(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
2 December 2004 (02.12.2004)

PCT

(10) International Publication Number
WO 2004/103410 A1

(51) International Patent Classification[7]: A61K 48/00

(21) International Application Number:
PCT/IL2003/000480

(22) International Filing Date: 8 June 2003 (08.06.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/385,881 6 June 2002 (06.06.2002) US
60/410,276 13 September 2002 (13.09.2002) US

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(81) Designated States *(national)*: AE, AG, AL, AM, AT (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), CZ, DE (utility model), DE, DK (utility model), DK, DM, DZ, EC, EE (utility model), EE, ES, FI (utility model), FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK (utility model), SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** METHODS COMPOSITIONS AND ARTICLES OF MANUFACTURE FOR MODULATING BONE GROWTH

(57) **Abstract:** Novel methods and pharmaceutical compositions suitable for modulating bone growth and remodeling, preventing bone diseases, inducing bone growth or repair by cannabinoid receptor-mediated effects on bone cells is disclosed. Methods of identifying bone growth modulating agents are also disclosed.

WO 2004/103410 A1

METHODS COMPOSITIONS AND ARTICLES OF MANUFACTURE FOR MODULATING BONE GROWTH

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to methods of modulating bone growth and, remodeling, methods of treating or preventing bone diseases, methods of inducing bone growth and peak bone mass or repair, pharmaceutical compositions for modulating bone growth, articles of manufacturing and methods of identifying bone growth modulating agents. Specifically, the present invention employs regulating the expression or activity of cannabinoid receptors in bone cells which in turn modulates bone growth.

Naturally occurring cannabinoids may be divided into two categories, plant-derived and endogenous. Plant-derived cannabinoids are known to elicit dramatic psychobehavioral effects, exemplified by the well-known Δ^9-tetrahydrocannabinol (THC), the psychotropic principle in marijuana. They are also known to have complex cardiovascular effects, a prominent component of which is hypotension [Vollmer *et al.*, J. Pharm. Pharmacol. 26:186-198 (1974)]. Endogenous cannabinoids (endocannabinoids) are a class of lipid-like molecules that share receptor binding sites with plant-derived cannabinoids and mimic many of their neurobehavioral effects [Mechoulam *et al.*, Adv. Exp. Bio. Med. 402:95-101 (1996)]. Two endocannabinoids have been characterized in some detail: arachidonyl ethanolamide (anandamide) [Devane *et al.*, Science 258:1946-1949 (1992); Felder *et al.*, Proc. Natl. Acad. Sci. USA. 90:7656-7660 (1993)] and 2-arachidonoyl glycerol (2-AG) [Mechoulam *et al.*, Biochem. Pharmacol 50:83-90 (1995)].

Additional natural or synthetic cannabinoids are described in U.S. Patent Nos. 4,371,720, 5,013,387, 5,081,122, 5,292,736, 5,461,034, 5,618,955, 6,166,066 and 6,531,636; International Patent applications WO 01/9773, WO 97/29079, WO 99/02499, WO 98/41519, and WO 94/12466; European Patent Nos. EP 0570920 and EP 0444451; French Patent No. FR 2735774; and Israeli Pat. Nos. IL 01/00551 and IL 99/00187; Gaoni and Mechoulam, J. Amer. Chem. Soc. 93, 217 (1971); Mechoulam *et al.*, Science 169, 611 (1970); Edery *et al.*, Ann. N.Y. Acad. Sci., 191,40 (1971); Mechoulam *et al.*, J. Amer. Chem. Soc., 94,7930 (1972); R. Mechoulam (ed.), "Marijuana: Chemistry, Metabolism, Pharmacology, and Clinical Effects" Academic Press, 1973, New-York; Houry *et al.*, J. Med. Chem., 17,287 (1974); Houry *et al.*, J.

Med. Chem., 18, 951 (1975); Mechoulam *et al.*, Chem. Reviews, 76,75 (1976); Mechoulam *et al.*, J. Med. Chem., 23, 1068 (1980); Srebnik *et al.*, J. Chem. Soc., Perkin Trans.I, 2881 (1984); Mechoulam *et al.*, Tetrahedron: Asymmetry, 1, 315 (1990); Devane *et al.*, Science, 258,1946 (1992); Burstein *et al.*, J. Med. Chem., 35, 3135 (1992); Hanus *et al.*, J. Med. Chem., 36, 3032 (1993); Mechoulam *et al.*, Biochem. Pharmacol., 50, 83 (1995); Sheskin *et al.*, J. Med. Chem., 40, 659 (1997); Rhee *et al.*, J. Med. Chem. 40, 3228 (1997); and Hanus *et al.*, PNAS, 98, 3662 (2001).

Endocannabinoids exert their effects by binding to specific receptors thereby activating neurotransmitters and hormone regulators [Piomelli *et al.*, Trends Pharmacol. Sci. 21: 218-224 (2000); Petwee, R.G., Curr. Med. Chem. 6:635-664 (1999); and Devane *et al.*, J. Med. Chem. 35: 2065-2069)]

To date, two types of high-affinity cannabinoid receptors have been identified by molecular cloning: (i) CB1 receptors, present mostly in brain [Devane *et al.*, Mol. Pharmacol. 34:605-613 (1988); Matsuda *et al.*, Nature 346:561-564 (1990)] but also in some peripheral tissues [Shire *et al.*, J. Biol. Chem. 270:3726-3731 (1995); Ishac *et al.*, Br. J. Pharmacol. 118:2023-2028 (1996)], and (ii) CB2 receptors, present on macrophages in the spleen [Munro *et al.*, Nature 365:61-65 (1993)]. Other types or subtypes of cannabinoid receptors have been recently described, designated CB1-like receptors, CB2-like receptors, and non-CB1 non-CB2 receptors [Hanus *et al.*, J. Pharmacol. Exper. Therapeutics 54: 161-202 (2002)].

The physiological roles of endogenous cannabinoids and the pathways of endocannabinoid signaling are the subject of intense investigation and have been reported to affect processes in the nervous, cardiovascular, immune, and reproductive systems [Mechoulam *et al.*, Eur. J. Pharmacol. 359: 1-18 (1998); Axelrod and Felder, Neurochem. Res. 23: 575-581(1998); Wagner *et al.*, J. Mol. Med. 76: 824-836 (1999); and Klein *et al.*, Immunol. Today 19: 373-381 (1998)].

Accordingly, cannabinoids or cannabinoids receptor ligands have been used or described as useful therapeutic agents for treating a variety of medical disorders.

Thus, THC has been extensively used to prevent excessive weight loss by cancer or AIDS patients [Mechoulam *et al.*, E. Prog. Med. Chem. 35: 199-243 (1998)].

U.S. Pat. No. 5,939,429 discloses use of agonists of CB1 receptors as well as other cannabinoid receptors to treat cardiovascular conditions, including hemorrhagic shock and in other conditions associated with excessive vasoconstriction, such as

hypertension, peripheral vascular disease, cirrhosis of the liver, and certain forms of angina pectoris. In addition it teaches use of antagonists of CB1 and other cannabinoid receptors for treating hypotension which is caused by endotoxin activation of macrophages.

U.S. Pat. No. 6,166,066 discloses use of cannabinoids which are selective for the CB2 receptor as immunosuppressive agents for preventing tissue rejection in organ transplant patients and for treating autoimmune associated diseases

U.S. Application Ser. No. 09/779,109 discloses use of cannabinoids receptor modulators for treating respiratory or non-respiratory leukocyte-activation associated diseases. Exemplary non-respiratory cannabinoid receptor-mediated diseases include transplant rejection, rheumatoid arthritis, multiple sclerosis, inflammatory bowel disease, lupus, graft v. host disease, T-cell mediated hypersensitivity disease, psoriasis, Hashimoto's thyroiditis, Guillain-Barre syndrome, cancer, contact dermatitis, allergic rhinitis, and ischemic or reperfusion injury.

US Application Ser. No. 10/032,163 discloses a method of increasing the activity of a cannabinoid agonist that binds specifically to an endogenous cannabinoid receptor, so as to protect the cells against glutamate-induced neurotoxicity.

Yet, while cannabinoids or cannabinoid receptor ligands have been suggested for use as therapeutic agents, application of cannabinoids for treating or preventing bone-related disease has never been described nor suggested in prior art.

While reducing the present invention to practice, the inventors of the present invention surprisingly uncovered the major role of endocannabinoids in modulating bone growth and remodeling, thus indicating the potential benefits of using cannabinoids or cannabinoids receptor ligands as therapeutic agents for treating bone diseases and injuries as well as promoting bone formation.

Bone is subject to constant breakdown and resynthesis in a complex process mediated by osteoblasts, which produce new bone, and osteoclasts, which destroy bone. This process is referred to as bone remodeling. The activities of these cells are regulated by a large number of cytokines and growth factors, many of which have now been identified and cloned.

There is a plethora of conditions which are characterized by the need to promote bone formation and/or to inhibit bone resorption. Perhaps the most obvious is the case of bone fractures, where it would be desirable to stimulate bone growth and to

hasten and complete bone repair. Agents that enhance bone formation would also be useful in endosseous implants and facial reconstruction procedures, and of great importance in the growing field of prosthetic and therapeutic bone implants. Other bone deficit conditions include bone segmental defects, periodontal disease, metastatic bone disease, osteolytic bone disease and conditions where connective tissue repair would be beneficial, such as healing or regeneration of cartilage defects or injury. Also of great significance is the chronic condition of osteoporosis, including age-related osteoporosis and osteoporosis associated with post-menopausal hormone status. Other conditions characterized by the need for bone growth include primary and secondary hyperparathyroidism, disuse osteoporosis, diabetes-related osteoporosis, and glucocorticoid-related osteoporosis.

On the other hand, there are conditions which are characterized by the need to inhibit bone formation or to promote bone resorption. These include certain stages of Paget's disease, blastic metastatic bone cancer, Hodgkin's lymphoma, degenerative sclerosis and osteomyelitis. Agents known to be effective in inhibition of bone growth, and in bone resorption, are the cyclooxygenase inhibitors, 1, 25 $(OH)_2$ vitamin D3, the glucocorticoids, omeprazole, the serum protein fetuin, noggin, chordin and DAN proteins and high concentrations of TGF-beta. However, all of the abovementioned agents (particularly the glucocorticoids and other hormones) are known to exert their influence on a wide variety of tissues, and as such are unsuited for pharmacological applications in bone diseases.

Various therapeutic agents and approaches to treatment of bone related diseases have been disclosed in patent publications.

U.S. Pat. No. 5,461,034 discloses osteogenic growth polypeptides identified from regenerating bone marrow, for the enhancement of bone formation and bone marrow in preparation for bone marrow transplant. U.S. Pat. No. 5,280,040 discloses antiestrogenic, oral contraceptive compounds, 3,4-diarylchromans, described as useful in the treatment of osteoporosis. U.S. Pat. No. 6,352,973 discloses a recombinant protein containing a bone morphogenic polypeptide of the TGF-beta superfamily of cytokines originally isolated from blood serum, for enhancing bone growth. U.S. Pat. No. 6,462,019 discloses inhibitors of proteasomal activity and production for inhibiting osteoclastic activity and stimulating bone growth, based on the observation

that mice lacking proteasomal activity develop the condition of excess bone formation known as osteopetrosis.

International patent application No. 92/15615 discloses a protein derived from a porcine pancreas which acts to depress serum calcium levels for treatment of bone disorders that cause elevation of serum calcium levels.

International patent application No. 92/14481 discloses a composition for inducing bone growth which contains activin and bone morphogenic protein.

European Patent Application No. 504 938 discloses the use of di- or tripeptides which inhibit cysteine protease in the treatment of bone diseases.

European Patent Application No. 499 242 discloses the use of cell growth factor compositions thought to be useful in bone diseases involving bone mass reduction because they cause osteoblast proliferation.

European Patent Application No. 451 867 discloses parathyroid hormone peptide antagonists for treating dysbolism associated with calcium or phosphoric acid, such as osteoporosis.

Yet, currently no satisfactory pharmaceutical approaches to managing bone defects. Bone fractures are still treated exclusively using casts, braces, anchoring devices and other strictly mechanical means. Further bone deterioration associated with post-menopausal osteoporosis has been treated with estrogens or bisphosphonates, which may have drawbacks for some individuals.

Although the Bone Morphogenic Proteins (BMPs) are potent stimulators of bone formation in vitro and in vivo, there are disadvantages to their use as therapeutic agents to enhance bone healing. Receptors for the bone morphogenetic proteins have been identified in many tissues, and the BMPs themselves are expressed in a large variety of tissues in specific temporal and spatial patterns. This suggests that BMPs may have effects on many tissues in addition to bone, potentially limiting their usefulness as therapeutic agents when administered systemically. Moreover, since they are peptides, they would have to be administered by injection. These disadvantages impose severe limitations to the development of BMPs as therapeutic agents.

The fluorides, suggested also for the purpose of enhancing bone formation, have a mode of action which may be related to tyrosine phosphorylation of growth factor receptors on osteoblasts, as described, for example, Burgener et al. J Bone Min

Res (1995) 10:164-171, but administration of fluorides is associated with increased bone fragility, presumably due to adverse effects on bone mineralization.

Parathyroid hormone, currently considered the leading agent for metabolic enhancement of bone formation, is inherently problematic, since it is only administered by injection.

Thus, although various approaches have been tried, such as described above, there remains a need for additions to the repertoire of agents which can be used to treat these conditions.

There is thus a widely recognized need for, and it would be highly advantageous to have novel effective bone growth modulating agents acting through normal signaling pathways, which can be used to treat these conditions. Accordingly, the present invention provides novel methods, pharmaceutical compositions and articles of manufacture for modulating bone growth and for treating or preventing bone defects based on regulating cannabinoid receptors.

SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a method of modulating bone growth and/or bone remodeling, comprising regulating an expression or activity of at least one cannabinoid receptor, thereby modulating bone growth and/or bone remodeling.

According to another aspect of the present invention there is provided a method of treating or preventing a bone disease in a subject in need thereof, comprising regulating an expression or activity of at least one cannabinoid receptor of the subject, thereby treating or preventing the bone disease in the subject.

According to yet another aspect of the present invention there is provided a method of inducing bone growth and/or repair in a subject in need thereof, comprising: (a) isolating bone cells; (b) regulating an expression or activity of at least one cannabinoid receptor of the bone cells; and (c) administering the bone cells resulting from step (b) to the subject, thereby inducing bone growth or repair in the subject.

According to further features in preferred embodiments of the invention described below, the subject is a vertebrate.

According to yet further features in preferred embodiments of the invention described below, the vertebrate is a human.

According to further features in preferred embodiments of the invention described below, the molecule which prevents activation or ligand binding of the bone cell or bone cell progenitor cannabinoid receptor is SR-141761A.

According to still further features in preferred embodiments of the invention described below, the subject suffers from a condition or disease selected from the group consisting of osteoporosis, bone fracture or deficiency, primary or secondary hyperparathyroidism, osteoarthritis, periodontal disease or defect, an osteolytic bone disease, post-plastic surgery, post-orthopedic implantation, and post-dental implantation.

According to further features in preferred embodiments of the invention described below, the method further comprising administering to the subject at least one compound capable of promoting bone formation and/or inhibiting bone resorption.

According to yet further features in preferred embodiments of the invention described below, the at least one compound is selected from the group consisting of a bone morphogenetic protein, an anti-resorptive agent, an osteogenic factor, a cartilage-derived morphogenetic protein, a parathyroid hormone, IGF1, FGF, a noggin, an osteogenic growth peptide, a growth hormone, an estrogen, a bisphosphonate, a statin and a differentiating factor.

According to still further features in preferred embodiments of the invention described below, the subject suffers from a condition or disease selected from the group consisting of Paget's disease, osteoblastic bone disease, blastic metastatic bone cancer, metastatic bone disease, Hodgkin's lymphoma, degenerative sclerosis and osteomyelitis.

