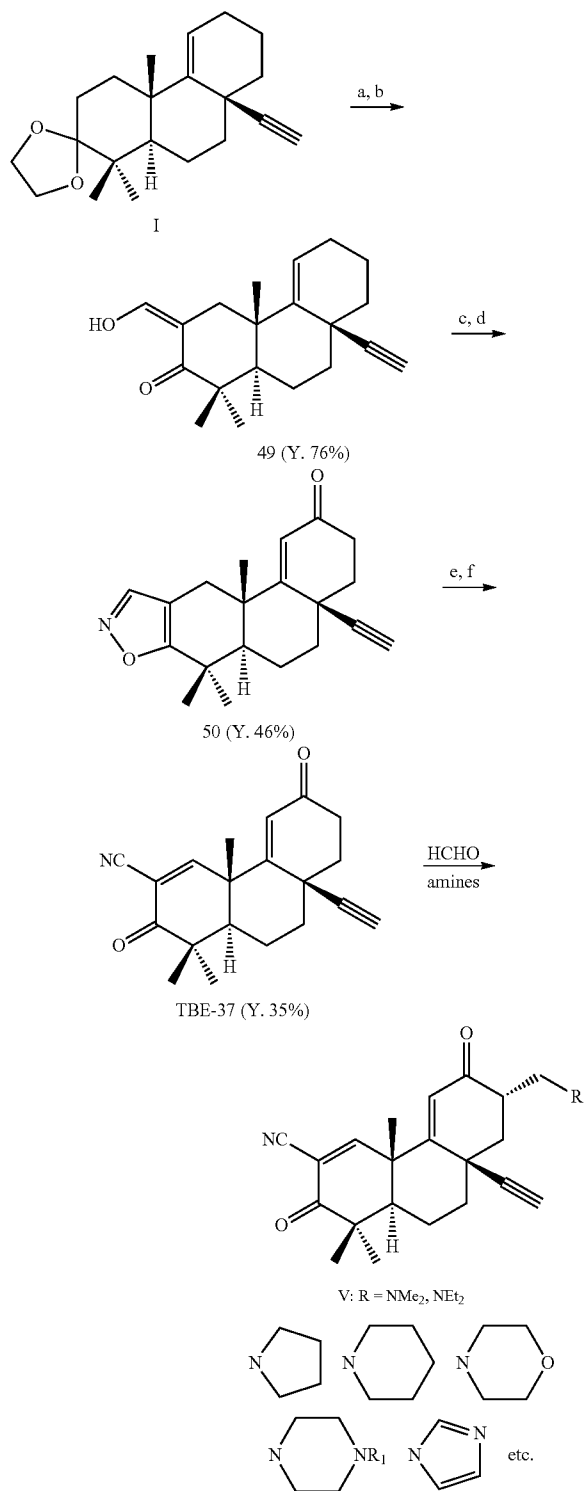
(a) MeLi, LDA, THF; TMSCl; (b) CrO₃, t-BuOOH, CH₂Cl₂; (c) p-TsCN, LDA, THF; (d) DDQ, PhH; (e) PPTS, acetone; (f) Stiles' reagent, DMF; (g) CH₃N₂; (h) PhSeCl, pyr., H₂O₂; (i) K₂CO₃.

[0163] Compound 43 can be synthesized by treatment of acetylide of I with TMSCl, followed by allylic oxidation. Cyanation of 43, followed by DDQ oxidation can afford 44. After removal of ketal of 44, 46 can be obtained from 45 by Stiles' reagent (Finkbeiner et al., 1963), followed by methylation. Addition of phenylselenenyl chloride (PhSeCl), followed by oxidation/elimination with H₂O₂ can give 47 (Liotta et al., 1981). The desired compound 48 can be prepared by treatment of 47 with K₂CO₃-MeOH-water (Cai et al., 1995).

[0164] viii. Design and Synthesis of New TBE-31 Analogs Containing Amino Side Chains from Compound I

[0165] A series of analogs with a C-8a alkyne group and C-7 amino side chains having general formula V (Scheme 16) was designed for the following reasons. In many cases, amine side chains like pyrrolidine, piperidine, imidazole etc. affect biological properties, e.g., potency and pharmacokinetics of the parent compounds. Also, salts of these amines would be soluble in water. Thirdly, because one Michael acceptor is diminished in these analogs in comparison with TBE-31 analogs, side effects and/or toxicity, which might be caused by Michael acceptors, may be reduced. They can be synthesized from TBE-37 by Mannich reactions with amines and formaldehyde under basic or acidic conditions. TBE-37 was synthesized from I by deketalization, followed by formylation with ethyl formate in the presence of sodium methoxide in benzene (Clinton et al., 1961). Treatment of 49 with hydroxylamine (Johnson et al., 1945), followed by allylic oxidation gave 50 in 46% yield. TBE-37 was prepared by cleavage of the isoxazole of 50 with sodium methoxide (Johnson et al., 1945), followed by DDQ oxidation (12% overall yield from I).

Scheme 16

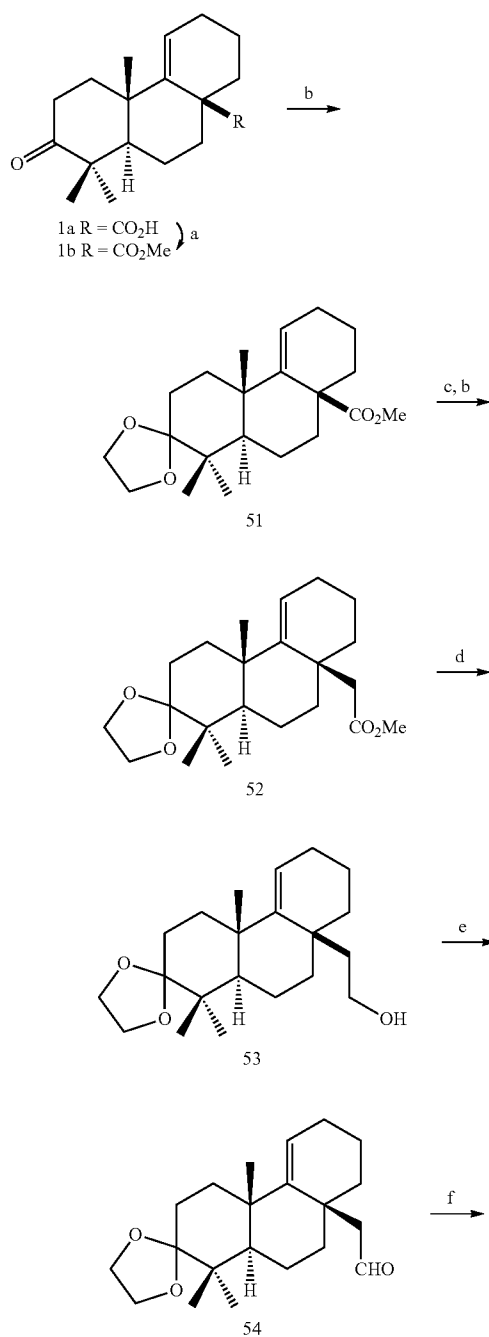


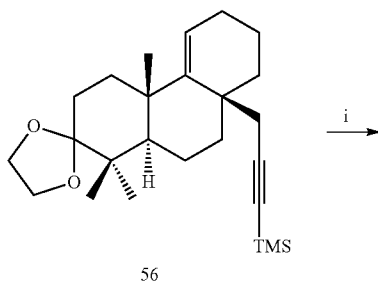
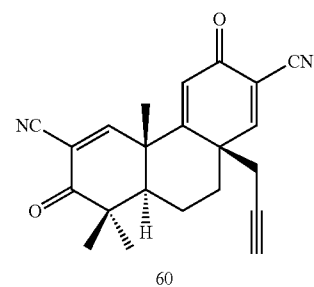
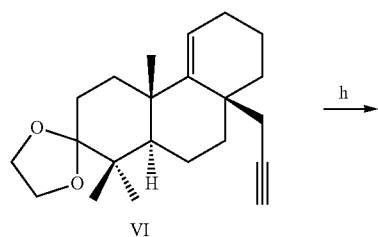
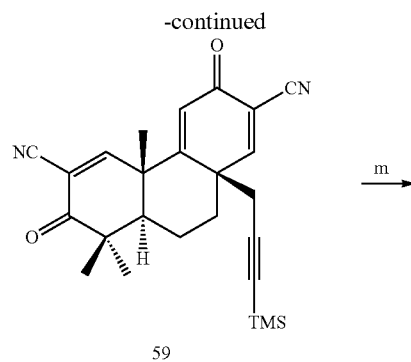
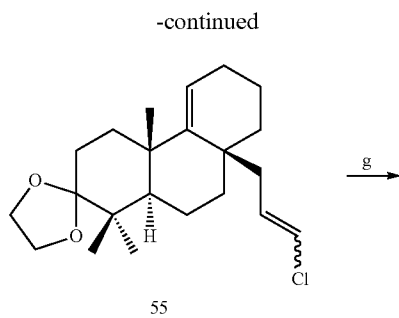
[0166] ix. The Design and Synthesis of Compound 60 Using Kowalski Ester Homologation

[0167] Compound 60, shown below, which has a three carbon chain including the terminal acetylene group at C-8a

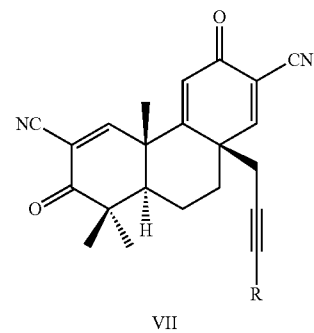
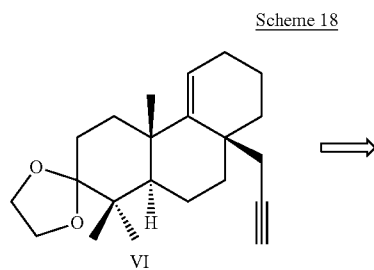
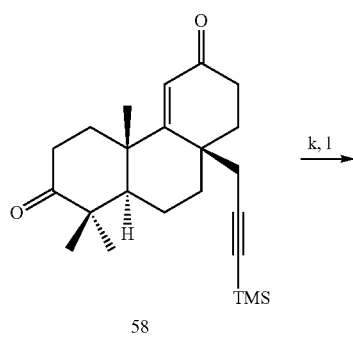
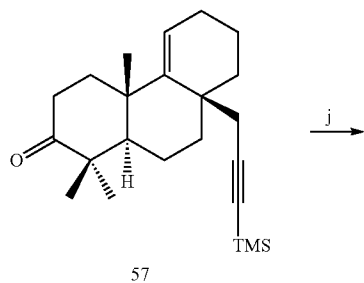
(contrast with TBE-31, which has a two carbon chain) can be made using the Kowalski method (Kowalski et al., 1992), shown in Scheme 17. Ketalization of 1b can give 51. Compound 51 can be converted to 52 by the Kowalski method. Compound 54 can be obtained from 52 by LiAlH₄ reduction, followed by Swern oxidation. Compound 60 can be synthesized via intermediate VI from 54 by the same sequence as for TBE-31. Intermediate VI is a key intermediate as well as I.

