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(54) **6-METHYLVITAMIN D₃ ANALOGS AND THEIR USES**

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A61K 31/59 (2006.01)
C07D 401/00 (2006.01)

(52) **U.S. Cl.** **514/167; 552/653**

(58) **Field of Classification Search** **514/167; 552/653**

See application file for complete search history.

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Primary Examiner — Sabiha Qazi

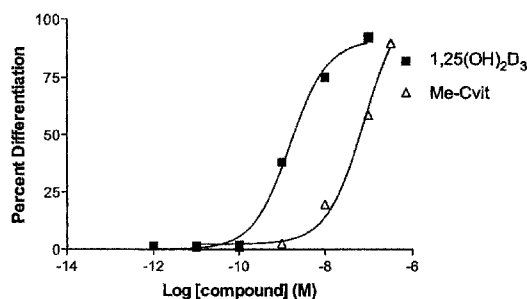
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(57) **ABSTRACT**

This invention discloses 6-methylvitamin D₃ analogs, and specifically 1α,25-dihydroxy-6-methylvitamin D₃, and pharmaceutical uses therefor. This compound exhibits vitamin D receptor binding activity and transcription activity as well as activity in arresting the proliferation of undifferentiated cells and inducing their differentiation to the monocyte thus evidencing use as an anti-cancer agent, especially for the treatment or prevention of leukemia, colon cancer, breast cancer, skin cancer or prostate cancer. This compound also exhibits low in vivo calcemic activity, but because it binds the receptor with the same affinity as the native hormone calcitriol, it may act as an antagonist to inhibit development of hypercalcemia.