According to still further features in preferred embodiments of the invention described below, the method further comprising administering to the subject at least one compound capable of inhibiting bone formation and/or promoting bone resorption.

According to still another aspect of the present invention there is provided a pharmaceutical composition for modulating bone growth and/or bone remodeling, comprising an agent capable of regulating an expression or activity of at least one

cannabinoid receptor of a bone cell, a compound capable of modulating bone growth and/or bone remodeling, and a pharmaceutically acceptable carrier.

According to yet another aspect of the present invention there is provided an article-of-manufacturing, comprising a packaging material and a therapeutically effective amount of a pharmaceutical composition being identified for the treatment of a bone disease or a bone defect, the pharmaceutical composition including an agent capable of regulating activity or expression of at least one cannabinoid receptor and a pharmaceutically acceptable carrier.

According to further features in preferred embodiments of the invention described below, the at least one compound is selected from the group consisting of a bone morphogenetic protein, an anti-resorptive agent, an osteogenic factor, a cartilage-derived morphogenetic protein, a parathyroid hormone, IGF1, FGF, a noggin, an osteogenic growth peptide, a growth hormone, an estrogen, a bisphosphonate, a statin and a differentiating factor.

According to yet further features in preferred embodiments of the invention described below, the pharmaceutical composition comprising at least one compound capable of inhibiting bone formation or promoting bone resorption.

According to an additional aspect of the present invention there is provided a method of identifying a bone growth modulating agent, comprising screening a plurality of molecules to thereby uncover a molecule capable of regulating an expression or activity of at least one cannabinoid receptor, the molecule being the bone growth modulating agent.

According to further features in preferred embodiments of the invention described below, the method further comprising determining an ability of the molecule to modify bone formation rate and/or altering bone mineralization perimeter.

According to yet further features in preferred embodiments of the invention described below the screening is effected by exposing bone cells to the plurality of molecules and determining the expression of at least one cannabinoid receptor in the bone cells.

According to further features in preferred embodiments of the invention described below, the at least one cannabinoid receptor is a bone cell or bone cell progenitor cannabinoid receptor.

According to yet further features in preferred embodiments of the invention described below expression of the cannabinoid receptor is determined by RT-PCR.

According to yet further features in preferred embodiments of the invention described below, the bone cell progenitor is an osteogenic cell, a stromal cell or a bone resorbing cell progenitor.

According to still further features in preferred embodiments of the invention described below, the regulating is upregulating, wherein the upregulating of the expression or activity is effected by an agent, or administering to the subject at least one agent selected from the group consisting of: (a) an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of the at least one cannabinoid receptor; (b) a compound which increases an expression of an endogenous DNA or mRNA encoding the at least one cannabinoid receptor; and (c) a molecule which activates the at least one cannabinoid receptor.

According to further features in preferred embodiments of the invention described below, the molecule which activates the at least one cannabinoid receptor is a cannabinoid.

According to still further features in preferred embodiments of the invention described below, the cannabinoid is 2AG.

According to yet further features in preferred embodiments of the invention described below, the regulating is downregulating, wherein the downregulating of the expression or activity is effected by an agent, or administering to the subject at least one agent selected from the group consisting of: (a) a molecule which binds the at least one cannabinoid receptor; (b) an enzyme which cleaves the at least one cannabinoid receptor; (c) an siRNA molecule capable of inducing degradation of mRNA transcripts of the at least one cannabinoid receptor; (d)a DNAzyme which specifically cleaves mRNA transcripts or DNA of the at least one cannabinoid receptor; (e) an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding the at least one cannabinoid receptor; (f) a ribozyme which specifically cleaves mRNA transcripts encoding the at least one cannabinoid receptor; (g) a non-functional analogue of at least a binding portion of the at least one cannabinoid receptor; and (h) a molecule which prevents activation or ligand binding of the at least one cannabinoid receptor.

According to still further features in preferred embodiments of the invention described below, the regulating of the expression or activity is effected by upregulating a first cannabinoid receptor of the at least one cannabinoid receptor and downregulating a second cannabinoid receptor of the at least one cannabinoid receptor.

According to further features in preferred embodiments of the invention described below, the at least one cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor and a non-CB1 non-CB2 receptor.

The present invention successfully addresses the shortcomings of the presently known configurations by providing methods of modulating bone growth and, remodeling, methods of treating or preventing bone diseases, methods of inducing bone growth and peak bone mass or repair by regulation of the expression or activity of cannabinoid receptors in bone cells. Specifically, the cannabinoid receptor-mediated effects, acting on both osteoblast (bone forming) and osteoclast (bone resorbing) activities, provide new methods for prevention as well as therapeutic intervention in diverse bone diseases. Also provided are pharmaceutical compositions for modulating bone growth and/or bone remodeling, articles of manufacturing and methods of identifying bone growth modulating agents based on cannabinoid receptor-mediated effects.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and

are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

FIGs. 1A-B illustrate qualitative micro-computed tomography (μCT) of femora of male $CB1^{-/-}$ [CB1 cannabinoid receptor knockout (deficient) mice] and of the wild type control (WT). Figures 1A and 1B show three dimensional μCT images indicating a marked decrease of trabecular bone-volume density in the distal femoral metaphysis of $CB1^{-/-}$ (Fig. 1A), as well as diminishing of the trabecular connectivity in the $CB1^{-/-}$ mice (Fig. 1A). The images were taken from representative femora with median trabecular bone volume density values.

FIGs. 2A-E illustrate comparative morphometric analyses of micro-computed tomography (μCT) of femora of male $CB1^{-/-}$ [CB1 cannabinoid receptor knockout (deficient) mice] and of the wild type control (WT). Figure 2A (top left) shows a significant increase of cortical thickness in $CB1^{-/-}$ mice ($p = 0.012$); Figure 2B (top right) shows a significant decrease in medullary space volume in $CB1^{-/-}$ mice ($p = 0.003$); Figure 2C (bottom left) shows a significant decrease of trabecular bone volume in $CB1^{-/-}$ mice ($p = 0.018$); Figure 2D (bottom middle) shows a significant decrease of trabecular number decrease in $CB1^{-/-}$ mice ($p = 0.0003$); and Figure 2E (bottom right) shows a significant decrease of trabecular connectivity in $CB1^{-/-}$ mice ($p = 0.0002$). The error bars indicate ± standard error.

FIGs. 3A-D illustrate micro computed-tomographic (μCT) morphometric analyses of femora of female CB1 receptor-knockout (deficient) mice ($CB1^{-/-}$) in comparison with female wild type control (WT). The error bars indicate ± standard error and the asterisks indicate statistical significance. Figure 3A (top left) shows a significant decrease of trabecular bone volume in $CB1^{-/-}$ mice; Figure 3B (top right) shows a non-significant decrease of trabecular connectivity in $CB1^{-/-}$ mice; Figure 3C (bottom left) shows a significant decrease of trabecular number in $CB1^{-/-}$ mice; while Figure 3D (bottom right) shows a significant increase of trabecular spacing in $CB1^{-/-}$ mice.

FIGs. 4A-D illustrate μCT morphometric analyses of femora of male $FAAH^{-/-}$ [fatty-acid amide hydrolase (FAAH) knockout (deficient) mice] and of the wild type control (WT). The error bars indicate ± standard error. Figure 4A (top left) shows a significant decrease the cortical thickness in $FAAH^{-/-}$ mice ($p = 0.049$); Figure 4B (top right) shows a non-significant decrease of trabecular bone volume $FAAH^{-/-}$ mice; while Figure 4C (bottom left) show a significant increase of medullary space volume in $FAAH^{-/-}$ mice. Figure 4D shows a linear regression analysis between the bone cortical thickness (Ct. Th.) and the medullary space volume (MV/TV), indicating a significant inverse correlation ($r = -0.985$, $p = 0.005$).

FIG. 5 illustrates RT-PCR expression analyses of CB2 cannabinoid receptor, fatty acid amide hydrolase (FAAH), parathyroid hormone receptor (PTHRc1) and tissue-nonspecific alkaline phosphatase (ALP), in differentiating osteoblast progenitor cells. Note that the RT-PCR analyses of ST2 bone-marrow derived stromal progenitor cells (left panel) reveals CB2 gene expression from as early as 5 days in osteogenic medium, while the RT-PCR analyses of MC3T3 E1 calvaria-derived osteoblast cells (right panel) indicate a much later appearance of CB2 receptor expression (10 and 20 days).

FIGs. 6A-C illustrate expression of the cannabinoid receptor CB2 and of fatty-acid amide hydrolase (FAAH) in differentiating osteoclasts . Figure 6A (left panel) is a micrograph of femoral monocytes cultured in osteoclast differentiation medium containing M-CSF and RANKL (osteoclast differentiating factors). Figure 6B (right panel) is a micrograph of differentiating osteoclasts stained with tartarate-resistant acid phosphatase. Differentiated osteoclasts are stained red to pink red color. Figure 6C (bottom) is a RT-PCR analysis which illustrates a positive expression of CB2 and of FAAH in both cultured monocytes and differentiated osteoclasts.

FIGs. 7A-D illustrate qualitative and histomorphometric analyses of mice treated or untreated with the endocannabinoid 2-arachidonoyl glycerol (2AG). Figure 7A (top left) shows a significant positive dose response effect of 2AG on bone formation rate ($p = 0.04$). Figure 7B (top right) shows representative fluorescent histological images of 2AG treated (2AG) and untreated (vehicle) mice, revealing the incorporation of calcein staining into sites of bone formation. Note the increased density of fluorescent calcein staining, indicating the higher density of mineralization fronts, in the 2AG-treated mice (right panel). The bone tissue of a 2AG treated mouse

(right image) appears substantially denser than a similar bone tissue of an untreated mouse (left image). Figure 7C (bottom left) shows a similar significant positive dose response effect of 2AG on mineralizing perimeter (p = 0.019). However, no significant effect of 2AG on mineral appositional rate was evident (Figure 7D, bottom right).

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to methods and pharmaceutical compositions suitable for modulating bone growth and remodeling, preventing bone diseases and inducing bone growth or repair. The present invention also relates to methods of identifying bone growth modulating agents. The principles and operation of the present invention may be better understood with reference to the drawings and accompanying descriptions.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details set forth in the following description or exemplified by the Examples. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Cannabinoid receptors belong to the superfamily of G-protein coupled receptors. They are classified into the predominantly neuronal CB1 receptors and the predominantly peripheral CB2 receptors. While the effects of CB1 receptors are principally associated with the central nervous system, CB2 receptors are believed to have peripheral effects related to immunomodulation and inflammation. In addition to the CB1 and CB2 receptors, recent pharmacological evidence indicates possible existence of additional types of cannabinoid receptors [e.g., Breivogel *et al.*, Mol Pharmacol 60: 155-163 (2001); Calignano A., Eur J Pharmacol 419: 191-198 (2001); Jarai *et al.*, Proc Natl Acad Sci USA 96: 14136-14141 (1999); and Di Marzo *et al.*, J. Neurochem 75: 2434-2444 (2000)].

Upregulation of CB1 receptors inhibits transmitter release, while upregulation of CB2 receptors inhibits monocyte/macrophage activity and the release of inflammatory cytokines [Howlett *et al.*, Pharmacol. Rev. 54:161-202 (2002)]. Accordingly, ligands of cannabinoids receptors have been described as therapeutic

agents for treating a range of diseases or disorders which relate to this described function of these receptors.

While reducing the present invention to practice the present inventors surprisingly and unexpectedly discovered that cannabinoid receptors are expressed in bone cells and participate in regulation of bone formation, remodeling and bone growth (see Examples 1-4 of the Examples section which follows).

As used herein, the term "bone growth" is defined as including all processes resulting in a maintenance of or positive increase in amount and integrity of bone tissue. Particularly, bone growth includes bone remodeling, bone formation, mineralization, etc.

The expression of cannabinoid receptors in bone tissue, the regulatory effect of cannabinoid receptors on bone growth and remodeling and the potential benefit of manipulating expression or activity of cannabinoid receptors for treating bone diseases have not been described, nor suggested, in prior art.

Thus, according to one aspect of the present invention there is provided a method of modulating bone growth and remodeling. The method according to this aspect is effected by regulating an expression or activity of one or more cannabinoid receptors.

The cannabinoid receptor of the present invention is preferably a bone cell or bone cell progenitor receptor. As used herein, the phrase "bone cell" refers to a skeletal tissue cell, such as, bone, cartilage, tendon, ligament, marrow stroma and connective tissue cells, including bone resorbing cells such as marrow monocyte-derived osteoclasts, macrophages and scavenger cells. As used herein, the term "bone cell progenitor" refers to a cell that can become committed, or partially committed, to a bone cell differentiation pathway, including stem cells and bone resorbing cell progenitors, but does not generally express markers or function as a mature, fully differentiated cell.

Preferably, the bone cell progenitor is a stromal or osteogenic cell, or a bone resorbing cell progenitor. As used herein, the term "stromal cell" refers to a pluripotent progenitor cell which is capable of dividing many times, and whose progeny will give rise to skeletal tissues, including cartilage, bone, tendon, ligament, marrow stroma and connective tissue [see A. Caplan J. Orthop. Res. 9:641-50 (1991)]. It will be noted that the term "stromal cell" also includes mesenchymal

cells. As used herein, the term "osteogenic cell" refers to an osteoblast or a progenitor osteoblast cell, which give rise to a bone tissue.

The cannabinoid receptor of the present invention, can be, for example, a CB1 or CB2 receptor, a CB1-like, or CB2-like receptor or any other type of cannabinoid receptor [Howlett *et al.* Pharmacol. Rev. 54:161-202 (2002)].

As used herein, the phrase "regulating an expression or activity" refers to either upregulation or downregulation of receptor expression or activity, or in select instances upregulation of one cannabinoid receptor expression or activity and downregulation of another cannabinoid receptor expression or activity.

As is further described hereinunder, up or down regulation of cannabinoid receptor expression or activity can be utilized to treat a variety of bone diseases or disorders. Such regulation can be achieved using a variety of agents and approaches well known to the ordinary skilled artisan. The section below provides several examples of such agents starting with a description of agents which can be used to upregulate activity of cannabinoid receptors.

One example of an agent capable of upregulating activity of cannabinoid receptors is a cannabinoid molecule. The term "cannabinoid" refers to any natural or synthetic agonist of a cannabinoid receptor, or an analogs or derivative thereof. Presently known cannabinoids include, for example, Δ^9-tetrahydrocannabinol (Δ^9-THC) , Δ^8-THC , Δ^9-THC-dimethylheptyl , 11-hydroxy-Δ^8-THC-dimethylheptyl (HU-210) , 5'-F-Δ^8-THC, 11-OH-cannabinol, Δ^8-THC-11-oic-dimethylheptyl acid, 1-deoxy-11-OH-Δ^8-THC-dimethylheptyl (JWH-051), 11-Hydroxy THCs, desacetyl-L-nantradol, 11-OH-cannabinol-dimethylheptyl, cannabinol-dimethylheptyl-11-oic acid, HU-308, HU 243, L-759633, L-759656, L-768242, JWH-133, JWH-139, JWH-051, JWH-015, CP55940, CP47497, CP55244, R-(+)-WIN55212, ACEA, ACPA, O-1812, arachidonyl ethanolamide (anandamide), 2-arachidonoylglycerol (2AG), 2-arachidonoylglyceryl ether, and methanandamide, and analogs or derivatives thereof. Additional cannabinoids are described in the references cited in the background section above.

Another method of upregulating receptor activity is by inhibiting metabolism of the endogenous (or exogenous) ligand, as in the SSRI (selective serotonin reuptake inhibitors) class of antidepressants or methylxanthine phosphodiesterase inhibitors upregulation of cAMP-dependent receptor activity. Inhibition of FAAH, for example

(as described in the Examples section below), can effectively increase cannabinoid receptor activity.