Scheme 17



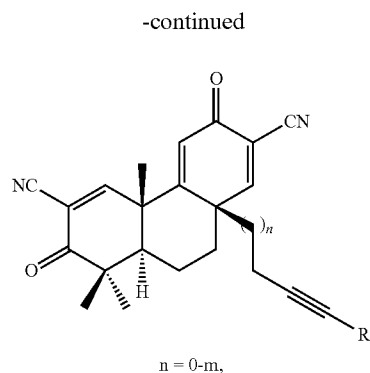


(a) CH_2N_2 , Et_2O , THF; (b) ethylene glycol, PPTS, PhH; (c) CH_2Br_2 , LiTMP; LiHMDS; *s*-BuLi; *n*-BuLi; MeOH, HCl (Kowalski method); (d) LAH, Et_2O ; (e) Swern oxidation; (f) $\text{Ph}_3\text{PCH}_2\text{Cl}_2$, *n*-BuLi, THF, HMPA; (g) MeLi, THF, aq NH_4Cl ; (h) MeLi, THF; TMSCl; (i) aq. HCl, MeOH; (j) CrO_3 , *t*-BuOOH, CH_2Cl_2 ; (k) *p*-TscN, LDA, THF; (l) DDQ, PhH; (m) TBAF, THF



[0168] Various analogs of compound VII can be prepared from compound VI using the same procedure as used for TBE-31 analogs (Scheme 18). Also, if one were to repeat the Kowalski method for 51, one can synthesize analogs shown in general formula VIII.

VIII:



IV. Bone- and Cartilage Forming Cells

[0169] The present invention describes methods for the *ex vivo* and *in vivo* formation of bone and cartilage using from osteogenic cells, chondrocytes, bone and cartilage precursor cells, as well as cell lines derived therefrom. The following section describes various sources for these cells, their isolation and characterization. Osteogenic or bone precursor cells are derived from primary sources such as bone marrow or bone. In addition, cells can be derived from several different species, including cells of human, bovine, equine, canine, feline and murine origin. Articular chondrocytes can generally be derived from humans according to the method taught by Hidvegi et al., 2006, which is incorporated herein by reference.

[0170] A. Bone Precursor Cells

[0171] Human bone precursor cells are characterized as small-sized cells that express low amounts of bone proteins (osteocalcin, osteonectin, and alkaline phosphatase) and have a low degree of internal complexity (Long et al., 1995). When stimulated to differentiate, these preosteoblast-like cells become osteoblast-like in their appearance, size, antigenic expression, and internal structure. Although these cells are normally present at very low frequencies in bone marrow, a process for isolating these cells has been described (Long et al., 1995). U.S. Pat. No. 5,972,703 further describes methods of isolating and using bone precursor cells, and is specifically incorporated herein by reference.

[0172] An example of a technique for isolating bone precursor cells involves the following steps. Mononuclear cells are prepared from bone marrow by separation on ficoll or other suitable equilibrium density separation techniques known to those of skill in the art. Low-density mononuclear cells are then cultured overnight culture to remove plastic-adherent cells. An enrichment step using immuno-affinity isolation involves collection of non-adherent low-density cells using anti-onectin (ON) and anti-osteocalcin (OC) antibodies immobilized on plastic as described (Long et al., 1995). The immune adherent cells were collected by trypsinization. Alternative enrichment steps may involve immuno-column chromatography or fluorescence-activated cell sorting. In addition to antibodies to osteonectin and osteocalcin, antibodies to alkaline phosphatase or other cell surface markers expressed on bone precursor cells can be utilized. These are described in greater detail in a following section.

[0173] As used herein, a bone precursor cell is any cell that is capable of differentiating or expanding into an osteoblast

cell. A bone precursor cell of the present invention is not hematopoietic and thus does not express the pan-hematopoietic antigen CD34. Preferred bone precursor cells include osteoprogenitor cells and preosteoblast cells.

[0174] Bone precursor cells can be further enriched by equilibrium-density centrifugation of bone marrow cells. Equilibrium-density centrifugation of bone marrow cells provides low density bone marrow cells enriched in bone precursor cells. In one embodiment, equilibrium-density centrifugation can be performed before the antibody purification. In a second embodiment, equilibrium-density centrifugation can be performed after the antibody purification. Alternatively, the equilibrium-density centrifugation purification step can be performed twice: before and after the antibody purification step.

[0175] In another aspect, the population of bone precursor cells can be enriched by removing stromal cells present in bone marrow cells. Removal of stromal cells can be accomplished by exposing bone marrow cells to an adherent surface, typically tissue culture plastic or glass. Stromal cells adhere to tissue culture plastic or glass while bone precursor cells do not. Stromal cells can be removed before or after the immune purification step. Preferably, stromal cells are removed prior to the immune purification step. The use of solid surfaces such as tissue culture plastic or glass is well known in the art. Tissue culture plastic and glass can be treated (e.g., silicone, nitrocellulose, nickel, etc.) to promote or inhibit cell adhesion. Treated and untreated surfaces are available commercially.

[0176] In another aspect, an enriched population of bone precursor cells is further fractionated according to size. In a preferred embodiment, size fractionation can be accomplished by fluorescence activated flow cytometry. Bone precursor cells of the present invention have average diameters of between about 8 microns and about 70 microns. Preferably, bone precursor cells have average diameters of between about 10 microns and about 20 microns.

[0177] B. Primary Human Osteoblasts

[0178] Another source of bone cells for use in the present invention are primary osteoblasts. An example of an isolation procedure for these cells can be found in Robey and Termaine (1985). Briefly, bone chips are obtained during orthopedic surgery. These are treated with Collagenase D for 2 hrs at 37° C., the non-adherent cells washed off, the bone pieces minced, and cultured in Ca²⁺-free media containing 10% FCS and Pen/Strep. After the cultures are confluent, the cells are collected by trypsinization and cultured in Ca²⁺-containing DMEM for 2-3 weeks. Bone-derived osteoblasts are recovered by trypsinization.

[0179] Alternative methods for isolating osteoblasts from bone are known in the art (see, for example, Aubin et al., 1982). As reported, the calvaria is excised, rinsed in a medium and minced with scissors. The minced bone is digested with collagenase for a short period of time in medium. The cells are removed by centrifugation and decanting the supernatant, leaving the bone pieces behind. Fetal calf serum is added to inhibit the collagenase digestion. Cells are plated at a low density in an appropriate growth medium, and clonal cell colonies are cultured in replicate for continuous culture and characterization.

[0180] C. Bone Cell Lines

[0181] In addition to primary osteoblasts and bone precursor cells as described above, various cell lines can be used as a starting point for *ex vivo* bone spheroid formation as

described by the methods in the present invention. Cell lines can be from a number of species, including human, bovine, equine, canine, feline and murine origin. Exemplary cell lines as described in the examples included in this invention are MG-63 cells (ATCC #CRL-1427), C3/H10T1/2 cells (ATCC #CCL-226) and SAOS-2 cells (ATCC #HTB-85). Other cell lines, also available through the American Type Culture Collection, include HOS cells (ATCC# CRL-1543) and various derivatives thereof, G-292 (ATCC# CRL-1423), SJS-1 cells (ATCC# CRL-2098), Hs 3.T cells (ATCC# CRL-7005), TE 415.T cells (ATCC# CRL-7764), TE 418.T cells (ATCC# CRL-7766), Hs 755(A).T cells (ATCC# CRL-7877), 143B cells (ATCC# CRL-8303), U-2 OS cells (ATCC# HTB-96) and T1-73 cells (ATCC# CRL-7943). These cell lines are all derived from human osteosarcomas. Similar osteosarcoma cell lines from several other species are available from ATCC.

[0182] D. Chondrocytes

[0183] Chondrocytes are the only cells found in cartilage. They produce and maintain the cartilagenous matrix. From least-to terminally-differentiated, the chondrocytic lineage is (a) colony-forming unit-fibroblast (CFU-F), (b) mesenchymal stem cell/marrow stromal cell (MSC), (c) chondrocyte, an (d) hypertrophic chondrocyte. When referring to bone or cartilage, mesenchymal stem cells (MSC) are commonly known as osteochondrogenic (or osteogenic, chondrogenic, osteoprogenitor, etc.) cells since a single MSC has shown the ability to differentiate into chondrocytes or osteoblasts, depending on the medium. In vivo, differentiation of a MSC in a vascularized area (such as bone) yields an osteoblasts, whereas differentiation of a MSC in a non-vascularized area (such as cartilage) yields a chondrocyte. Chondrocytes undergo terminal differentiation when they become hypertrophic during endochondral ossification. This last stage is characterized by major phenotypic changes in the cell. Although chondroblast is still commonly used to describe an immature chondrocyte, use of the term is discouraged, for it is technically inaccurate, since the progenitor of chondrocytes (which are mesenchymal stem cells) can also differentiate into osteoblasts.

V. Cellular Markers

[0184] A. Bone Cells and Precursors

[0185] Various cellular markers are used to define and/or purify osteogenic precursor cells for use in the present invention. Bone precursor cells, such as those described in U.S. Pat. No. 5,972,703, herein incorporated in its entirety by reference, are immunoreactive with bone precursor cell antibody. A bone precursor cell antibody is used to enrich the population of bone precursor cells. Bone precursor cell antibodies include anti-osteocalcin, anti-osteonectin, and anti-bone alkaline phosphatase. Anti-osteocalcin, anti-osteonectin, and anti-bone alkaline phosphatase were described in Shull et al. (1984). As bone precursor cells are further characterized, other antibodies which immunoreact with a bone precursor cell may be generated by one of ordinary skill in the art. The use of these other antibodies immunoreactive with a bone precursor cell are contemplated as well. In a particular embodiment, a bone precursor cell antibody is conjugated to a solid substrate. The solid substrate is preferably a tissue culture or petri dish. The use of solid surfaces such as tissue culture plastic or glass is well known in the art. Tissue culture plastic and glass can be treated (e.g., silicone, nitrocellulose, nickel, etc.) to promote or inhibit protein adhesion. Treated and untreated surfaces are available commercially. Antibody

coated tissue culture dishes can be utilized to "pan" for bone precursor cells. Briefly, bone marrow cells containing bone precursor cells are incubated on antibody coated dishes. Bone precursor cells adhere to the antibodies while all other cells do not adhere to the dish. After incubation, the dish non-adherent cells are removed by gently washing the dish with media. Bone precursor cells were removed from the dish and further analyzed, purified or differentiated into osteoblasts.

[0186] In another embodiment, a second antibody immunoreactive with a bone precursor cell antibody can be used to enrich the population of bone precursor cells. The use of a secondary antibody is generally known in the art. Typically, secondary antibodies are antibodies immunoreactive with the constant regions of the first antibody. Preferred secondary antibodies include anti-rabbit, anti-mouse, anti-rat, anti-goat, and anti-horse and are available commercially. In a preferred embodiment, secondary antibodies are conjugated to a solid substrate including tissue culture dish, agarose, polyacrylamide, and magnetic particles. In this embodiment, a bone precursor cell antibody is first immunoreacted to a bone precursor cell. The bone precursor cell with the attached antibody is next exposed to the secondary antibody that is conjugated to a solid substrate. Enrichment of precursor cells is achieved because only cells that present a bone precursor cell antibody immunoreact with the secondary antibody. A commercially available kit provides secondary antibodies conjugated to magnetic particles. In this system, bone precursor cells that present a bone precursor cell antibody are purified by exposure to a magnetic field.

[0187] The preparation of bone antibodies (i.e., to osteonectin, osteocalcin and alkaline phosphatase) was reported in Shull et al., 1989, incorporated herein by reference. Both polyclonal and monoclonal antibodies are contemplated by the present invention. Means for preparing and characterizing antibodies are well known in the art (see, e.g., Harlow and Lane, 1988).