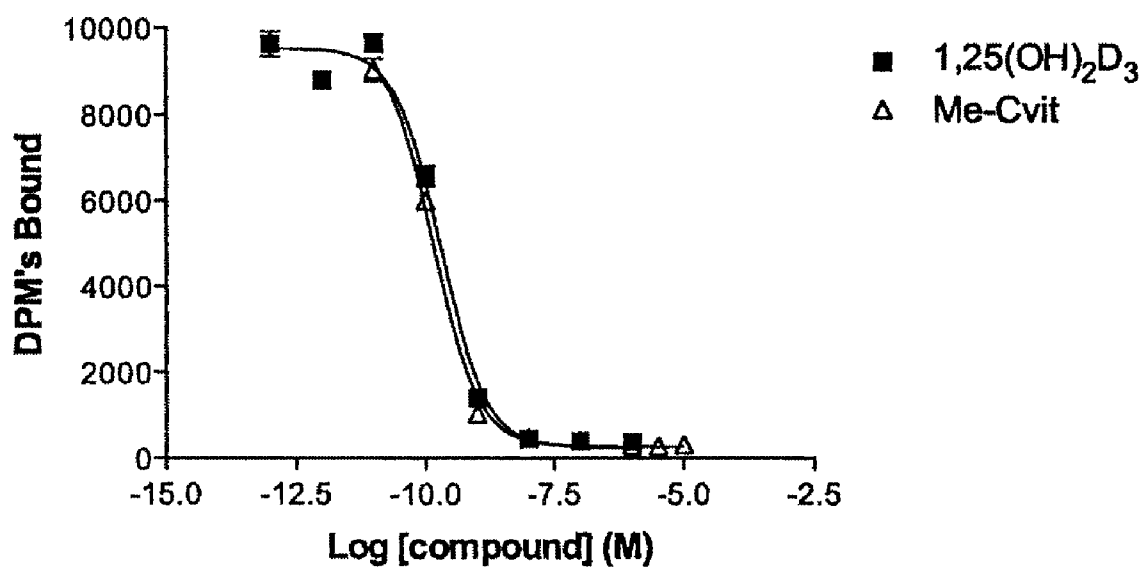
29 Claims, 5 Drawing Sheets

HL-60 Cell Differentiation



EC₅₀: 1,25(OH)₂D₃ = 2 × 10⁻⁹ M
Me-Cvit = ~8 × 10⁻⁸ M

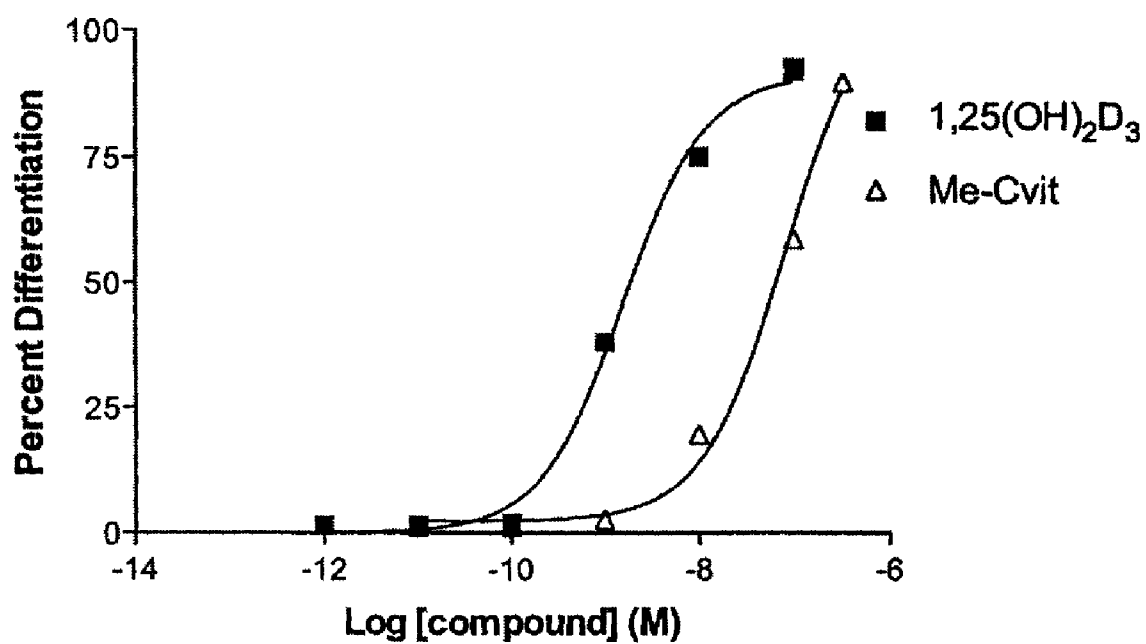
Competitive VDR Binding



K_i : 1,25(OH)₂D₃ = 3×10^{-11} M

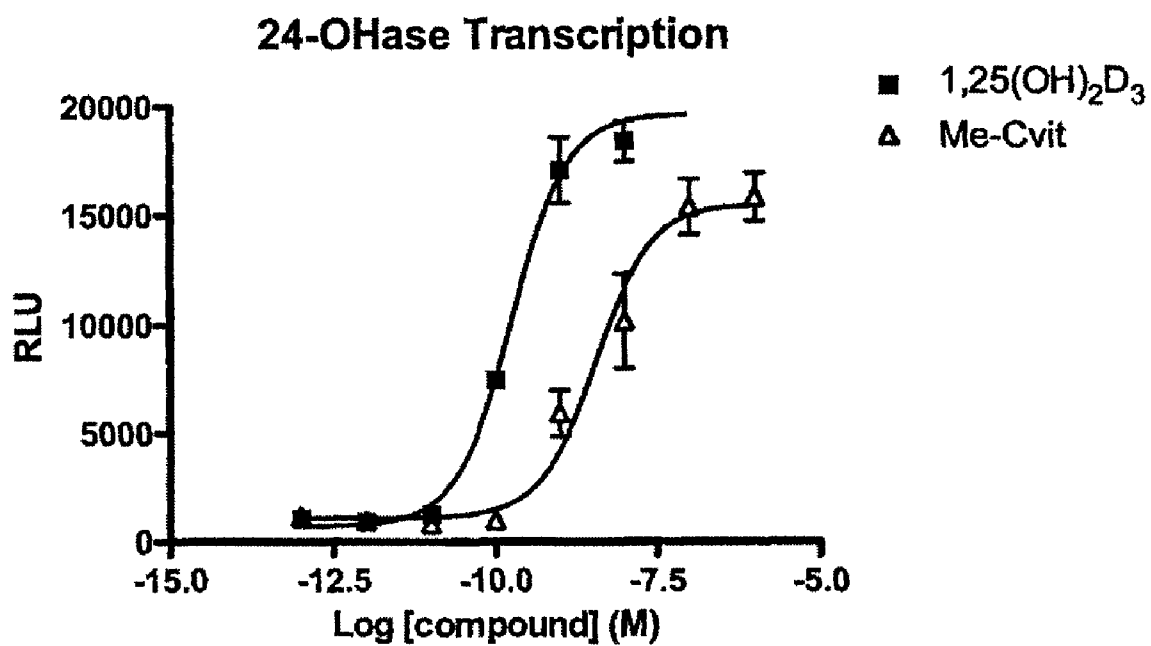
Me-Cvit = 2×10^{-11} M

FIGURE 1

HL-60 Cell Differentiation

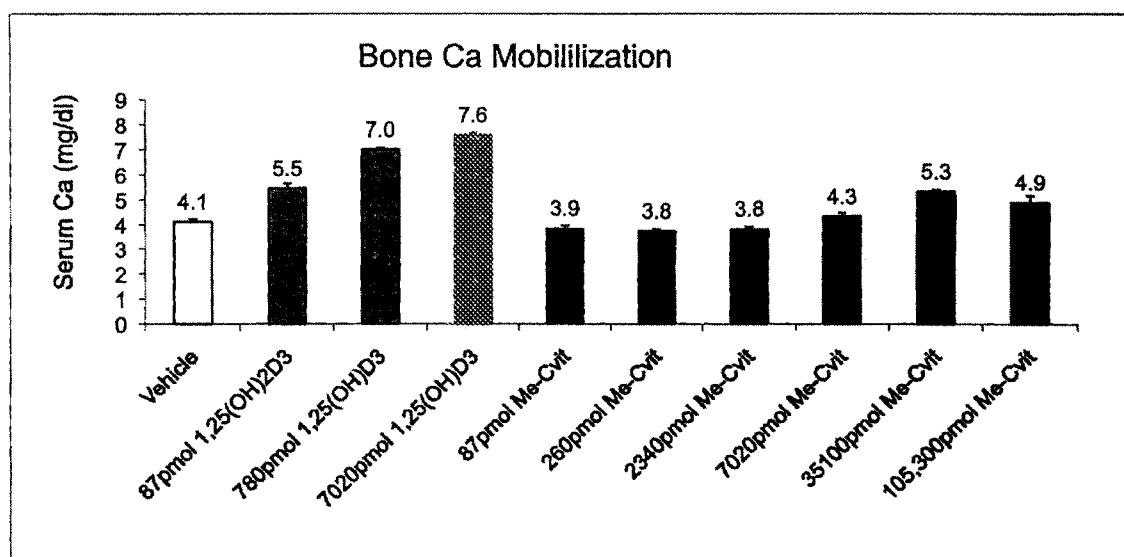
EC₅₀: 1,25(OH)₂D₃ = 2×10^{-9} M
Me-Cvit = $\sim 8 \times 10^{-8}$ M

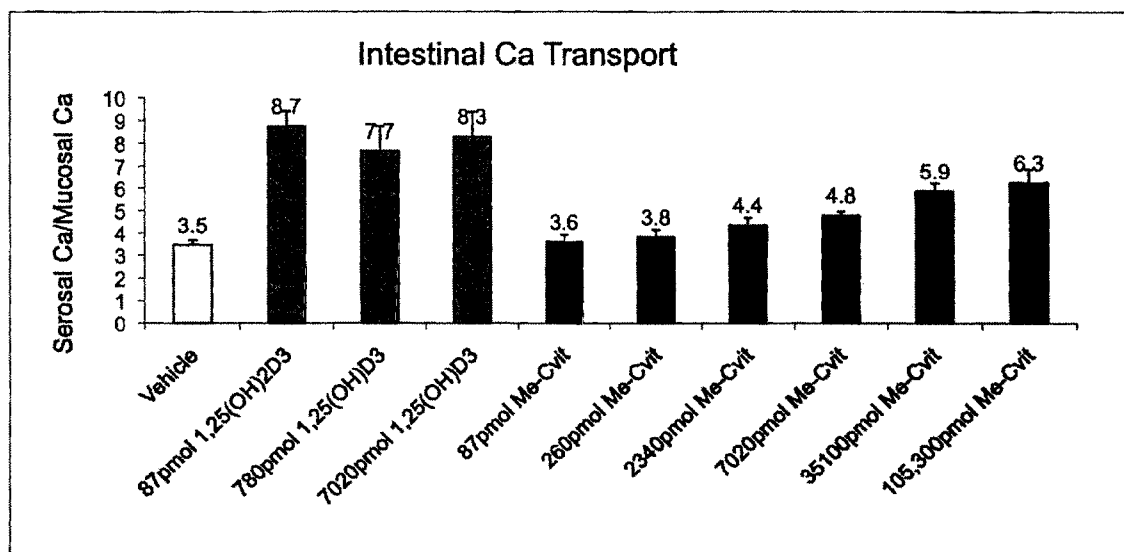
FIGURE 2



EC₅₀: 1,25(OH)₂D₃ = 2×10^{-10} M
Me-Cvit = 4×10^{-9} M

FIGURE 3

**FIGURE 4**

**FIGURE 5**

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6-METHYLVITAMIN D₃ ANALOGS AND THEIR USES**BACKGROUND OF THE INVENTION**

This invention relates to vitamin D compounds, and more particularly to 6-methylvitamin D₃ analogs and their pharmaceutical uses.

The most active metabolite of vitamin D₃, 1 α ,25-dihydroxyvitamin D₃ is a potent calcium and phosphorous-regulating hormone playing an important role in bone homeostasis in animals and humans. Also, in addition to this classical role, the natural hormone elicits immunomodulation as well as cell differentiation and proliferation activities in numerous malignant cells and keratinocytes [Feldman et al, Vitamin D, 2nd ed.; Elsevier Academic Press: New York, 2005]. 1 α ,25-Dihydroxyvitamin D₃ expresses these functions by binding to the vitamin D receptor (VDR), a ligand-regulated transcription factor. Structural analogs of this metabolite have been prepared and tested such as 1 α -hydroxyvitamin D₃, 1 α -hydroxyvitamin D₂, and various other side-chain and A-ring modified vitamins. Some potent synthetic analogs have been used clinically to treat bone disorders such as osteoporosis and the skin disorder—psoriasis. Some of these compounds exhibit separation of activities in cell differentiation and calcium regulation. The difference in activity may be advantageous in treating a variety of diseases such as renal osteodystrophy, vitamin D-resistant rickets, osteoporosis, psoriasis, and other malignancies.

Although more than 3000 synthetic analogs of the natural hormone have been obtained and tested to date, very few of them were characterized by substitution of the intericyclic C(5)=C(6)-C(7)=C(8) diene moiety. 6-Fluorovitamin D₃ was synthesized by Dauben et al. [J. Org. Chem. 50, 2007 (1985)] and this compound has been shown to antagonize 1 α ,25-(OH)₂D₃ activity, especially intestinal calcium absorption, in vivo in chicken [Wilhelm et al., Arch. Biochem. Biophys. 233, 127 (1984)]. The synthesis of 6-methylvitamin D₃ was reported by Sheves and Mazur [J. Chem. Soc., Chem. Commun. 21 (1977)] using 6-oxo-3,5-cyclovitamin D precursor; the same compound was also obtained by Yamada et al. [Tetrahedron Letters 22, 3085 (1981)] by reductive thermal desulfonation of the 6-methylated vitamin D₃-sulfur dioxide adduct. Recently, 1 α -hydroxy-6-methylvitamin D₃ was synthesized by a novel approach involving Pd-catalyzed carbocyclization—Negishi cross-coupling cascade [Reino et al., Org. Lett. 7, 5885 (2005)].

