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(54) **BISPHOSPHONATE COMPOUNDS AND METHODS FOR BONE RESORPTION DISEASES, CANCER, BONE PAIN, IMMUNE DISORDERS, AND INFECTIOUS DISEASES**

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See application file for complete search history.

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(57) **ABSTRACT**

Bisphosphonate compounds and related methods of making and using are disclosed, including pyridinium-1-yl, quinolinium-1-yl, and related compounds. The activity of compounds is disclosed in the context of functional assays such as *Leishmania major* farnesyl diphosphate synthase (FPPS) inhibition, *Dictyostelium discoideum* growth inhibition, human gamma delta T cell activation, and bone resorption. The applicability of bisphosphonate compounds in the context of parasitic infections, for example against trypanosomes, is disclosed. Further potential applications of the invention are disclosed regarding the treatment of one or more conditions such as bone resorption disorders, cancer, bone pain, infectious diseases, and in immunotherapy.

27 Claims, 10 Drawing Sheets

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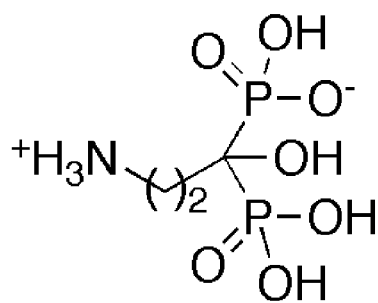
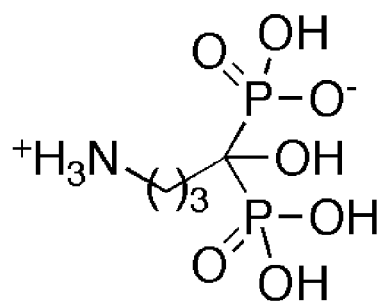
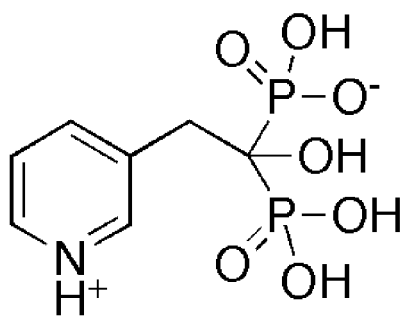
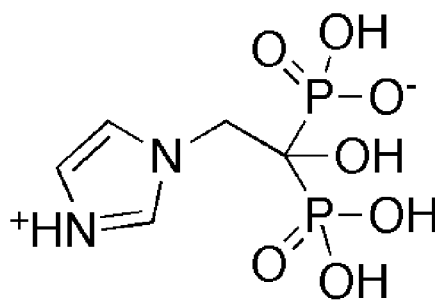
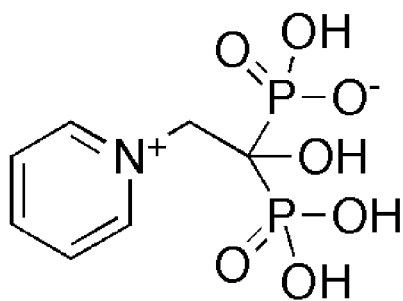
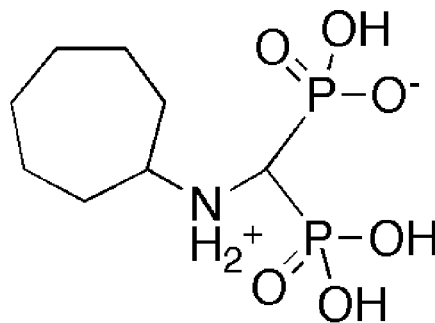
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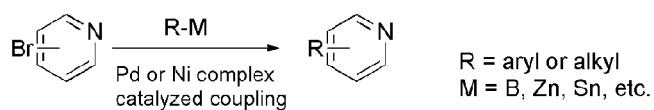
Compounds C1 – C6.

FIG. 1

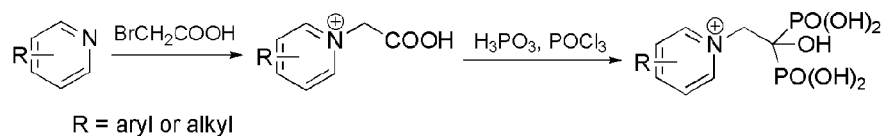
Synthetic Routes

General synthetic routes

1. Preparation of substituted pyridine (if not commercially available)



2a. Preparation of 1-hydroxy-2-(substitutedpyridinium-1-yl)ethyl-1,1-diphosphonic acid



2b. Preparation of 2-(substitutedpyridinium-1-yl)ethyl-1,1-diphosphonic acid

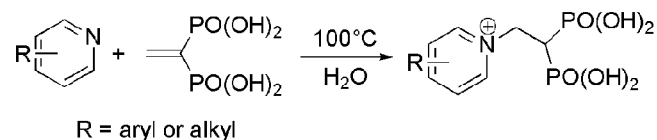
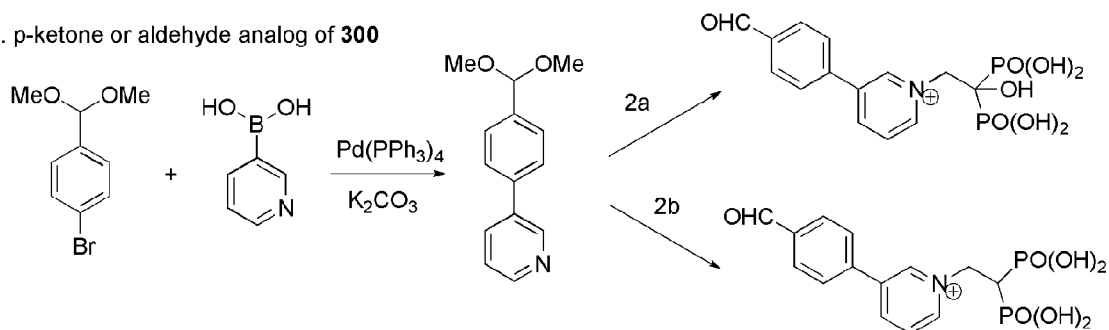
3. p-ketone or aldehyde analog of **300**