[0188] Cell surface antigens on normal cells of the osteogenic lineage have been reported for avian and rodent species (Brunder and Caplan, 1989; 1990; Turksen et al., 1992). Some of these antibodies reported also react with cells other than those found in bone. Monoclonal antibodies have been raised against intracellular antigens in normal human osteoblasts and against the surface of transformed human osteogenic cell lines (Embleton et al., 1981; Hosoi et al., 1982; Heiner et al., 1987; Bruland et al., 1988; Tsai et al., 1990; Walsh et al., 1994). Examples of osteogenic cell markers, production of antibodies and hybridomas, as well as methods of using these markers are described in U.S. Pat. No. 5,643,736. An example of a monoclonal antibody against a cell surface epitope capable of identifying human osteogenic cells is one directed against alkaline phosphatase (Lawson et al., 1985). This well-characterized cell surface enzyme has served as the historical standard for identifying a large family of osteogenic cells, and is readily demonstrated by a simple histochemical stain.

[0189] Other preferred antigens include osteocalcin and osteonectin. Osteocalcin is a vitamin K-dependent bone calcium binding protein also called bone gla protein (BGP). Particularly, human osteocalcin is a relatively small protein composed of 49 amino acids and having a molecular weight of 5800. This protein is produced from osteoblast, and occupies about 20% of the constituent components of non-collagen protein of the bones. This protein contains gamma-carboxyglutamic acid residues and has a strong affinity for hydroxyapatite, and it is therefore presumed to have an

important role in the formation of the bone matrices. Osteonectin, also termed BM40 or SPARC (secreted protein, acidic and rich in cysteine) is a multifunctional glycoprotein involved in tissue mineralization, cell-extracellular matrix interactions as well as angiogenesis. Non-collagenous, calcium-binding glycoprotein of developing bone. It links collagen to mineral in the bone matrix.

[0190] The monoclonal antibodies against precursor cells can be labeled with suitable radioactive, enzymatic, fluorescent or other labels by conventional methods and/or bound to suitable solid carriers, which will be apparent to those skilled in the art. For example, monoclonal antibodies can be used in combination with, or coupled to, an immunochemical such as fluorescein isothiocyanate, peroxidase, biotin and its analogs (e.g., iminobiotin), avidin and its analogs (streptavidin), or other such markers. Moreover, monoclonal antibodies can be bound or attached to certain substrates and utilized to capture osteogenic cells when tissue samples such as bone cell isolates, periosteal biopsies, or cultured cells are brought in contact with the attached monoclonal antibodies. The bound cells may then be separated from the solid phase by known methods depending essentially upon the nature of the solid phase and the antibody. The bound cells can be recovered and used for various therapeutic purposes such as for the regeneration of bone, etc., depending upon the various external and internal factors.

[0191] As a result, the present invention contemplates any method of employing monoclonal antibodies to separate normal osteogenic cell subsets from other cells such as fibroblastic or hemopoietic cells. For example, a further embodiment of the present invention is directed to a method of producing a population of normal human osteogenic cell subsets comprising the steps of providing a cell suspension of tissue containing such cells; contacting the cell suspension with monoclonal antibodies which recognize an epitope on the osteogenic cells but do not recognize an epitope on the fibroblastic or hemopoietic cells; and separating and recovering from the cell suspension the cells bound by the monoclonal antibodies.

[0192] B. Cartilage Cells and Precursors

[0193] Chondrocytes are cells found in cartilage. They produce and maintain the cartilaginous matrix. From least-to terminally-differentiated, the chondrocytic lineage starts with colony-forming unit-fibroblasts (CFU-F), which develop into mesenchymal stem cells/marrow stromal cells (MSC), continues to develop into chondrocytes, and then hypertrophic chondrocytes. In the context of bone or cartilage, mesenchymal stem cells (MSC) are commonly known as osteochondrogenic (or osteogenic, chondrogenic, osteoprogenitor, etc.) cells since a single MSC can differentiate into chondrocytes or osteoblasts, depending on the medium. In vivo, differentiation of a MSC in a vascularized area (such as bone) yields an osteoblast, whereas differentiation of a MSC in a non-vascularized area (such as cartilage) yields a chondrocyte. Chondrocytes undergo terminal differentiation when they become hypertrophic, which occurs during endochondral ossification. This last stage is characterized by major phenotypic changes on the cellular level.

[0194] The classic markers of the chondrocytic phenotype are Sox9, collagen II, and aggrecan (Sive et al., 2002). Sox9 is known to play a major role in chondrocyte differentiation and maintenance of the chondrocytic phenotype. The product of the collagen II (Col2a1) gene is an early and practically

unique marker of chondrocyte differentiation, and aggrecan is the characteristic proteoglycan produced by chondrocytes.

VI. Bone/Cartilage Growth Factors

[0195] The use of growth factors from the TGF- β gene superfamily to produce bone ex vivo is an important aspect of the present invention. The following section details attributes of the TGF- β gene superfamily. Of particular use are growth factors that induce the formation of a bone cell spheroid, as defined in the previous section.

[0196] The transforming growth factor- β superfamily is a well-characterized family of proteins involved in cellular proliferation and differentiation of cells into various tissues. Members of the TGF- β superfamily are generally dimeric in structure, comprising two monomeric units which are produced by proteolytic cleavage from a larger precursor protein, of which the processed monomer represents the carboxyl terminal portion. The dimeric TGF- β proteins generally have molecular weights of approximately 20,000 to 35,000 and share a common cysteine pattern in the mature protein region. See, for example, Sporn et al. (1986) and the papers cited therein. The TGF- β superfamily includes several subgroups beside TGF- β 1 through - β 5. These are the bone morphogenetic proteins (BMPs), growth and differentiation factors (GDFs), the inhibins, as well as GDNF and Mullerian inhibitory substance and other structurally related proteins. The TGF- β superfamily also includes proteins from other species, which have been characterized and are highly conserved compared to the mammalian TGF- β s, including Vg1 (Xenopus), (Weeks and Melton, 1987); Dpp, Screw and 60A (Drosophila), (Padgett et al., 1987; Doctor et al., 1992); and more recently identified proteins including Univin (sea urchin), Dorsalin-1 (chicken) and Radar (Zebrafish). Other factors which may be effectively used in the composition include synthetic molecules or fragments of a TGF- β superfamily member which are able to bind to a TGF- β receptor molecule.

[0197] The transforming growth factor- β (TGF- β) family of proteins consists of a number of related, but functionally distinct, proteins (Barnard, 1990; Roberts and Sporn, 1990). One member of the TGF- β family of proteins, TGF- β 1, is a multifunctional cytokine with both growth promoting and inhibiting activities. Recently, TGF- β 1 has been found to play a role in modulating repair of vascular injuries such as restenosis lesions (Nikol et al., 1992) and atherosclerotic plaques (Kojima et al., 1991).

[0198] Members of the TGF- β family of proteins initiate cell signaling by binding to heteromeric receptor complexes of type I (T β RI) and type II (T β RII) serine/threonine kinase receptors (reviewed by Massague et al., 1994; Miyazono et al., 1994). Activation of this heteromeric receptor complex occurs when TGF- β binds to T β RII, which then recruits and phosphorylates T β RI. Activated T β RI then propagates the signal to downstream targets (Chen and Weinberg, 1995; Wrana et al., 1994).

[0199] Until now, three distinct types of TGF- β s designated as TGF- β 1, TGF- β 2 and TGF- β 3 which are functionally closely related and share a high degree of receptor cross-reactivity have been cloned and characterized by sequence analysis. All TGF- β s are synthesized as 390 to 412 amino acid precursors that undergo proteolytic cleavage to produce the monomeric forms, which consist of the C-terminal 112 amino acids. In their mature, biologically active forms, TGF- β s are acid- and heat-stable disulfide-linked homodimers of two

polypeptide chains of 112 amino acids each. The complete amino acid sequences of human (Derynck et al., 1985), murine (Derynck et al., 1986) and simian TGF- β 1 (Sharples et al., 1987) show remarkable sequence conservation, differing only in a single amino acid residue. Comparison of the amino acid sequence of human TGF- β 1, human TGF- β 2 (de Martin et al., 1987; Marquardt et al., 1987) and human TGF- β 3 (Ten Dijke et al. 1988) has demonstrated that the three proteins exhibit in their mature forms about 70-80% sequence identity. A heterodimeric TGF- β 1.2 has been isolated from porcine platelets and consists of one subunit of TGF- β 1 disulfide-linked to one subunit of TGF- β 2 (Cheifetz et al., 1987).

[0200] The search for the molecule or molecules responsible for formation of bone, cartilage, tendon and other tissues present in bone and other tissue extracts has led to the discovery of a novel set of molecules called the Bone Morphogenetic Proteins (BMPs), which are also members of the TGF- β gene family. The structures of several proteins, designated BMP-1 through BMP-15, have previously been elucidated. The unique inductive activities of these proteins, along with their presence in bone, cartilage and/or other vital tissues, suggests that they are important regulators of bone and other tissue repair processes, and may be involved in tissue formation, maintenance and repair. There is a need to identify improved methods and compositions for formation, maintenance and repair of such tissues.

[0201] Members of the bone morphogenetic protein family have been shown to be useful for induction of cartilage and bone formation. For example, BMP-2 has been shown to be able to induce the formation of new cartilage and/or bone tissue *in vivo* in a rat ectopic implant model, see U.S. Pat. No. 5,013,649; in mandibular defects in dogs (Toriumi et al., 1991); in femoral segmental defects in sheep (Gerhart et al., 1991). Other members of the BMP family have also been shown to have osteogenic activity, including BMP-4, -6 and -7 (Wozney, 1993). BMP proteins have also been shown to demonstrate inductive and/or differentiation potentiating activity on a variety of other tissues, including cartilage, tendon, ligament, neural tissue.

[0202] Other factors that are useful in accordance with the present invention include the following: BMP-3 (Vukicevic et al., 1989); growth factors, such as basic fibroblast growth factor (bFGF); glucocorticoids, such as dexamethasone (Cheng et al., 1994); and prostaglandins, such as prostaglandin E1 (Chen et al., 1991). Further, ascorbic acid and its analogs, such as ascorbic acid-2-phosphate (Tennenbaum et al., 1982) and glycerol phosphates, such as β -glycerophosphate (Bruder et al., 1991) are effective adjunct factors for advanced differentiation, although alone they do not induce osteogenic differentiation. Other factors include Inhibin A (Chen et al., 1993), chondrogenic stimulatory activity factor (CSA) (Syftestad et al., 1985), collagenous extracellular matrix molecules, including type I collagen, particularly as a gel (Kimura et al., 1984), and vitamin A analogs, such as retinoic acid (Langille et al., 1989).

[0203] Also of interest in the present invention are insulin-like growth factors. IGF-I and IGF-II each have a molecular weight of about 7,500 daltons. Each of IGF-I and IGF-II possesses A and B domains that are highly homologous to the corresponding domains of proinsulin. A and B domains are connected to each other by a C domain. A carboxy-terminal extension, the D domain, is present in IGF, but is not found in proinsulin. Both IGF-I and IGF-II are single-chain polypeptides each with 3 disulfide bridges and have a sequence iden-

tity of 49% and 47%, respectively, to human insulin A chain and B chain. Like insulin, IGFs stimulate phosphorylation of specific tyrosine residues within the cytoplasmic domain of the receptors to which they bind, as described in WO 93/98826. The designation "insulin-like growth factor" was chosen to express the insulin-like effects and the insulin-like structure of these polypeptides which act as mitogens on a number of cells, as described in EP 128 733. IGF-I is a 70 amino acid peptide, while IGF-II is a 67 amino acid peptide, as described in Rinderknecht (1978a) and (1978b). IGF-I and IGF-II have 62% structural homology to each other. Both have been isolated from human serum.