Compounds alkylated at C-6 seemed to be interesting targets for synthetic and biological studies. Such vitamin D analogs easily undergo thermal conversion to their previtamin forms. Moreover, the results of molecular modeling indicate that significant deviation from planarity must be present in their diene system, connecting the ring A to the C,D-hydrindane fragment. This is obviously associated with the interaction of the 6-alkyl substituent and hydrogens from the C-ring (at C-9). Such deviation from the planar geometry can be of importance when the vitamin D analog forms a complex with VDR. Recently, Moras et al. reported the X-ray crystal structure of the ligand binding domain (LBD) of the hVDR complexed with the native hormone [Moll. Cell, 5, 173 (2000)]. Later, many other crystal structures of the LBD-VDR bound to different vitamin D compounds were solved and it became clear that VDR binds (at least in the crystalline state) the vitamin D ligands having their intericyclic C(5)=C(6)-C(7)=C(8) diene moiety in the s-trans conformation, exhibiting a torsion angle of ca. -150°. Therefore, in a continuing effort to develop 1 α ,25-dihydroxyvitamin D₃ analogs with biological

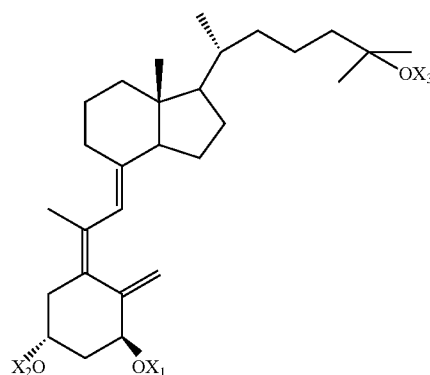
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profiles suitable for pharmaceutical uses we have synthesized 6-methyl analog of 1 α ,25-dihydroxyvitamin D₃.

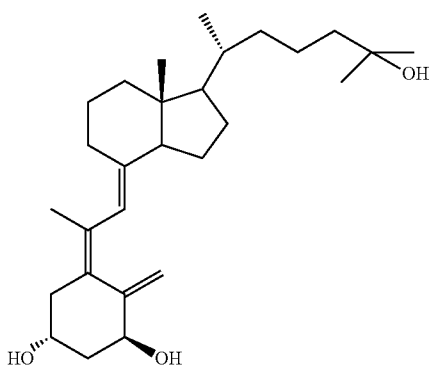
SUMMARY OF THE INVENTION

The present invention is directed toward 6-methylvitamin D₃ analogs, their biological activity, and various pharmaceutical uses for these compounds. These new vitamin D compounds not known heretofore are the vitamin D₃ analogs having a hydroxyl substituent at the carbon-1-position (C-1), a hydroxyl substituent attached to the 25-position (C-25) in the side chain, and a methyl group attached at the 6 position (C-6). The preferred vitamin D analog is 1 α ,25-dihydroxy-6-methylvitamin D₃ (hereinafter referred to as "Me-Cvit").

Structurally these 6-methylvitamin D₃ analogs are characterized by the general formula I shown below:



where X₁, X₂ and X₃, which may be the same or different, are each selected from hydrogen or a hydroxy-protecting group. The preferred analog is 1 α ,25-dihydroxy-6-methylvitamin D₃ which has the following formula Ia:



The above compounds I, particularly Ia, exhibit a desired, and highly advantageous, pattern of biological activity. These compounds are characterized by relatively high binding to vitamin D receptors, which is about the same as that of the native hormone 1 α ,25-dihydroxyvitamin D₃. These compounds are less potent (about 2 logs) in causing cellular differentiation and are also less potent (about one log) in stimulating 24-OHase gene expression compared to 1,25-(OH)₂D₃. These compounds also have less ability to promote intestinal calcium transport in vivo than 1,25-(OH)₂D₃, especially at the recommended lower doses. They are greater than

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1,000 times less potent than the native hormone, and thus would be classified as having lower activity and thus lower potency in vivo in stimulating intestinal calcium transport activity, as compared to that of $1\alpha,25$ -dihydroxyvitamin D_3 . These compounds I, and particularly Ia, also have less ability to mobilize calcium from bone, and they are about 400 times less potent than the native hormone, and thus would be classified as having lower potency in vivo in bone calcium mobilizing activity as compared to $1\alpha,25$ -dihydroxyvitamin D_3 .

The above compounds I, and particularly Ia, are characterized by relatively high cell differentiation activity and in promoting transcription of the 24-hydroxylase gene. Thus, because these compounds have cellular differentiation activity and are more potent than the native hormone in causing transcription, but are less potent in causing intestinal calcium transport, they have potential as an anti-cancer agent, especially for the prevention or treatment of leukemia, colon cancer, breast cancer, skin cancer and prostate cancer. Also, because compounds of formula I, and especially the compound Me-Cvit of formula Ia, bind to the Vitamin D receptor with the same affinity as the native hormone but has markedly lower potency in biological calcemic activities downstream from receptor binding, it is possible this compound could act as a dominant negative and be useful as an antidote for vitamin D intoxication, i.e. it may act in vivo as an antagonist against hypercalcemia caused by a vitamin D compound.

One or more of the compounds may be present in a composition to treat the above-noted diseases in an amount from about 0.01 $\mu\text{g/gm}$ to about 1000 $\mu\text{g/gm}$ of the composition, preferably from about 0.1 $\mu\text{g/gm}$ to about 500 $\mu\text{g/gm}$ of the composition, and may be administered topically, transdermally, orally, rectally, nasally, sublingually or parenterally in dosages of from about 0.01 $\mu\text{g/day}$ to about 1000 $\mu\text{g/day}$, preferably from about 0.1 $\mu\text{g/day}$ to about 500 $\mu\text{g/day}$.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIGS. 1-5 illustrate various biological activities of $1\alpha,25$ -dihydroxy-6-methylvitamin D_3 , hereinafter referred to as "Me-Cvit", as compared to the native hormone $1\alpha,25$ -dihydroxyvitamin D_3 , hereinafter " $1,25(\text{OH})_2D_3$."

FIG. 1 is a graph illustrating the relative activity of Me-Cvit and $1,25(\text{OH})_2D_3$ to compete for binding with [^3H]- $1,25(\text{OH})_2D_3$ to the full-length recombinant rat vitamin D receptor;

FIG. 2 is a graph illustrating the percent HL-60 cell differentiation as a function of the concentration of Me-Cvit and $1,25(\text{OH})_2D_3$;

FIG. 3 is a graph illustrating the in vitro transcription activity of $1,25(\text{OH})_2D_3$ as compared to Me-Cvit;

FIG. 4 is a graph illustrating the bone calcium mobilization activity of $1,25(\text{OH})_2D_3$ as compared to Me-Cvit in a group of animals; and

FIG. 5 is a graph illustrating the intestinal calcium transport activity of $1,25(\text{OH})_2D_3$ as compared to Me-Cvit in a group of animals.