An agent capable of upregulating expression of a cannabinoid receptor may be an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of the receptor. Accordingly, the exogenous polynucleotide sequence may be a DNA or RNA sequence encoding a cannabinoid receptor molecule, capable of modulating bone growth and/or bone remodeling.

Cannabinoid receptors CB1 and CB2 have been cloned from human, rat and mouse sources [Chakrabarti *et al.*, DNA Sequence 5: 385-388 (1995); Gérard *et al.*, Nucleic Acids Res 18: 7142 (1990); Griffin *et al.*, J Pharmacol Exp Ther 292: 886-894 (2000); Shire *et al.*, Biochim Biophys Acta 1307: 132-136 (1996); and Munro *et al.*, Nature 365: 61-65 (1993)]. Thus, coding sequences information for both CB1 and CB2 is available from several databases including the GenBank database available through http://www4.ncbi.nlm.nih.gov/.

To express exogenous cannabinoid receptors in mammalian cells, a polynucleotide sequence encoding a cannabinoid receptor (for example, CB1 receptor cDNA: GenBank Accession No. NM007726; CB2 receptor cDNA: GenBank Accession No. NM001841) is preferably ligated into a nucleic acid construct suitable for mammalian cell expression. Such a nucleic acid construct includes a promoter sequence for directing transcription of the polynucleotide sequence in the cell in a constitutive or inducible manner. A suitable promoter can be, for example, a human osteocalcin gene promoter which is capable of directing bone specific gene expression (see U.S. Pat. No. 5,948,951), or the human collagenase 1 (MMP-1) promoter (GenBank Accession No. AF023338). The nucleic acid construct of the present invention can further include additional polynucleotide sequences such as for example, sequences encoding selection markers or reporter polypeptides, sequences encoding origin of replication in bacteria, sequences that allow for translation of several proteins from a single mRNA (IRES), sequences for genomic integration of the promoter-chimeric polypeptide encoding region and/or sequences generally included in mammalian expression vector such as pcDNA3, pcDNA3.1(+/-), pZeoSV2(+/-), pSecTag2, pDisplay, pEF/myc/cyto, pCMV/myc/cyto, pCR3.1, which are available from Invitrogen, pCI which is available from Promega, pBK-RSV and

pBK-CMV which are available from Stratagene, pTRES which is available from Clontech, and their derivatives.

An agent capable of upregulating a cannabinoid receptor may also be any compound which is capable of increasing the transcription and/or translation of an endogenous DNA or mRNA encoding the cannabinoid receptor.

As is mentioned hereinabove, the method according to this aspect of the present invention also provides downgulation of expression or activity of at least one cannabinoid receptor.

One example of an agent capable of downregulating a cannabinoid receptor is an antibody or antibody fragment capable of specifically binding a cannabinoid receptor. Preferably, the antibody specifically binds at least one epitope of a cannabinoid receptor. Preferably, this epitope resides in an extracellular portion or most preferably, a ligand binding portion of the cannabinoid receptor. Examples of anti-cannabinoid receptor antibodies suitable for use in downregulation of cannabinoid receptor activity are the specific antibodies for CB1 described by Katona et al (J. Neurosci 1999; 19:4544-58).

As used herein, the term "epitope" implies any antigenic determinant on an antigen to which the paratope of an antibody binds.

Epitopic determinants usually consist of chemically active surface groupings of molecules such as amino acids or carbohydrate side chains and usually have specific three-dimensional structural characteristics, as well as specific charge characteristics.

The term "antibody" as used in this invention includes intact molecules as well as functional fragments thereof, such as Fab, F(ab')2, and Fv that are capable of binding to macrophages. These functional antibody fragments are defined as follows: (1) Fab, the fragment which contains a monovalent antigen-binding fragment of an antibody molecule, can be produced by digestion of whole antibody with the enzyme papain to yield an intact light chain and a portion of one heavy chain; (2) Fab', the fragment of an antibody molecule that can be obtained by treating whole antibody with pepsin, followed by reduction, to yield an intact light chain and a portion of the heavy chain; two Fab' fragments are obtained per antibody molecule; (3) (Fab')2, the fragment of the antibody that can be obtained by treating whole antibody with the enzyme pepsin without subsequent reduction; F(ab')2 is a dimer of two Fab' fragments

held together by two disulfide bonds; (4) Fv, defined as a genetically engineered fragment containing the variable region of the light chain and the variable region of the heavy chain expressed as two chains; and (5) Single chain antibody ("SCA"), a genetically engineered molecule containing the variable region of the light chain and the variable region of the heavy chain, linked by a suitable polypeptide linker as a genetically fused single chain molecule.

Methods of producing polyclonal and monoclonal antibodies as well as fragments thereof are well known in the art (See for example, Harlow and Lane, Antibodies: A Laboratory Manual, Cold Spring Harbor Laboratory, New York, 1988, incorporated herein by reference). Specifically, several cannabinoid CB_1 and CB_2 receptor-specific antibodies have been successfully developed and described by Egertová *et al.*, J Comp Neurol 422: 159-171 (2000); Tsou *et al.*, Neuroscience 83: 393-411(1998); Daaka *et al.*, J Pharmacol Exp Ther 276: 776-783 (1996); Sinha *et al.*, J Neuroimmunol 82: 13-21 (1998); Waksman *et al.*, J Pharmacol Exp Ther 288: 1357-1366; Galiègue *et al.*, Eur J Biochem 232: 54-61(1995); and Carayon *et al.*, Blood 92: 3605-3615 (1998).

Antibody fragments according to the present invention can be prepared by proteolytic hydrolysis of the antibody or by expression in E. coli or mammalian cells (e.g. Chinese hamster ovary cell culture or other protein expression systems) of DNA encoding the fragment. Antibody fragments can be obtained by pepsin or papain digestion of whole antibodies by conventional methods. For example, antibody fragments can be produced by enzymatic cleavage of antibodies with pepsin to provide a 5S fragment denoted F(ab')2. This fragment can be further cleaved using a thiol reducing agent, and optionally a blocking group for the sulfhydryl groups resulting from cleavage of disulfide linkages, to produce 3.5S Fab' monovalent fragments. Alternatively, an enzymatic cleavage using pepsin produces two monovalent Fab' fragments and an Fc fragment directly. These methods are described, for example, by Goldenberg, U.S. Pat. Nos. 4,036,945 and 4,331,647, and references contained therein, which patents are hereby incorporated by reference in their entirety. See also Porter, R. R. [Biochem. J. 73: 119-126 (1959)]. Other methods of cleaving antibodies, such as separation of heavy chains to form monovalent light-heavy chain fragments, further cleavage of fragments, or other enzymatic, chemical, or genetic

techniques may also be used, so long as the fragments bind to the antigen that is recognized by the intact antibody.

Fv fragments comprise an association of VH and VL chains. This association may be noncovalent, as described in Inbar *et al.* [Proç. Nat'l Acad. Sci. USA 69:2659-62 (19720]. Alternatively, the variable chains can be linked by an intermolecular disulfide bond or cross-linked by chemicals such as glutaraldehyde. Preferably, the Fv fragments comprise VH and VL chains connected by a peptide linker. These single-chain antigen binding proteins (sFv) are prepared by constructing a structural gene comprising DNA sequences encoding the VH and VL domains connected by an oligonucleotide. The structural gene is inserted into an expression vector, which is subsequently introduced into a host cell such as E. coli. The recombinant host cells synthesize a single polypeptide chain with a linker peptide bridging the two V domains. Methods for producing sFvs are described, for example, by [Whitlow and Filpula, Methods 2: 97-105 (1991); Bird *et al.*, Science 242:423-426 (1988); Pack *et al.*, Bio/Technology 11:1271-77 (1993); and U.S. Pat. No. 4,946,778, which is hereby incorporated by reference in its entirety.

Another form of an antibody fragment is a peptide coding for a single complementarity-determining region (CDR). CDR peptides ("minimal recognition units") can be obtained by constructing genes encoding the CDR of an antibody of interest. Such genes are prepared, for example, by using the polymerase chain reaction to synthesize the variable region from RNA of antibody-producing cells. See, for example, Larrick and Fry [Methods, 2: 106-10 (1991)].

Humanized forms of non-human (e.g., murine) antibodies are chimeric molecules of immunoglobulins, immunoglobulin chains or fragments thereof (such as Fv, Fab, Fab', F(ab').sub.2 or other antigen-binding subsequences of antibodies) which contain minimal sequence derived from non-human immunoglobulin. Humanized antibodies include human immunoglobulins (recipient antibody) in which residues form a complementary determining region (CDR) of the recipient are replaced by residues from a CDR of a non-human species (donor antibody) such as mouse, rat or rabbit having the desired specificity, affinity and capacity. In some instances, Fv framework residues of the human immunoglobulin are replaced by corresponding non-human residues. Humanized antibodies may also comprise residues which are found neither in the recipient antibody nor in the imported CDR or

framework sequences. In general, the humanized antibody will comprise substantially all of at least one, and typically two, variable domains, in which all or substantially all of the CDR regions correspond to those of a non-human immunoglobulin and all or substantially all of the FR regions are those of a human immunoglobulin consensus sequence. The humanized antibody optimally also will comprise at least a portion of an immunoglobulin constant region (Fc), typically that of a human immunoglobulin [Jones *et al.*, Nature, 321:522-525 (1986); Riechmann *et al.*, Nature, 332:323-329 (1988); and Presta, Curr. Op. Struct. Biol., 2:593-596 (1992)].

Methods for humanizing non-human antibodies are well known in the art. Generally, a humanized antibody has one or more amino acid residues introduced into it from a source which is non-human. These non-human amino acid residues are often referred to as import residues, which are typically taken from an import variable domain. Humanization can be essentially performed following the method of Winter and co-workers [Jones *et al.*, Nature, 321:522-525 (1986); Riechmann *et al.*, Nature 332:323-327 (1988); Verhoeyen *et al.*, Science, 239:1534-1536 (1988)], by substituting rodent CDRs or CDR sequences for the corresponding sequences of a human antibody. Accordingly, such humanized antibodies are chimeric antibodies (U.S. Pat. No. 4,816,567), wherein substantially less than an intact human variable domain has been substituted by the corresponding sequence from a non-human species. In practice, humanized antibodies are typically human antibodies in which some CDR residues and possibly some FR residues are substituted by residues from analogous sites in rodent antibodies.

Human antibodies can also be produced using various techniques known in the art, including phage display libraries [Hoogenboom and Winter, J. Mol. Biol., 227:381 (1991); Marks *et al.*, J. Mol. Biol., 222:581 (1991)]. The techniques of Cole *et al.* and Boerner *et al.* are also available for the preparation of human monoclonal antibodies (Cole *et al.*, Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, p. 77 (1985) and Boerner *et al.*, J. Immunol., 147(1):86-95 (1991)]. Similarly, human antibodies can be made by introduction of human immunoglobulin loci into transgenic animals, e.g., mice in which the endogenous immunoglobulin genes have been partially or completely inactivated. Upon challenge, human antibody production is observed, which closely resembles that seen in humans in all respects, including gene rearrangement, assembly, and antibody repertoire. This approach is described,

for example, in U.S. Pat. Nos. 5,545,807; 5,545,806; 5,569,825; 5,625,126; 5,633,425; 5,661,016, and in the following scientific publications: Marks *et al.*, Bio/Technology 10,: 779-783 (1992); Lonberg *et al.*, Nature 368: 856-859 (1994); Morrison, Nature 368 812-13 (1994); Fishwild *et al.*, Nature Biotechnology 14, 845-51 (1996); Neuberger, Nature Biotechnology 14: 826 (1996); and Lonberg and Huszar, Intern. Rev. Immunol. 13, 65-93 (1995).

Downregulating of a cannabinoid receptor may also be effected by an enzyme which cleaves the cannabinoid receptor.

Another agent capable of downregulating a cannabinoid receptor is a small interfering RNA (siRNA) molecule. RNA interference is a two step process. the first step, which is termed as the initiation step, input dsRNA is digested into 21-23 nucleotide (nt) small interfering RNAs (siRNA), probably by the action of Dicer, a member of the RNase III family of dsRNA-specific ribonucleases, which processes (cleaves) dsRNA (introduced directly or via a transgene or a virus) in an ATP-dependent manner. Successive cleavage events degrade the RNA to 19-21 bp duplexes (siRNA), each with 2-nucleotide 3' overhangs [Hutvagner and Zamore Curr. Opin. Genetics and Development 12:225-232 (2002); and Bernstein Nature 409:363-366 (2001)].

In the effector step, the siRNA duplexes bind to a nuclease complex to from the RNA-induced silencing complex (RISC). An ATP-dependent unwinding of the siRNA duplex is required for activation of the RISC. The active RISC then targets the homologous transcript by base pairing interactions and cleaves the mRNA into 12 nucleotide fragments from the 3' terminus of the siRNA [Hutvagner and Zamore Curr. Opin. Genetics and Development 12:225-232 (2002); Hammond *et al.* (2001) Nat. Rev. Gen. 2:110-119 (2001); and Sharp Genes. Dev. 15:485-90 (2001)]. Although the mechanism of cleavage is still to be elucidated, research indicates that each RISC contains a single siRNA and an RNase [Hutvagner and Zamore Curr. Opin. Genetics and Development 12:225-232 (2002)].

Because of the remarkable potency of RNAi, an amplification step within the RNAi pathway has been suggested. Amplification could occur by copying of the input dsRNAs which would generate more siRNAs, or by replication of the siRNAs formed. Alternatively or additionally, amplification could be effected by multiple turnover events of the RISC [Hammond *et al.* Nat. Rev. Gen. 2:110-119 (2001),

Sharp Genes. Dev. 15:485-90 (2001); Hutvagner and Zamore Curr. Opin. Genetics and Development 12:225-232 (2002)]. For more information on RNAi see the following reviews Tuschl ChemBiochem. 2:239-245 (2001); Cullen Nat. Immunol. 3:597-599 (2002); and Brantl Biochem. Biophys. Act. 1575:15-25 (2002).

Synthesis of RNAi molecules suitable for use with the present invention can be effected as follows. First, the cannabinoid receptor mRNA sequence is scanned downstream of the AUG start codon for AA dinucleotide sequences. Occurrence of each AA and the 3' adjacent 19 nucleotides is recorded as potential siRNA target sites. Preferably, siRNA target sites are selected from the open reading frame, as untranslated regions (UTRs) are richer in regulatory protein binding sites. UTR-binding proteins and/or translation initiation complexes may interfere with binding of the siRNA endonuclease complex [Tuschl ChemBiochem. 2:239-245]. It will be appreciated though, that siRNAs directed at untranslated regions may also be effective, as demonstrated for GAPDH wherein siRNA directed at the 5' UTR mediated about 90 % decrease in cellular GAPDH mRNA and completely abolished protein level (www.ambion.com/techlib/tn/91/912.html).

Second, potential target sites are compared to an appropriate genomic database (e.g., human, mouse, rat etc.) using any sequence alignment software, such as the BLAST software available from the NCBI server (www.ncbi.nlm.nih.gov/BLAST/). Putative target sites which exhibit significant homology to other coding sequences are filtered out.

Qualifying target sequences are selected as template for siRNA synthesis. Preferred sequences are those including low G/C content as these have proven to be more effective in mediating gene silencing as compared to those with G/C content higher than 55 %. Several target sites are preferably selected along the length of the target gene for evaluation. For better evaluation of the selected siRNAs, a negative control is preferably used in conjunction. Negative control siRNA preferably include the same nucleotide composition as the siRNAs but lack significant homology to the genome. Thus, a scrambled nucleotide sequence of the siRNA is preferably used, provided it does not display any significant homology to any other gene.