[0204] Insulin-like growth factors are also known under the class name somatomedins, and have been identified in various animal species as polypeptides that act to stimulate growth of cells in a variety of tissues and cell types, particularly during development. Growth promoting effects of somatomedins include enhancement of cell multiplication and stimulation of cartilage proliferation, stimulation of transport of amino acids, stimulation of synthesis of RNA, DNA and protein, and stimulation of incorporation of sulfate into proteoglycan and of proline into collagen. Much mammalian postnatal growth is due to stimulation of cartilage growth by somatomedins and growth *in utero* may also be somatomedin-dependent.

[0205] Yet another important growth factor that can be utilized according to the present invention is vascular endothelial growth factor/vascular permeability factor (VEGF/VPF). This protein is an endothelial cell-specific mitogen which has been shown to be stimulated by hypoxia and required for tumor angiogenesis. Sanger et al. (1986); Kim et al. (1993); Schweiki et al. (1992); Plate et al. (1992). It is a 34-43 kDa (with the predominant species at about 45 kDa) dimeric, disulfide-linked glycoprotein synthesized and secreted by a variety of tumor and normal cells. VEGF appears to play a principle role in many pathological states and processes related to neovascularization

VII. Ex Vivo Culturing of Bone and Cartilage Cells

[0206] The present invention calls for the use of serum-free media for growth and differentiation of the bone and cartilage cells and precursors thereof. The use of serum-free culture for the manufacture of recombinant biopharmaceuticals from mammalian cells has been thoroughly reviewed (Barnes, 1987; Barnes and Sam, 1980; Broad et al., 1991; Jayme, 1991). The list of the main additives which are used as supplements for serum-free media is summarized by Barnes (1987) and Barnes & Sam (1980). Most commercially available serum-free media contain a carrier protein such as albumin. The presence of carrier protein might be required for protection of the cell viability.

[0207] An example of serum free culture medium can be found in U.S. Pat. No. 5,063,157, herein incorporated by reference. The media described is for non-adherent mammalian cells comprises, in addition to the base medium, transferrin, insulin, a peptone, a β -D-xylopyranose derivative, selenite and a biological polyamine. Another serum free cell growth medium for mammalian cells is disclosed in U.S. Pat. No. 4,443,546. This growth medium, in addition to the basic medium, contains seven ingredients. European Patent Application 481,791 discloses a culture medium for CHO cells comprising water, an osmolality regulator, a buffer, an energy source, amino acids, an iron source, a growth factor and other

optional components. The two media exemplified contain 19 and 17 components, respectively. Other additives are disclosed below.

[0208] A. Albumin

[0209] Albumin is preferably supplied in the form of bovine (BSA) or human serum albumin (HSA) in an effective amount for the growth of cells. Albumin provides a source of protein in the media. Albumin is thought to act as a carrier for trace elements and essential fatty acids. Preferably, the albumin used in the present formulations is free of pyrogens and viruses, and when necessary, is approved regulatory agencies for infusion into human patients. The HSA may be deionized using resin beads prior to use. The concentration of human serum albumin is 1-8 mg/ml, more particularly 3-5 mg/ml, and specifically 4 mg/ml.

[0210] B. Soluble Carrier/Fatty Acid Complex

[0211] The albumin mentioned above could be substituted by a soluble carrier/essential fatty acid complex and a soluble carrier cholesterol complex which can effectively deliver the fatty acid and cholesterol to the cells. An example of such a complex is a cyclodextrin/linoleic acid, cholesterol and oleic acid complex. This is advantageous as it would allow for the replacement of the poorly characterized albumin with a well defined molecule. The use of cyclodextrin removes the need for the addition of human/animal serum albumin, thereby eliminating any trace undesired materials which the albumin would introduce into the media. The use of cyclodextrin simplifies the addition of specific lipophilic nutrients to a serum-free culture.

[0212] The lipophilic substances which can be complexed with cyclodextrin include unsaturated fatty acids such as linoleic acid, cholesterol and oleic acid. The linoleic acid, cholesterol and oleic acid are present in effective amounts and can be present in equal proportions such that the total amount is 0.001 to 100 µg/ml, particularly 0.1 to 10 µg/ml. The preparation of such complexes is known in the art and is described, for example, in U.S. Pat. No. 4,533,637, the entire contents of which is hereby incorporated by reference.

[0213] C. Iron Source

[0214] A source of iron in an effective amount and in a form that can be utilized by the cells can be added to the media. The iron can be supplied by saturating transferrin, its carrier molecule, in an effective amount. The transferrin may be derived from animal sera or recombinantly synthesized. It is understood that when transferrin is derived from an animal source, it is purified to remove other animal proteins, and thus is usually at least 99% pure. The transferrin concentration is usually between 80 and 500 µg/ml, in particular between 120 and 500 µg/ml, more particularly between 130 and 500 µg/ml, even more particularly between 275 and 400 µg/ml and specifically 300 µg/ml. An iron salt, preferably a water soluble iron salt, such as iron chloride (e.g., FeCl₃·6H₂O) dissolved in an aqueous solution such as an organic acid solution (e.g., citric acid) is used to supply the iron to transferrin. One mole of iron chloride is usually used for every mole of citric acid. The concentration of iron chloride is 0.0008 to 8 µg/ml, more particularly 0.08 to 0.8 µg/ml, and specifically 0.08 µg/ml.

[0215] D. Insulin Growth Factor

[0216] Insulin also may be added to the media of the present invention in an effective amount. The insulin concentration is between 0.25 and 2.5 U/ml, more preferably 0.4-2.1 U/ml, most preferably 0.48 U/ml. In the conversion of Units to mass, 27 U=1 mg. Therefore, incorporating the conversion, the insulin concentration is approximately between 9.26

µg/ml and 92.6 µg/ml, more particularly between 14.8 µg/ml and 77.8 µg/ml, and specifically 17.7 µg/ml. It is again understood that human insulin is more desirable than animal insulin. Highly purified recombinant insulin is most preferred. An insulin like growth factor such as insulin like growth factor 1 and insulin like growth factor 2 may be used in place of or in addition to insulin in an amount which provides substantially the same result as a corresponding amount of insulin. Thus, the term "insulin growth factor" includes both insulin and insulin like growth factors.

[0217] E. Additional Components

[0218] The addition of other lipids to the above essential reagents could enhance the proliferative potential of precursor cells. These components, however, are preferably not added unless they are necessary for a particular experiment or to grow a particular type of cell. Optionally, triglycerides and/or phospholipids may be included as additional sources of lipid. A preferable source of lipid contains a mixture of neutral triglycerides of predominantly unsaturated fatty acids such as linoleic, oleic, palmitic, linolenic, and stearic acid. Such a preparation may also contain phosphatidylethanolamine and phosphatidylcholine. Another source of lipid is a human plasma fraction precipitated by ethanol and preferably rendered virus free by pasteurization.

[0219] Other ingredients which can optionally be added to the media are cited in the following references: WO 95/06112, U.S. Pat. No. 4,533,637, U.S. Pat. No. 5,405,772. The entire contents of all of these references are incorporated by reference.

[0220] F. Undesired Components

[0221] When the media is to be used to grow cells for introduction into a human patient, the media preferably does not contain ingredients such as bovine serum albumin, mammalian serum, and/or any natural proteins of human or mammalian origin (as explained above). It is preferable that recombinant or synthetic proteins, if they are available and of high quality, are used. Most preferably, the amino acid sequences of the recombinant or synthetic proteins are identical to or highly homologous with those of humans. Thus, the most preferable serum-free media formulations herein contain no animal-derived proteins and do not have even a non-detectable presence of animal protein.

[0222] In the most ideal system, optional components which are not necessary are preferably not added to the medium. Such optional components are described in the prior art cited above and may be selected from the group consisting of meat extract, peptone, phosphatidylcholine, ethanolamine, anti-oxidants, deoxyribonucleosides, ribonucleosides, soy bean lecithin, corticosteroids, myoinositol, monothioglycerol, and bovine or other animal serum albumin.

VIII. Pharmaceutical Formulations and Routes of Administration

[0223] The compounds of the present invention may be administered by a variety of methods, e.g., orally or by injection (e.g. subcutaneous, intravenous, intraperitoneal, etc.). Depending on the route of administration, the active compounds may be coated in a material to protect the compound from the action of acids and other natural conditions which may inactivate the compound. They may also be administered by continuous perfusion/infusion of a disease or wound site.

[0224] To administer the therapeutic compound by other than parenteral administration, it may be necessary to coat the compound with, or co-administer the compound with, a mate-

rial to prevent its inactivation. For example, the therapeutic compound may be administered to a patient in an appropriate carrier, for example, liposomes, or a diluent. Pharmaceutically acceptable diluents include saline and aqueous buffer solutions. Liposomes include water-in-oil-in-water CGF emulsions as well as conventional liposomes (Strejan et al., 1984).

[0225] The therapeutic compound may also be administered parenterally, intraperitoneally, intraspinally, or intracerebrally. Dispersions can be prepared in glycerol, liquid polyethylene glycols, and mixtures thereof and in oils. Under ordinary conditions of storage and use, these preparations may contain a preservative to prevent the growth of microorganisms.

[0226] Pharmaceutical compositions suitable for injectable use include sterile aqueous solutions (where water soluble) or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. In all cases, the composition must be sterile and must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (such as, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), suitable mixtures thereof, and vegetable oils. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Prevention of the action of microorganisms can be achieved by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, ascorbic acid, thimerosal, and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars, sodium chloride, or polyalcohols such as mannitol and sorbitol, in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent which delays absorption, for example, aluminum monostearate or gelatin.

[0227] Sterile injectable solutions can be prepared by incorporating the therapeutic compound in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the therapeutic compound into a sterile carrier which contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying which yields a powder of the active ingredient (i.e., the therapeutic compound) plus any additional desired ingredient from a previously sterile-filtered solution thereof.

[0228] The therapeutic compound can be orally administered, for example, with an inert diluent or an assimilable edible carrier. The therapeutic compound and other ingredients may also be enclosed in a hard or soft shell gelatin capsule, compressed into tablets, or incorporated directly into the subject's diet. For oral therapeutic administration, the therapeutic compound may be incorporated with excipients and used in the form of ingestible tablets, buccal tablets, troches, capsules, elixirs, suspensions, syrups, wafers, and the like. The percentage of the therapeutic compound in the compositions and preparations may, of course, be varied. The

amount of the therapeutic compound in such therapeutically useful compositions is such that a suitable dosage will be obtained.

[0229] It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the subjects to be treated; each unit containing a predetermined quantity of therapeutic compound calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the dosage unit forms of the invention are dictated by and directly dependent on (a) the unique characteristics of the therapeutic compound and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding such a therapeutic compound for the treatment of a selected condition in a patient.

[0230] Active compounds are administered at a therapeutically effective dosage sufficient to treat a condition associated with a condition in a patient. A "therapeutically effective amount" preferably reduces the amount of symptoms of the condition in the infected patient by at least about 20%, more preferably by at least about 40%, even more preferably by at least about 60%, and still more preferably by at least about 80% relative to untreated subjects. For example, the efficacy of a compound can be evaluated in an animal model system that may be predictive of efficacy in treating the disease in humans, such as the model systems shown in the examples and drawings.

IX. Diseases and Conditions Requiring Bone Repair

[0231] The following is a brief discussion of several conditions to exemplify the variety of diseases and disorders that would benefit from the development of new technology to improve bone/cartilage repair and healing processes. In addition to the following, several other conditions, such as vitamin D deficiency, may also benefit from such treatments.