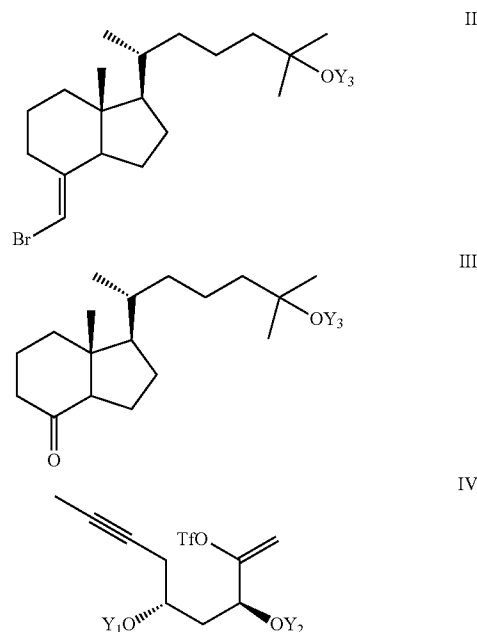
DETAILED DESCRIPTION OF THE INVENTION

$1\alpha,25$ -dihydroxy-6-methylvitamin D_3 (referred to herein as "Me-Cvit") a vitamin D analog which is characterized by the presence of a methylene substituent at the carbon 1 (C-1), a hydroxyl substituent attached to the 25-position (C-25) in the side chain, and a methyl group attached at the 6 position (C-6), was synthesized and tested. Structurally, this vitamin D analog is characterized by the general formula Ia previously

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illustrated herein, and its pro-drug (in protected hydroxy form) is characterized by general formula I previously illustrated herein.

The preparation of 6-methylvitamin D_3 analogs having the structure I can be accomplished by a common general method, i.e. the coupling of a bicyclic vinyl bromide II, easily prepared from a Grundmann ketone III, with the acyclic unit, vinyl triflate IV, followed by deprotection at C-1, C-3 and C-25 in the latter compound to arrive at the compound Me-Cvit having the structure Ia (see Scheme 1 herein):



In the structures II, III and IV groups Y_1 , Y_2 and Y_3 are selected from the group consisting of hydrogen and a hydroxy-protecting group. The method shown above represents an application of a new, highly efficient convergent strategy in which ring A and the triene unit of the vitamin D compound are constructed by one-pot Pd-catalyzed tandem cyclization-Negishi coupling process. Such strategy has been applied effectively for the preparation of the 1α -hydroxyvitamin D_3 and $1\alpha,25$ -dihydroxyvitamin D_3 [Reino et al., Org. Lett. 7, 5885 (2005)].

Hydrindanones of the general structure III are known, or can be prepared by known methods. Specific important example of such known bicyclic ketones is 25-hydroxy Grundmann's ketone [Baggiolini et al., J. Org. Chem., 51, 3098 (1986)]. Bromoolefines of the general structure II are known [for $\text{Y}_3 = \text{TES}$, see: Maeyama et al., Heterocycles 70, 295 (2006)] or can be prepared from III according to Trost procedure [J. Am. Chem. Soc. 114, 1924, 9836 (1992)].

Vinyl triflates of the general structure IV are known, or can be prepared by known methods [Reino et al., Org. Lett. 7, 5885 (2005)].

For the preparation of the required vitamin D compounds of general structure I, a synthetic route has been developed starting from the known alkenyl bromide 1 [Maeyama et al., Heterocycles 70, 295 (2006)] and the known vinyl triflate 2 [Reino et al., Org. Lett. 7, 5885 (2005)]. Process of their coupling and further transformation into the desired $1\alpha,25$ -dihydroxy-6-methylvitamin D_3 is shown on the SCHEME I. Thus, metalation of the bromide 1 with tert-butyllithium and

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subsequent transmetalation with zinc bromide provided the intermediate organozinc derivative. To this derivative was added the vinyl triflate 2 together with triethylamine and a catalytic amount of tetrakis(triphenylphosphine)palladium (0). Removal of the silyl protecting groups in the obtained 6-methylvitamin 3 was performed in the acidic conditions using hydrofluoric acid-pyridine complex. The final 1 α ,25-dihydroxy-6-methylvitamin D₃ (4) was purified by HPLC. Although the vitamin 4 very easily isomerizes to its previtamin D form 5, it can be stored by a prolonged time in a freezer.

As used in the description and in the claims, the term "hydroxy-protecting group" signifies any group commonly used for the temporary protection of hydroxy functions, such as for example, alkoxycarbonyl, acyl, alkylsilyl or alkylarylsilyl groups (hereinafter referred to simply as "silyl" groups), and alkoxyalkyl groups. Alkoxycarbonyl protecting groups are alkyl-O—CO— groupings such as methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, isopropoxycarbonyl, butoxycarbonyl, isobutoxycarbonyl, tert-butoxycarbonyl, benzyloxycarbonyl or allyloxycarbonyl. The term "acyl" signifies an alkanoyl group of 1 to 6 carbons, in all of its isomeric forms, or a carboxyalkanoyl group of 1 to 6 carbons, such as an oxalyl, malonyl, succinyl, glutaryl group, or an aromatic acyl group such as benzoyl, or a halo, nitro or alkyl substituted benzoyl group. The word "alkyl" as used in the description or the claims, denotes a straight-chain or branched alkyl radical of 1 to 10 carbons, in all its isomeric forms. "Alkoxy" refers to any alkyl radical which is attached by oxygen, i.e. a group represented by "alkyl-O." Alkoxyalkyl protecting groups are groupings such as methoxymethyl, ethoxymethyl, methoxyethoxymethyl, or tetrahydrofuranyl and tetrahydropyranyl. Preferred silyl-protecting groups are trimethylsilyl, triethylsilyl, t-butyltrimethylsilyl, dibutylmethylsilyl, diphenylmethylsilyl, phenyldimethylsilyl, diphenyl-t-butylsilyl and analogous alkylated silyl radicals. The term "aryl" specifies a phenyl-, or an alkyl-, nitro- or halo-substituted phenyl group.

A "protected hydroxy" group is a hydroxy group derivatised or protected by any of the above groups commonly used for the temporary or permanent protection of hydroxy functions, e.g. the silyl, alkoxyalkyl, acyl or alkoxycarbonyl groups, as previously defined. The terms "hydroxyalkyl", "deuteroalkyl" and "fluoroalkyl" refer to an alkyl radical substituted by one or more hydroxy, deuterium or fluoro groups respectively. An "alkylidene" refers to a radical having the general formula C_kH_{2k}— where k is an integer.

More specifically, reference should be made to the following illustrative example and description as well as to Scheme 1 herein for a detailed illustration of the preparation of compound Me-Cvit.

In this example specific products identified by Arabic numerals (1, 2, 3, etc.) refer to the specific structures so identified in the Scheme 1.

EXAMPLES

Chemistry. Ultraviolet (UV) absorption spectra were recorded with a Perkin-Elmer Lambda 313 UV-VIS spectrophotometer in ethanol. ¹H nuclear magnetic resonance (NMR) spectra were recorded in deuteriochloroform at 400 and 500 MHz with a Bruker DMX-400 and Bruker DMX-500 spectrometers, respectively. ¹³C nuclear magnetic resonance (NMR) spectra were recorded at 100 and 125 MHz with the same spectrometers in deuteriochloroform. Chemical shifts (6) were reported downfield from internal Me₄Si (δ 0.00). High-performance liquid chromatography (HPLC) was performed on a Waters Associates liquid chromatograph equipped with a Model 6000A solvent delivery system, a Model U6K Universal injector, and a Model 486 tunable

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absorbance detector. THF was freshly distilled before use from sodium benzophenone ketyl under argon.