FIG. 2

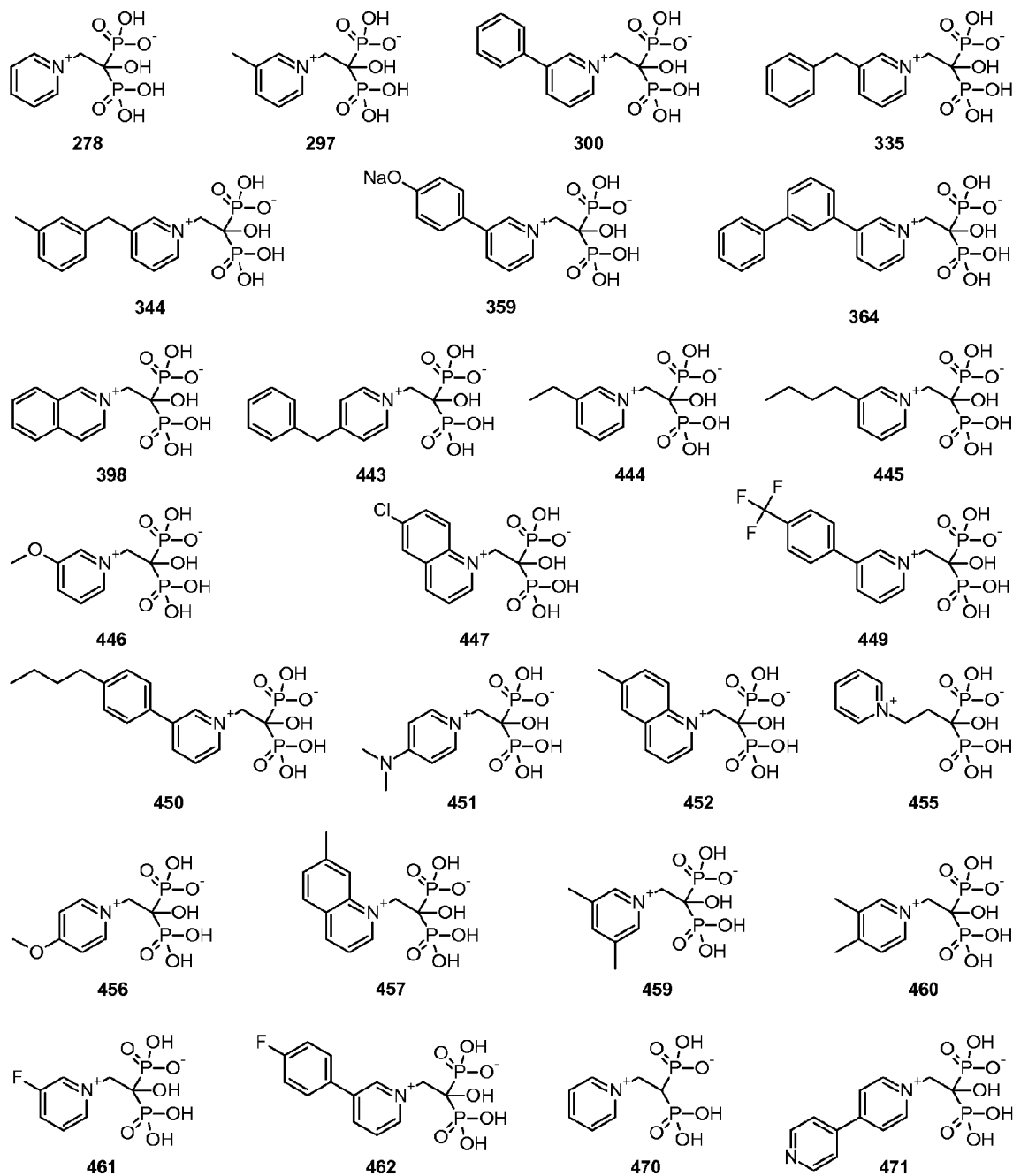


FIG. 3

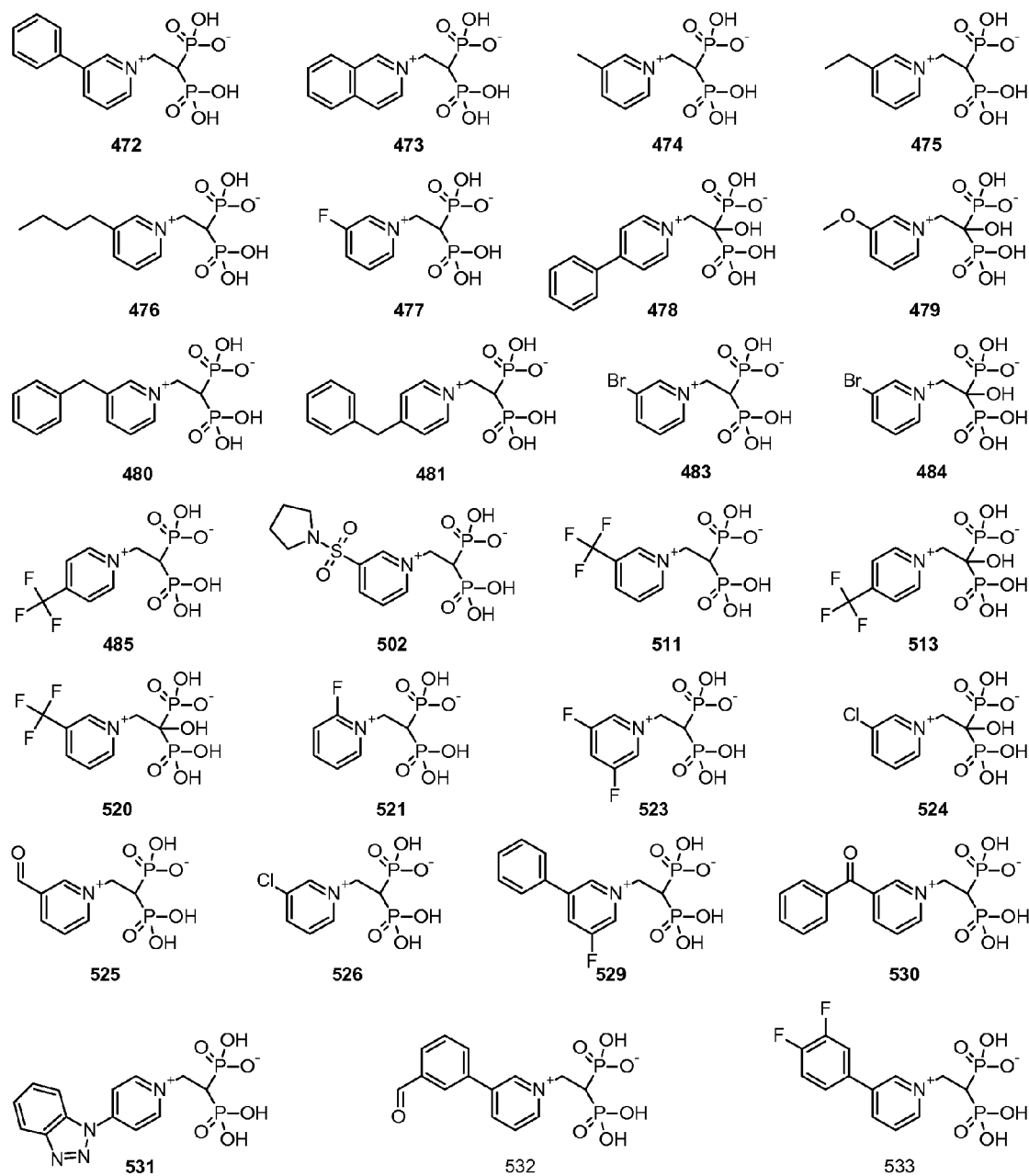


FIG. 4

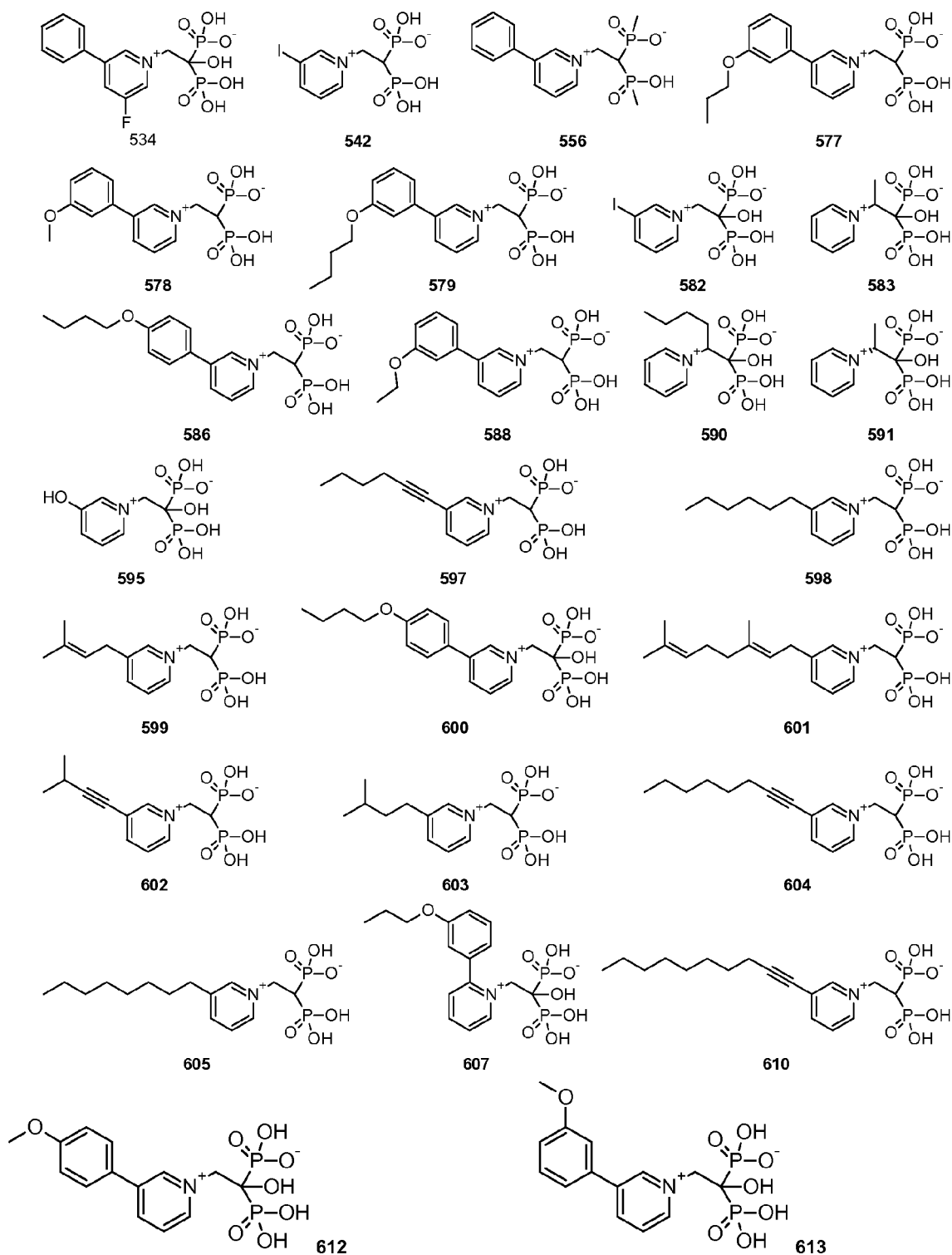


FIG. 5

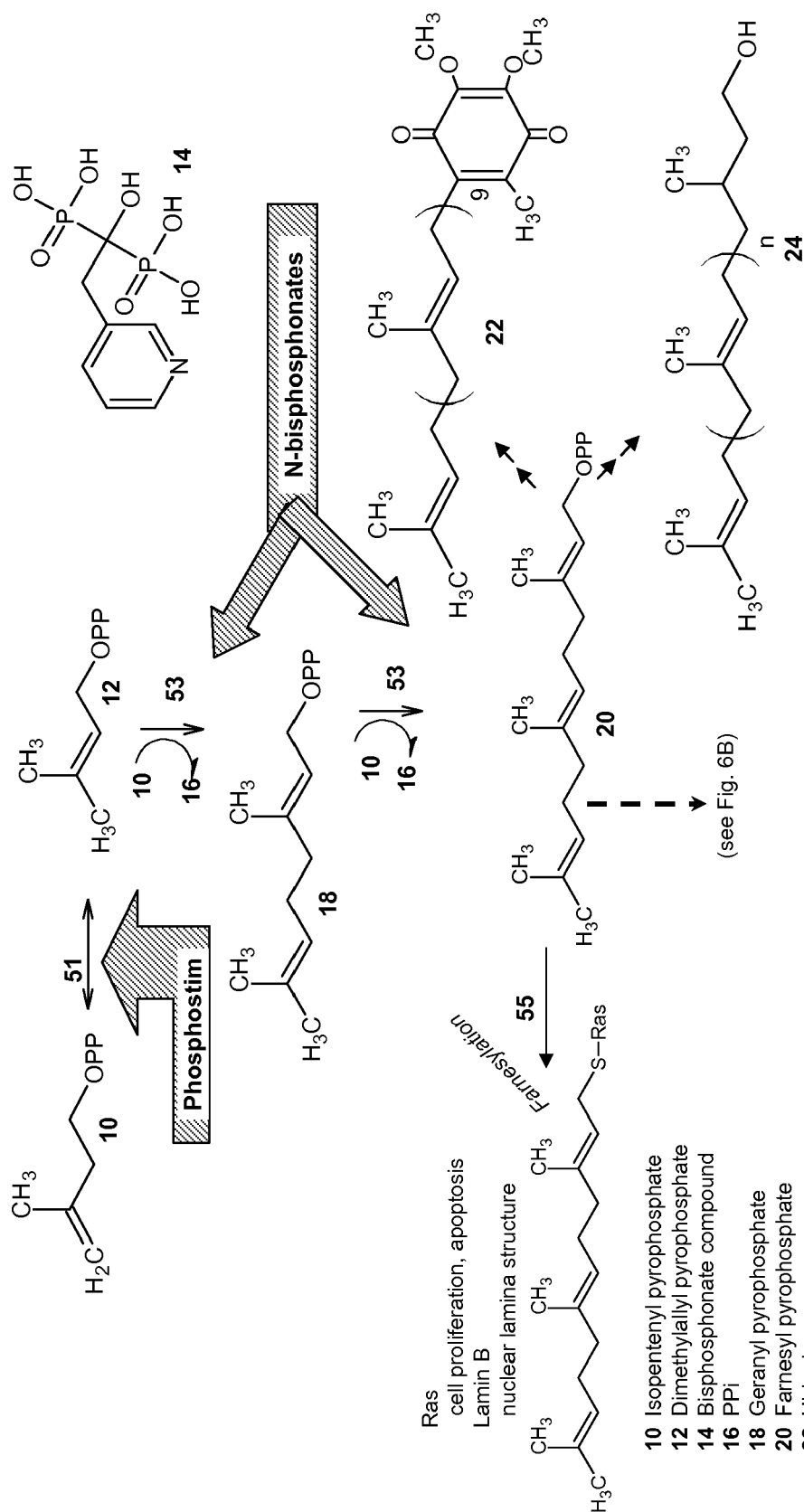


FIG. 6A

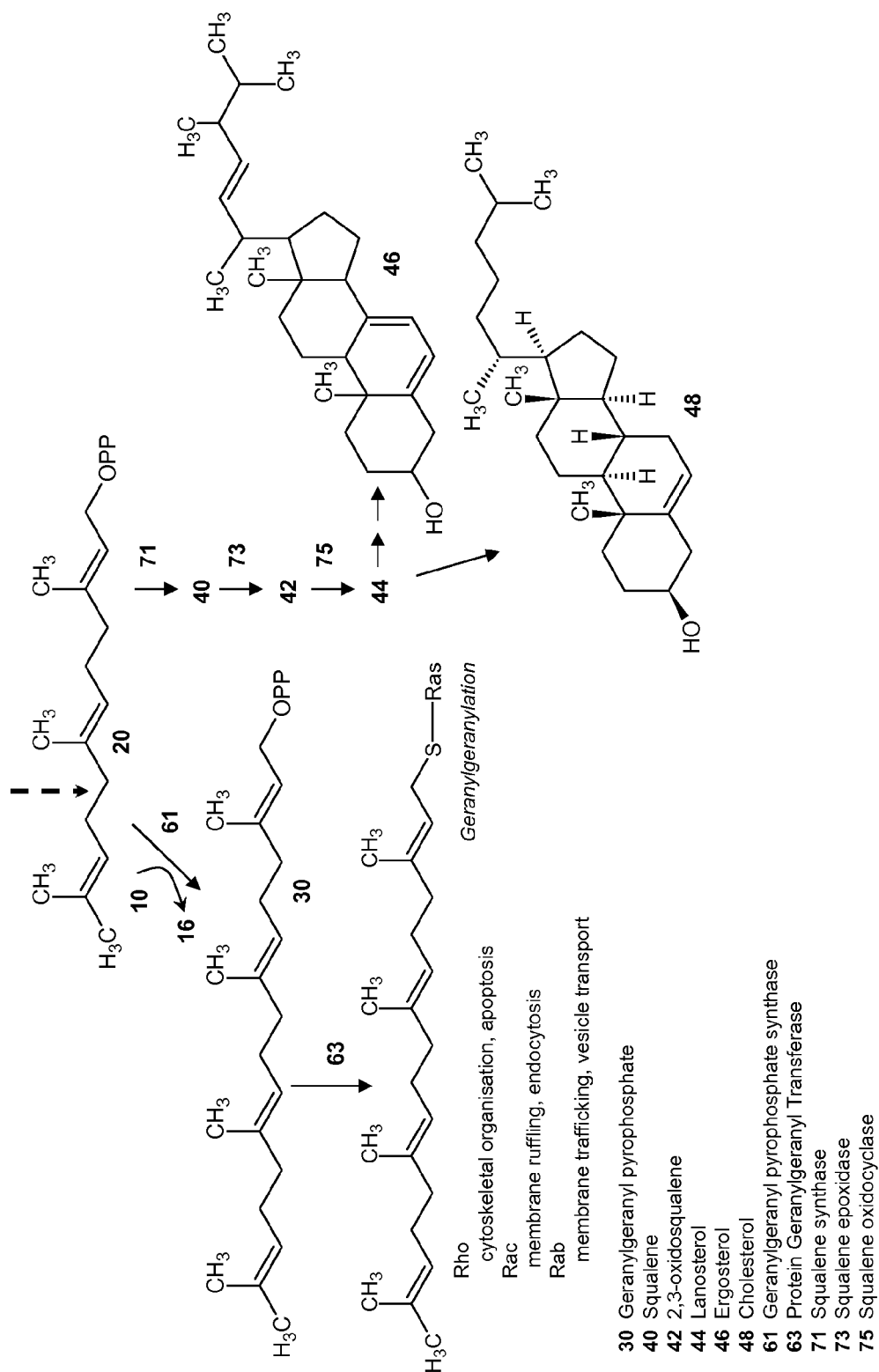
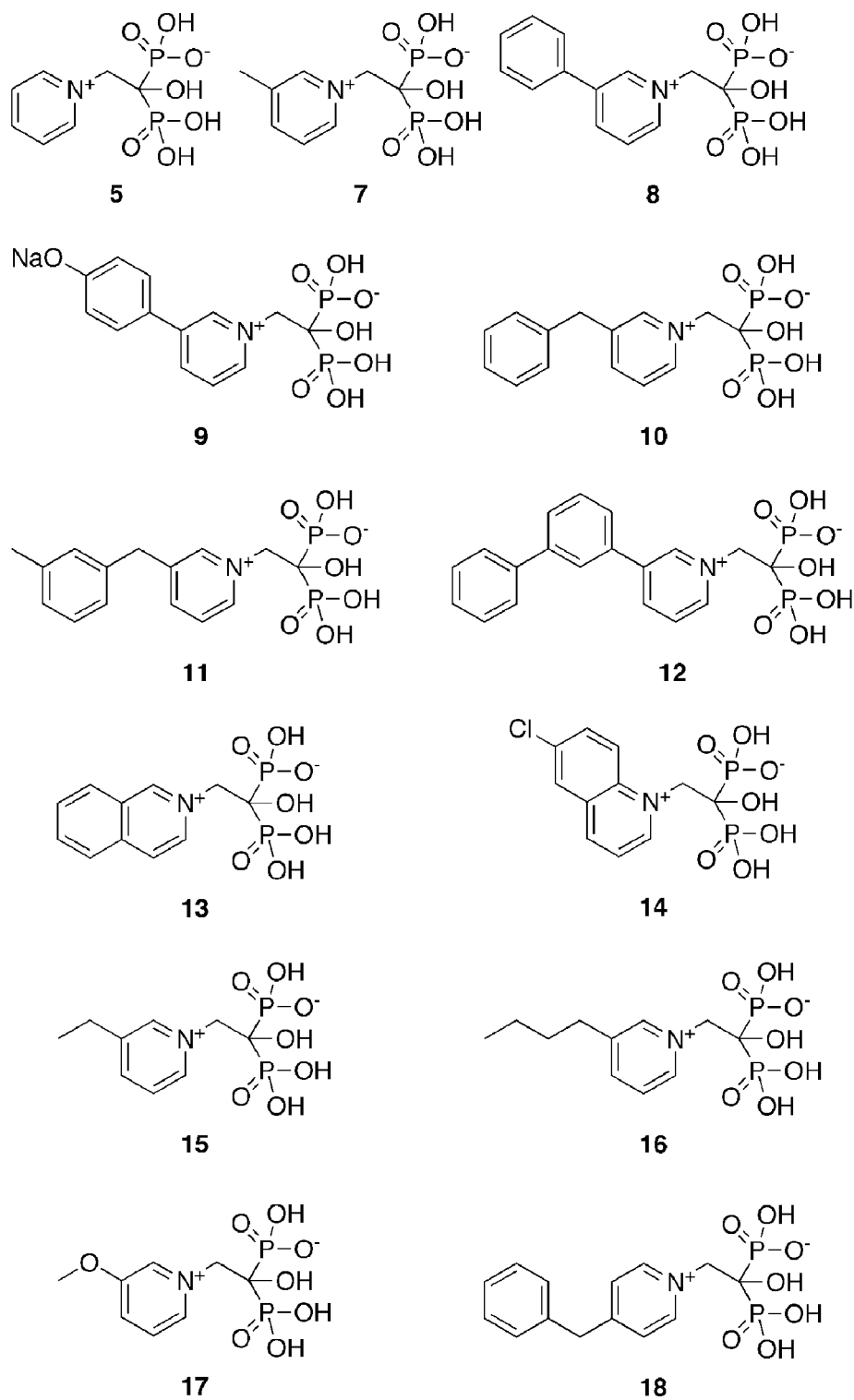


FIG. 6B