[0232] A. Fracture

[0233] The first example is the otherwise healthy individual who suffers a fracture. Often, clinical bone fracture is treated by casting to alleviate pain and allow natural repair mechanisms to repair the wound. There has been progress in the treatment of fracture in recent times, however, even without considering the various complications that may arise in treating fractured bones, any new procedures to increase bone healing in normal circumstances would be represent a great advance.

[0234] B. Osteogenesis Imperfecta

[0235] A second example which may benefit from new treatment methods is osteogenesis imperfecta (OI). OI encompasses various inherited connective tissue diseases that involve bone and soft connective tissue fragility in humans (Byers & Steiner, 1992; Prockop, 1990). About one child per 5,000-14,000 born is affected with OI and the disease is associated with significant morbidity throughout life. A certain number of deaths also occur, resulting from the high propensity for bone fracture and the deformation of abnormal bone after fracture repair (OI types II-IV; Bonadio & Goldstein, 1993). The relevant issue here is quality of life; clearly, the lives of affected individuals would be improved by the development of new therapies designed to stimulate and strengthen the fracture repair process.

[0236] OI type I is a mild disorder characterized by bone fracture without deformity, blue sclerae, normal or near nor-

mal stature, and autosomal dominant inheritance (Bonadio & Goldstein, 1993). Osteopenia is associated with an increased rate of lone bone fracture upon ambulation (the fracture frequency decreases dramatically at puberty and during young adult life, but increases once again in late middle age). Hearing loss, which often begins in the second or third decade, is a feature of this disease in about half the families and can progress despite the general decline in fracture frequency. Dentinogenesis imperfecta is observed in a subset of individuals.

[0237] In contrast, OI types II-VI represent a spectrum of more severe disorders associated with a shortened life-span. OI type II, the perinatal lethal form, is characterized by short stature, a soft calvarium, blue sclerae, fragile skin, a small chest, floppy appearing lower extremities (due to external rotation and abduction of the femurs), fragile tendons and ligaments, bone fracture with severe deformity, and death in the perinatal period due to respiratory insufficiency. Radiographic signs of bone weakness include compression of the femurs, bowing of the tibiae, broad and beaded ribs, and calvarial thinning

[0238] OI type III is characterized by short stature, a triangular facies, severe scoliosis, and bone fracture with moderate deformity. Scoliosis can lead to emphysema and a shortened life-span due to respiratory insufficiency. OI type IV is characterized by normal sclerae, bone fracture with mild to moderate deformity, tooth defects, and a natural history that essentially is intermediate between OI type II and OI type I.

[0239] More than 150 OI mutations have been characterized since 1989 (reviewed in Byers & Steiner, 1992; Prockop, 1990). The vast majority occur in the COL1A1 and COL1A2 genes of type I collagen. Most cases of OI type I appear to result from heterozygous mutations in the COL1A1 gene that decrease collagen production but do not alter primary structure, i.e., heterozygous null mutations affect COL1A1 expression.

[0240] C. Osteoporosis

[0241] A third, important example is osteoporosis. The term osteoporosis refers to a heterogeneous group of disorders characterized by decreased bone mass and fractures. An estimated 20-25 million people are at increased risk for fracture because of site-specific bone loss. Risk factors for osteoporosis include increasing age, gender (more females), low bone mass, early menopause, race (Caucasians), low calcium intake, reduced physical activity, genetic factors, environmental factors (including cigarette smoking and abuse of alcohol or caffeine), and deficiencies in neuromuscular control that create a propensity to fall.

[0242] More than a million fractures in the USA each year can be attributed to osteoporosis, and in 1986 alone the treatment of osteoporosis cost an estimated 7-10 billion health care dollars. Demographic trends (i.e., the gradually increasing age of the U.S. population) suggest that these costs may increase to \$62 billion by the year 2020. Clearly, osteoporosis is a significant health care problem.

[0243] Clinically, osteoporosis is segregated into type I and type II. Type I osteoporosis occurs predominantly in middle aged women and is associated with estrogen loss at the menopause, while osteoporosis type II is associated with advancing age. Much of the morbidity and mortality associated with osteoporosis results from immobilization of elderly patients following fracture.

[0244] Current therapies for osteoporosis patients focus on fracture prevention, not fracture repair. This remains an

important consideration because of the literature, which clearly states that significant morbidity and mortality are associated with prolonged bed rest in the elderly, particularly those who have suffered hip fractures. Complications of bed rest include blood clots and pneumonia. These complications are recognized and measures are usually taken to avoid them, but these is hardly the best approach to therapy. thus, the osteoporotic patient population would benefit from new therapies designed to strengthen bone and speed up the fracture repair process, thus getting these people on their feet before the complications arise.

[0245] D. Osteoarthritis

[0246] Current estimations suggest that 40 million Americans of all ages are affected by osteoarthritis and that 70 to 90 percent of Americans older than 75 years have at least one involved joint. Estimates of the prevalence of osteoarthritis based on radiographic evidence range from 30 to 90 percent. Men and women are equally affected, but symptoms occur earlier and appear to be more severe in women. Common synonyms for osteoarthritis include osteoarthrosis and degenerative joint disease. Osteoarthritis is not an inevitable consequence of aging. It is an acquired degenerative process that can be managed effectively by family physicians.

[0247] The exact etiology of osteoarthritis is unknown. Multiple factors (e.g., heredity, trauma, and obesity) interact to cause this disorder. Any event that changes the environment of the chondrocyte has the potential to cause osteoarthritis. Although usually occurring as a primary disorder, osteoarthritis can occur secondary to other processes. Although the term "osteoarthritis" is often used, "osteoarthrosis" may be more appropriate. Degenerative changes are the predominant factor contributing to disability. In joints with osteoarthritis, inflammation may be present; however, it is usually mild and involves only the periarticular tissues.

[0248] The pathophysiology involves a combination of mechanical, cellular, and biochemical processes. The interaction of these processes leads to changes in the composition and mechanical properties of the articular cartilage. Cartilage is composed of water, collagen, and proteoglycans. In healthy cartilage, continual internal remodeling occurs as the chondrocytes replace macromolecules lost through degradation. This process becomes disrupted in osteoarthritis, leading to increased degenerative changes and an abnormal repair response.

[0249] Joint use provides physiologic stimulation through the noncellular matrix that helps direct chondrocyte synthetic activity and internal tissue remodeling. Prolonged decreased joint use leads to changes in the matrix composition, resulting in subsequent loss of tissue function. The resumption of joint use can help restore the properties of the joint toward normal.

[0250] The strong association between age and osteoarthritis may be best explained by age-related changes in the matrix composition and a decrease in chondrocyte function and responsiveness to stimuli. These changes can interfere with continued internal remodeling, maintenance of the tissue, and loss of cartilage. This leads to an increased risk for cartilage degradation and injury to include surface defects in the articular cartilage. The abnormal repair process leads to the formation of osteophytes and subchondral cysts as the disease progresses. These changes are evident on radiographs.

[0251] Primary and secondary prevention should be emphasized in the management of patients with osteoarthritis. Maintaining appropriate body weight may be the single most important factor in preventing osteoarthritis from occur-

ring in weight-bearing joints.⁸ A relationship has been shown between weight loss and a reduction in the risk of developing osteoarthritis.

[0252] The role of exercise in the development of osteoarthritis has been difficult to ascertain for a variety of reasons. Results of studies have demonstrated radiographic evidence of osteoarthritis in former athletes. In some of these studies, the symptoms were greater in the athletes than in the control subjects, while in other studies, the athletes were either asymptomatic or had symptoms similar to those of the control subjects. However, results from case-control and long-term prospective studies of runners have demonstrated that distance running does not increase the risk for osteoarthritis. Nevertheless, it is clear that a history of significant injury, particularly of the knee or hip, is a risk factor for the development of osteoarthritis. A history of meniscectomy is also considered a risk factor; therefore, sports that have a high risk for injury may lead to a greater risk for the development of osteoarthritis. High-risk sports include collision sports and those with a high-loading or torsional impact.

[0253] In general, mild-to-moderate activity is not likely to lead to osteoarthritis in normal joints. Persons with previous joint injury or surgery, or abnormal joint alignment, are likely to be at a higher risk for developing osteoarthritis.

[0254] Vitamin D intake may also affect osteoarthritis. Low dietary intake or serum levels of vitamin D are associated with increased rates of progression.

[0255] The diagnosis of osteoarthritis is largely made by obtaining a detailed history and conducting a complete physical examination. Ancillary diagnostic tests may occasionally be necessary when the diagnosis remains uncertain. The usual presenting symptom is pain involving one or only a few joints. Joint involvement is usually symmetric. Morning joint stiffness that usually resolves within 30 minutes or occurs with mild-to-moderate activity is also common. As the disease progresses, prolonged joint stiffness and joint enlargement are evident. Crepitus, or a grating sensation in the joint, is a late manifestation. Limitation of joint movement may be due to flexion contractures or mechanical obstructions.

[0256] Secondary causes should be considered when making decisions about having ancillary tests performed. Further evaluation is indicated when the diagnosis remains uncertain, response to therapy is not as expected, or significant clinical changes occur. Clinically indicated laboratory work may include tests for erythrocyte sedimentation rate and rheumatoid factor. Synovial fluid analysis may be conducted to help exclude other diagnoses. In osteoarthritis, the white blood cell count is usually less than 500 cells per mm³ (0.5 \times 10⁹ per L) and is composed predominantly of mononuclear cells. In inflammatory aspirates, the white blood cell count is usually greater than 2,000 cells per mm³ (2.0 \times 10⁹ per L), and the predominant cell type is usually the neutrophil.

[0257] Radiographs can provide objective evidence of the disease. Findings consistent with osteoarthritis include presence of joint space narrowing, osteophyte formation, pseudocyst in subchondral bone, and increased density of subchondral bone. The absence of radiographic changes, however, does not exclude the diagnosis of osteoarthritis. Many patients with radiographic changes consistent with osteoarthritis are asymptomatic or do not exhibit any disability, suggesting that the presence of radiographic changes in the absence of symptoms should not lead to the diagnosis of osteoarthritis. In large joints, radiographs can exclude other causes of joint pain.

[0258] Radiographs are not required for every person who presents with symptoms consistent with osteoarthritis. Patients whose clinical history or course suggests other etiologies should undergo radiographic evaluation. This includes patients with trauma, joint pain at night, progressive joint pain (without prior radiography), significant family history of inflammatory arthritis, and children younger than 18 years.

[0259] The primary goals of treatment are improved function and quality of life. Treatment should be tailored to the needs of the individual patient. Patient education, rehabilitation, exercise, modification of activities of daily living, pharmacotherapy, alternative medicine and surgery are all treatment modalities that should be considered.

[0260] Patients should be thoroughly educated about the natural course of osteoarthritis. Their role in the management of the disease is critical, and a proper understanding will allow appropriate expectations of treatment to be established. Family physicians should be familiar with pharmacologic and nonpharmacologic treatment modalities to maximize effective utilization and a thorough understanding of the short- and long-term complications and cost. Some treatment modalities (e.g., heat, ice, and electrical stimulation) may make the patient feel better but may not be sufficient alone. Most modalities and therapies do not change the outcome.

[0261] Combinations of treatment modalities for symptom control are better than isolated therapy for symptom relief. The proper mix of modalities and exercises is based on individualized treatment goals agreed on by the family physician and the patient.