Example 1

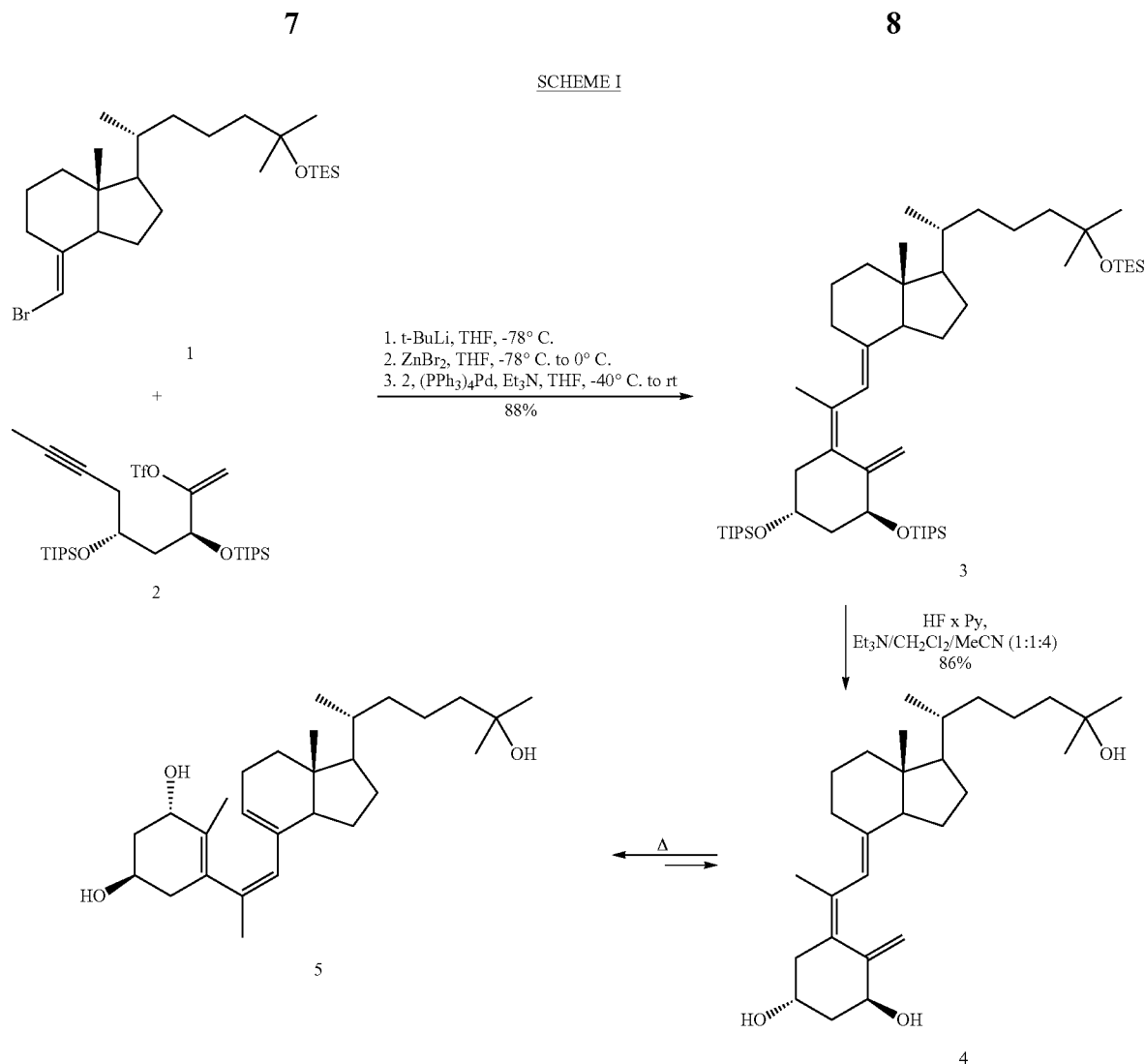
Preparation of 1 α ,25-dihydroxy-6-methylvitamin D₃ (4)

(a) Coupling of alkenyl bromide 1 with vinyl triflate 2 (SCHEME I). A solution of t-BuLi (1.55 M in pentane; 0.31 mL, 0.466 mmol) was added dropwise to a solution of vinyl bromide 1 (100 mg, 0.210 mmol) in anhydrous THF (2 mL) at -78° C. under argon. After 30 min, a solution of ZnBr₂ (0.48 M in THF; 0.53 mL, 0.252 mmol) was added. The reaction mixture was stirred at 0° C. for 1 h. After cooling to -40° C., a mixture of vinyl triflate 2 (90 mg, 0.146 mmol), Et₃N (0.13 mL, 1.05 mmol) and (Ph₃P)₄Pd (14 mg, 0.012 mmol) in anhydrous THF (2 mL) was transferred via cannula. The mixture was stirred at room temperature for 14 h. Then it was quenched by addition of water, poured into saturated aqueous solution of NH₄Cl and diluted with ether. Organic phase was dried (Na₂SO₄) and concentrated. The residue was purified by flash chromatography on silica. Elution with hexane/Et₂O (98:2) provided the crude product that was purified by HPLC (9.4 mm \times 25 cm Zorbax-Sil column, 4 mL/min) using hexane. The protected 6-methyl analog of the natural hormone (compound 3) was eluted at R_f 15 mL (61 mg, 49%; 88% based on recovered substrate).

3: ¹H NMR (500 MHz, CDCl₃) δ 5.68 (1H, s, 7-H), 5.21 (1H, d, J=0.5 Hz, 19E-H), 4.79 (1H, d, J=1.6 Hz, 19Z-H), 4.54 (1H, dd, J=9.0 and 4.0 Hz, 1 \square -H), 4.32 (1H, br s, 3 \square -H), 2.55 (1H, m), 2.26 (1H, m), 1.90 (1H, m), 1.83 (3H, s, 6-CH₃), 1.19 (6H, s, 26- and 27-H₃), 1.06 (36H, 6 \times SiCH(CH₃)₂), 0.95 (9H, t, J=7.9 Hz, 3 \times SiCH₂CH₃), 0.93 (3H, d, J=6.2 Hz, 21-H₃), 0.88 (6H, m, 6 \times SiCH(CH₃)₂), 0.56 (s, 3H, 18-H₃), 0.56 (6H, q, J=7.9 Hz, 3 \times SiCH₂CH₃); ¹³C NMR (125 MHz) δ 150.9 (s, C-10), 138.5 (s, C-8), 132.6 (s, C-5), 129.2 (s, C-6), 124.1 (d, C-7), 110.7 (t, C-19), 73.5 (s, C-25), 70.6 (d, C-1), 68.0 (d, C-3), 56.6 (d), 55.9 (d), 45.5 (t), 40.6 (t), 39.1 (t), 36.5 (t), 36.2 (d), 31.6 (t), 30.5 (t), 30.0 and 29.8 (2 \times q, C-26 and C-27), 27.7 (t), 25.3 (s), 23.5 (t), 22.7 (t), 22.5 (t), 20.9 (t), 20.3 (q, 6-CH₃), 18.8 (q, C-21), 18.27, 18.2, 18.18, 18.15, 18.12 and 18.1 (6 \times q, CH₃-TIPS), 12.4 and 12.3 (2 \times d, CH-TIPS), 11.9 (q, C-18), 7.1 (q, SiCH₂CH₃), 6.8 (t, SiCH₂CH₃).

(b) Hydroxyls deprotection in the silylated vitamin 3. A solution of HF-pyridine complex (ca 70% HF, 0.1 mL) was added dropwise to a solution of protected 6-methylvitamin 3 (37 mg, 0.086 mmol) in CH₃CN (0.5 mL), CH₂Cl₂ (0.25 mL) and Et₃N (0.25 mL) at 0° C. The reaction mixture was stirred at room temperature for 20 min. Next portion of HF-pyridine complex (0.2 mL) was added during 1 h and the mixture was stirred at room temperature for 2 h. The reaction was cooled to 0° C., quenched by slow addition of saturated aqueous solution of NaHCO₃, and diluted with AcOEt. Organic phase was washed with saturated aqueous solution of NaHCO₃, dried (Na₂SO₄) and concentrated. The residue applied on Sep-Pak (2 g) and eluted with hexane/AcOEt (3:7). The product was then purified by HPLC (9.4 mm \times 25 cm Zorbax-Sil column, 4 mL/min) using hexane/2-propanol (8:2) solvent system and 1 α ,25-dihydroxy-6-methylvitamin D₃ (4) was eluted at R_f 31 mL (16 mg, 86%).