Another agent capable of downregulating a cannabinoid receptor is a DNAzyme molecule capable of specifically cleaving an mRNA transcript or DNA sequence of the cannabinoid receptor. DNAzymes are single-stranded polynucleotides

which are capable of cleaving both single and double stranded target sequences (Breaker, R.R. and Joyce, G. Chemistry and Biology 1995;2:655; Santoro, S.W. & Joyce, G.F. Proc. Natl, Acad. Sci. USA 1997;943:4262) A general model (the "10-23" model) for the DNAzyme has been proposed. "10-23" DNAzymes have a catalytic domain of 15 deoxyribonucleotides, flanked by two substrate-recognition domains of seven to nine deoxyribonucleotides each. This type of DNAzyme can effectively cleave its substrate RNA at purine:pyrimidine junctions (Santoro, S.W. & Joyce, G.F. Proc. Natl, Acad. Sci. USA 199; for rev of DNAzymes see Khachigian, LM [Curr Opin Mol Ther 4:119-21 (2002)].

Examples of construction and amplification of synthetic, engineered DNAzymes recognizing single and double-stranded target cleavage sites have been disclosed in U.S. Pat. No. 6,326,174 to Joyce *et al.* DNAzymes of similar design directed against the human Urokinase receptor were recently observed to inhibit Urokinase receptor expression, and successfully inhibit colon cancer cell metastasis in vivo (Itoh *et al*, 20002, Abstract 409, Ann Meeting Am Soc Gen Ther www.asgt.org). In another application, DNAzymes complementary to bcr-ab1 oncogenes were successful in inhibiting the oncogenes expression in leukemia cells, and lessening relapse rates in autologous bone marrow transplant in cases of CML and ALL.

Downregulation of a cannabinoid receptor can also be effected by using an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding the cannabinoid receptor.

Design of antisense molecules which can be used to efficiently downregulate a cannabinoid receptor must be effected while considering two aspects important to the antisense approach. The first aspect is delivery of the oligonucleotide into the cytoplasm of the appropriate cells, while the second aspect is design of an oligonucleotide which specifically binds the designated mRNA within cells in a way which inhibits translation thereof.

The prior art teaches of a number of delivery strategies which can be used to efficiently deliver oligonucleotides into a wide variety of cell types [see, for example, Luft J Mol Med 76: 75-6 (1998); Kronenwett *et al.* Blood 91: 852-62 (1998); Rajur *et al.* Bioconjug Chem 8: 935-40 (1997); Lavigne *et al.* Biochem Biophys Res Commun 237: 566-71 (1997) and Aoki *et al.* (1997) Biochem Biophys Res Commun 231: 540-

5 (1997)]. Of particular interest is the method described by Erikkson (U.S. Pat. No. 6,525,030) for periosteal transformation using microinjection of DNA at the bone surface.

In addition, algorithms for identifying those sequences with the highest predicted binding affinity for their target mRNA based on a thermodynamic cycle that accounts for the energetics of structural alterations in both the target mRNA and the oligonucleotide are also available [see, for example, Walton *et al.* Biotechnol Bioeng 65: 1-9 (1999)].

Such algorithms have been successfully used to implement an antisense approach in cells. For example, the algorithm developed by Walton et al. enabled scientists to successfully design antisense oligonucleotides for rabbit beta-globin (RBG) and mouse tumor necrosis factor-alpha (TNF alpha) transcripts. The same research group has more recently reported that the antisense activity of rationally selected oligonucleotides against three model target mRNAs (human lactate dehydrogenase A and B and rat gp130) in cell culture as evaluated by a kinetic PCR technique proved effective in almost all cases, including tests against three different targets in two cell types with phosphodiester and phosphorothioate oligonucleotide chemistries.

In addition, several approaches for designing and predicting efficiency of specific oligonucleotides using an *in vitro* system were also published (Matveeva *et al.*, Nature Biotechnology 16: 1374 - 1375 (1998)].

Several clinical trials have demonstrated safety, feasibility and activity of antisense oligonucleotides. For example, antisense oligonucleotides suitable for the treatment of cancer have been successfully used [Holmund *et al.*, Curr Opin Mol Ther 1:372-85 (1999)], while treatment of hematological malignancies via antisense oligonucleotides targeting c-myb gene, p53 and Bcl-2 had entered clinical trials and had been shown to be tolerated by patients [Gerwitz Curr Opin Mol Ther 1:297-306 (1999)].

More recently, antisense-mediated suppression of human heparanase gene expression has been reported to inhibit pleural dissemination of human cancer cells in a mouse model [Uno *et al.*, Cancer Res 61:7855-60 (2001)].

Thus, the current consensus is that recent developments in the field of antisense technology which, as described above, have led to the generation of highly

accurate antisense design algorithms and a wide variety of oligonucleotide delivery systems, enable an ordinarily skilled artisan to design and implement antisense approaches suitable for downregulating expression of known sequences without having to resort to undue trial and error experimentation.

Another agent capable of downregulating a cannabinoid receptor is a ribozyme molecule capable of specifically cleaving an mRNA transcript encoding a cannabinoid receptor. Ribozymes are being increasingly used for the sequence-specific inhibition of gene expression by the cleavage of mRNAs encoding proteins of interest [Welch *et al.*, Curr Opin Biotechnol. 9:486-96 (1998)]. The possibility of designing ribozymes to cleave any specific target RNA has rendered them valuable tools in both basic research and therapeutic applications. In the therapeutics area, ribozymes have been exploited to target viral RNAs in infectious diseases, dominant oncogenes in cancers and specific somatic mutations in genetic disorders [Welch *et al.*, Clin Diagn Virol. 10:163-71 (1998)]. Most notably, several ribozyme gene therapy protocols for HIV patients are already in Phase 1 trials. More recently, ribozymes have been used for transgenic animal research, gene target validation and pathway elucidation. Several ribozymes are in various stages of clinical trials. ANGIOZYME was the first chemically synthesized ribozyme to be studied in human clinical trials. ANGIOZYME specifically inhibits formation of the VEGF-r (Vascular Endothelial Growth Factor receptor), a key component in the angiogenesis pathway. Ribozyme Pharmaceuticals, Inc., as well as other firms have demonstrated the importance of anti-angiogenesis therapeutics in animal models. HEPTAZYME, a ribozyme designed to selectively destroy Hepatitis C Virus (HCV) RNA, was found effective in decreasing Hepatitis C viral RNA in cell culture assays (Ribozyme Pharmaceuticals, Incorporated - WEB home page).

Another agent capable of downregulating a cannabinoid receptor can be a non-functional analogue of a binding portion of the cannabinoid receptor. Examples include truncated CB1 or CB2 sequences (lacking for example the N-terminal portion).

Yet another agent capable of downregulating a cannabinoid receptor is a molecule which can prevent activation of, or ligand binding on, the cannabinoid receptor. The molecule may be a cannabinoid antagonist or an inverse agonist, such as, for example, SR141716A, SR144528, AM251, AM281, SR144528, LY320135,

AM630, WIN56098, WIN54461, O-1184 and O-1238 [see in Howlett *et al.*, Pharmacol. Rev. 54:161-202 (2002)].

Cannabinoid receptor activity can also be downregulated by specifically targeting the natural ligand of the cannabinoid receptor, such as anandamine, 2AG or any other endocannabinoid capable of binding a cannabinoid receptor in a bone cell.

As is mentioned hereinabove, regulation of cannabinoid receptor expression or activity can be upregulation of one or more cannabinoid receptors, downregulation of one or more cannabinoid receptors or upregulation of one receptor and downregulation of another. While the latter scenario has not yet been described in prior art in any application related to cannabinoid receptor activity, the results of Example 4 of the Examples section that follows, suggest that such a case exists with the CB1 cannabinoid-receptor antagonist SR-141761A which may also act as an agonist of another yet unknown cannabinoid receptor.

Regulation of cannabinoid receptor expression or activity may be effected *ex vivo* by exposing cultured bone cells to an upregulating or downregulating agent, or *in vivo* by administering such an agent to a subject.

Thus, according to another aspect of the present invention, there is provided a method of inducing bone growth or repair in a subject of need thereof.

The term "subject" used herein refers to human as well as other animal species, such as, for example, canine, feline, bovine, porcine, rodent, and the like.

The phrase "treating or preventing" used herein refers to a postponement of development of bone deficit symptoms and/or a reduction in the severity of such symptoms that will or are expected to develop. These further include ameliorating existing bone or cartilage deficit symptoms, preventing additional symptoms, ameliorating or preventing the underlying metabolic causes of symptoms, preventing or reversing bone resorption and/or encouraging bone growth. Thus, the phrase denotes that a beneficial result has been conferred on a vertebrate subject with a cartilage, bone or skeletal deficit, or with the potential to develop such deficit. The phrase further refers to a postponement of development of bone overgrowth symptoms and/or a reduction in the severity of such symptoms that will or are expected to develop.

The method can be effected using two alternative approaches. In a first approach, bone cells are isolated from the subject or an allogeneic or syngeneic donor

and expression or activity of one or more cannabinoid receptors of these bone cells is either downregulated or preferably upregulated (or both) as described above. Once expression or activity is either upregulated or downregulated cells displaying modified cannabinoid receptor activity are administered to the subject (preferably via local injection).

In a second approach, the agent is directly administered to the subject via one of several alternative administration modes (further described hereinbelow).

The above described approaches can be utilized to treat a variety of bone related diseases or disorders. For example, agents capable of upregulating cannabinoid receptor expression or activity can be used for treating or preventing any bone deficit-related disease or condition such as, for example, preventing bone defects and deficiencies in closed, open and non-union fractures; augmenting bone mass in young individuals at risk; prophylactic treatment in young individuals by enhancing peak bone mass in closed and open fracture reduction; promotion of bone healing in plastic surgery; stimulation of bone ingrowth into non-cemented post orthopedic and dental implants; elevation of peak bone mass in pre-menopausal women; treatment of growth deficiencies; treatment of primary or secondary hyperparathyroidism; treatment of osteolytic bone disease such as cancer; treatment of periodontal disease and defects, and other tooth repair processes; increase in bone formation during distraction osteogenesis; and treatment of other skeletal disorders, such as age-related osteoporosis, post-menopausal osteoporosis, glucocorticoid-induced osteoporosis or disuse osteoporosis and arthritis, osteoarthritis or any condition that benefits from stimulation of bone formation, on the one hand, and inhibition of bone resorption, on the other. The agents of the present invention can also be useful in repair of congenital, trauma-induced or surgical resection of bone (for instance, for cancer treatment), and in cosmetic surgery. Further, the compounds of the present invention can be used for limiting or treating cartilage defects or disorders, and may be useful in wound healing or tissue repair.

Agents capable of downregulating cannabinoid receptors, such as described hereinabove, can be used for treating or preventing any bone overgrowth-related disease or condition such as, for example, certain stages of Paget's disease, an osteoblastic bone disease, a metastatic bone disease such as breast cancer and

prostate cancer, a blastic metastatic bone cancer, Hodgkin's lymphoma, degenerative sclerosis and osteomyelitis.

The agents of the present invention can be in therapy *per se* or as part (active ingredient) of a pharmaceutical composition.

As used herein a "pharmaceutical composition" refers to a preparation of one or more of the active ingredients described herein with other chemical components such as physiologically suitable carriers and excipients. The purpose of a pharmaceutical composition is to facilitate administration of a compound to an organism.

Hereinafter, the phrases "physiologically acceptable carrier" and "pharmaceutically acceptable carrier" which may be interchangeably used refer to a carrier or a diluent that does not cause significant irritation to an organism and does not abrogate the biological activity and properties of the administered compound. An adjuvant is included under these phrases.

Herein the term "excipient" refers to an inert substance added to a pharmaceutical composition to further facilitate administration of an active ingredient. Examples, without limitation, of excipients include calcium carbonate, calcium phosphate, various sugars and types of starch, cellulose derivatives, gelatin, vegetable oils and polyethylene glycols.

A pharmaceutical composition which includes one or more cannabinoid receptor upregulating agents may also include one or more compounds which promote bone formation and/or inhibiting bone resorption, such as, for example, a bone morphogenic factors, bone morphogenic protein, parathyroid hormone, noggin, osteogenic growth peptide, anti-resorptive agents, osteogenic factors, cartilage-derived morphogenic proteins, growth hormones, cytokines such as fibroblast growth factor (FGF), insulin-like growth factor-I (IGF-I), transforming growth factors, estrogens, bisphosphonates, statin, calcitonin, dihydroxy vitamin D_3, and calcium preparations are preferred for this purpose.

Alternatively, a pharmaceutical composition which includes one or more cannabinoid receptor downregulating agents may also include one or more compounds which inhibit bone formation and/or promote bone resorption.

Further, up- or downregulating agents can be targeted to bone or other specific sites of activity using targeting molecules.

Techniques for formulation and administration of drugs may be found in "Remington's Pharmaceutical Sciences," Mack Publishing Co., Easton, PA, latest edition, which is incorporated herein by reference.

Suitable routes of administration may, for example, include oral, rectal, transmucosal, especially transnasal, intestinal or parenteral delivery, including intramuscular, subcutaneous and intramedullary injections as well as intrathecal, direct intraventricular, intravenous, inrtaperitoneal, intranasal, or intraocular injections.

Alternately, one may administer the pharmaceutical composition in a local rather than systemic manner, for example, via injection of the pharmaceutical composition directly into a bone tissue region of a patient.

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

Pharmaceutical compositions for use in accordance with the present invention thus may be formulated in conventional manner using one or more physiologically acceptable carriers comprising excipients and auxiliaries, which facilitate processing of the active ingredients into preparations which can be used pharmaceutically. Proper formulation is dependent upon the route of administration chosen.

For injection, the active ingredients of the pharmaceutical composition may be formulated in aqueous solutions, preferably in physiologically compatible buffers such as Hank's solution, Ringer's solution, or physiological salt buffer. One route of administration which is suited for the pharmaceutical compositions of the present invention is sub-periosteal injection, as described in U.S. Pat. No. 6,525,030 to Erikkson. For transmucosal administration, penetrants appropriate to the barrier to be permeated are used in the formulation. Such penetrants are generally known in the art.

For oral administration, the pharmaceutical composition can be formulated readily by combining the active compounds with pharmaceutically acceptable carriers well known in the art. Such carriers enable the pharmaceutical composition to be formulated as tablets, pills, dragees, capsules, liquids, gels, syrups, slurries, suspensions, and the like, for oral ingestion by a patient. Pharmacological

preparations for oral use can be made using a solid excipient, optionally grinding the resulting mixture, and processing the mixture of granules, after adding suitable auxiliaries if desired, to obtain tablets or dragee cores. Suitable excipients are, in particular, fillers such as sugars, including lactose, sucrose, mannitol, or sorbitol; cellulose preparations such as, for example, maize starch, wheat starch, rice starch, potato starch, gelatin, gum tragacanth, methyl cellulose, hydroxypropylmethyl-cellulose, sodium carbomethylcellulose; and/or physiologically acceptable polymers such as polyvinylpyrrolidone (PVP). If desired, disintegrating agents may be added, such as cross-linked polyvinyl pyrrolidone, agar, or alginic acid or a salt thereof such as sodium alginate. As used herein, the term "oral administration" includes administration of the pharmaceutical compound to any oral surface, including the tongue, gums, palate, or other buccal surfaces. Addition methods of oral administration include provision of the pharmaceutical composition in a mist, spray or suspension compatible with tissues of the oral surface.

Dragee cores are provided with suitable coatings. For this purpose, concentrated sugar solutions may be used which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, titanium dioxide, lacquer solutions and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of active compound doses.

Pharmaceutical compositions which can be used orally, include push-fit capsules made of gelatin as well as soft, sealed capsules made of gelatin and a plasticizer, such as glycerol or sorbitol. The push-fit capsules may contain the active ingredients in admixture with filler such as lactose, binders such as starches, lubricants such as talc or magnesium stearate and, optionally, stabilizers. In soft capsules, the active ingredients may be dissolved or suspended in suitable liquids, such as fatty oils, liquid paraffin, or liquid polyethylene glycols. In addition, stabilizers may be added. All formulations for oral administration should be in dosages suitable for the chosen route of administration.

For buccal administration, the compositions may take the form of tablets or lozenges formulated in conventional manner.