Compounds C5 and C7-C18.

FIG. 7

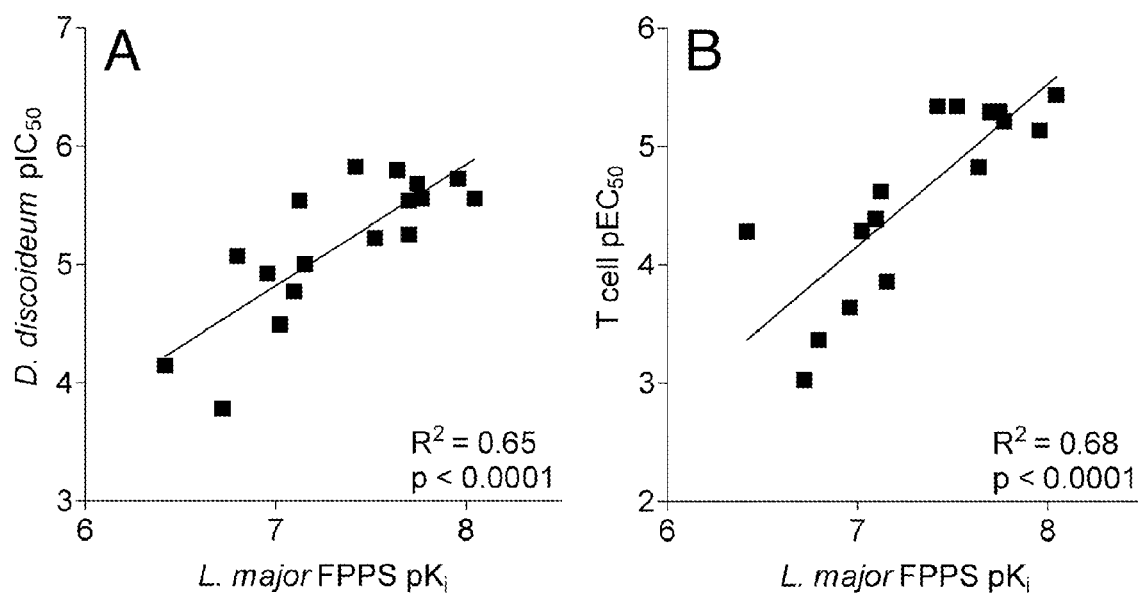


FIG. 8

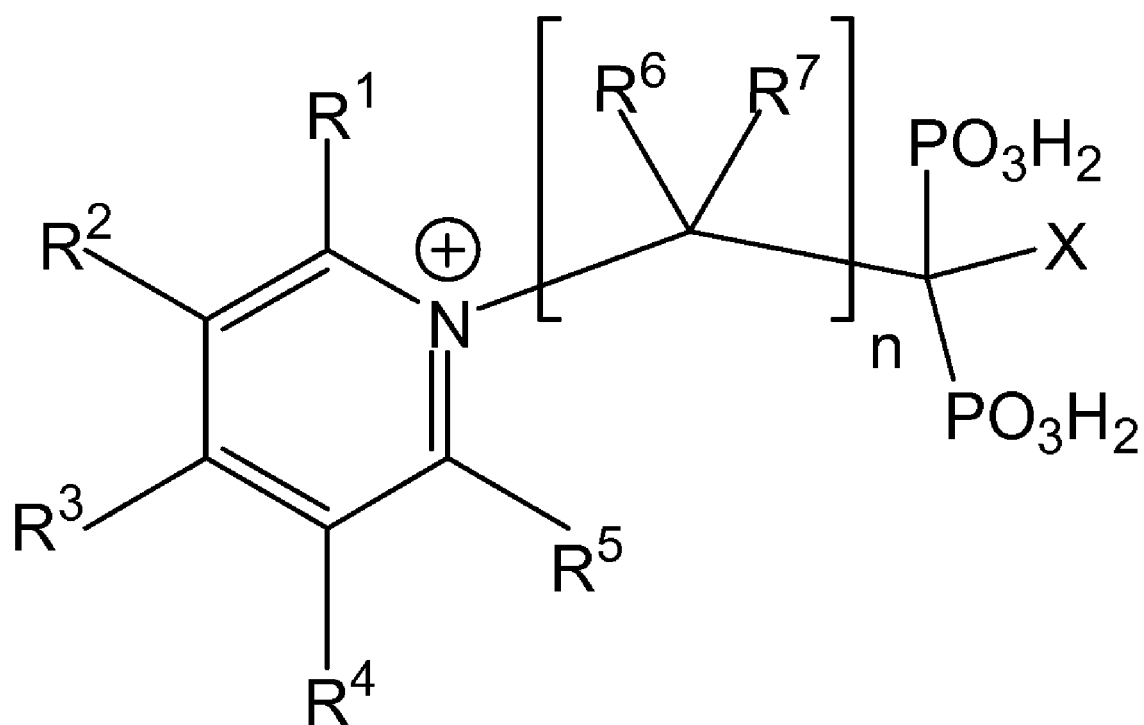


FIG. 9

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BISPHOSPHONATE COMPOUNDS AND METHODS FOR BONE RESORPTION DISEASES, CANCER, BONE PAIN, IMMUNE DISORDERS, AND INFECTIOUS DISEASES