4: UV (in EtOH) λ_{max} 240.0 nm; ¹H NMR (400 MHz, MeOD) δ 5.71 (1H, s, 7-H), 5.15 (1H, br s, 19-H), 4.79 (1H, d, J=1.7 Hz, 19-H), 4.34 (1H, m, 1 \square -H); 4.13 (1H, m, 3 \square -H), 2.56 (1H, br d, J=11 Hz, 9 \square -H), 2.43 (1H, br s), 2.03 (1H, br d), 1.88 (3H, s, 6-CH₃), 1.18 (6H, s, 26- and 27-H₃), 0.97 (3H, d, J=6.3 Hz, 21-H₃), 0.61 (3H, s, 18-H₃).



Biological Activity of
1 α ,25-Dihydroxy-6-Methylvitamin D₃ Analog 4,
Me-Cvit

The introduction of a methyl group to the 6-position, as well as a hydroxyl substituent attached to the 25-position (C-25) in the side chain, and having another hydroxyl substituent located at the 1-position (C-1) of the vitamin D₃ compound had little effect on binding of Me-Cvit to the full length recombinant rat vitamin D receptor, as compared to 1 α ,25-dihydroxyvitamin D₃. The compound Me-Cvit bound with the same affinity to the nuclear vitamin D receptor as compared to the standard 1,25-(OH)₂D₃ (FIG. 1). It might be expected from these results that compound Me-Cvit would have equivalent biological activity. Surprisingly, however, compound Me-Cvit is a highly selective analog with unique biological activity.

FIG. 5 shows that Me-Cvit has relatively low ability to increase intestinal calcium transport activity in vivo at low dosages. It clearly has lower potency in vivo (greater than 1,000 times less potent) as compared to that of 1,25-dihydroxyvitamin D₃ (1,25(OH)₂D₃), the natural hormone, in stimulating intestinal calcium transport, especially at the recommended lower doses.

FIG. 4 demonstrates that Me-Cvit also has low bone calcium mobilization activity, as compared to 1,25(OH)₂D₃. Me-Cvit demonstrated less bone calcium mobilization activity than 1,25(OH)₂D₃ (4.3 mg/dL of Me-Cvit versus 7.6 mg/dL of 1,25(OH)₂D₃ at 7020 pmol dosage). Thus, Me-Cvit clearly is less effective in mobilizing calcium from bone as compared to 1,25(OH)₂D₃.

FIGS. 4 and 5 thus illustrate that Me-Cvit may be characterized as being less potent than 1,25(OH)₂D₃ in promoting intestinal calcium transport activity, and also less potent than 1,25(OH)₂D₃ in promoting bone calcium mobilization activity.

FIG. 2 illustrates that Me-Cvit is only about 2 logs or 20 times less potent than 1,25(OH)₂D₃ on HL-60 cell differentiation, i.e. causing the differentiation of HL-60 cells into monocytes. Thus, Me-Cvit may be a candidate for the treatment of a cancer, especially against leukemia, colon cancer, breast cancer, skin cancer and prostate cancer.

FIG. 3 illustrates that in bone cells the compound Me-Cvit is only about 1 log or 10 times less potent than 1,25(OH)₂D₃ in increasing transcription of the 24-hydroxylase gene. This result, together with the cell differentiation activity of FIG. 2, suggests that Me-Cvit may be effective in treating the above

referred to cancers because it has direct cellular activity in causing cell differentiation, gene transcription, and in suppressing cell growth.

Also, because Me-Cvit binds the receptor with the same affinity as the native hormone but has markedly lower potency in biological calcemic activities downstream from receptor binding, it is possible this compound could act as a dominant negative and be useful as an antidote for vitamin D or analog intoxication. In other words, Me-Cvit may act in vivo as an antagonist against hypercalcemia caused by a vitamin D compound.

Experimental Methods

Vitamin D Receptor Binding

Test Material

Protein Source

Full-length recombinant rat receptor was expressed in *E. coli* BL21 (DE3) Codon Plus RIL cells and purified to homogeneity using two different column chromatography systems. The first system was a nickel affinity resin that utilizes the C-terminal histidine tag on this protein. The protein that was eluted from this resin was further purified using ion exchange chromatography (S-Sepharose Fast Flow). Aliquots of the purified protein were quick frozen in liquid nitrogen and stored at -80°C . until use. For use in binding assays, the protein was diluted in TEDK₅₀ (50 mM Tris, 1.5 mM EDTA, pH 7.4, 5 mM DTT, 150 mM KCl) with 0.1% Chaps detergent. The receptor protein and ligand concentration were optimized such that no more than 20% of the added radiolabeled ligand was bound to the receptor.

Study Drugs

Unlabeled ligands were dissolved in ethanol and the concentrations determined using UV spectrophotometry ($1,25(\text{OH})_2\text{D}_3$; molar extinction coefficient=18,200 and $\lambda_{\text{max}}=265\text{ nm}$; Analogs: molar extinction coefficient=42,000 and $\lambda_{\text{max}}=252\text{ nm}$). Radiolabeled ligand ($3\text{H}-1,25(\text{OH})_2\text{D}_3$, ~159 Ci/mmol) was added in ethanol at a final concentration of 1 nM.

Assay Conditions

Radiolabeled and unlabeled ligands were added to 100 μl of the diluted protein at a final ethanol concentration of $\leq 10\%$, mixed and incubated overnight on ice to reach binding equilibrium. The following day, 100 μl of hydroxylapatite slurry (50%) was added to each tube and mixed at 10-minute intervals for 30 minutes. The hydroxylapatite was collected by centrifugation and then washed three times with Tris-EDTA buffer (50 mM Tris, 1.5 mM EDTA, pH 7.4) containing 0.5% Triton X-100. After the final wash, the pellets were transferred to scintillation vials containing 4 ml of Biosafe II scintillation cocktail, mixed and placed in a scintillation counter. Total binding was determined from the tubes containing only radiolabeled ligand.

HL-60 Differentiation

Test Material

Study Drugs

The study drugs were dissolved in ethanol and the concentrations determined using UV spectrophotometry. Serial dilutions were prepared so that a range of drug concentrations could be tested without changing the final concentration of ethanol ($\leq 0.2\%$) present in the cell cultures.

Cells

Human promyelocytic leukemia (HL60) cells were grown in RPMI-1640 medium containing 10% fetal bovine serum. The cells were incubated at 37°C . in the presence of 5% CO_2 .

Assay Conditions

HL60 cells were plated at 1.2×10^5 cells/ml. Eighteen hours after plating, cells in duplicate were treated with drug. Four days later, the cells were harvested and a nitro blue tetrazolium reduction assay was performed (Collins et al., 1979; J. Exp. Med. 149:969-974). The percentage of differentiated cells was determined by counting a total of 200 cells and recording the number that contained intracellular black-blue formazan deposits. Verification of differentiation to monocytic cells was determined by measuring phagocytic activity (data not shown).

In Vitro Transcription Assay

Transcription activity was measured in ROS 17/2.8 (bone) cells that were stably transfected with a 24-hydroxylase (24Oase) gene promoter upstream of a luciferase reporter gene (Arbour et al., 1998). Cells were given a range of doses. Sixteen hours after dosing the cells were harvested and luciferase activities were measured using a luminometer.

RLU=relative luciferase units.

Intestinal Calcium Transport and Bone Calcium Mobilization

Male, weanling Sprague-Dawley rats were placed on Diet 11 (0.47% Ca) diet+AEK oil for one week followed by Diet 11 (0.02% Ca)+AEK oil for 3 weeks. The rats were then switched to a diet containing 0.47% Ca for one week followed by two weeks on a diet containing 0.02% Ca. Dose administration began during the last week on 0.02% calcium diet. Four consecutive ip doses were given approximately 24 hours apart. Twenty-four hours after the last dose, blood was collected from the severed neck and the concentration of serum calcium determined as a measure of bone calcium mobilization. The first 10 cm of the intestine was also collected for intestinal calcium transport analysis using the everted gut sac method.