For administration by nasal inhalation, the active ingredients for use according to the present invention are conveniently delivered in the form of an

aerosol spray presentation from a pressurized pack or a nebulizer with the use of a suitable propellant, e.g., dichlorodifluoromethane, trichlorofluoromethane, dichlorotetrafluoroethane or carbon dioxide. In the case of a pressurized aerosol, the dosage unit may be determined by providing a valve to deliver a metered amount. Capsules and cartridges of, e.g., gelatin for use in a dispenser may be formulated containing a powder mix of the compound and a suitable powder base such as lactose or starch.

The pharmaceutical composition described herein may be formulated for parenteral administration, e.g., by bolus injection or continuous infusion. Formulations for injection may be presented in unit dosage form, e.g., in ampoules or in multidose containers with optionally, an added preservative. The compositions may be suspensions, solutions or emulsions in oily or aqueous vehicles, and may contain formulatory agents such as suspending, stabilizing and/or dispersing agents.

Pharmaceutical compositions for parenteral administration include aqueous solutions of the active preparation in water-soluble form. Additionally, suspensions of the active ingredients may be prepared as appropriate oily or water based injection suspensions. Suitable lipophilic solvents or vehicles include fatty oils such as sesame oil, or synthetic fatty acids esters such as ethyl oleate, triglycerides or liposomes. Aqueous injection suspensions may contain substances, which increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol or dextran. Optionally, the suspension may also contain suitable stabilizers or agents which increase the solubility of the active ingredients to allow for the preparation of highly concentrated solutions.

Alternatively, the active ingredient may be in powder form for constitution with a suitable vehicle, e.g., sterile, pyrogen-free water based solution, before use.

The pharmaceutical composition of the present invention may also be formulated in rectal compositions such as suppositories or retention enemas, using, e.g., conventional suppository bases such as cocoa butter or other glycerides.

Pharmaceutical compositions suitable for use in context of the present invention include compositions wherein the active ingredients are contained in an amount effective to achieve the intended purpose. More specifically, a therapeutically effective amount means an amount of active ingredients (e.g. antisense oligonucleotide) effective to prevent, alleviate or ameliorate symptoms of a

disorder (e.g., mammary tumor progression) or prolong the survival of the subject being treated.

Determination of a therapeutically effective amount is well within the capability of those skilled in the art, especially in light of the detailed disclosure provided herein.

For any preparation used in the methods of the invention, the therapeutically effective amount or dose can be estimated initially from *in vitro* and cell culture assays. For example, a dose can be formulated in an animal model, such as the murine Neu model [Muller *et al.*, Cell *54*, 105-115 (1988)], to achieve a desired concentration or titer. Other such exemplary model system suitable for use with the methods of the present invention are differentiating osteoclasts (see Example 3 hereinbelow), and differentiating cultured osteogenic cells (see Example 2 hereinbelow). Such information can be used to more accurately determine useful doses in humans.

Toxicity and therapeutic efficacy of the active ingredients described herein can be determined by standard pharmaceutical procedures *in vitro*, in cell cultures or experimental animals. The data obtained from these *in vitro* and cell culture assays and animal studies can be used in formulating a range of dosage for use in human. The dosage may vary depending upon the dosage form employed and the route of administration utilized. The exact formulation, route of administration and dosage can be chosen by the individual physician in view of the patient's condition. (See e.g., Fingl, *et al.*, 1975, in "The Pharmacological Basis of Therapeutics", Ch. 1 p.1).

Dosage amount and interval may be adjusted individually to levels of the active ingredient which are sufficient to, for example, retard tumor progression in the case of blastic metastases (minimal effective concentration, MEC). The MEC will vary for each preparation, but can be estimated from *in vitro* data. Dosages necessary to achieve the MEC will depend on individual characteristics and route of administration. Detection assays can be used to determine plasma concentrations.

Depending on the severity and responsiveness of the condition to be treated, dosing can be of a single or a plurality of administrations, with course of treatment lasting from several days to several weeks or diminution of the disease state is achieved.

The amount of a composition to be administered will, of course, be dependent on the subject being treated, the severity of the affliction, the manner of administration, the judgment of the prescribing physician, etc.

Compositions of the present invention may, if desired, be presented in a pack or dispenser device, such as an FDA approved kit, which may contain one or more unit dosage forms containing the active ingredient. The pack may, for example, comprise metal or plastic foil, such as a blister pack. The pack or dispenser device may be accompanied by instructions for administration. The pack or dispenser may also be accommodated by a notice associated with the container in a form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceuticals, which notice is reflective of approval by the agency of the form of the compositions or human or veterinary administration. Such notice, for example, may be of labeling approved by the U.S. Food and Drug Administration for prescription drugs or of an approved product insert. Compositions comprising a preparation of the invention formulated in a compatible pharmaceutical carrier may also be prepared, placed in an appropriate container, and labeled for treatment of an indicated condition, as if further detailed above.

In order to facilitate practice of the methods described hereinabove, and/or production of pharmaceutical compositions and articles of manufacture as described hereinabove, the present invention further provides a method of identifying novel bone growth and remodeling modulating agents.

The method of identifying a drug candidate includes screening a plurality of molecules for a molecule capable of regulating an expression or activity of one or more cannabinoid receptors of bone cells. Screening may be accomplished *in vitro* by exposing cultured bone cell progenitors, such as murine bone marrow-derived osteoprogenitor cells (ST2 cell line) or calvaria-derived osteoblastic cells (MC3T3 E1 cell line) to test molecules followed by Reverse Transcription Polymerase Chain Reaction (RT-PCR) analysis for cannabinoid receptors expression, using a standard RT-PCR procedure, such as described in Example 2 of the Examples section which follows. Selected molecules may be further evaluated for a bone-growth modulating activity *in vivo* by administering selected test molecules to laboratory animals followed by determining their effect on bone growth in the treated animals. For example, a test molecule may be dissolved in 1:1:18 ethanol:emulfor:saline (v/v/v)

vehicle and injected intraperitoneally to a C3H (Harlan) mouse, using a protocol such as described in Example 4 of the Examples section below. The efficacy of the test molecules may be determined by comparing the bone growth rate and/or bone mineralization perimeter in the treated mice with the bone growth parameters in similar untreated mice. Molecules which induce significant stimulation, or inhibition, of a bone growth parameter become candidate for additional evaluations as bone-growth modulating agents.

Thus, the present invention provides novel methods, compositions and articles of manufacture for use in treatment or prevention of bone diseases. Since the present invention is based on natural specific mechanisms of modulating new bone growth, it can be applied to treat or to prevent a wide range of bone deficit-related as well as bone overgrowth-related diseases safely and effectively.

Additional objects, advantages, and novel features of the present invention will become apparent to one ordinarily skilled in the art upon examination of the following examples, which are not intended to be limiting. Additionally, each of the various embodiments and aspects of the present invention as delineated hereinabove and as claimed in the claims section below finds experimental support in the following examples.

EXAMPLES

Reference is now made to the following examples, which together with the above descriptions, illustrate the invention in a non limiting fashion.

EXAMPLE 1

Effect of CB1 cannabinoid receptor expression in bone cells: CB1 expression regulates bone growth and remodeling

Materials and Methods

Animals: C57BL/6J mice [Zimmer, A. *et al.* Proc. Natl Acad. Sci. USA. 96: 5780-5785 (1999)] were used as wild type control (WT) and were compared with CB1 receptor knockout mice ($CB1^{-/-}$) (Ledent *et al.*, Science 283: 401-404 (1999)] or with fatty-acid amide hydrolase knockout mice ($FAAH^{-/-}$) [Cravatt *et al.*, PNAS USA 2001;198:9371-76 (2001)].

Micro-computed tomography: Femora obtained from ten week old mice were subjected to qualitative and quantitative micro-computed tomography (μCT) and analyzed using procedures as described by Alexander *et al.* [J. Bone Min. Res. 16: 1665-1673 (2001)]. The femora were sampled from ten weeks old mice since the WT mice reach their peak trabecular bone mass at this age. The representative μCT images displayed were obtained from mice with median bone volume density or cortical thickness values, and were thus representative. Data shown are mean ± standard error (SE) obtained from 8 mice replications.

Results

Comparative three-dimensional μCT images of the secondary spongiosa in male CB1 knockout (deficient) ($CB1^{-/-}$) and wild-type (WT) mice are illustrated in Figures 1A and B. These images show a substantial decrease of trabecular network density and a substantial increase of bone-marrow spaces in the $CB1^{-/-}$ mice.

The μCT morphometric analyses of male $CB1^{-/-}$ mice as compared with the WT are summarized in Figures 2A-E. These Figures corroborate the results shown in Figures 1A and B: the $CB1^{-/-}$ mice developed a significantly higher cortical thickness [Figure 2A; $p = 0.012$ (t test)]; a significantly lower medullary space volume [Figure 2B; $p = 0.003$ (t test)]; a significantly lower trabecular bone volume density [Figure 2C; BV/TV= 11.5 ± 1.7 % vs. 18.8 ± 2.1 % (mean ± SE), $p= 0.018$ (t-test)]; a significantly lower trabecular number [Figure 2D; Tb.N.= 1.9 ± 0.2 mm-1 vs. 3.0 ± 0.1 mm-1 (mean ± SE), $p= 0.0003$ (t-test)]; and a significantly lower trabecular connectivity [Figure 2E; bottom right graph; Conn.D = 21.6 ± 3.6 mm-3 vs. 48.5 ± 3.9 mm-3 (mean ± SE), $p= 0.0002$ (t-test)] as compared to their age-matched wild type (WT) controls.

The μCT morphometric analyses of female $CB1^{-/-}$ as compared with the WT are illustrated in Figures 3A-D. These analyses show that the metaphyseal changes observed in the female $CB1^{-/-}$ were similar to those seen with male $CB1^{-/-}$, i.e., having a decreased trabecular bone volume (Figure 3A), a decreased trabecular connectivity (Figure 3B), decreased trabecular number (Figure 3C), and an increased trabecular spacing (Figure 3D).

The μCT morphometric analyses of male fatty acid amide hydrolase knockout (deficient) mice ($FAAH^{-/-}$), having impaired endocannabinoid degradation, as compared with the WT are illustrated in Figures 4A-D. The Figures show that the

FAAH$^{-/-}$ mice developed a significantly lower cortical thickness [Figure 4A, top left graph; p = 0.049 (t-test)]; and a significantly higher medullary space volume [Figure 4C, left bottom graph; p = 0.049 (t-test)]. These effects were expectedly the opposite from what was observed with CB1$^{-/-}$ mice (see Figures 4B and 4C above) since the FAAH enzyme is known to degrade endocannabinoides (Cravatt *et al.*, PNAS USA 198:9371-76 (2001)]).

These results clearly show that CB1 knockout (deficient) mice have a substantial disruption of the trabecular structural integrity with possible severe consequences to the bone load bearing capacity, as compared with wild type controls. Because the body weight and neurological sign score of the CB1$^{-/-}$ mice do not differ from those of their WT littermates, it appears that this osteopenic phenotype of the CB1 knockout (deficient) mice is not secondary to impaired food intake or physical activity.

Hence, these results clearly demonstrate that CB1 receptor expression regulates bone growth and remodeling in mice, and that cannabinoids capable of regulating CB1 expression or activity can thereby modulate the bone growth and remodeling.

EXAMPLE 2

Expression of cannabinoid receptors in differentiating cultured osteogenic cells

Materials and Methods

Cell cultures: the expression of cannabinoid receptors (Cnrs) CB1 and CB2, endocannabinoid-degrading enzyme fatty-acid amide hydrolase (FAAH), osteoblast differentiation-marker alkaline phosphatase (ALP), and osteoblast differentiation-marker parathyroid hormone-receptor I (PTH-Rc1), were analyzed in murine bone marrow-derived osteoprogenitor cells (ST2 cell line) and in calvaria-derived osteoblastic cells (MC3T3 E1 cell line). Osteoblastic differentiation of these cells was induced by growing them in "osteogenic medium" which contains ascorbic acid, dexamethasone and β-glycerophosphate [Frank *et al.* J. Cell. Biochem. 85: 737-746 (2002)].

Reverse Transcription Polymerase Chain Reaction (RT-PCR): RNA was extracted from cultured cells after 5, 10, 20 and 30 days of incubation and was analyzed by RT-PCR. The primers and RT-PCR methodology and conditions used for analyzing the expression receptor CB1 were essentially as described by: Noe *et al.*

[Adv. Exp Med Biol. 437:223-9 (1998)], and by Noe *et al.* [Adv. Exp. Med. Biol. 493:215-21 (2001]. The primers and RT-PCR methodology and conditions used for analyzing the expression receptor CB2 were essentially as described by Lee *et al.* [Eur. J. Pharmacol. 423:235-41 (2001). The primers and RT-PCR methodology and conditions used for analyzing the expression of osteoblast markers tissue-nonspecific alkaline phosphatase receptor (ALP) were essentially as described by Ohkubo *et al.* [Br J Pharmacol. 131:1667-1672 (2000). The primers and RT-PCR methodology and conditions used for analyzing the expression of parathyroid hormone receptor I (PTH-Rc1; 12) were essentially as described by Kato *et al.* [J. Bone Min. Res. 16:1622-1633 (2001), as follows: CB1, sense: 5'-TGGTGTATGATGTCTTTGGG-3' (SEQ ID NO:1), antisense: 5'-ATGCTGGCTGTGTTATTGGC-3' (SEQ ID NO:2); CB2, sense: 5'-AACGGTGGCTTGGAGTTCAAC-3' (SEQ ID NO: 3); antisense: 5-'TAGGTAGCGGTCAACAGCG-GTTAG (SEQ ID NO: 4); FAAH, sense: 5'-GCCTGAAAGCTCTACTGTGTGAGC-3' (SEQ ID NO: 5); antisense: 5'-GAAGGTCCAGACTTGGTTGTGGCT-3' (SEQ ID NO: 6), ALP (Accession No. J02980), sense: 5'-GACA-CAAGCATTCCCACTAT-3' (967 ± 986) (SEQ ID NO: 7); antisense: 5'-ATCAG-CAGTAACCACAGTCA-3' (1316 ± 1297) (SEQ ID NO: 8); parathyroid hormone (PTH-Rc1), sense: 5'-CAAGAAGTGGATCATCCAGGT-3' (SEQ ID NO: 9); antisense: 5'-GCTGCTACTCCCACTTCGTGCTTT-3' (SEQ ID NO: 10).

Results

After 5 days in culture with the osteogenic medium, both the ST2 stromal progenitor calls and the MC3T3 calvaria derived preosteoblast cells exhibited minimal or no expression of CB1 or CB2 cannabinoid receptors. This was followed by a temporal increase to a considerably high steady level of CB2 mRNA expression by day (Figure 5). On the other hand, no expression of CB1 mRNA was evident even in the most differentiated cells (data not shown). The CB2 expression pattern was similar to the temporal expression patterns of FAAH, ALP and PTH-Rc1 (Figure 5) which are consistent with osteoblastic differentiation.

Hence, the positive expression of cannabinoid receptor CB2, and FAAH in differentiating progenitor osteoblasts as shown, indicates that developing osteoblasts become sensitive to endocannabinoid signaling early in osteogenesis, and that this

upregulation of CB2 receptor expression, and endocannabinoid receptor activity may be crucial to induction of osteoblast differentiation and bone formation.

EXAMPLE 3

Expression of cannabinoid receptor CB2 and FAAH in differentiating osteoclasts

Materials and Methods

Mouse femoral monocytes were separated on a Ficoll gradient and grown in culture for 5 days in medium containing the osteoclast differentiation factors M-CFS and RANKL as described by Zou et al FASEB J 2002;16:274-82). At the end of incubation cultures were analyzed for CB2 and FAAH expression by RT-PCR as described above, and were stained with an osteoclast marker tartarate-resistant acid phosphatase for direct observation of differentiated osteoclasts.