[0262] Patients with osteoarthritis often demonstrate significant disability. The symptoms and disability may limit their ability to participate in regular physical activity, and they may also be reluctant to exercise for fear that it will exacerbate their symptoms. It has been shown that aerobic and resistance exercises do not exacerbate symptoms in patients with osteoarthritis and do not appear to produce or exacerbate joint symptoms in persons without osteoarthritis. Results of randomized studies have demonstrated that aerobic and resistance exercises produce only modest gains in measures of improving disability, physical performance, and symptoms. Participation in regular exercise appears to be safe and effective in managing the symptoms and disability associated with osteoarthritis. Exercise programs such as those sponsored by the Arthritis Foundation should be recommended to patients with osteoarthritis. It is important for patients to note that any lifestyle changes they make are not curative and must be continued throughout life.

[0263] Pain is the primary symptom of osteoarthritis, and multiple medications are available to relieve pain and improve function. The choice of a pain-control medication must be individualized, prescribing medications with the best side effect profile first and adding other pain-control medications as indicated. In comparison with nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, in a dosage of 1 g four times daily, is considered an initial drug of choice. NSAIDs and aspirin have analgesic and anti-inflammatory properties but also have adverse effects on the stomach and kidney, especially in elderly patients. The cyclooxygenase-2 (COX-2) inhibitors celecoxib (Celebrex) and rofecoxib (Vioxx) cause fewer gastrointestinal side effects and, while thought to be no more effective than other NSAIDs, can be considered for use in patients with a history of gastrointestinal bleeding or those who may be taking certain medications

(e.g., warfarin [Coumadin] or oral steroids). The COX-2 inhibitors have not been shown to be safer than acetaminophen. Cost should be a consideration in treatment decisions. In addition, there is accumulating data about the side effects of the COX-2 inhibitors. Early evidence indicated that side effects might vary between the medications in this class.

[0264] Sodium hyaluronate (Synvisc, Hyalgan) is indicated only for the treatment of patients with osteoarthritis of the knee. This treatment is an alternative to consider in patients who do not respond to NSAID therapy or who have a history of gastric ulcer disease, with some evidence suggesting symptomatic and functional improvement following a series of weekly injections.

[0265] Intra-articular steroid injections are another treatment option but should not, in most circumstances, be administered more than three to four times per year. Results of a multicenter, randomized study demonstrated that intra-articular knee injections significantly reduced pain for up to four weeks. No functional improvement was noted compared to placebo. Results from this same study revealed that joint lavage significantly relieved pain for up to 24 weeks. The effects of steroid injection and joint lavage on pain relief were additive, but neither procedure significantly improved functional status. Topical capsaicin cream should be considered for adjunctive treatment of focal joint pain.

[0266] Alternative medicines (e.g., glucosamine sulfate, chondroitin sulfate) in the prevention and treatment of osteoarthritis continue to receive coverage in the media; however, research evaluating their efficacy and potential benefits is incomplete. Glucosamine sulfate, a popular treatment for osteoarthritis, is an amino-monosaccharide and a substrate of glycosaminoglycans and proteoglycans. These are substrates of hyaluronic acid, a major component of joint fluid. Glucosamine is often taken alone or in combination with chondroitin sulfate. Results from some studies have shown glucosamine to be as effective as ibuprofen in relieving the pain of osteoarthritis. Chondroitin sulfate also has demonstrated efficacy in improving the symptoms of osteoarthritis. A full review of alternative treatment modalities is beyond the scope of this article.

[0267] Family physicians should be aware of commonly used alternative treatments. This allows monitoring of potential benefits and possible interactions with other medications. An awareness of the medical literature also permits physicians to provide evidence-based recommendations for individual patient therapeutic trials. Alternative care should be critically assessed like any other medical care. It is through such assessments that a medication such as capsaicin, which is derived from the red pepper plant, has become part of conventional medicine.

[0268] E. Bone Reconstruction

[0269] A fourth example is related to bone reconstruction and, specifically, the ability to reconstruct defects in bone tissue that result from traumatic injury; as a consequence of cancer or cancer surgery; as a result of a birth defect; or as a result of aging. There is a significant need for more frequent orthopedic implants, and cranial and facial bone are particular targets for this type of reconstructive need. The availability of new implant materials, e.g., titanium, has permitted the repair of relatively large defects. Titanium implants provide excellent temporary stability across bony defects. However, experience has shown that a lack of viable bone bridging the defect can result in exposure of the appliance, infection, structural instability and, ultimately, failure to repair the defect.

[0270] Autologous bone grafts are another possibility, but they have several demonstrated disadvantages in that they must be harvested from a donor site such as iliac crest or rib, they usually provide insufficient bone to completely fill the defect, and the bone that does form is sometimes prone to infection and resorption. Partially purified xenogeneic preparations are not practical for clinical use because microgram quantities are purified from kilograms of bovine bone, making large scale commercial production both costly and impractical. Allografts and demineralized bone preparations are therefore often employed.

[0271] Microsurgical transfers of free bone grafts with attached soft tissue and blood vessels can close bony defects with an immediate source of blood supply to the graft. However, these techniques are time consuming, have been shown to produce a great deal of morbidity, and can only be used by specially trained individuals. Furthermore, the bone implant is often limited in quantity and is not readily contoured. In the mandible, for example, the majority of patients cannot wear dental appliances using presently accepted techniques (even after continuity is established), and thus gain little improvement in the ability to masticate. Toriumi et al. 1991 have written the "Reconstructive surgeons should have at their disposal a bone substitute that would be reliable, biocompatible, easy to use, and long lasting and that would restore mandibular continuity with little associated morbidity."

[0272] In connection with bone reconstruction, specific problem areas for improvement are those concerned with treating large defects, such as created by trauma, birth defects, or particularly, following tumor resection; and also the area of artificial joints. The success of orthopaedic implants, interfaces and artificial joints could conceivably be improved if the surface of the implant, or a functional part of an implant, were to be coated with a bone stimulatory agent. The surface of implants could be coated with one or more appropriate materials in order to promote a more effective interaction with the biological site surrounding the implant and, ideally, to promote tissue repair.

X. Polymers for Implanting of Bone Cell Spheroids

[0273] Over the last decade there has been a tremendous increase in applications for polymeric materials. These materials are well suited to implantation as they can serve as a temporary scaffold to be replaced by host tissue, degrade by hydrolysis to non-toxic products, and be excreted, as described by Kulkarni et al. (1971) and Hollinger and Battistone (1986).

[0274] Either natural or synthetic polymers can be used to form the matrix, although synthetic polymers are preferred for reproducibility and controlled release kinetics. Synthetic polymers that can be used include bioerodible polymers such as poly(lactide) (PLA), poly(glycolic acid) (PGA), poly(lactide-co-glycolide) (PLGA), and other poly(alpha-hydroxy acids), poly(caprolactone), polycarbonates, polyamides, polyanhydrides, polyamino acids, polyortho esters, polyacetals, polycyanoacrylates and degradable polyurethanes, and non-erodible polymers such as polyacrylates, ethylene-vinyl acetate polymers and other acyl substituted cellulose acetates and derivatives thereof, non-erodible polyurethanes, polystyrenes, polyvinyl chloride, polyvinyl fluoride, poly(vinyl imidazole), chlorosulphonated polyolifins, polyethylene oxide, polyvinyl alcohol, and nylon. Although non-degradable materials can be used to form the matrix or a portion of the matrix, they are not preferred. Examples of natural polymers

include proteins such as albumin, fibrin or fibrinogen, collagen, synthetic polyamino acids, and prolamines, and polysaccharides such as alginate, heparin, and other naturally occurring biodegradable polymers of sugar units.

[0275] Four polymers widely used in medical applications are poly(paradoxanone) (PDS), poly(lactic acid) (PLA), poly(glycolic acid) (PGA), and PLAGA copolymers. Copolymerization enables modulation of the degradation time of the material. By changing the ratios of crystalline to amorphous polymers during polymerization, properties of the resulting material can be altered to suit the needs of the application. These polymers, including poly(lactide-co-glycolic acid) (PLGA), have been used as polymer composites for bone replacement as reported by Elgendy et al. (1993). Substituted polyphosphazenes have been shown to support osteogenic cell growth, as reported by Laurencin et al. (1993). Poly(organophosphazenes) are high molecular weight polymers containing a backbone of alternating phosphorus and nitrogen atoms. There are a wide variety of polyphosphazenes, each derived from the same precursor polymer, poly(dichlorophosphazene). The chlorine-substituted species can be modified by replacement of the chlorine atoms by different organic nucleophiles such as o-methylphenoxide along with amino acids. The physical and chemical properties of the polymer can be altered by adding various ratios of hydrolytic sensitive side chains such as ethyl glycinate, as described by Wade et al. (1978) and Allcock and Fuller (1981). This will affect the degradation of the polymer as an implantable and biodegradable material as well as vary the support of osteogenic cells for bone and tissue implants, as shown by Laruecin et al. (1993).

[0276] PLA, PGA and PLA/PGA copolymers are particularly useful for forming the biodegradable matrices. PLA polymers are usually prepared from the cyclic esters of lactic acids. Both L(+) and D(-) forms of lactic acid can be used to prepare the PLA polymers, as well as the optically inactive DL-lactic acid mixture of D(-) and L(+) lactic acids. Methods of preparing polylactides are well documented in the patent literature. The following U.S. patents, the teachings of which are hereby incorporated by reference, describe in detail suitable polylactides, their properties and their preparation: U.S. Pat. Nos. 1,995,970; 2,703,316; 2,758,987; 2,951,828; 2,676,945; 2,683,136; and 3,531,561. PGA is the homopolymer of glycolic acid (hydroxyacetic acid). In the conversion of glycolic acid to poly(glycolic acid), glycolic acid is initially reacted with itself to form the cyclic ester glycolide, which in the presence of heat and a catalyst is converted to a high molecular weight linear-chain polymer. PGA polymers and their properties are described in more detail in "Cyanamid Research Develops World's First Synthetic Absorbable Suture," Chemistry and Industry, 905 (1970).

[0277] The erosion of the matrix is related to the molecular weights of PLA, PGA or PLA/PGA. The higher molecular weights, weight average molecular weights of 90,000 or higher, result in polymer matrices which retain their structural integrity for longer periods of time; while lower molecular weights, weight average molecular weights of 30,000 or less, result in both slower release and shorter matrix lives. Poly(lactide-co-glycolide) (50:50), degrades in about six weeks following implantation.

[0278] All polymers for use in the matrix must meet the mechanical and biochemical parameters necessary to provide adequate support for the cells with subsequent growth and proliferation. The polymers can be characterized with respect

to mechanical properties such as tensile strength using an Instron tester, for polymer molecular weight by gel permeation chromatography (GPC), glass transition temperature by differential scanning calorimetry (DSC) and bond structure by infrared (IR) spectroscopy, with respect to toxicology by initial screening tests involving Ames assays and in vitro teratogenicity assays, and implantation studies in animals for immunogenicity, inflammation, release and degradation studies.

[0279] These polymers are particularly useful in forming fibrous or sponge type matrices for implantation. Polymers can also be used to form hydrogels in which the cells are suspended and then implanted.

[0280] A. Other Matrix Materials

[0281] Another class of materials for making the matrix is hydroxyapatite, or a similar ceramic formed of tricalcium phosphate (TCP) or calcium phosphate (CaPO_4). Calcium hydroxyapatites occur naturally as geological deposits and in normal biological tissues, principally bone, cartilage, enamel, dentin, and cementum of vertebrates and in many sites of pathological calcifications such as blood vessels and skin. Synthetic calcium hydroxyapatite is formed in the laboratory either as pure $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ or hydroxyapatite that is impure, containing other ions such as carbonate, fluoride, chloride for example, or crystals deficient in calcium or crystals in which calcium is partly or completely replaced by other ions such as barium, strontium and lead. Essentially none of the geological and biological apatites are "pure" hydroxyapatite since they contain a variety of other ions and cations and may have different ratios of calcium to phosphorus than the pure synthetic apatites.