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 11/245,612 filed Oct. 7, 2005, which claims the benefit of U.S. Provisional Patent Application 60/617,108 by Sanders et al., filed Oct. 8, 2004; each of which is incorporated by reference in entirety to the extent not inconsistent herewith.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made, at least in part, with government support under Grant Nos. GM50694 and GM65307 awarded by the National Institutes of Health. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

Nitrogen-containing bisphosphonates such as pamidronate (Aredia®) C1; alendronate (Fosamax®) C2; risedronate (Actonel®) C3; and zoledronate (Zometa®) C4; shown in their zwitterionic forms in FIG. 1, represent an important class of drugs, currently used to treat osteoporosis, Paget's disease and hypercalcemia due to malignancy. See references 1-4. These compounds function primarily by inhibiting the enzyme farnesyl diphosphate synthase (FPPS) (references 5-12) resulting in decreased levels of protein prenylation in osteoclasts (references 13-15). Certain bisphosphonates have also been found to have anti-parasitic activity (references 16-25) and have been found to stimulate human $\gamma\delta$ T cells (references 26-30); there is currently interest in their use as vaccines for a variety of B cell malignancies (reference 31).

Differences in substituents, however, can strongly influence the pharmacologic properties of such compounds (Green, 2001). Structural differences may also be significant in the potential expansion of therapies. For example, Bonefos (clodronate) is a bisphosphonate indicated for the treatment of tumor-induced osteolysis and hypercalcemia. It has been reported to increase survival and reduce the risk of bone metastasis in women with stage II/III breast cancer. This is noteworthy as approximately 70% of women who develop recurrence of breast cancer will experience bone metastasis, and breast cancer remains the leading cause of death among women aged 40 to 55 years.

For even second generation bisphosphonates, it is recognized that small changes of structure can lead to marked improvements in activity or function, for example in the inhibition of osteoclastic resorption potency (Widler et al., 2002). Therefore, there is great interest in the further development of alternative bisphosphonate compounds and the exploration of methods of use such as clinical applications.

SUMMARY OF THE INVENTION

The present invention surprisingly provides the first report of the synthesis and testing of a series of pyridinium-1-yl and related bisphosphonates. Bisphosphonate compounds of the invention can demonstrate activity in one or more contexts, including a farnesyl diphosphate synthase (FPPS) assay, a *D. discoideum* growth inhibition assay, a T cell activation assay, a bone resorption assay, the treatment of infectious disease, the treatment of a bone resorption clinical disorder, an immunotherapeutic treatment, the treatment of cancer, and the treatment of bone pain.

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The invention broadly provides bisphosphonate compounds and related methods of making and using. The invention specifically provides compounds with an N-linkage including pyridinium-1-yl, quinolinium-1-yl, and related bisphosphonate compounds.

The following abbreviations are applicable. FPPS, farnesyl diphosphate synthase; $\text{pIC}_{50}/\text{pEC}_{50}$, negative log of IC_{50} and EC_{50} , respectively, where IC_{50} and EC_{50} are the concentrations that produce half-maximal inhibition or activation, respectively; *L. major*, *Leishmania major*; *D. discoideum*, *Dictyostelium discoideum*; $\gamma\delta$ T cells, gammadelta T cells. Compounds are optionally designated by a number or in some cases a number preceded by a letter to help distinguish a compound designation from a cardinal number, e.g. C1 is compound 1.

The following definitions are applicable.

Alkyl groups include straight-chain, branched and cyclic alkyl groups. Alkyl groups include those having from 1 to 20 carbon atoms. Alkyl groups include small alkyl groups having 1 to 3 carbon atoms. Alkyl groups include medium length alkyl groups having from 4-10 carbon atoms. Alkyl groups include long alkyl groups having more than 10 carbon atoms, particularly those having 10-20 carbon atoms. Cyclic alkyl groups include those having one or more rings. Cyclic alkyl groups include those having a 3-, 4-, 5-, 6-, 7-, 8-, 9- or 10-member carbon ring and particularly those having a 3-, 4-, 5-, 6-, or 7-member ring. The carbon rings in cyclic alkyl groups can also carry alkyl groups. Cyclic alkyl groups can include bicyclic and tricyclic alkyl groups. Alkyl groups optionally include substituted alkyl groups. Substituted alkyl groups include among others those which are substituted with aryl groups, which in turn can be optionally substituted. Specific alkyl groups include methyl, ethyl, n-propyl, iso-propyl, cyclopropyl, n-butyl, s-butyl, t-butyl, cyclobutyl, n-pentyl, branched-pentyl, cyclopentyl, n-hexyl, branched hexyl, and cyclohexyl groups, all of which are optionally substituted.

Alkenyl groups include straight-chain, branched and cyclic alkenyl groups. Alkenyl groups include those having 1, 2 or more double bonds and those in which two or more of the double bonds are conjugated double bonds. Alkenyl groups include those having from 2 to 20 carbon atoms. Alkenyl groups include small alkyl groups having 2 to 3 carbon atoms. Alkenyl groups include medium length alkenyl groups having from 4-10 carbon atoms. Alkenyl groups include long alkenyl groups having more than 10 carbon atoms, particularly those having 10-20 carbon atoms. Cyclic alkenyl groups include those having one or more rings. Cyclic alkenyl groups include those in which a double bond is in the ring or in an alkenyl group attached to a ring. Cyclic alkenyl groups include those having a 3-, 4-, 5-, 6-, 7-, 8-, 9- or 10-member carbon ring and particularly those having a 3-, 4-, 5-, 6- or 7-member ring. The carbon rings in cyclic alkenyl groups can also carry alkyl groups. Cyclic alkenyl groups can include bicyclic and tricyclic alkyl groups. Alkenyl groups are optionally substituted. Substituted alkenyl groups include among others those which are substituted with alkyl or aryl groups, which groups in turn can be optionally substituted. Specific alkenyl groups include ethenyl, prop-1-enyl, prop-2-enyl, cycloprop-1-enyl, but-1-enyl, but-2-enyl, cyclobut-1-enyl, cyclobut-2-enyl, pent-1-enyl, pent-2-enyl, branched pentenyl, cyclopent-1-enyl, hex-1-enyl, branched hexenyl, cyclohexenyl, all of which are optionally substituted.

Aryl groups include groups having one or more 5- or 6-member aromatic or heteroaromatic rings. Aryl groups can contain one or more fused aromatic rings. Heteroaromatic rings can include one or more N, O, or S atoms in the ring. Heteroaromatic rings can include those with one, two or three N, those with one or two O, and those with one or two S. Aryl groups are optionally substituted. Substituted aryl groups include among others those which are substituted with alkyl

or alkenyl groups, which groups in turn can be optionally substituted. Specific aryl groups include phenyl groups, biphenyl groups, pyridinyl groups, and naphthyl groups, all of which are optionally substituted.

Arylalkyl groups are alkyl groups substituted with one or more aryl groups wherein the alkyl groups optionally carry additional substituents and the aryl groups are optionally substituted. Specific alkylaryl groups are phenyl-substituted alkyl groups, e.g., phenylmethyl groups.

Alkylaryl groups are aryl groups substituted with one or more alkyl groups wherein the alkyl groups optionally carry additional substituents and the aryl groups are optionally substituted. Specific alkylaryl groups are alkyl-substituted phenyl groups such as methylphenyl.

The rings that may be formed from two or more of R^1 - R^5 together can be optionally substituted cycloalkyl groups, optionally substituted cycloalkenyl groups or aromatic groups. The rings may contain 3, 4, 5, 6, 7 or more carbons. The rings may be heteroaromatic in which one, two or three carbons in the aromatic ring are replaced with N, O or S. The rings may be heteroalkyl or heteroalkenyl, in which one or more CH_2 groups in the ring are replaced with O, N, NH, or S.

Optional substitution of any alkyl, alkenyl and aryl groups includes substitution with one or more of the following substituents: halogens, $-CN$, $-COOR$, $-OR$, $-COR$, $-OCOOR$, $-CON(R)_2$, $-OCON(R)_2$, $-N(R)_2$, $-NO_2$, $-SR$, $-SO_2R$, $-SO_2N(R)_2$ or $-SOR$ groups. Optional substitution of alkyl groups includes substitution with one or more alkenyl groups, aryl groups or both, wherein the alkenyl groups or aryl groups are optionally substituted. Optional substitution of alkenyl groups includes substitution with one or more alkyl groups, aryl groups, or both, wherein the alkyl groups or aryl groups are optionally substituted. Optional substitution of aryl groups includes substitution of the aryl ring with one or more alkyl groups, alkenyl groups, or both, wherein the alkyl groups or alkenyl groups are optionally substituted.

Optional substituents for alkyl, alkenyl and aryl groups include among others:

$-COOR$ where R is a hydrogen or an alkyl group or an aryl group and more specifically where R is methyl, ethyl, propyl, butyl, or phenyl groups all of which are optionally substituted;

$-COR$ where R is a hydrogen, or an alkyl group or an aryl groups and more specifically where R is methyl, ethyl, propyl, butyl, or phenyl groups all of which groups are optionally substituted;

$-CON(R)_2$ where each R, independently of each other R is a hydrogen or an alkyl group or an aryl group and more specifically where R is methyl, ethyl, propyl, butyl, or phenyl groups all of which groups are optionally substituted; R and R can form a ring which may contain one or more double bonds;

$-OCON(R)_2$ where each R, independently of each other R, is a hydrogen or an alkyl group or an aryl group and more specifically where R is methyl, ethyl, propyl, butyl, or phenyl groups all of which groups are optionally substituted; R and R can form a ring which may contain one or more double bonds;

$-N(R)_2$ where each R, independently of each other R, is a hydrogen, or an alkyl group, acyl group or an aryl group and more specifically where R is methyl, ethyl, propyl, butyl, or phenyl or acetyl groups all of which are optionally substituted; or R and R can form a ring which may contain one or more double bonds.