Results

As illustrated in Figure 6A-C both CB2 and FAAH are expressed in differentiating osteoclasts and their monocyte precursors. Since it is known that CB2 expression in monocyte/macrophage cells, which are osteoclast progenitors, inhibits their cellular activity (Parolaro et al Life Sci 1999;65:637-44), these results suggest that CB2 expression in osteoclasts may similarly inhibit differentiation and cellular activity of the monocyte-derived octeoclast cells. Thus endocannabinoids, and other cannabinoid receptor ligands, can activate receptors on both osteoblast and osteoclast cells, and may on one hand suppress the bone resorptive activity of osteoclasts, while on the other hand promoting bone growth and remodeling activity of osteoblasts. Such a ligand, capable of effectively stimulating bone formation as well as inhibiting bone resorption, would constitute an ideal therapeutic agent for treating bone disorders.

EXAMPLE 4

Effect of cannabinoids on bone formation activity in vivo

Materials and Methods:

The endocannabinoid 2-arachidonoyl glycerol (2AG) and the CB1 cannabinoid receptor antagonist N-(piperidin-1-yl)-5-(4-chlorophenyl)-1-(2,4-dichlorophenyl)-4-methyl-1H-pyrazole-3-carboxamide hydrochloride (SR-141761A; Panikashvili *et al.,* Nature 413: 527-531 (2001)] were dissolved in 1:1:18 ethanol:emulfor:saline (v/v/v)

vehicle. Different dosages of each agent were daily injected intraperitoneally to 11 week-old C3H (Harlan) mice. 2AG was administered at 0 (vehicle control), 0.5, 5, and 20 mg/Kg body weight per day for 9 days; SR-141761A was administered at 1 and 10 mg/Kg body weight per day for 9 days.

To assess the *in vivo* bone formation activity the mice were given 15 mg/Kg body weight calcein intrapertoneally, four days and one day (same day as the last 2AG injection) prior to sacrifice. Femoral bones were separated immediately after sacrifice and subjected, undecalcified, to histological processing. Dynamic bone histomorphometric parameters were analyzed in the distal metaphysis (secondary spongiosa) in unstained longitudinal mid-saggital sections, using the procedure described by Parfitt *et al.* [J. Bone Miner. Res. 2: 595–610 (1987)]. The data obtained were statistically analyzed by Mann-Whitney U-test to determine significance of differences between the treatments.

Results

The administration of the endocannabinoid 2AG to mice at up to 5 mg/Kg/day for 9 days resulted in a dose-dependent stimulation of bone-formation rate (BFR; an expression of overall osteoblastic activity), followed by a plateau (Figure 7A). The mice which were treated with 2AG at 5 and 20 mg/Kg/day showed substantially (up to 44%) and significantly (p= 0.04) higher BFRs than the vehicle control. The osteogenic effect of 2AG administration is also evident from comparison of fluorescent histological images of the bones from mice treated with 2AG (5mg/Kg/day), compared with their vehicle-treated controls (Figure 7C), indicated by the visibly increased uptake of fluorescently labeled calcein in the treated animal's bone tissue. Similarly, the administration of 2AG at up to 5 mg/Kg/day resulted in a dose-dependent increase of mineralizing perimeter (MP; an expression of osteoblast number), followed by a plateau (Figure 7B). The treatment of 2AG at 5 and 20 mg/Kg/day also resulted in substantially and significantly higher MPs than the control (p= 0.019). Thus, the administration of effective dosages of 2AG to mice substantially stimulated bone accrual and bone formation activity *in vivo*.

Administration of the CB1 cannabinoid-receptor antagonist SR-141761A to mice at up to 10 mg/Kg/day for 9 days also resulted in higher (but not statistically different) BFR (osteoblastic activity) and in higher and statistically different MP (osteoblast number), than the vehicle control (data is not shown).

These results clearly demonstrate that the administration of the cannabinoid ligands 2AG and SR-141761A to mice substantially increased the number of osteoblasts and the bone formation rate, thereby effectively increasing bone accrual and structural integrity in the treated mice.

Hence, when viewed together, the results described hereinabove show unequivocally that cannabinoid receptors expression significantly affects bone growth and remodeling. It is further demonstrated that administering agents capable of regulating the expression of cannabinoid receptor may effectively modulate bone formation both *in vitro* and in vivo.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention.

WHAT IS CLAIMED IS:

1. A method of modulating bone growth and/or bone remodeling, comprising regulating an expression or activity of at least one cannabinoid receptor, thereby modulating bone growth and/or bone remodeling.

2. The method of claim 1, wherein said at least one cannabinoid receptor is a bone cell or bone cell progenitor cannabinoid receptor.

3. The method of claim 2, wherein said bone cell progenitor is an osteogenic cell.

4. The method of claim 2, wherein said bone cell progenitor is a stromal cell.

5. The method of claim 2, wherein said bone cell progenitor is a bone resorbing cell progenitor.

6. The method of claim 1, wherein said regulating is upregulating.

7. The method of claim 6, wherein said upregulating of said expression or activity is effected by an agent selected from the group consisting of:

(a) an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of said at least one cannabinoid receptor;

(b) a compound which increases an expression of an endogenous DNA or mRNA encoding said at least one cannabinoid receptor; and

(c) a molecule which activates said at least one cannabinoid receptor.

8. The method of claim 7, wherein said molecule which activates said at least one cannabinoid receptor is a cannabinoid.

9. The method of claim 8, wherein said cannabinoid is 2AG.

10. The method of claim 1, wherein said regulating is downregulating.

11. The method of claim 10, wherein said downregulating of said expression or activity is effected by an agent selected from the group consisting of:

(a) a molecule which binds said at least one cannabinoid receptor;

(b) an enzyme which cleaves said at least one cannabinoid receptor;

(c) an siRNA molecule capable of inducing degradation of mRNA transcripts of said at least one cannabinoid receptor;

(d) a DNAzyme which specifically cleaves mRNA transcripts or DNA of said at least one cannabinoid receptor;

(e) an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding said at least one cannabinoid receptor;

(f) a ribozyme which specifically cleaves mRNA transcripts encoding said at least one cannabinoid receptor;

(g) a non-functional analogue of at least a binding portion of said at least one cannabinoid receptor; and

(h) a molecule which prevents activation or ligand binding of said at least one cannabinoid receptor.

12. The method of claim 1, wherein said regulating of said expression or activity is effected by upregulating a first cannabinoid receptor of said at least one cannabinoid receptor and downregulating a second cannabinoid receptor of said at least one cannabinoid receptor.

13. The method of claim 1, wherein said at least one cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor and a non-CB1 non-CB2 receptor.

14. A method of treating or preventing a bone disease in a subject in need thereof, comprising regulating an expression or activity of at least one cannabinoid receptor of the subject, thereby treating or preventing the bone disease in said subject.

15. The method of claim 14, wherein the subject is a vertebrate.

16. The method of claim 15, wherein said vertebrate is a human.

17. The method of claim 16, wherein said at least one cannabinoid receptor is a bone cell or bone cell progenitor cannabinoid receptor.

18. The method of claim 17, wherein said bone cell progenitor is an osteogenic cell.

19. The method of claim 17, wherein said bone cell progenitor is a stromal cell.

20. The method of claim 17, wherein said bone cell progenitor is a bone resorbing cell progenitor.

21. The method of claim 17, wherein said regulating is upregulating.

22. The method of claim 21, wherein said upregulating of said expression or activity is effected by administering to the subject at least one agent selected from the group consisting of:

(a) an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(b) a compound which increases expression of an endogenous DNA or mRNA encoding said bone cell or bone cell progenitor cannabinoid receptor of said subject; and

(c) a molecule which activates said bone cell or bone cell progenitor cannabinoid receptor of said subject.

23. The method of claim 22, wherein said molecule which activates said bone cell or bone cell progenitor cannabinoid receptor is a cannabinoid.

24. The method of claim 22, wherein said cannabinoid is 2AG.

25. The method of claim 17, wherein said regulating is downregulating.

26. The method of claim 25, wherein said downregulating of said expression or activity is effected by administering to the subject at least one agent selected from the group consisting of:

(a) a molecule which binds said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(b) an enzyme which cleaves said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(c) an siRNA molecule capable of inducing degradation of mRNA transcripts of said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(d) a DNAzyme which specifically cleaves mRNA transcripts or DNA of said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(e) an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(f) a ribozyme which specifically cleaves mRNA transcripts encoding said bone cell or bone cell progenitor cannabinoid receptor of said subject;

(g) a non-functional analogue of at least a binding portion of said bone cell or bone cell progenitor cannabinoid receptor of said subject; and

(h) a molecule which prevents activation or ligand binding of said bone cell or bone cell progenitor cannabinoid receptor of said subject.

27. The method of claim 26, wherein said molecule which prevents activation or ligand binding of said bone cell or bone cell progenitor cannabinoid receptor is SR-141761A.

28. The method of claim 17, wherein said regulating of said expression is effected by upregulating a first cannabinoid receptor of said bone cell or bone cell

progenitor cannabinoid receptor and downregulating a second cannabinoid receptor of said bone cell or bone cell progenitor cannabinoid receptor.

29. The method of claim 14, wherein said at least one cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor and a non-CB1 non-CB2 receptor.

30. The method of claim 14, wherein the subject suffers from a condition or disease selected from the group consisting of osteoporosis, bone fracture or deficiency, primary or secondary hyperparathyroidism, osteoarthritis, periodontal disease or defect, an osteolytic bone disease, post-plastic surgery, post-orthopedic implantation, and post-dental implantation.

31. The method of claim 30, further comprising administering to the subject at least one compound capable of promoting bone formation and/or inhibiting bone resorption.

32. The method of claim 31, wherein said at least one compound is selected from the group consisting of a bone morphogenetic protein, an anti-resorptive agent, an osteogenic factor, a cartilage-derived morphogenetic protein, a parathyroid hormone, IGF1, FGF, a noggin, an osteogenic growth peptide, a growth hormone, an estrogen, a bisphosphonate, a statin and a differentiating factor.

33. The method of claim 14, wherein the subject suffers from a condition or disease selected from the group consisting of Paget's disease, osteoblastic bone disease, blastic metastatic bone cancer, metastatic bone disease, Hodgkin's lymphoma, degenerative sclerosis and osteomylitis.

34. The method of claim 33, further comprising administering to said subject at least one compound capable of inhibiting bone formation and/or promoting bone resorption.

35. A method of inducing bone growth and/or repair in a subject in need thereof, comprising:

(a) isolating bone cells;

(b) regulating an expression or activity of at least one cannabinoid receptor of said bone cells; and

(c) administering said bone cells resulting from step (b) to the subject, thereby inducing bone growth and/or repair in said subject.

36. The method of claim 35, wherein said bone cells are bone cell progenitors.

37. The method of claim 35, wherein said bone cell progenitors are osteogenic cells.

38. The method of claim 35, wherein said bone cell progenitors are stromal cells.

39. The method of claim 35, wherein said bone cell progenitor is a bone resorbing cell progenitor.

40. The method of claim 35, wherein said at least one cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor and a non-CB1 non-CB2 receptor.

41. The method of claim 35, wherein said regulating is upregulating.

42. The method of claim 41, wherein said upregulating of said expression or activity is effected by exposing said bone cells to said at least one agent selected from the group consisting of:

(a) an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of said at least one cannabinoid receptor of said bone cells;

(b) a compound which increases expression of an endogenous DNA or mRNA encoding said at least one cannabinoid receptor of said bone cells; and

(c) a molecule which activates said at least one cannabinoid receptor of said bone cells.

43. The method of claim 42, wherein said molecule which activates said at least one cannabinoid receptor of said bone cells is a cannabinoid.

44. The method of claim 43, wherein said cannabinoid is 2AG.

45. The method of claim 35, wherein said regulating is downregulating.

46. The method of claim 45, wherein said downregulating of said expression or activity is effected by exposing said bone cells to said at least one agent selected from the group consisting of:

(a) a molecule which binds said at least one cannabinoid receptor of said bone cells;

(b) an enzyme which cleaves said at least one cannabinoid receptor of said bone cells;

(c) an siRNA molecule capable of inducing degradation of mRNA transcripts of said at least one cannabinoid receptor of said bone cells;

(d) a DNAzyme which specifically cleaves mRNA transcripts or DNA of said at least one cannabinoid receptor of said bone cells;

(e) an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding said at least one cannabinoid receptor of said bone cells;

(f) a ribozyme which specifically cleaves mRNA transcripts encoding said at least one cannabinoid receptor of said bone cells;

(g) a non-functional analogue of at least a binding portion of said at least one cannabinoid receptor of said bone cells; and

(h) a molecule which prevents activation or ligand binding of said at least one cannabinoid receptor of said bone cells.

47. The method of claim 35, further comprising a step of administering to said subject at least one compound capable of promoting bone formation and/or inhibiting bone resorption.

48. The method of claim 47, wherein said at least one compound is selected from the group consisting of a bone morphogenetic protein, an anti-resorptive agent, an osteogenic factor, a cartilage-derived morphogenetic protein, a parathyroid hormone, IGF1, FGF, noggin, an osteogenic growth peptide, a growth hormone, an estrogen, a bisphosphonate, a statin and a differentiating factor.

49. The method of claim 35, further comprising a step of administering to said subject at least one compound capable of inhibiting bone formation and/or promoting bone resorption.

50. A pharmaceutical composition for modulating bone growth and/or bone remodeling, comprising an agent capable of regulating an expression or activity of at least one cannabinoid receptor of a bone cell, a compound capable of modulating bone growth and/or bone remodeling, and a pharmaceutically acceptable carrier.

51. The pharmaceutical composition of claim 50, wherein said cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor, and a non-CB1 non-CB2 receptor.

52. The pharmaceutical composition of claim 50, wherein said agent is selected from the group consisting of:

(a) an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of said at least one cannabinoid receptor of said bone cell;

(b) a compound which increases an expression of an endogenous DNA or mRNA encoding said at least one cannabinoid receptor of said bone cell; and

(c) a molecule which activates said at least one cannabinoid receptor of said bone cell.

53. The pharmaceutical composition of claim 52, wherein said agent is a cannabinoid.

54. The pharmaceutical composition of claim 52, wherein said cannabinoid is 2AG.

55. The pharmaceutical composition of claim 50, wherein said agent is selected from the group consisting of:

(a) a molecule which binds said at least one cannabinoid receptor of said bone cell;

(b) an enzyme which cleaves said at least one cannabinoid receptor of said bone cell;

(c) an siRNA molecule capable of inducing degradation of mRNA transcripts of said at least one cannabinoid receptor of said bone cell;

(d) a DNAzyme which specifically cleaves mRNA transcripts or DNA of said at least one cannabinoid receptor of said bone cell;

(e) an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding said at least one cannabinoid receptor of said bone cell;

(f) a ribozyme which specifically cleaves mRNA transcripts encoding said at least one cannabinoid receptor of said bone cell;

(g) a non-functional analogue of at least a binding portion of said at least one cannabinoid receptor of said bone cell; and

(h) a molecule which prevents activation or ligand binding of said at least one cannabinoid receptor of said bone cell.

56. The pharmaceutical composition of claim 50, wherein said compound is selected from the group consisting of a bone morphogenetic protein, an anti-resorptive agent, an osteogenic factor, a cartilage-derived morphogenetic protein, a parathyroid hormone, IGF1, FGF, a noggin, an osteogenic growth peptide, a growth hormone, an estrogen, a bisphosphonate, a statin and a differentiating factor.

57. An article-of-manufacturing, comprising a packaging material and a therapeutically effective amount of a pharmaceutical composition being identified for the treatment of a bone disease or a bone defect, said pharmaceutical composition including an agent capable of regulating activity or expression of at least one cannabinoid receptor and a pharmaceutically acceptable carrier.

58. The article-of-manufacturing of claim 57, wherein said cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor, and a non-CB1 non-CB2 receptor.