Interpretation of Data

Summary of Biological Findings. This compound Me-Cvit binds the VDR with the same affinity as the native hormone, and can be considered to be equally potent as $1,25(\text{OH})_2\text{D}_3$ in this activity. Me-Cvit also displays approximately 20 times less cell differentiation activity and about 10 times less in vitro gene transcription activity compared to $1,25(\text{OH})_2\text{D}_3$. While this compound has activity comparable to $1,25(\text{OH})_2\text{D}_3$ in vitro, it shows less activity in vivo on bone calcium mobilization compared to the native hormone, and less activity in vivo in promoting intestinal calcium transport compared to the native hormone. Because this compound exhibits relatively significant cell differentiation and transcriptional activity, but relatively low calcemic activity on bone, it might be useful for treating patients with various types of cancers, especially for the treatment of leukemia, colon cancer, breast cancer, skin cancer and prostate cancer. Me-Cvit might not only be useful in the treatment of the above listed cancers, but also in the prevention of the above listed cancers.

Also, because Me-Cvit binds the receptor as well as the native hormone but has markedly lower potency in biological activities downstream from receptor binding, it is possible this compound could act as a dominant negative and be useful as an antidote for vitamin D or analog intoxication. In other words, Me-Cvit may act in vivo as an antagonist against hypercalcemia caused by a vitamin D compound.

VDR binding, HL60 cell differentiation, and transcription activity. Me-Cvit ($K_i=2 \times 10^{-11}\text{ M}$) has about the same activity as the natural hormone $1\alpha,25\text{-dihydroxyvitamin D}_3$ ($K_i=3 \times 10^{-11}\text{ M}$) in its ability to compete with $[^3\text{H}]-1,25(\text{OH})_2\text{D}_3$ for binding to the full-length recombinant rat vitamin D receptor

(FIG. 1). Me-Cvit displays about 2 logs or 20 times less activity ($EC_{50}=8 \times 10^{-8}M$) in its ability (efficacy or potency) to promote HL-60 cell differentiation as compared to $1\alpha,25$ -dihydroxyvitamin D_3 ($EC_{50}=2 \times 10^{-9}M$) (See FIG. 2). Also, compound Me-Cvit ($EC_{50}=4 \times 10^{-9}M$) has about 1 log or 10 times less transcriptional activity in bone cells than $1\alpha,25$ -dihydroxyvitamin D_3 ($EC_{50}=2 \times 10^{-10}M$) (See FIG. 3). These results suggest that Me-Cvit may have significant activity as an anti-cancer agent and may be very effective because it has direct cellular activity in causing cell differentiation, gene transcription, and in suppressing cell growth.

Calcium mobilization from bone and intestinal calcium absorption in vitamin D-deficient animals. Using vitamin D-deficient rats on a low calcium diet (0.02%), the activities of Me-Cvit and $1,25(OH)_2D_3$ in intestine and bone were tested. As expected, the native hormone ($1,25(OH)_2D_3$) increased serum calcium levels at all dosages (FIG. 4). The study reported in FIG. 4 shows that Me-Cvit has little activity in mobilizing calcium from bone and is about 400 times less potent than $1,25(OH)_2D_3$. The administration of 7020 pmol/day of Me-Cvit for 4 consecutive days did not cause mobilization of bone calcium (4.3 mg/dL) but the native hormone $1,25(OH)_2D_3$ had significant activity at 7020 pmol/day where a substantial effect was seen (7.6 mg/dL).

Intestinal calcium transport was evaluated in the same group of animals using the everted gut sac method (FIG. 5). The study reported in FIG. 5 shows Me-Cvit has little intestinal calcium transport activity as compared to $1,25(OH)_2D_3$. Administration of 7020 pmol/day of Me-Cvit for 4 consecutive days resulted in substantially less activity as compared to $1,25(OH)_2D_3$ at the same 7020 pmol/day dosage (4.8 versus 8.3 respectively).

These results show that the compound Me-Cvit promotes intestinal calcium transport in a dose dependent manner. Thus, it may be concluded that Me-Cvit has lower intestinal calcium transport activity to that of $1,25(OH)_2D_3$ at the recommended lower doses.

These results further illustrate that Me-Cvit is an excellent candidate for numerous human therapies as described herein. Me-Cvit is a candidate for treating a cancer because: (1) it has VDR binding, transcription activity and cellular differentiation activity; (2) it has lower risk of hypercalcemic liability, unlike $1,25(OH)_2D_3$; and (3) it is easily synthesized.

Also, because Me-Cvit binds the receptor as well as the native hormone but has markedly lower potency in biological activities downstream from receptor binding, it is possible this compound could act as a dominant negative and be useful as an antidote for vitamin D or analog intoxication. In other words, Me-Cvit may act in vivo as an antagonist against hypercalcemia caused by a vitamin D compound.

For prevention and/or treatment purposes, the compounds of this invention defined by formula I, particularly Me-Cvit, may be formulated for pharmaceutical applications as a solution in innocuous solvents, or as an emulsion, suspension or dispersion in suitable solvents or carriers, or as pills, tablets or capsules, together with solid carriers, according to conventional methods known in the art. Any such formulations may also contain other pharmaceutically-acceptable and non-toxic excipients such as stabilizers, anti-oxidants, binders, coloring agents or emulsifying or taste-modifying agents.

The compounds of formula I and particularly Me-Cvit, may be administered orally, topically, parenterally, rectally, nasally, sublingually or transdermally. The compound is advantageously administered by injection or by intravenous infusion or suitable sterile solutions, or in the form of liquid or solid doses via the alimentary canal, or in the form of creams, ointments, patches, or similar vehicles suitable for transder-

mal applications. A dose of from 0.01 μg to 1000 μg per day of the compounds I, particularly Me-Cvit, preferably from about 0.1 μg to about 500 μg per day, is appropriate for prevention and/or treatment purposes, such dose being adjusted according to the disease to be treated, its severity and the response of the subject as is well understood in the art. Since the compound exhibits specificity of action, each may be suitably administered alone, or together with graded doses of another active vitamin D compound—e.g. 1α -hydroxyvitamin D_2 or D_3 , or $1\alpha,25$ -dihydroxyvitamin D_3 —in situations where different degrees of bone mineral mobilization and calcium transport stimulation is found to be advantageous.

Compositions for use in the above-mentioned treatments comprise an effective amount of the compounds I, particularly Me-Cvit, as defined by the above formula I and Ia as the active ingredient, and a suitable carrier. An effective amount of such compound for use in accordance with this invention is from about 0.01 μg to about 1000 μg per gm of composition, preferably from about 0.1 μg to about 500 μg per gram of composition, and may be administered topically, transdermally, orally, rectally, nasally, sublingually, or parenterally in dosages of from about 0.01 μg /day to about 1000 μg /day, and preferably from about 0.1 μg /day to about 500 μg /day.

The compounds I, particularly Me-Cvit, may be formulated as creams, lotions, ointments, topical patches, pills, capsules or tablets, suppositories, aerosols, or in liquid form as solutions, emulsions, dispersions, or suspensions in pharmaceutically innocuous and acceptable solvent or oils, and such preparations may contain in addition other pharmaceutically innocuous or beneficial components, such as stabilizers, antioxidants, emulsifiers, coloring agents, binders or taste-modifying agents.

The compounds I, particularly Me-Cvit, may be advantageously administered in amounts sufficient to effect the differentiation of promyelocytes to normal macrophages. Dosages as described above are suitable, it being understood that the amounts given are to be adjusted in accordance with the severity of the disease, and the condition and response of the subject as is well understood in the art.