$-SR$, $-SO_2R$, or $-SOR$ where R is an alkyl group or an aryl groups and more specifically where R is methyl, ethyl, propyl, butyl, phenyl groups all of which are optionally substituted; for $-SR$, R can be hydrogen;

$-OCOOR$ where R is an alkyl group or an aryl groups;

$-SO_2N(R)_2$ where R is a hydrogen, an alkyl group, or an aryl group and R and R can form a ring;

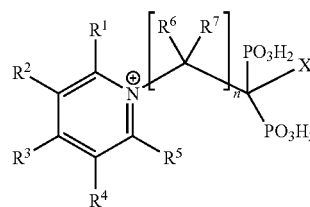
$-OR$ where $R=H$, alkyl, aryl, or acyl; for example, R can be an acyl yielding $-OCOR^*$ where R^* is a hydrogen or an alkyl group or an aryl group and more specifically where R^* is methyl, ethyl, propyl, butyl, or phenyl groups all of which groups are optionally substituted;

Specific substituted alkyl groups include haloalkyl groups, particularly trihalomethyl groups and specifically trifluoromethyl groups. Specific substituted aryl groups include mono-, di-, tri-, tetra- and pentahalo-substituted phenyl groups; mono-, di-, tri-, tetra-, penta-, hexa-, and hepta-halo-substituted naphthalene groups; 3- or 4-halo-substituted phenyl groups, 3- or 4-alkyl-substituted phenyl groups, 3- or 4-alkoxy-substituted phenyl groups, 3- or 4- RCO -substituted phenyl, 5- or 6-halo-substituted naphthalene groups. More specifically, substituted aryl groups include acetylphenyl groups, particularly 4-acetylphenyl groups; fluorophenyl groups, particularly 3-fluorophenyl and 4-fluorophenyl groups; chlorophenyl groups, particularly 3-chlorophenyl and 4-chlorophenyl groups; methylphenyl groups, particularly 4-methylphenyl groups, and methoxyphenyl groups, particularly 4-methoxyphenyl groups.

Pharmaceutically acceptable salts comprise pharmaceutically-acceptable anions and/or cations. Pharmaceutically-acceptable cations include among others, alkali metal cations (e.g., Li^+ , Na^+ , K^+), alkaline earth metal cations (e.g., Ca^{2+} , Mg^{2+}), non-toxic heavy metal cations and ammonium (NH_4^+) and substituted ammonium ($N(R')_4^+$, where R' is hydrogen, alkyl, or substituted alkyl, i.e., including, methyl, ethyl, or hydroxyethyl, specifically, trimethyl ammonium, triethyl ammonium, and triethanol ammonium cations). Pharmaceutically-acceptable anions include among other halides (e.g., Cl^- , Br^-), sulfate, acetates (e.g., acetate, trifluoroacetate), ascorbates, aspartates, benzoates, citrates, and lactate.

Compounds of the invention can have prodrug forms. Prodrugs of the compounds of the invention are useful in the methods of this invention. Any compound that will be converted in vivo to provide a biologically, pharmaceutically or therapeutically active form of a compound of the invention is a prodrug. Various examples and forms of prodrugs are well known in the art. Examples of prodrugs are found, inter alia, in Design of Prodrugs, edited by H. Bundgaard, (Elsevier, 1985), Methods in Enzymology, Vol. 42, at pp. 309-396, edited by K. Widder, et. al. (Academic Press, 1985); A Textbook of Drug Design and Development, edited by Krosgaard-Larsen and H. Bundgaard, Chapter 5, "Design and Application of Prodrugs," by H. Bundgaard, at pp. 113-191, 1991; H. Bundgaard, Advanced Drug Delivery Reviews, Vol. 8, p. 1-38 (1992); H. Bundgaard, et al., Journal of Pharmaceutical Sciences, Vol. 77, p. 285 (1988); and Nogrady (1985) Medicinal Chemistry A Biochemical Approach, Oxford University Press, New York, pages 388-392).

The invention provides compounds having the formula CA1:



(see also FIG. 9)

or a pharmaceutically acceptable salt, ester or hydrate thereof; wherein:

X is H, $-OH$, or a halogen;

n is 1, 2, or 3;

R^1 - R^5 , independently of one another and other R groups, are selected from the group consisting of a hydrogen, a halo-

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gen, a —CN, —OR, —COOR, —OCOOR, —COR, —CON(R)₂, —OCON(R)₂, —N(R)₂, —NO₂, —SR, —SO₂R, —SO₂N(R)₂ or —SOR group, an optionally substituted alkyl group, an optionally substituted alkenyl group, and an optionally substituted aryl group, where each R, independent of any other R in any listed group, is selected from H, an optionally substituted alkyl group, an optionally substituted aryl group, and an optionally substituted acyl group;

two or more of R¹-R⁵ can together form one or more rings which may contain one or more double bonds or which may be aromatic;

R⁶ and R⁷, independently of each other and other R⁶ and R⁷ in the compound, are selected from the group consisting of a hydrogen, a halogen, a —N(R)₂, or —SR group, an optionally substituted alkyl group, an optionally substituted alkenyl group, an optionally substituted alkoxy group, and an optionally substituted aryl group, where each R, independent of any other R in any listed group, is selected from H, an optionally substituted alkyl group and an optionally substituted aryl group; and

wherein R⁶ and R⁷ can together form a ring which may contain one or more double bonds.

In specific embodiments, the invention relates to compounds having the above formula where X is OH.

In other specific embodiments, the invention relates to compounds having the above formula where X is H.

In other specific embodiments, compounds of the invention are those of formula CA1, with the exception of the compound of formula CA1 where X is H, n is 1 and all of R¹-R⁷ are hydrogens.

In other specific embodiments, the invention relates to compounds having the above formula wherein n is 1.

In other specific embodiments, the invention relates to compounds having the above formula where X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein one or both of R⁶ and R⁷ are hydrogens.

In other specific embodiments, the invention relates to compounds having the above formula wherein both of R⁶ and R⁷ are hydrogens.

In other specific embodiments, the invention relates to compounds having the above formula wherein both of R⁶ and R⁷ are hydrogens and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein both of R⁶ and R⁷ are hydrogens, n is 1 and X is OH.

In other specific embodiments, the invention relates to compounds having the above formula wherein both of R⁶ and R⁷ are hydrogens, n is 1 and X is H.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹-R⁵ are all hydrogens.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹-R⁵ are all hydrogens, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹-R⁵ are all hydrogens, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, X is OH and n is 1.

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In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogen, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogen and one or more of R², R³ or R⁴ is a halogen.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a halogen, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a halogen, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an optionally substituted alkyl group, particularly a small alkyl group and more particularly a methyl group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an optionally substituted alkyl group, particularly a small alkyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a methyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a trifluoromethyl group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an optionally substituted alkyl group, particularly a small alkyl group, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an optionally substituted alkoxy group. A specific alkoxy group is a methoxy group. Specific compounds of this invention are those as in the formula above in which R² or R³ is a methoxy group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an optionally substituted alkoxy group, X is OH and n is 1. Specific compounds of the invention are those as in the formula above wherein R¹ and R⁵ are both hydrogens, R² or R³ is a methoxy group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an optionally substituted alkoxy group, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an optionally substituted phenyl group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an optionally substituted phenyl group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an optionally substituted phenyl group, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an alkyl-

substituted phenyl group. Specific alkyl groups are methyl, ethyl and n-propyl groups. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-alkylphenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-methylphenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-ethylphenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-n-butylphenyl group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an alkyl-substituted phenyl group, X is OH and n is 1. Specific alkyl groups are methyl, ethyl and n-propyl groups. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-methylphenyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-ethylphenyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-n-propylphenyl group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an alkyl-substituted phenyl group, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is a halo-substituted phenyl group. Specific halogens are fluorine, chlorine and bromine. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-halophenyl group or a 3-, 4-dihalophenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-fluorophenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-chlorophenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-bromophenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3-bromo-4-fluorophenyl group or a 3-chloro-4-fluorophenyl group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a halo-substituted phenyl group, X is OH and n is 1. Specific halogens are fluorine, chlorine, and bromine. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-fluorophenyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-chlorophenyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-bromophenyl group, X is OH and n is 1. Specific compounds of this invention are those as above in which R² or R³ is a 3-bromo-4-fluorophenyl group or a 3-chloro-4-fluorophenyl group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a halo-substituted phenyl group, X is H and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is a hydroxy-substituted phenyl group which may be in the form of a phenoxy anion or salt thereof. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-hydroxyphenyl group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-hydroxyphenyl group. Specific compounds of this invention are those in which R² or R³ is a 3- or 4-oxyphenyl anion or a salt

thereof. Salts of the oxyphenyl anion include Na⁺, K⁺, and other pharmaceutically acceptable salts containing pharmaceutically acceptable cations.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is a hydroxy-substituted phenyl group, which may be in the form of a phenoxy anion or salt thereof, X is OH and n is 1. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-hydroxyphenyl group, X is OH and n is 1. Specific compounds of this invention are those in which R² or R³ is a 3- or 4-oxyphenyl anion or a salt thereof, X is OH, and n is 1. Salts of the oxyphenyl anion include Na⁺, K⁺, and other pharmaceutically acceptable salts containing pharmaceutically acceptable cations.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an alkoxy-substituted phenyl group. A specific alkoxy group is a methoxy group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-methoxy phenyl group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an alkoxy substituted phenyl group, X is OH and n is 1. A specific alkoxy group is a methoxy group. Specific compounds of this invention are those as above in which R² or R³ is a 3- or 4-methoxy phenyl group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, and one or more of R², R³ or R⁴ is an optionally substituted arylalkyl group. A specific arylalkyl group is a phenylmethyl group, particularly the compound as above wherein R² or R³ is a phenylmethyl group.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an optionally substituted arylalkyl group, X is OH and n is 1. A specific compound of this invention is one in which R¹ and R⁵ are both hydrogens, R² or R³ is a phenylmethyl group, X is OH and n is 1.

In other specific embodiments, the invention relates to compounds having the above formula wherein R¹ and R⁵ are both hydrogens, one or more of R², R³ or R⁴ is an optionally substituted arylalkyl group, X is H and n is 1.