59. The article-of-manufacturing of claim 57, wherein said agent is selected from the group consisting of:

(a) an exogenous polynucleotide sequence designed and constructed to express at least a functional portion of said at least one cannabinoid receptor;

(b) a compound which increases an expression of an endogenous DNA or mRNA encoding said at least one cannabinoid receptor; and

(c) a molecule which activates said at least one cannabinoid receptor.

60. The article-of-manufacturing of claim 57, wherein said agent is a cannabinoid.

61. The article-of-manufacturing of claim 60, wherein said cannabinoid is 2AG.

62. The article-of-manufacturing of claim 57, wherein said agent is selected from the group consisting of:

(a) a molecule which binds said at least one cannabinoid receptor;

(b) an enzyme which cleaves said at least one cannabinoid receptor;

(c) an siRNA molecule capable of inducing degradation of mRNA transcripts of said at least one cannabinoid receptor;

(d) a DNAzyme which specifically cleaves mRNA transcripts or DNA of said at least one cannabinoid receptor;

(e) an antisense polynucleotide capable of specifically hybridizing with an mRNA transcript encoding said at least one cannabinoid receptor;

(f) a ribozyme which specifically cleaves mRNA transcripts encoding said at least one cannabinoid receptor;

(g) a non-functional analogue of at least a binding portion of said at least one cannabinoid receptor of said bone cell; and

(h) a molecule which prevents activation or ligand binding of said at least one cannabinoid receptor.

63. The article-of-manufacturing of claim 57, further comprising at least one compound capable of promoting bone formation or inhibiting bone resorption.

64. The article-of-manufacturing of claim 63, wherein said at least one compound is selected from the group consisting of a bone morphogenetic protein, an anti-resorptive agent, an osteogenic factor, a cartilage-derived morphogenetic protein, a parathyroid hormone, IGF1, FGF, a noggin, an osteogenic growth peptide, a growth hormone, an estrogen, a bisphosphonate, a statin and a differentiating factor.

65. The article-of-manufacturing of claim 57, further comprising at least one compound capable of inhibiting bone formation or promoting bone resorption.

66. A method of identifying a bone growth modulating agent, comprising screening a plurality of molecules to thereby uncover a molecule capable of regulating an expression or activity of at least one cannabinoid receptor, said molecule being the bone growth modulating agent.

67. The method of claim 66, further comprising determining an ability of said molecule to modify bone formation rate and/or altering bone mineralization perimeter.

68. The method of claim 66, wherein said screening is effected by exposing bone cells to said plurality of molecules and determining said expression of said at least one cannabinoid receptor in said bone cells.

69. The method of claim 66, wherein said cannabinoid receptor is selected from the group consisting of a CB1 receptor, a CB1-like receptor, a CB2 receptor, a CB2-like receptor, and a non-CB1 non-CB2 receptor.

70. The method of claim 66, wherein said at least one cannabinoid receptor is a bone cell or bone cell progenitor cannabinoid receptor.

71. The method of claim 70, wherein said bone cell progenitor is an osteogenic cell.

72. The method of claim 70, wherein said bone cell progenitor is a stromal cell.

73. The method of claim 70, wherein said bone cell progenitor is a bone resorbing cell progenitor.

74. The method of claim 66, wherein said expression of said cannabinoid receptor is determined by RT-PCR

FIG. 1A

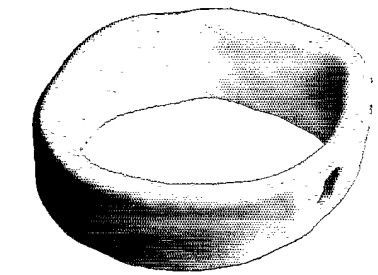
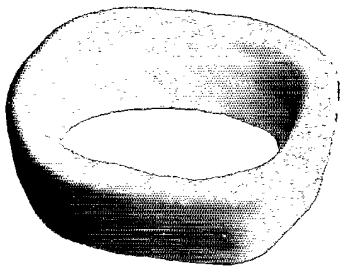
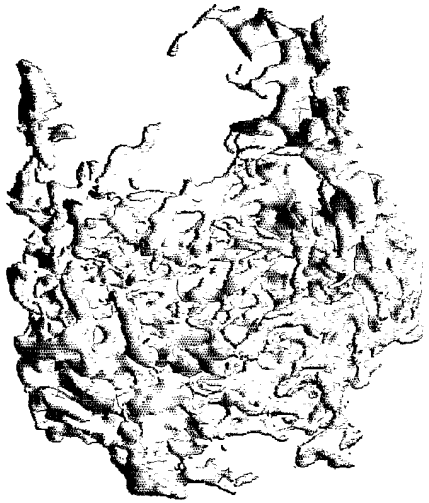


FIG. 1B





WT

CB1$^{-/-}$

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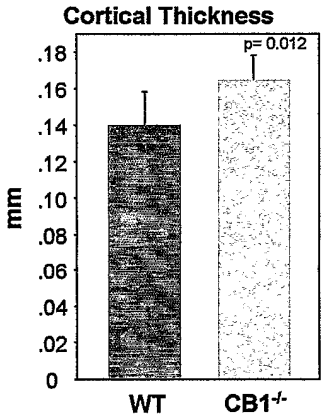
FIG. 2A



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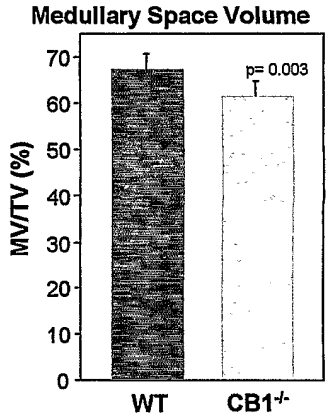

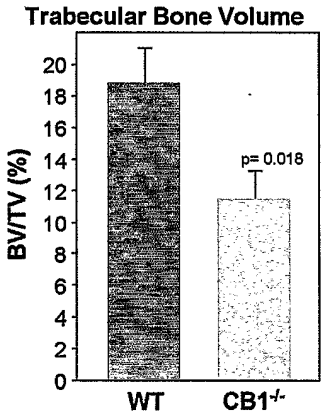

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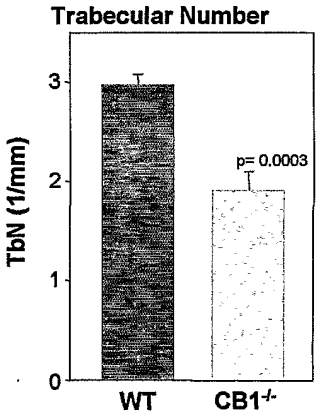
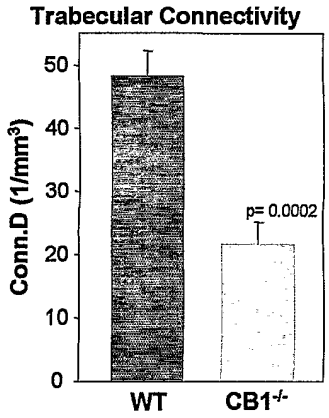


FIG. 2D



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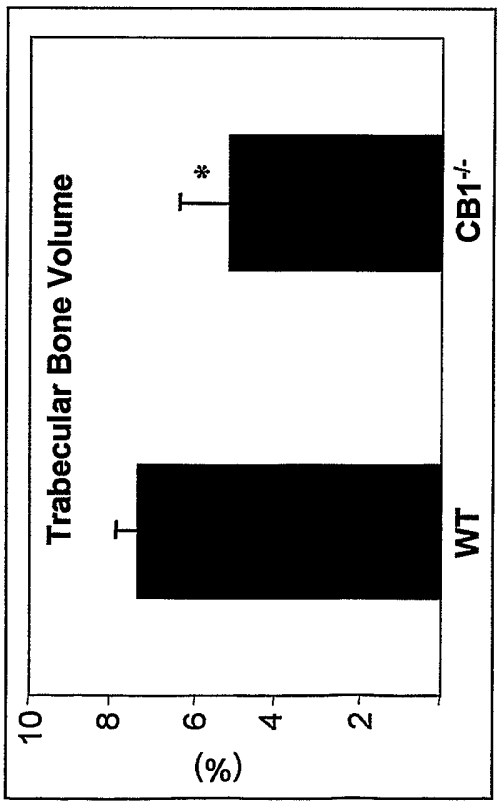

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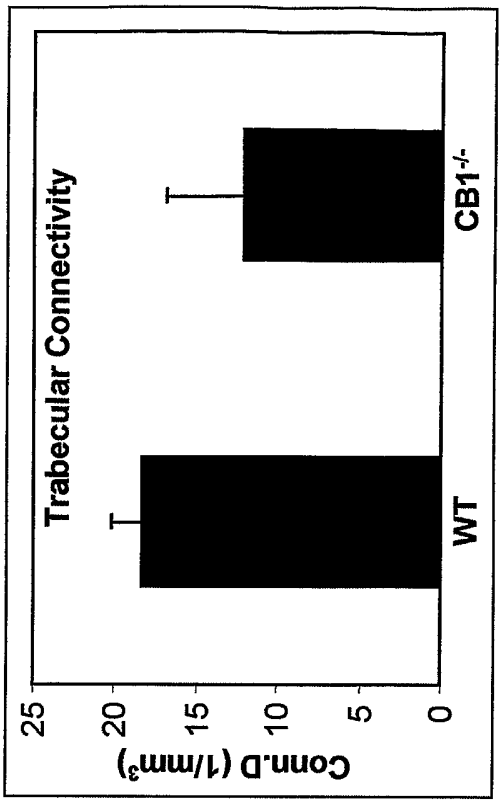

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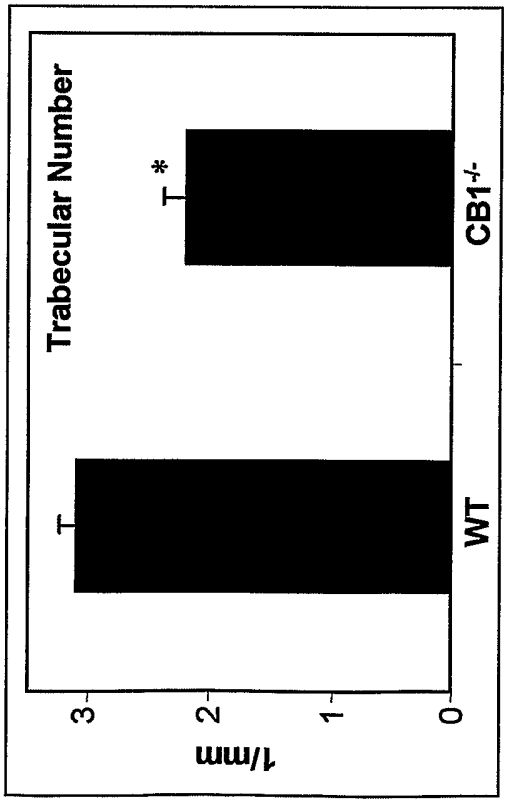

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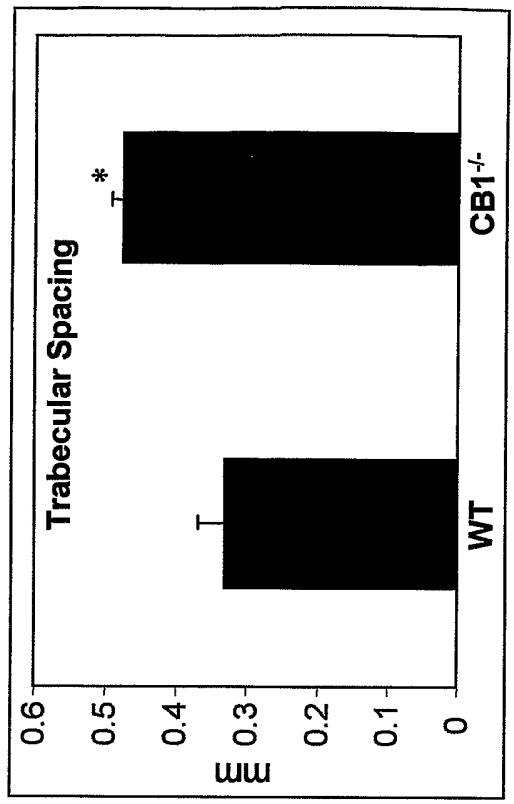
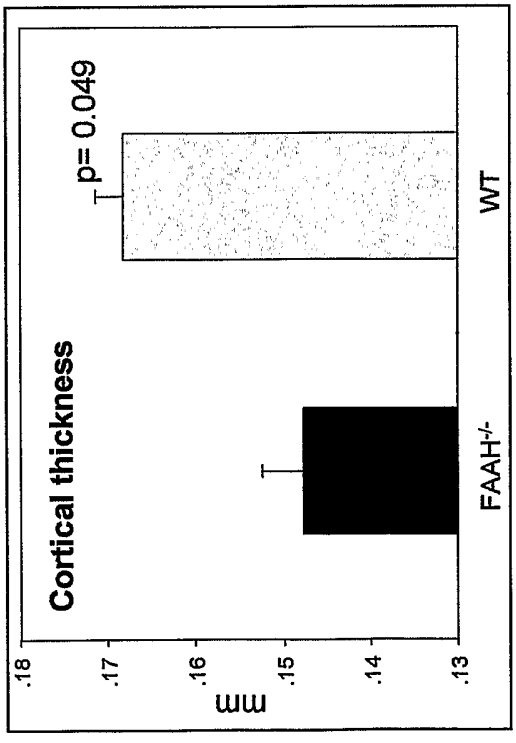


FIG. 3D

FIG. 4A



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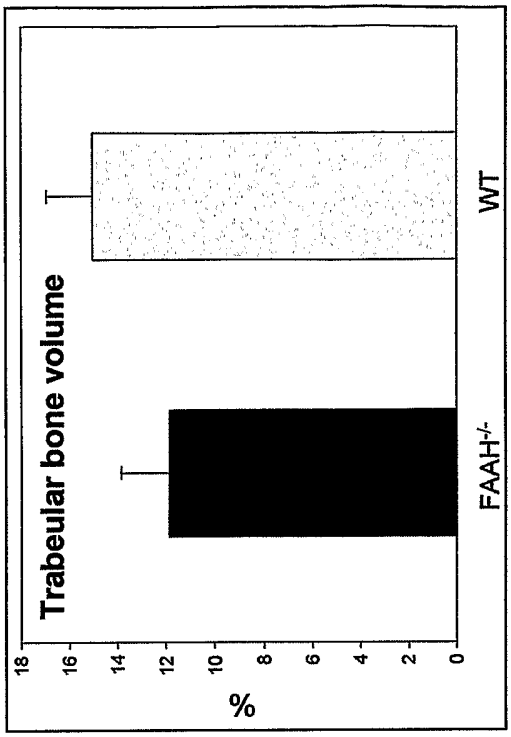