[0282] In general, the crystals of pure synthetic apatites, geological apatites and many impure synthetically produced apatites are larger and more crystalline than the biological crystals of bone, dentin, cementum and cartilage. The crystals of bone, dentin and cementum are very small, irregularly shaped, very thin plates whose rough average dimensions are approximately 10 to 50 angstroms in thickness, 30 to 150 angstroms in width, and 200 to 600 angstroms in length. The synthetic materials are highly diverse, as reported in the literature. For example, the characterization of four commercial apatites was reported by Pinholt et al. (1992); Marden et al. (1990) reports on a protein, biodegradable material; Pinholt et al. (1991) reports on the use of a bovine bone material called Bio-Oss™; Friedman et al. (1991) and Costantino et al. (1991) report on a hydroxyapatite cement; Roesgen (1990) reports on the use of calcium phosphate ceramics in combination with autogenic bone; Ono et al. (1990) reports on the use of apatite-wollastonite containing glass ceramic granules, hydroxyapatite granules, and alumina granules; Passuti et al. (1989) reports on macroporous calcium phosphate ceramic performance; Harada (1989) reports on the use of a mixture of hydroxyapatite particles and tricalcium phosphate powder for bone implantation; Ohgushi et al. (1989) reports on the use of porous calcium phosphate ceramics alone and in combination with bone marrow cells; Pochon et al. (1986) reports on the use of beta-tricalcium phosphate for implantation; and Glowacki et al. (1985), reports on the use of demineralized bone implants.

[0283] As used herein, all of these materials are generally referred to as "hydroxyapatite." In the preferred form, the hydroxyapatite is particles having a diameter between approximately ten and 100 microns in diameter, most preferably about 50 microns in diameter.

[0284] Calcium phosphate ceramics can be used as implants in the repair of bone defects because these materials are non-toxic, non-immunogenic, and are composed of calcium and phosphate ions, the main constituents of bone (Frame, 1987; Parsons et al., 1988). Both tricalcium phosphate (TCP) $\text{Ca}_3(\text{PO}_4)_2$ and hydroxyapatite (HA) $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ have been widely used. Calcium phosphate implants are osteoinductive, and have the apparent ability to become directly bonded to bone. As a result, a strong bone-implant interface is created.

[0285] Calcium phosphate ceramics have a degree of bioreabsorbability which is governed by their chemistry and material structure. High density HA and TCP implants exhibit little resorption, while porous ones are more easily broken down by dissolution in body fluids and resorbed by phagocytosis. However, TCP degrades more quickly than HA structures of the same porosity in vitro. HA is relatively insoluble in aqueous environments. However, the mechanical properties of calcium phosphate ceramics make them ill-suited to serve as a structural element under load bearing circumstances. Ceramics are not preferred since they are brittle and have low resistance to impact loading.

[0286] B. Polymers for Forming Hydrogels

[0287] Polymers that can form ionic hydrogels which are malleable can also be used to support the cells. Injecting a suspension of cells in a polymer solution may be performed to improve the reproducibility of cell seeding throughout a device, to protect the cells from shear forces or pressure induced necrosis, or to aid in defining the spatial location of cell delivery. The injectable polymer may also be utilized to deliver cells and promote the formation of new tissue without the use of any other matrix. In a preferred embodiment, the hydrogel is produced by cross-linking the ionic salt of a polymer with ions, whose strength increases with either increasing concentrations of ions or polymer. The polymer solution is mixed with the cells to be implanted to form a suspension, which is then injected directly into a patient prior to polymerization of the suspension. The suspension subsequently polymerizes over a short period of time due to the presence in vivo of physiological concentrations of ions such as calcium in the case where the polymer is a polysaccharide such as alginate.

[0288] A hydrogel is defined as a substance formed when an organic polymer (natural or synthetic) is cross-linked via covalent, ionic, or hydrogen bonds to create a three-dimensional open-lattice structure which entraps water molecules to form a gel. Examples of materials which can be used to form a hydrogel include polysaccharides such as alginate, polyphosphazenes, and polyacrylates such as hydroxyethyl methacrylate (HEMA), which are crosslinked ionically, or block copolymers such as Pluronic™ or Tetronics™, polyethylene oxide-polypropylene glycol block copolymers which are crosslinked by temperature or pH, respectively. Other materials include proteins such as fibrinogen, collagen, polymers such as polyvinylpyrrolidone, hyaluronic acid and collagen.

[0289] In general, these polymers are at least partially soluble in aqueous solutions, such as water, buffered salt solutions, or aqueous alcohol solutions, that have charged side groups, or a monovalent ionic salt thereof. Examples of polymers with acidic side groups that can be reacted with cations are poly(phosphazenes), poly(acrylic acids), poly(methacrylic acids), copolymers of acrylic acid and methacrylic acid, poly(vinyl acetate), and sulfonated polymers,

such as sulfonated polystyrene. Copolymers having acidic side groups formed by reaction of acrylic or methacrylic acid and vinyl ether monomers or polymers can also be used. Examples of acidic groups are carboxylic acid groups, sulfonic acid groups, halogenated (preferably fluorinated) alcohol groups, phenolic OH groups, and acidic OH groups. Examples of polymers with basic side groups that can be reacted with anions are poly(vinyl amines), poly(vinyl pyridine), poly(vinyl imidazole), and some imino substituted polyphosphazenes. The ammonium or quaternary salt of the polymers can also be formed from the backbone nitrogens or pendant imino groups. Examples of basic side groups are amino and imino groups.

[0290] Alginate can be ionically cross-linked with divalent cations, in water, at room temperature, to form a hydrogel matrix. Due to these mild conditions, alginate has been the most commonly used polymer for hybridoma cell encapsulation, as described, for example, in U.S. Pat. No. 4,352,883. Described therein is an aqueous solution containing the biological materials to be encapsulated is suspended in a solution of a water soluble polymer, the suspension is formed into droplets which are configured into discrete microcapsules by contact with multivalent cations, then the surface of the microcapsules is crosslinked with polyamino acids to form a semipermeable membrane around the encapsulated materials.

[0291] The polyphosphazenes suitable for cross-linking have a majority of side chain groups which are acidic and capable of forming salt bridges with di- or trivalent cations. Examples of preferred acidic side groups are carboxylic acid groups and sulfonic acid groups. Hydrolytically stable polyphosphazenes are formed of monomers having carboxylic acid side groups that are crosslinked by divalent or trivalent cations such as Ca^{2+} or Al^{3+} . Polymers can be synthesized that degrade by hydrolysis by incorporating monomers having imidazole, amino acid ester, or glycerol side groups. Bioerodible polyphosphazenes have at least two differing types of side chains, acidic side groups capable of forming salt bridges with multivalent cations, and side groups that hydrolyze under in vivo conditions, e.g., imidazole groups, amino acid esters, glycerol and glucosyl.

[0292] The water soluble polymer with charged side groups is crosslinked by reacting the polymer with an aqueous solution containing multivalent ions of the opposite charge, either multivalent cations if the polymer has acidic side groups or multivalent anions if the polymer has basic side groups. The preferred cations for cross-linking of the polymers with acidic side groups to form a hydrogel are divalent and trivalent cations such as copper, calcium, aluminum, magnesium, strontium, barium, and tin, although di-, tri- or tetra-functional organic cations such as alkylammonium salts can also be used. Aqueous solutions of the salts of these cations are added to the polymers to form soft, highly swollen hydrogels and membranes. The higher the concentration of cation, or the higher the valence, the greater the degree of cross-linking of the polymer. Concentrations from as low as 0.005M have been demonstrated to cross-link the polymer. Higher concentrations are limited by the solubility of the salt. The preferred anions for cross-linking of the polymers to form a hydrogel are divalent and trivalent anions such as low molecular weight dicarboxylic acids, for example, terephthalic acid, sulfate ions and carbonate ions. Aqueous solutions of the salts of these

anions are added to the polymers to form soft, highly swollen hydrogels and membranes, as described with respect to cations.

[0293] A variety of polycations can be used to complex and thereby stabilize the polymer hydrogel into a semi-permeable surface membrane. Examples of materials that can be used include polymers having basic reactive groups such as amine or imine groups, having a preferred molecular weight between 3,000 and 100,000, such as polyethylenimine and polylysine. These are commercially available. One polycation is poly(L-lysine), examples of synthetic polyamines are: polyethylenimine, poly(vinylamine), and poly(allyl amine). There are also natural polycations such as the polysaccharide, chitosan. Polyanions that can be used to form a semi-permeable membrane by reaction with basic surface groups on the polymer hydrogel include polymers and copolymers of acrylic acid, methacrylic acid, and other derivatives of acrylic acid, polymers with pendant SO_3H groups such as sulfonated polystyrene, and polystyrene with carboxylic acid groups.

XI. Examples

[0294] The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventor to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

Example 1

Materials and Methods

[0295] Neonatal Murine Calvarial Bone Formation Assay.

[0296] The technique for studying organ cultures of neonatal murine calvarial bones has been described in detail previously (Traianedes et al., 1999, Mundy et al., 1999). The bones were removed from the calvaria of 4-5 day old ICR Swiss mice, and then cultured in BGJ medium with 0.1% BSA for 7 Days using 4 calvarial bones per group. triterpenoids in differing amounts were added for 7 days. Alkaline phosphatase was determined at 4 and 7 days and expressed as arbitrary units of alkaline phosphatase activity. At the end of the experiment the media was saved and assayed for the presence of alkaline phosphatase and the calvaria bones were then fixed overnight in 10% formalin, decalcified in 14% EDTA overnight and were then embedded in paraffin wax. Sections were cut, using a standard microtome, along the midline suture to reveal the sagittal suture and the region posterior to this suture. Four micrometer sections were taken initially and at two sequential 400 nm depths. Sections were placed on coated glass slides (Superfrost plus, Fisher Scientific, Pittsburgh, Pa.) and stained with hematoxylin and eosin. The effects on bone formation were evaluated by morphologic assessment.

[0297] Imaging.

[0298] Digital images across sections of the neonatal murine calvaria were taken from each group. Histomorphometric analysis was performed on these calvarial images using the Osteomeasure System (Osteometrics Inc., Atlanta,

Ga.). The total and new bone area (expressed as $\text{mm}^2 \times 10^{-3}$) was determined on all images across the calvarial section.

[0299] Bovine Calf Stifle Joint SZP Assay.

[0300] Bovine calf stifle joints were dissected under aseptic conditions. The superficial zone of articular cartilage of femoral condyles (approximately 100 μm thickness) was harvested using a dermatome. The cartilage slices were digested with 0.2% collagenase P in culture medium. Isolated chondrocytes were plated in monolayer at a density of 1×10^5 cells/well (approximately 2.5×10^4 cells/ cm^2) in 12-well culture plates and incubated at 37° C. in a moist atmosphere of 5% carbon dioxide and 95% air. Chondrocytes were cultured in D-MEM/F-12 containing 10% fetal bovine serum over night, and then the media were changed in serum-free D-MEM/F-12 supplemented with ITSL (insulin, transferrin, selenious acid, and linoleic acid). Both media contain 100 U/ml penicillin, 100 $\mu\text{g}/\text{ml}$ streptomycin, 50 $\mu\text{g}/\text{ml}$ ascorbate-2phosphate, and 0.1% bovine serum albumin. After changing the media with serum into the serum-free chemically defined media, various concentration of synthetic triterpenoids were added into the cell culture.