In a particular embodiment of CA1, X is OH, n=1, and R¹-R⁷ are H. In a particular embodiment of CA1, X is a halogen. In a more particular embodiment, the halogen is selected from the group consisting of Cl or F. In an embodiment of CA1, X is Cl. In an embodiment of CA1, X is F. In an embodiment of CA1, X is not H.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH or H and R² is selected from the group consisting of H, optionally substituted alkyl groups, optionally substituted alkoxy groups and optionally substituted phenyl groups. Of particular interest are those compounds in which the optional substitution is one or more halogens, including one or more fluorines or chlorines.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH and R² is selected from the group consisting of H, optionally substituted alkyl groups, optionally substituted alkoxy groups and optionally substituted phenyl groups. Of particular interest are those compounds in which the optional substitution is one or more halogens, including one or more fluorines or chlorines.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH or H and R² is selected from the group consisting of optionally substituted alkyl groups, optionally substituted alkoxy groups and optionally substituted phenyl groups. Of particular interest are those compounds in which the optional substitution is one or more halogens, including one or more fluorines or chlorines.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH and R² is selected from the group consisting of optionally substituted alkyl groups, optionally substituted alkoxy groups and optionally substituted phenyl groups. Of particular interest are those compounds in which the optional substitution is one or more halogens, including one or more fluorines or chlorines.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH or H and R² is selected from the group consisting of H, alkyl groups, alkoxy groups and a phenyl group.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH and R² is selected from the group consisting of H, alkyl groups, alkoxy groups and a phenyl group.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH or H and R² is selected from the group consisting of H, a methyl group, an ethyl group, propyl groups, butyl groups, a methoxy group, an ethoxy group, propyloxy groups, butyloxy groups and a phenyl group.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH and R² is selected from the group consisting of H, a methyl group, an ethyl group, propyl groups, butyl groups, a methoxy group, an ethoxy group, propyloxy groups, butyloxy groups and a phenyl group.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH or H and R² is selected from the group consisting of H, a methyl group, a methoxy group, and a phenyl group.

In other specific embodiments, the invention includes compounds of formula CA1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, X is OH and R² is selected from the group consisting of H, a methyl group, a methoxy group, and a phenyl group.

In a specific embodiment, compounds 278, 297, 300 and 446; and pharmaceutically acceptable salts, and esters thereof; are useful for treatment of a bone resorption clinical disorder.

In a specific embodiment, compounds 278, 297, 300, 444, 445 and 446; and pharmaceutically acceptable salts, and esters thereof; are useful in treatment of protozoan diseases, useful for treatment of a bone resorption clinical disorder, and for immunotherapy.

In a specific embodiment, compounds, the des-hydroxy (where X is H) analogs of compounds 278, 297, 300, 444, 445 and 446; and pharmaceutically acceptable salts, and esters thereof; are useful in the treatment of a bone resorption clinical disorder.

Compounds of this invention and compounds useful in the methods of this invention include those of the above formulas and pharmaceutically-acceptable salts and esters of those compounds. Salts include any salts derived from the acids of the formulas herein which acceptable for use in human or veterinary applications. The term esters refers to hydrolyz-

able esters of diphosphonate compounds of the formulas herein. Salts and esters of the compounds of the formulas herein are those which have the same therapeutic or pharmaceutical (human or veterinary) properties as the diphosphonate compounds of the formulas herein. Various combinations of salts are possible, with each phosphonate carrying a 2-, 1- or neutral charge. In principle there are multiple charge states possible, for example 9 charge states, for certain bisphosphonates of this invention.

In an embodiment, the invention provides a compound selected from the group consisting of 278, 297, 300, 335, 344, 359, 364, 398, 443-447, 449-452, 455-457, 459-462, 470-481, 483-485, ZZ1, 502, 511, 513, 520, 521, 523-526, 529-534, 542, 556, 577-579, 582, 583, 586, 588, 590, 591, 595, 597-605, 607, 610, 612, and 613; and for each respective said compound, a pharmaceutically acceptable salt or ester thereof.

In an embodiment, the invention provides a therapeutic composition comprising one or more compounds selected from the group consisting of 278, 297, 300, 335, 344, 359, 364, 398, 443-447, 449-452, 455-457, 459-462, 470-481, 483-485, ZZ1; and for each numbered compound a pharmaceutically acceptable salt or ester thereof; wherein the compounds are present in the composition in an amount or in a combined amount effective for obtaining the desired therapeutic benefit. The therapeutic compositions of this invention optionally further comprise a pharmaceutically acceptable carrier as known in the art.

In a specific embodiment, the invention includes compounds of the above formula CA1 where n=1, R¹ and R³-R⁷ are hydrogens, X=OH, and R²=H, optionally substituted alkyl, optionally substituted alkoxy, and optionally substituted phenyl. In a more specific embodiment, the invention includes compounds where n=1, R¹ and R³-R⁷=H, X=OH, and R²=H, alkyl, alkoxy, and phenyl. In a further specific embodiment, the invention includes compounds where n=1, R¹ and R³-R⁷=H, X=OH, and R²=H, methyl, ethyl, propyl, butyl, methoxy, ethoxy, propoxy, butoxy, or phenyl.

In an embodiment, the invention provides various methods relating to the treatment of clinical disease. In an embodiment, the invention provides a method of treating a bone resorption disorder comprising administering to a patient in need a composition comprising a compound of the invention.

In an embodiment, the invention provides a method of treating a cancer disorder comprising administering to a patient in need a composition comprising a compound of the invention. In a specific embodiment, the cancer is breast cancer. In a specific embodiment, the breast cancer involves an actual or potential bone metastatic condition. In a specific embodiment, the invention provides a method of treating myeloma, lymphoma, prostate cancer, an epidermoid cancer, or orthotopic tumors.

In an embodiment, the invention provides compounds and methods for use in a combination therapy in the treatment of cancer. In a specific embodiment, a combination therapy utilizes a bisphosphonate compound of the invention and a different chemotherapeutic agent which can optionally be a distinct other bisphosphonate compound. In a particular embodiment the different chemotherapeutic agent is alendronate, zoledronate, risedronate, pamidronate, fas ligand (FasL), mevastatin, dexamethasone, paclitaxel, epirubicin, docetaxel, imatinib mesylate, tumor necrosis factor (TNF)-related apoptosis inducing ligand (TRAIL), uracil-tegafur, gemcitabine, melphalan, doxorubicin, vincristine, or R115777 farnesyl transferase inhibitor (FTI) (Zarnestra®). In a particular embodiment, the combination of the bisphosphonate compound of the invention and the different chemothera-

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peutic agent has a synergistic effect. In another particular embodiment the combination has an additive effect.

In an embodiment, the invention provides a method of treating an infectious disease comprising administering to a patient in need a composition comprising a compound of the invention. In a specific embodiment, the infectious disease relates to an agent selected from the group consisting of: a virus, a bacterium, a fungus, and a protozoan parasite. In a specific embodiment, the virus is a retrovirus. In a more specific embodiment, the retrovirus is human immunodeficiency virus (HIV). In an embodiment, the protozoan parasite is *Leishmania major*. In an embodiment, the protozoan parasite is selected from the group consisting of: *Leishmania*, *Toxoplasma*, *Cryptosporidium*, *Plasmodium*, and *Trypanosoma*. In an embodiment, the infectious disease is selected from the group consisting of leishmaniasis, toxoplasmosis, cryptosporidiosis, sleeping sickness, and malaria.

In an embodiment, the invention provides a method of immunotherapy comprising administering to a patient in need a composition comprising a compound of the invention. In a specific embodiment, the method stimulates T cells in the patient. In a more specific embodiment, the method stimulates gamma delta T cells.

In an embodiment, the invention provides a method of screening a bisphosphonate test compound for a potential therapeutic activity, comprising: providing said bisphosphonate test compound, measuring a performance attribute of said test compound in at least three assays selected from the group consisting of: a *Leishmania major* farnesyl diphosphate synthase (FPPS) assay, a *Dictyostelium discoideum* assay, a T cell activation assay, and a bone resorption assay, analyzing said performance attribute; and selecting said bisphosphonate test compound based on said attribute; thereby screening said bisphosphonate test compound. In a specific embodiment, the method further comprises providing a reference compound and comparing a performance attribute of said reference compound with said performance attribute of said test compound.

In an embodiment, the invention provides a method of synthesizing a bisphosphonate compound of the invention, for example formula CA1, comprising: syntheses as shown and described herein, e.g. in schemes, FIG. 2, etc.; and as further would be understood in the art.

In an embodiment, the invention provides a method of treating bone pain comprising administering to a patient in need a compound of the invention. In a particular embodiment, the treatment of bone pain is in the context of a bone disease. In a particular embodiment, the treatment of bone pain is in the context of a patient with a metastatic cancer. In a particular embodiment, the metastatic cancer has spread to a bone location or originated in a bone location. For example, the treatment of bone pain can be achieved in a breast cancer patient wherein a metastatic breast cancer can or has spread to a bone location.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 illustrates compounds C1-C6, including pamidronate (Aredia®) C1; alendronate (Fosamax®) C2; risedronate (Actonel®) C3; zoledronate (Zometa®) C4; C5; and C6 shown in their zwitterionic forms.

FIG. 2 illustrates synthetic routes in the preparation of compounds.

FIG. 3 illustrates structures of compounds.

FIG. 4 illustrates structures of selected compounds.

FIG. 5 illustrates structures of selected compounds.

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FIG. 6 illustrates cellular pathways of isoprenoid biosynthesis.

FIG. 7 illustrates the structures of pyridinium-1-yl bisphosphonates, compounds C5 and C7-C18.

FIG. 8 illustrates correlations: A, between FPPS inhibition and *D. discoideum* growth inhibition; and B, between FPPS inhibition and $\gamma\delta$ T cell activation (as determined by TNF- α release). The R^2 and p values are $R^2=0.65$ and $p<0.0001$ in A and $R^2=0.68$ and $p<0.0001$ in B.

FIG. 9 illustrates a structure of a bisphosphonate compound.

DETAILED DESCRIPTION OF THE INVENTION

The invention may be further understood by the following non-limiting examples.

EXAMPLE 1

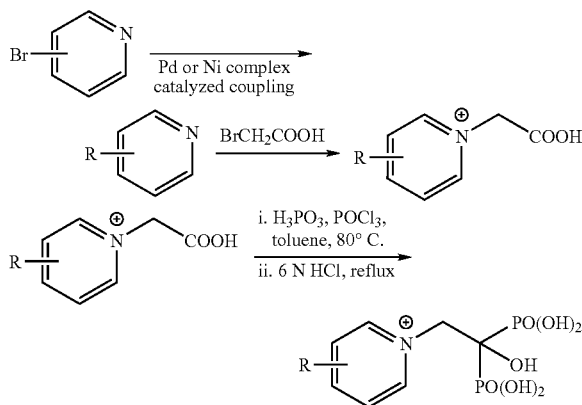
Bisphosphonate Compounds

We report the design, synthesis and testing of a series of novel bisphosphonates. The most potent molecules have high activity and can represent useful compositions for a variety of applications such as in bone resorption disorders, parasitic diseases, immunomodulation, and cancer.

Our efforts led to the prediction of the importance of the presence of a positive charge at a relatively localized position in the bisphosphonate side chain. This can be related to the position of the positive charge expected in the pyridinium and imidazolium forms of compounds C3 and C4, shown above.

We explored the possibility that the pyridinium-1-yl species, compound C5, might have useful activity. We synthesized C5 and a series of derivatives (compounds C7-C18, FIG. 7), using the following general scheme, Scheme 1.