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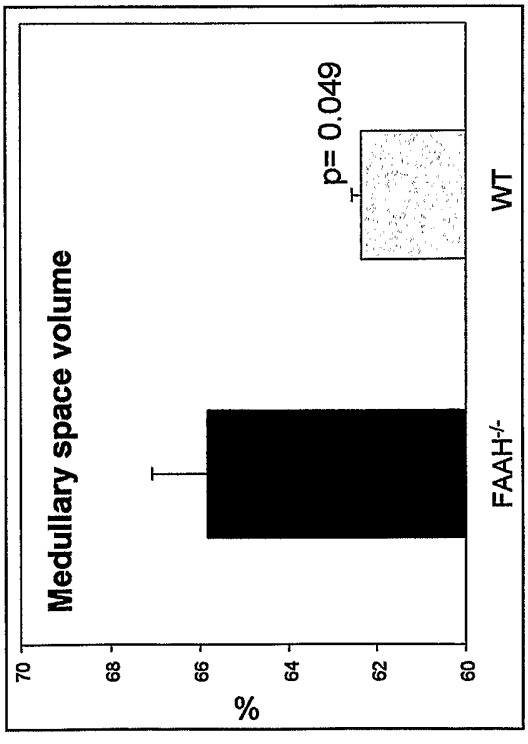
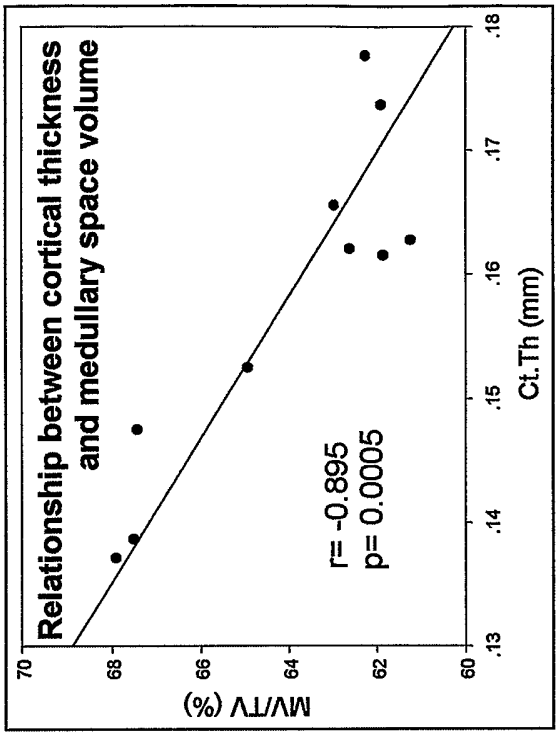
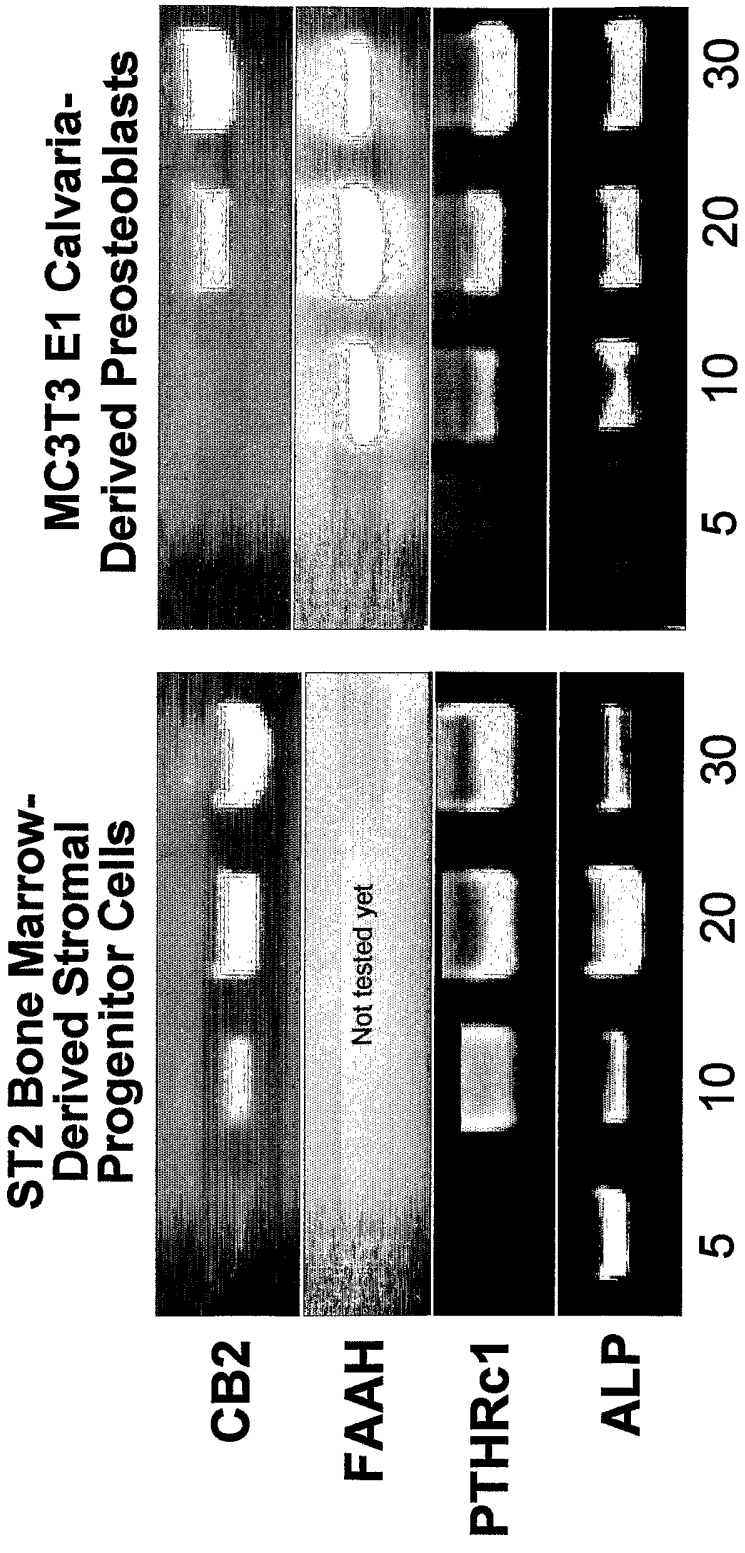


FIG. 4D

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10
20
30
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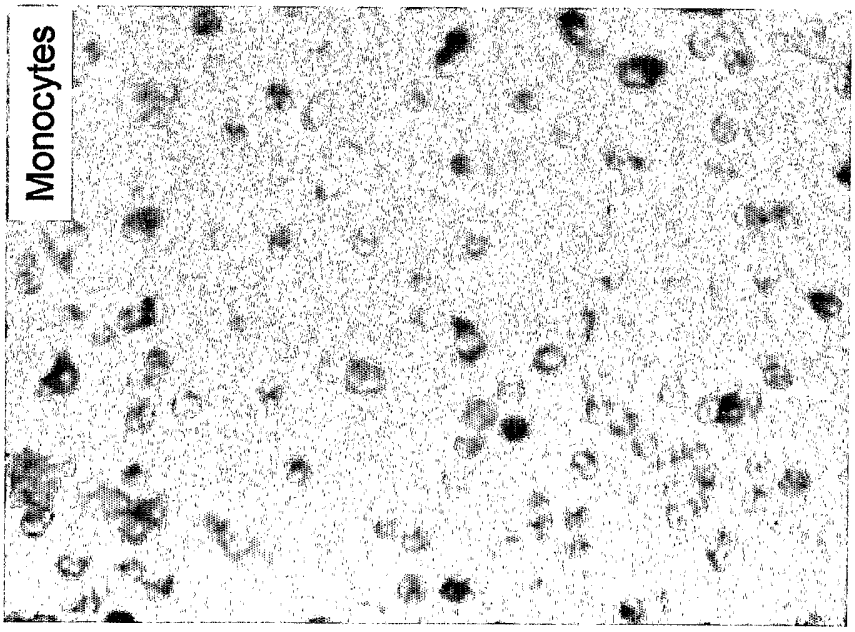
FIG. 5

FIG. 6A



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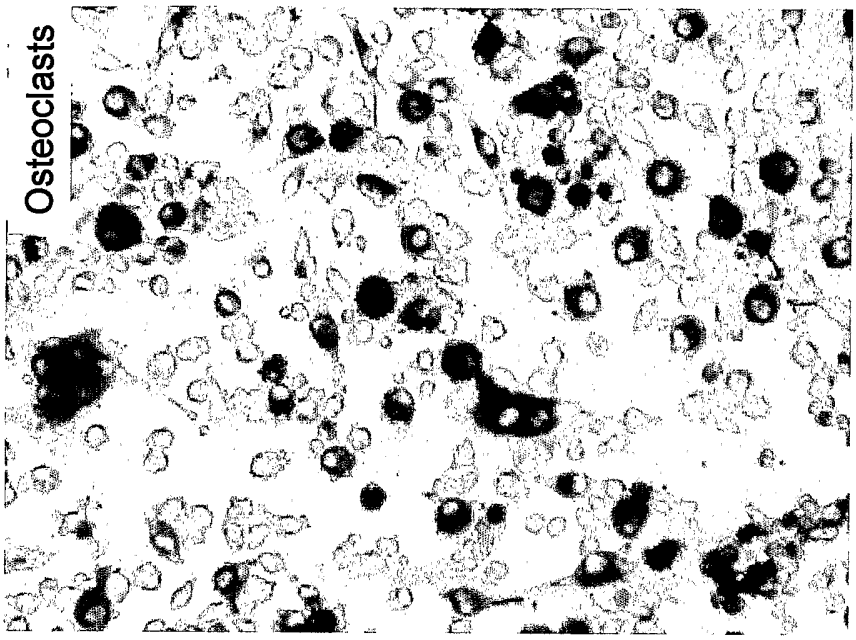
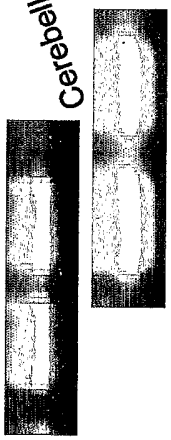
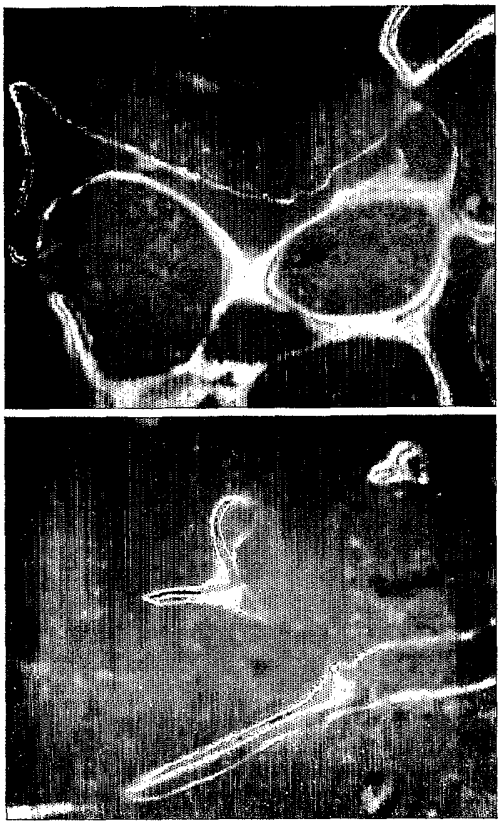


FIG. 6C





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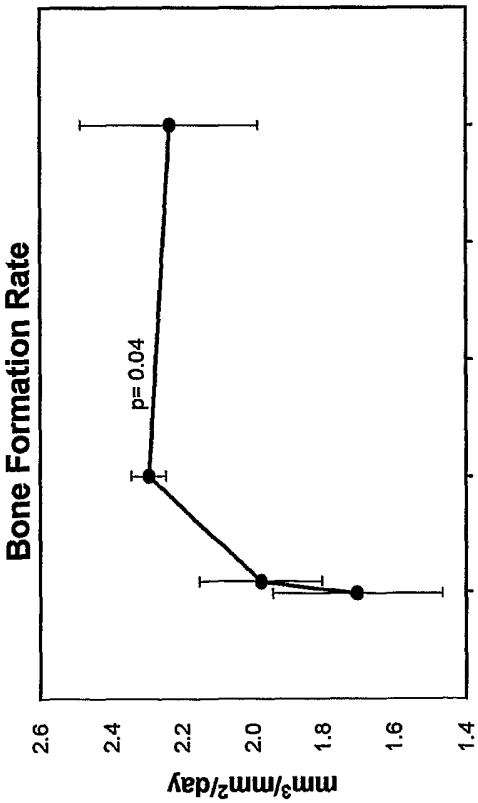

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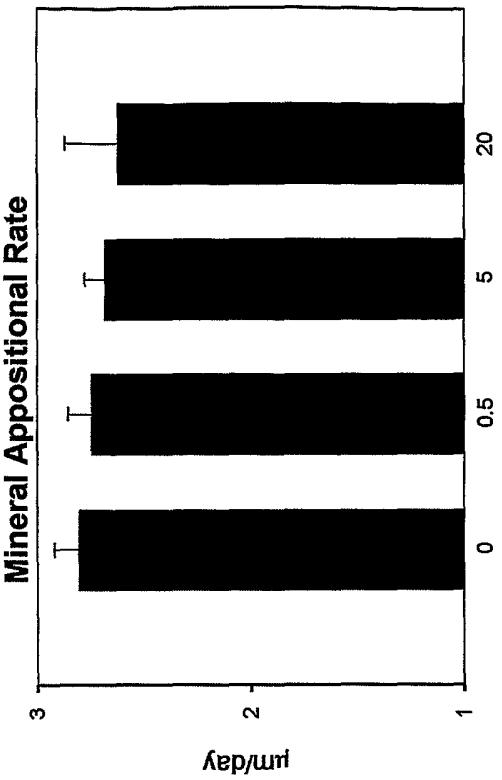

FIG. 7D

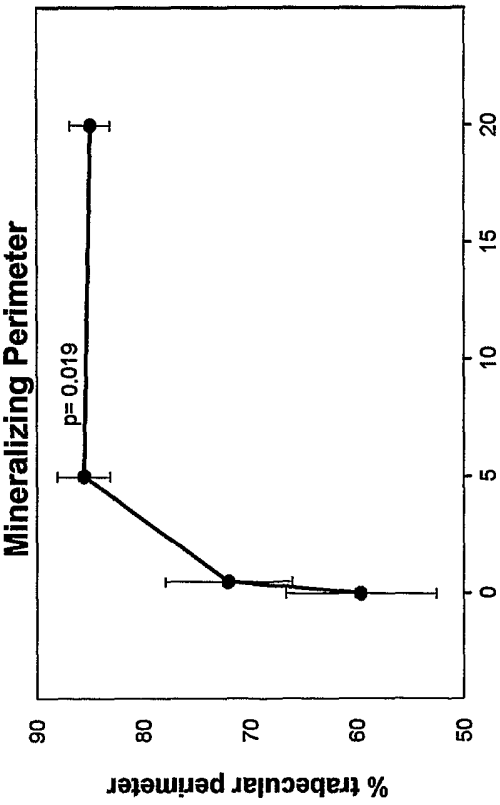

FIG. 7C

SEQUENCE LISTING

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Mechoulam, Raphael
Shohami, Esther

<120> METHODS COMPOSITIONS AND ARTICLES OF MANUFACTURE FOR MODULATING BONE GROWTH

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL03/00480

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : A61K 48/00
US CL : 514/44
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 514/44

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
CAPLUS, MEDLINE, EMBASE, BIOSIS- cannabinoid receptors, bone, bone cell, 2AG, CB1, CB2, DNA expression

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,100,259 A (XIANG ET AL) 08 August 2000(08/08/00), see entire document, especially column 2, line 34-39 and claim 12, column 20 line 32-36.	1-4,6-7,10-11,13-19,21-22,25-26,29-30,35-38,40-42,45-46,50-52,55,57-59,62
X	WO 98 41519 A1 (SMITHKLINE BEECHAM) 24 September 1998 (24.09.98), see entire document, especially page 3, line 3-7.	1-4,6-7,10-11,13-19,21-22,25-26,29-30,35-38,40-42,45-46,50-52,55,57-59,62
X	WO 99 26612 A1 (SMITHKLINE BEECHAM) 03 June 1999 (03.06.99), see entire document, especially page 4, line 5-11.	1-4,6-7,10-11,13-19,21-22,25-26,29-30,35-38,40-42,45-46,50-52,55,57-59,62

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
10 June 2004 (10.06.2004)

Date of mailing of the international search report
23 JUL 2004

Name and mailing address of the ISA/US
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Facsimile No. (703) 872-9306

Authorized officer
Tracy Vivlemore
Valerie Bell-Harris for

Telephone No. 571-272-1600

Form PCT/ISA/210 (second sheet) (July 1998)