[0301] As most of SZP is secreted into the culture medium, supernatants were harvested as samples and the SZP synthesis was analyzed by SDS-PAGE and Western blotting using a monoclonal antibody 56.79, obtained from Rush Medical College, Chicago, Ill. SZP accumulation into the culture medium was also quantified by ELISA using purified SZP as standard.

[0302] The accumulation of SZP into the culture media increased in a time-dependent manner (Day 1 < Day 2 < Day 3). Therefore the culture of media of Day 3 was used for all the studies.

Example 2

Calvarial Bone Formation Results

[0303] Experimental groupings for FIGS. 1-12 are shown below (The alphabet at the end of each compound number denotes synthesis batch of each one.):

Gp1—Control	
Gp2—TP-151F	40 Nm
Gp3—TP-151F	200 nM
Gp4—TP-151F	1000 nM
Gp5—Control	
Gp6—TP-155C	40 nM
Gp7—TP-155C	200 nM
Gp8—TP-155C	1000 nM
Gp9—Control	
Gp10—TP-235H	40 nM
Gp11—TP-235H	200 nM
Gp12—TP-235H	1000 nM
Gp13—Control	
Gp14—TP-319A	40 nM
Gp15—TP-319A	200 nM
Gp16—TP-319A	100 nM

Results were expressed as new bone formation and alkaline phosphatase in the media at 4 and 7 days. Midshaft transverse fractures were induced in all animals. Fractures were tolerated and remained immobilized without surgical complications. Animals were freely mobile after recovery from anesthesia. Callus formation was observed on radiographic examination by 2 weeks in all animals. The animals were

euthanized at 3 weeks and callus formation and the biomechanical strength of the bones assessed

[0304] TP-151.

[0305] Significant increase in new bone formation (FIG. 1) with increases in alkaline phosphatase in the calvarial culture media (FIG. 2). No evidence of cartilage formation was seen in these cultures (FIG. 3). This indicates this agent is capable of stimulating bone formation, however no cartilage formation was seen.

[0306] TP-155.

[0307] Significant increase in new bone formation (FIG. 4) with increases in alkaline phosphatase in the calvarial culture media (FIG. 5). Some evidence of cartilage formation was seen in these cultures (FIG. 3) however this was not significant. This indicates this agent is capable of stimulating bone formation and possibly cartilage formation.

[0308] TP-235.

[0309] Significant increase in new bone formation at 40 nM (FIG. 7) however really no convincing change in alkaline phosphatase in the calvarial culture media (FIG. 8). No evidence of cartilage formation was seen in these cultures (FIG. 9) however this was not significant.

[0310] TP-319.

[0311] Some increases in new bone formation (FIG. 10) and there was also dose responsive increases in alkaline phosphatase in the calvarial culture media (FIG. 11). There was clear evidence increases in cartilage formation was seen in these cultures (FIG. 12).

Example 3

Articular Cartilage Results

[0312] TGF- β 1.

[0313] Recombinant human TGF- β 1 was found to up-regulate SZP synthesis in a dose-dependent manner (0.4-120 pM).

[0314] Triterpenoids at Higher Concentrations.

[0315] All four triterpenoids tested, TP-151, TP-155, TP-235, and TP-319, down-regulated SZP synthesis in a dose-dependent manner at high concentrations (100-1000 nM). Concurrent treatment with TGF- β 1 (4 pM) also demonstrated the same trend.

[0316] Triterpenoids at Lower Concentrations.

[0317] TP-151 and TP-155 up-regulated SZP synthesis at lower concentrations, with SZP synthesis increasing as the concentration of these two triterpenoids was increased from 0.01 to 1 nM. TP-235 and TP-319 had no obvious effects in this range.

[0318] The results suggest that sub-nanomolar concentrations concentration were optimal for articular cartilage.

[0319] All of the compositions and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are

deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

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[0320] The following references, to the extent that they provide exemplary procedural or other details supplementary to those set forth herein, are specifically incorporated herein by reference.

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[0322] U.S. Pat. No. 2,676,945

[0323] U.S. Pat. No. 2,683,136

[0324] U.S. Pat. No. 2,703,316

[0325] U.S. Pat. No. 2,758,987

[0326] U.S. Pat. No. 2,951,828

[0327] U.S. Pat. No. 3,531,561

[0328] U.S. Pat. No. 4,352,883

[0329] U.S. Pat. No. 4,443,546

[0330] U.S. Pat. No. 4,533,637

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[0333] U.S. Pat. No. 5,972,703

[0334] U.S. Patent Publ. US2003/0232786

[0335] EP 128 733

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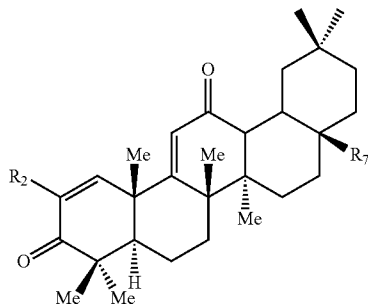
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1-64. (canceled)

65. A three-dimensional matrix comprising a matrix material and a compound having the structure:



wherein,

R_2 is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_6 - C_{15} -aryl, C_7 - C_{15} -aralkyl, C_1 - C_{15} -heteroaryl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -

alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryl amino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroaryl amino, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido;

R_7 is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_7 - C_{15} -aralkyl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynylamino, C_6 - C_{15} -aryl amino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroaryl amino, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido, or

a pharmaceutically acceptable salt or tautomer thereof.

66. The three-dimensional matrix of claim 65, wherein the three-dimensional matrix comprises an orthopedic implant, interface, artificial joint, or dental implant.

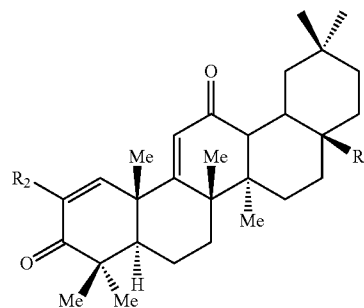
67. The three-dimensional matrix of claim 66, wherein the compound is coated on the surface of the orthopedic implant, interface or artificial joint.

68. The three-dimensional matrix of claim 65, further comprising a bone-producing, cartilage-producing or osteochondrogenic cell.

69. The three-dimensional matrix of claim 65, wherein the matrix material comprises an alginate gel, collagen gel, fibrin gel, polylactic acid, polyglycolic acid, poly(lactide-co-glycolide), hydroxyapatite, devitalized animal bone, devitalized human bone, or a porous ceramic structure.

70. The three-dimensional matrix of claim 65, further comprising a bone or cartilage growth factor.

71. A hydrogel comprising an organic polymer and a compound having the structure:



wherein,

R_2 is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_6 - C_{15} -aryl, C_7 - C_{15} -aralkyl, C_1 - C_{15} -heteroaryl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryloxy, C_7 - C_{15} -aralkoxy, C_1 - C_{15} -heteroaryloxy, C_2 - C_{15} -heteroaralkoxy, C_1 - C_{15} -acyloxy, C_1 - C_{15} -alkylamino, C_2 - C_{15} -alkenylamino, C_2 - C_{15} -alkynyloxy, C_6 - C_{15} -aryl amino, C_7 - C_{15} -aralkylamino, C_1 - C_{15} -heteroaryl amino, C_2 - C_{15} -heteroaralkylamino, or C_2 - C_{15} -amido;

R_7 is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C_1 - C_{15} -alkyl, C_2 - C_{15} -alkenyl, C_2 - C_{15} -alkynyl, C_7 - C_{15} -aralkyl, C_2 - C_{15} -heteroaralkyl, C_1 - C_{15} -acyl, C_1 - C_{15} -alkoxy, C_2 - C_{15} -alkenyloxy,

C₂-C₁₅-alkynyloxy, C₆-C₁₅-aryloxy, C₇-C₁₅-aralkoxy, C₁-C₁₅-heteroaryloxy, C₂-C₁₅-heteroaralkoxy, C₁-C₁₅-acyloxy, C₁-C₁₅-alkylamino, C₂-C₁₅-alkenylamino, C₂-C₁₅-alkynylamino, C₆-C₁₅-aryl amino, C₇-C₁₅-aralkylamino, C₁-C₁₅-heteroaryl amino, C₂-C₁₅-heteroaralkylamino, or C₂-C₁₅-amido, or

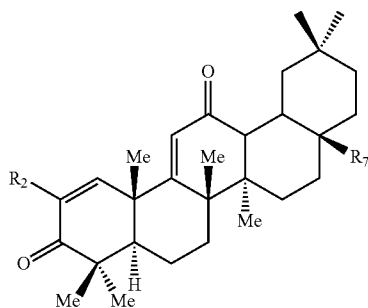
a pharmaceutically acceptable salt or tautomer thereof.

72. The hydrogel of claim 71, further comprising a bone-producing, cartilage-producing or osteochondrogenic cell.

73. The hydrogel of claim 71, wherein the polymer comprises a polysaccharide, polyphosphazene, polyacrylate, block copolymer, or protein.

74. The hydrogel of claim 71, further comprising a bone or cartilage growth factor.

75. A medium for ex vivo culturing of bone and cartilage cells comprising a serum free culture medium that supports growth and differentiation of a bone-producing, cartilage-producing or osteochondrogenic cell and a compound having the structure:



wherein,

R₂ is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C₁-C₁₅-alkyl, C₂-C₁₅-alkenyl, C₂-C₁₅-alkynyl, C₆-C₁₅-aryl, C₇-C₁₅-aralkyl, C₁-C₁₅-heteroaryl, C₂-C₁₅-heteroaralkyl, C₁-C₁₅-acyl, C₁-C₁₅-alkoxy, C₂-C₁₅-alkenyloxy, C₂-C₁₅-alkynyloxy, C₆-C₁₅-aryloxy, C₇-C₁₅-aralkoxy, C₁-C₁₅-heteroaryloxy, C₂-C₁₅-heteroaralkoxy, C₁-C₁₅-acyloxy, C₁-C₁₅-alkylamino, C₂-C₁₅-alkenylamino, C₂-C₁₅-alkynylamino, C₆-C₁₅-aryl amino, C₇-C₁₅-aralkylamino, C₁-C₁₅-heteroaryl amino, C₂-C₁₅-heteroaralkylamino, or C₂-C₁₅-amido;

R₇ is —H, hydroxy, amino, cyano, halo, or substituted or unsubstituted versions of C₁-C₁₅-alkyl, C₂-C₁₅-alkenyl, C₂-C₁₅-alkynyl, C₇-C₁₅-aralkyl, C₂-C₁₅-heteroaralkyl, C₁-C₁₅-acyl, C₁-C₁₅-alkoxy, C₂-C₁₅-alkenyloxy, C₂-C₁₅-alkynyloxy, C₆-C₁₅-aryloxy, C₇-C₁₅-aralkoxy, C₁-C₁₅-heteroaryloxy, C₂-C₁₅-heteroaralkoxy, C₁-C₁₅-acyloxy, C₁-C₁₅-alkylamino, C₂-C₁₅-alkenylamino, C₂-C₁₅-alkynylamino, C₆-C₁₅-aryl amino, C₇-C₁₅-aralkylamino, C₁-C₁₅-heteroaryl amino, C₂-C₁₅-heteroaralkylamino, or C₂-C₁₅-amido, or

a pharmaceutically acceptable salt or tautomer thereof.

76. The medium of claim 75, further comprising one or more of albumin, a soluble carrier-fatty acid complex, an iron source, or insulin growth factor.

77. The medium of claim 75, further comprising a bone or cartilage growth factor.

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