SCHEME 1:



In the first step, we used (where necessary) coupling reactions of arylmetallic compounds with bromopyridines, catalyzed by $\text{Pd}(\text{PPh}_3)_4$ (ref. 32) or $\text{NiCl}_2(\text{PPh}_3)_2$ (ref. 33) to produce substituted pyridines. The substituted pyridines were then alkylated by using bromoacetic acid (ref. 34) and the resulting pyridinium-1-yl acetic acids were converted to the corresponding bisphosphonates by using $\text{H}_3\text{PO}_3/\text{POCl}_3$ (ref. 35).

We then investigated the activity of each compound in inhibiting the FPPS from *L. major*, in *Dictyostelium discoideum* growth inhibition and in $\gamma\delta$ T cell activation. We used the FPPS from *L. major* since this enzyme is the putative

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bisphosphonate target in several trypanosomatid species. We used *D. discoideum* to test for cell growth inhibition, since this organism has been useful in the context of the development of bone resorption drugs (ref. 36). To determine the stimulatory activity of compounds C5 and C7-C18 for Vγ2Vδ2 T cells, we used the TNF-α release assay (ref. 30).

In the *L. major* FPPS inhibition assay, C5 was found to have a K_i of 18 nM (Table 6) and was thus slightly less active than the most potent commercially available bisphosphonates, zoledronate (4, K_i =11 nM in this assay) and risedronate (3, K_i =17 nM in this assay) (Table 6). In order to try to enhance activity, we next investigated the desirability of placing substituents at the meta position. We thus prepared compounds C7-C9 (FIG. 7) and tested them in the FPPS assay. The meta-methyl analog of C5 (C7) was not as active as C5 (K_i =38 nM versus 18 nM), but substitution with a meta-phenyl group, giving C8, resulted in a very potent species, having a K_i =9 nM, slightly more active than zoledronate, 4 (K_i =11 nM). The para-phenoxy derivative of C5 (C9) was found to be less active (K_i =75 nM), possibly due to unfavorable electrostatic interactions of the OH group in the FPPS active site.

TABLE 1

Activities of bisphosphonates as <i>L. major</i> FPPS inhibitors, <i>D. discoideum</i> cell growth inhibitors and gammadelta T cell stimulators.*				
Compound	Compound Alias	<i>L. major</i> FPPS K_i (nM)	<i>D. discoideum</i> IC_{50} (μM)	gammadelta T cell stimulation, EC_{50} (μM)
1 (pamidronate) ^{a,b}		190	167	940
2 (alendronate) ^{a,b}		95	32	52
3 (risedronate) ^{a,b}		17	2.8	6.2
4 (zoledronate) ^{a,b}		11	1.9	7.3
5	278	18	2.1	5.1
6 (incadronate) ^{a,b}		23	1.6	15
7	297	38	1.5	4.6
8	300	9	2.8	3.7
9	359	75	2.9	24
10	335	160	8.5	430
11	344	70	9.9	140
12	364	950	2.3	>1000
13	398	80	20	41
14	447	380	72	53
15	444	20	5.6	5.1
16	445	20	2.9	5.2
17	446	30	6	4.6
18	443	110	12	230

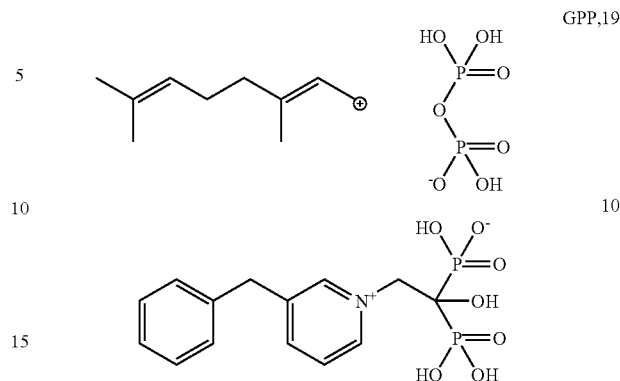
^a*L. major* FPPS inhibition data from Ref. 17

^bGammadelta T cell stimulation data from Ref. 30

*Note that compound designations here are referred to by numbers and may optionally be designated with a preceding "C" yielding, e.g., C1, C2, etc.

Since the phenylpyridinium species, C8, displayed good activity, we next synthesized C10 and C11. Both of these compounds contain a methylene linker between the two aromatic groups and it seemed possible that they might better mimic the putative geranyl diphosphate reactive intermediate (C19):

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but each of these compounds was approximately ten-fold less active than C8, with K_i values in the 70-160 nM range, Table 1. We also prepared the biphenylpyridinium compound, C12, since the added hydrophobicity of C8 appeared encouraging, but C12 proved to be relatively inactive, having a K_i of 950 nM. The isoquinoline and quinoline species, C13 and C14, had modest activity (80 and 380 nM, respectively, for C13 and C14), but the meta-ethyl (C15), butyl (C16), methoxy (C17) and para-benzyl (C18) pyridinium species were generally more active (20, 20, 30 and 110 nM, respectively), although they were less active than compounds C3-C6, C8. See Table 1.

We next investigated *D. discoideum* growth inhibition by compounds 1-18 (Table 1; alternatively referred to as C1-C18). The most active compound found was the meta-methylpyridinium compound, C7, which had an IC_{50} of 1.5 μM, followed by incadronate (C6, IC_{50} =1.6 μM) and zoledronate (C4, IC_{50} =1.9 μM). The unsubstituted pyridinium bisphosphonate, C5, was slightly more active (IC_{50} =2.1 μM) than was risedronate (C3, IC_{50} =2.8 μM). As with the FPPS inhibition results, the benzylpyridinium bisphosphonates (C10, C11, C18) were less active than the pyridinium and phenylpyridinium species (C5, C7-9). Surprisingly, C12 showed high activity, due perhaps to the possibility of an additional target in *D. discoideum* or the possibility of structural differences between *L. major* and *D. discoideum* FPPS enzymes. With the exception of C12, the activity results for the 17 bisphosphonates are highly correlated (R^2 =0.65, p <0.0001), as shown in FIG. 8A.

Next, we investigated the ability of C5 and compounds C7-C18 to stimulate gammadelta T cells, using the TNF-α release assay (ref. 30). The most active compound was found to be C8 (EC_{50} =3.7 μM), followed by C7 and C17 (EC_{50} =4.6 μM), with these compounds having more activity than risedronate (C3, EC_{50} =6.2 μM) (ref. 30) or zoledronate (C4, EC_{50} =7.3 μM) (ref. 30) in this TNF-α release assay. Addition of the para hydroxyl group (8→9) again reduced activity (Table 1), and again all three methylene bridged compounds (C10, C11, C18) had poor activity. The activity results for FPPS inhibition were found to be highly correlated with gammadelta T cell TNF-α release results (R^2 =0.68, p <0.0001), as shown in FIG. 8B, suggesting the likely importance of FPPS inhibition in gammadelta T cell activation (refs. 29, 30).

We also explored the idea that electron withdrawing substituents on the ring could improve activity in bone resorption. To test this, compound 461 was prepared and tested, and indeed this species was found to be very potent in bone resorption. See Table 4.

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Without wishing to be bound by a particular theory, these results may confirm the importance of a positive charge at the N-1 position. This suggests that the further development of this class of compounds can continue to be of interest in the context of the chemotherapy of infectious diseases, bone resorption, cancer, bone pain, and in immunotherapy.

EXAMPLE 2

Structures of Bisphosphonate Compounds

Particular bisphosphonate compounds were synthesized. See Table 2 and the following figures: FIG. 3, FIG. 4, and FIG. 5. Note that in Table 2, the first column with the heading "Item" is not intended to refer to a compound designation, whereas the second column does refer to compound designations.

TABLE 2

Summary list of compounds with corresponding structures illustrated in FIGS. 3-5.	
Item	Compound Designation
1	278
2	297
3	300
4	335
5	344
6	359
7	364
8	398
9	443
10	444
11	445
12	446
13	447
14	449
15	450
16	451
17	452
18	455
19	456
20	457
21	459
22	460
23	461
24	462
25	470
26	471
27	472
28	473
29	474
30	475
31	476
32	477
33	478
34	479
35	480
36	481
37	483
38	484
39	485
40	ZZ1
41	502
42	511
43	513
44	520
45	521
46	523
47	524
48	525
49	526
50	529
51	530
52	531

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TABLE 2-continued

Summary list of compounds with corresponding structures illustrated in FIGS. 3-5.	
Item	Compound Designation
53	532
54	533
55	534
56	542
57	556
58	577
59	578
60	579
61	582
62	583
63	586
64	588
65	590
66	591
67	595
68	597
69	598
70	599
71	600
72	601
73	602
74	603
75	604
76	605
77	607
78	610
79	612
80	613

EXAMPLE 3

Activity of Bisphosphonate Compounds in T Cell Stimulation and Applications in Immunotherapy

Additional compounds were tested for the ability to stimulate gammadelta T cells. Results are shown in Table 3.

TABLE 3

gammadelta T cell stimulation results for selected bisphosphonate compounds.		
	Compound	EC ₅₀ (μM)
	2	4.7
	2	3.5
	278	4.8
	297	4.9
	300	2.1
	335	63.4
	398	40.6
	442	27.5
	443	186.6
	444	2.8
	445	2.5
	461	2.7
	470	3.3
	472	2.1
	473	20.1
	474	2.4
	475	2.8
	476	2.0
	477	1.8
	480	68.7
	481	83.4
	482	12.5
	483	2.9
	484	4.6

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EXAMPLE 4

Exploration of Activity of Bisphosphonate
Compounds and Strategic Design of Compounds

We explored the hypothesis of whether analogs of pyrophosphate could block pyrophosphatase enzymes and/or inhibit cellular growth or function. We used certain bisphosphonate compounds that are currently applied in bone resorption therapy. The compounds included pamidronate (Aredia®, Novartis), alendronate (Fosamax®, Merck), and risedronate (Actonel®, Procter & Gamble). The compounds did not appear necessarily to inhibit pyrophosphatases but did inhibit parasite cell growth. Without wishing to be bound by a particular theory, the compounds appeared to act as inhibitors of isoprenoid biosynthesis (FIG. 6).

The FPP synthase inhibitor pamidronate was observed to be effective in treating cutaneous leishmaniasis in mice. The average lesion size in treated mice was reduced during a time period of several weeks and in a dose-dependent manner relative to treated mice.

In an embodiment, a compound of the invention inhibits deoxyxylulose-5-phosphate reductoisomerase (DXR), an enzyme involved in isoprenoid biosynthesis. In a particular embodiment, a compound is able to affect *Plasmodium* in vitro or in vivo.

In an embodiment of the invention, a compound inhibits the mevalonate pathway. In an embodiment of the invention, a compound interacts with IPP isomerase (next to FPP synthase in the isoprene biosynthesis pathway) and activates gammadelta T cells.