The formulations of the present invention comprise an active ingredient in association with a pharmaceutically acceptable carrier therefore and optionally other therapeutic ingredients. The carrier must be "acceptable" in the sense of being compatible with the other ingredients of the formulations and not deleterious to the recipient thereof.

Formulations of the present invention suitable for oral administration may be in the form of discrete units as capsules, sachets, tablets or lozenges, each containing a predetermined amount of the active ingredient; in the form of a powder or granules; in the form of a solution or a suspension in an aqueous liquid or non-aqueous liquid; or in the form of an oil-in-water emulsion or a water-in-oil emulsion.

Formulations for rectal administration may be in the form of a suppository incorporating the active ingredient and carrier such as cocoa butter, or in the form of an enema.

Formulations suitable for parenteral administration conveniently comprise a sterile oily or aqueous preparation of the active ingredient which is preferably isotonic with the blood of the recipient.

Formulations suitable for topical administration include liquid or semi-liquid preparations such as liniments, lotions, applicants, oil-in-water or water-in-oil emulsions such as creams, ointments or pastes; or solutions or suspensions such as drops; or as sprays.

For nasal administration, inhalation of powder, self-propelling or spray formulations, dispensed with a spray can, a

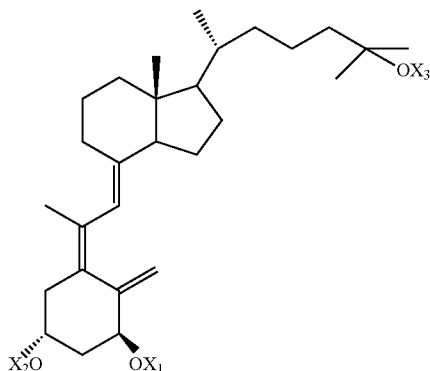
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nebulizer or an atomizer can be used. The formulations, when dispensed, preferably have a particle size in the range of 10 to 100 μ .

The formulations may conveniently be presented in dosage unit form and may be prepared by any of the methods well known in the art of pharmacy. By the term "dosage unit" is meant a unitary, i.e. a single dose which is capable of being administered to a patient as a physically and chemically stable unit dose comprising either the active ingredient as such or a mixture of it with solid or liquid pharmaceutical diluents or carriers.

We claim:

1. A compound having the formula:



where X₁, X₂ and X₃, which may be the same or different, are each selected from hydrogen or a hydroxy-protecting group.

2. The compound of claim 1 wherein X₃ is hydrogen.

3. The compound of claim 1 wherein X₁ is hydrogen.

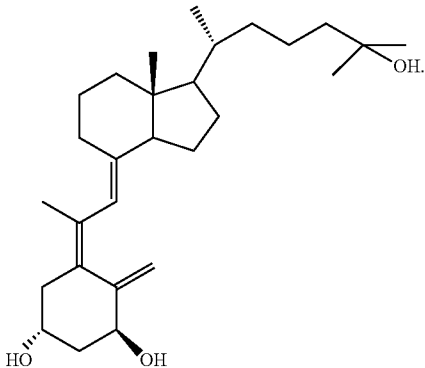
4. The compound of claim 1 wherein X₁, X₂ and X₃ are all t-butyl dimethylsilyl.

5. A pharmaceutical composition containing an effective amount of at least one compound as claimed in claim 1 together with a pharmaceutically acceptable excipient.

6. The pharmaceutical composition of claim 5 wherein said effective amount comprises from about 0.01 μ g to about 1000 μ g per gram of composition.

7. The pharmaceutical composition of claim 5 wherein said effective amount comprises from about 0.1 μ g to about 500 μ g per gram of composition.

8. 1 α ,25-dihydroxy-6-methylvitamin D₃ having the formula:



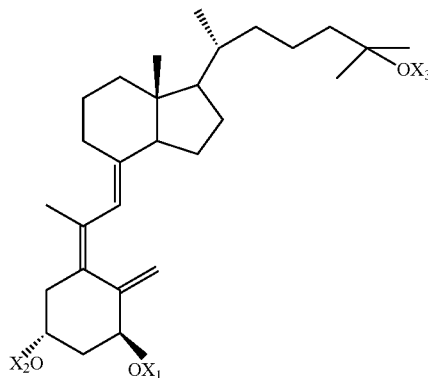
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9. A pharmaceutical composition containing an effective amount of 1 α ,25-dihydroxy-6-methylvitamin D₃ together with a pharmaceutically acceptable excipient.

10. The pharmaceutical composition of claim 9 wherein said effective amount comprises from about 0.01 μ g to about 1000 μ g per gram of composition.

11. The pharmaceutical composition of claim 9 wherein said effective amount comprises from about 0.1 μ g to about 500 μ g per gram of composition.

12. A method of treating a disease selected from the group consisting of leukemia, colon cancer, breast cancer, skin cancer or prostate cancer comprising administering to a subject with said disease an effective amount of a compound having the formula:



where X₁, X₂ and X₃ which may be the same or different, are each selected from hydrogen or a hydroxy-protecting group.

13. The method of claim 12 wherein the compound is administered orally.

14. The method of claim 12 wherein the compound is administered parenterally.

15. The method of claim 12 wherein the compound is administered transdermally.

16. The method of claim 12 wherein the compound is administered rectally.

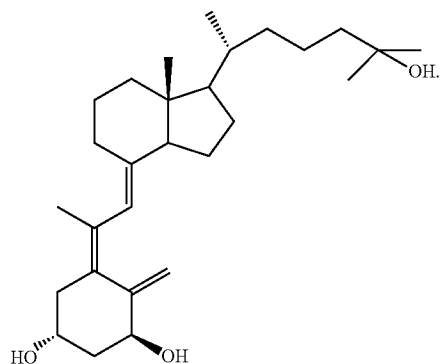
17. The method of claim 12 wherein the compound is administered nasally.

18. The method of claim 12 wherein the compound is administered sublingually.

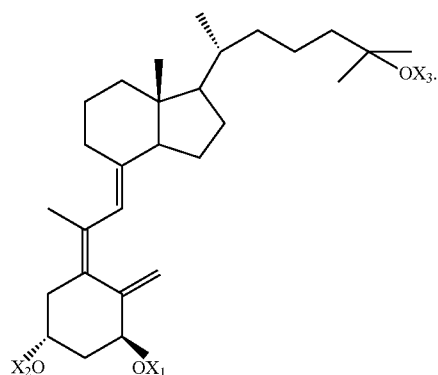
19. The method of claim 12 wherein the compound is administered in a dosage of from about 0.01 μ g/day to about 1000 μ g/day.

20. The method of claim 12 wherein the compound is 1 α ,25-dihydroxy-6-methylvitamin D₃ having the formula:

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21. A method of inhibiting development of hypercalcemia comprising administering to a subject an effective amount of a compound having the formula:



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22. The method of claim 21 wherein the compound is administered orally.

23. The method of claim 21 wherein the compound is administered parenterally.

24. The method of claim 21 wherein the compound is administered transdermally.

25. The method of claim 21 wherein the compound is administered rectally.

26. The method of claim 21 wherein the compound is administered nasally.

27. The method of claim 21 wherein the compound is administered sublingually.

28. The method of claim 21 wherein the compound is administered in a dosage of from about 0.01 $\mu\text{g/day}$ to about 1000 mg/day.

29. The method of claim 21 wherein the compound is 1 α ,25-dihydroxy-6-methylvitamin D₃ having the formula:

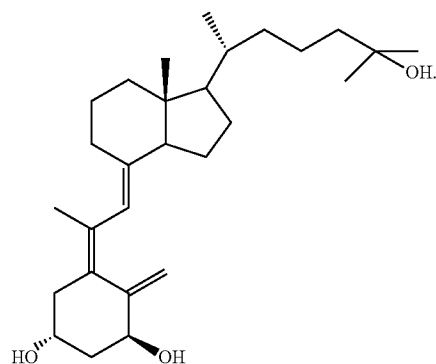
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