EXAMPLE 5

Activity of Bisphosphonate Compounds in Bone
Resorption

Compounds are tested in a bone resorption assay: $^{45}\text{Ca}^{2+}$ release from 17-day old fetal mouse metatarsals (ref. 37). Results of IC_{50} values for test compounds are observed and optionally compared to those for reference compounds such as risedronate (C3), alendronate (C2), and pamidronate (C1) and/or other bisphosphonate compounds known in the art. In a preferred embodiment, bisphosphonates of the invention such as the pyridinium-1-yl bisphosphonates are comparable to or more active in the bone resorption assay or in treatment of a bone resorption clinical disorder than one or more other reference bisphosphonates.

EXAMPLE 6

Application of Bisphosphonate Compounds in the
Treatment of Cancer

Compounds are tested for efficacy in reducing the occurrence, severity, or course of bone metastases in stage II/III breast cancer patients. A compound of the invention is found effective and administered to a patient in need of treatment. Treatment with a compound of the invention is effective in reducing the risk of bone metastasis and/or increasing the likelihood of survival, optionally in relation to treatment with a placebo. A compound is effective in enhancing a survival outcome in patients with more advanced disease. A compound administered to a cancer patient can simultaneously

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provide a benefit in the treatment of osteolysis and/or hypercalcemia while assisting in the prevention of bone metastases and significantly increasing overall survival in breast cancer patients.

Compositions of the invention are applied in the treatment of skin metastases and mediastinal lymphomas. See Wilhelm et al., 2003.

Compositions of the invention are useful in the treatment of cancers such as lymphoma and myeloma and/or other forms of cancer. See Green J R, 2004, *The Oncologist* 9(supp 4):3-13; Forsea A-M et al., 2004, *British Journal of Cancer* 91:803-810.

Compositions of the invention are used in a combination therapy in the treatment of cancer. In a specific embodiment, a combination therapy utilizes a bisphosphonate compound of the invention and a different chemotherapeutic agent which can optionally be a distinct other bisphosphonate compound. See Caraglia M et al., 2004, *Oncogene* 23:6900-6913. See Salomo M et al., 2003, *British Journal of Haematology* 122:202-210.

EXAMPLE 7

Application of Bisphosphonate Compounds in the
Treatment of HIV Infection and AIDS

Many HIV drugs are suboptimally effective in partial relation to mutations of HIV-1 reverse transcriptase that confer resistance to a drug. For example, the effectiveness of azidothymidine (AZT; zidovudine, Retrovir), is believed to be so diminished. Bisphosphonate compounds of the invention are used in conjunction with AZT to provide an improved composition and therapy. Without wishing to be bound by a particular theory, a bisphosphonate compound inhibits AZT excision caused by ATP or PPi ; the inhibition results in increased AZT activity in enzyme and cellular assays. A reversion of resistance phenotype is achieved by rendering an HIV-1 strain more sensitive to AZT activity.

EXAMPLE 8

Additional Bisphosphonate Compounds

Further bisphosphonate compounds were synthesized. The structures are indicated in FIG. 9, FIG. 10, and FIG. 11. As noted in other Examples herein, the functional activity of certain of these compounds was assessed.

EXAMPLE 9

Bisphosphonate Compounds have Activity in Several
Contexts Relating to Bone Resorption and Immune
Regulation

We have obtained data for selected bisphosphonate compounds in the contexts of *D. discoideum* assays, human FPPS assays, gammadelta T cell stimulation assays, and bone resorption assays. Several compounds showed substantial activity in one or more functional assays. Some toxicity testing was also performed. See Table 4 (in some instances, the same data depicted elsewhere herein, e.g., in Table 1, may be presented again to facilitate comparative analysis).

TABLE 4

Compound	(1) <i>D. discoideum</i> IC ₅₀ (uM)	(2) human FPPS IC ₅₀ (uM)	(3) gammadelta T cell stimulation EC ₅₀	(4) Bone resorption IC ₅₀ (uM)	(5) Toxicity IC ₅₀ (ug/mL - human nasopharyngeal carcinoma cells)
278	2.6	1.6	5.1	0.67	300
297	2.8	NT	4.6	0.22	5.3
300	2.8	1.7	3.7	0.41	5.4
335	11	NT	430	NT	NT
344	8.5	17	140	NT	NT
359	2.9	NT	24	NT	NT
364	2.3	37	>1000	NT	NT
398	20	NT	41	NT	NT
443	12	NT	230	NT	NT
444	5.6	NT	5.1	NT	NT
445	3	NT	5.2	NT	NT
446	6	NT	4.6	0.37	NT
447	72	NT	53	NT	NT
449	4	NT	12	NT	NT
450	4.2	NT	6.8	NT	NT
451	31	280	inactive	NT	NT
452	73	NT	250	NT	NT
455	27	NT	25	NT	NT
456	27	NT	19	NT	NT
457	14	NT	1900	NT	NT
459	27	NT	14	NT	NT
460	14	NT	13	NT	NT
461	3.7	NT	2.7	0.075	NT
462	2.7	NT	15	NT	NT
470	3.5	NT	NT	NT	NT
471	inactive	NT	inactive	NT	NT
472	2.5	NT	NT	NT	NT
473	20	NT	NT	NT	NT
474	4.4	NT	NT	NT	NT
475	4.1	NT	NT	NT	NT
476	2.3	NT	NT	NT	NT
477	2.7	1.4	NT	NT	NT
478	760	NT	inactive	NT	NT
479	6	NT	15	NT	NT
480	3	NT	NT	NT	NT
481	3.5	NT	NT	NT	NT
483	2.5	NT	NT	NT	NT
484	3.5	2.5	NT	NT	NT
485	58	NT	370	NT	NT
502	100	NT	inactive	NT	NT
511	4.1	2.5	14	NT	NT
513	1500	NT	550	NT	NT
520	6.3	NT	14	NT	NT
521	570	NT	790	NT	NT
523	4.6	NT	11	NT	NT
524	2.4	NT	10	NT	NT
525	8.4	NT	11	NT	NT
526	2.1	1.2	8.6	NT	NT
529	3.3	NT	9.4	NT	NT
530	190	NT	6500	NT	NT
531	20	NT	inactive	NT	NT
532	4.1	NT	41	NT	NT
533	NT	NT	19	NT	NT
534	no tested	NT	16	NT	NT
542	1.7	1.2	12	NT	NT
556	inactive	NT	2300	NT	NT
577	4.1	NT	21	NT	NT
578	4	NT	20	NT	NT
579	6	NT	20	NT	NT
582	3.5	1.6	NT	NT	NT
583	14	NT	50	NT	NT
586	6	NT	90	NT	NT
588	3.3	11	120	NT	NT
590	9.1	23	300	NT	NT
591	38	29	NT	NT	NT
595	49	2.7	210	NT	NT
597	2.0	1.9	58	NT	NT
598	1.7	NT	35	NT	NT
599	1.7	NT	69	NT	NT
600	11	NT	290	NT	NT
601	2.4	NT	220	NT	NT
602	2.04	NT	18	NT	NT
603	NT	NT	22	NT	NT

TABLE 4-continued

Compound	(1) <i>D. discoideum</i> IC ₅₀ (uM)	(2) human FPPS IC ₅₀ (uM)	(3) gammadelta T cell stimulation EC ₅₀	(4) Bone resorption IC ₅₀ (uM)	(5) Toxicity IC ₅₀ (ug/mL - human nasopharyngeal carcinoma cells)
604	NT	NT	10	NT	NT
605	NT	NT	6	NT	NT
607	NT	NT	NT	NT	NT
610	NT	NT	NT	NT	NT
612	NT	NT	NT	NT	NT
613	NT	NT	NT	NT	NT
614	NT	NT	NT	NT	NT
615	NT	5.2	NT	NT	NT

NT, not tested.

EXAMPLE 10

Activity of Bisphosphonate Compounds against
Trypanosoma and *Leishmania* Parasites

We have obtained data for selected bisphosphonate compounds against parasites including *Trypanosoma brucei*, *Trypanosoma cruzi*, and *Leishmania major*. Several compounds showed substantial activity in one or more functional assays. See Table 5 (in some instances, the same data depicted elsewhere herein, e.g., in Table 1, may be presented again to facilitate comparative analysis).

TABLE 5

Com- pound	(6) <i>T. brucei</i> FPPS IC ₅₀ (uM)	(7) <i>L. major</i> FPPS Ki (nM)	(8) <i>T. cruzi</i> IC ₅₀ (ug/mL)	(9) <i>T. brucei</i> soluble vacuolar pyrophosphatase IC ₅₀ (uM)
278	0.83	18	3.07	NT
297	NT	38	NT	NT
300	0.58	9	NT	35
335	NT	160	NT	70
344	NT	70	NT	78
359	NT	75	NT	NT
364	NT	950	NT	NT
398	NT	80	NT	NT
443	NT	110	NT	NT
444	NT	20	NT	NT
445	NT	20	NT	NT
446	NT	30	NT	NT
447	NT	380	NT	NT
449	NT	NT	NT	NT
450	NT	NT	NT	NT
451	NT	NT	NT	NT
452	NT	NT	NT	NT
455	NT	NT	NT	NT
456	NT	NT	NT	NT
457	NT	NT	NT	NT
459	NT	NT	NT	NT
460	NT	NT	NT	NT
461	0.54	50	NT	NT
462	NT	NT	NT	NT
470	0.79	NT	NT	NT
471	NT	NT	NT	NT
472	NT	NT	NT	NT
473	NT	NT	NT	NT
474	NT	NT	NT	NT
475	NT	NT	NT	NT
476	NT	NT	NT	NT
477	0.89	NT	NT	NT
478	NT	NT	NT	NT
479	NT	NT	NT	NT
480	NT	NT	NT	NT
481	NT	NT	NT	NT
483	0.43	NT	NT	NT

TABLE 5-continued

Com- pound	(6) <i>T. brucei</i> FPPS IC ₅₀ (uM)	(7) <i>L. major</i> FPPS Ki (nM)	(8) <i>T. cruzi</i> IC ₅₀ (ug/mL)	(9) <i>T. brucei</i> soluble vacuolar pyrophosphatase IC ₅₀ (uM)
484	1.1	NT	NT	NT
485	NT	NT	NT	NT
502	NT	NT	NT	NT
511	0.76	NT	NT	NT
513	NT	NT	NT	NT
520	0.65	NT	NT	NT
521	NT	NT	NT	NT
523	NT	NT	NT	NT
524	0.26	NT	NT	NT
525	NT	NT	NT	NT
526	0.54	NT	NT	NT
529	NT	NT	NT	NT
530	NT	NT	NT	NT
531	NT	NT	NT	NT
532	NT	NT	NT	NT
533	NT	NT	NT	NT
534	NT	NT	NT	NT
542	0.39	NT	NT	NT
556	NT	NT	NT	NT
577	NT	NT	NT	NT
578	NT	NT	NT	NT
579	NT	NT	NT	NT
582	NT	NT	NT	NT
583	4.6	NT	NT	NT
586	NT	NT	NT	NT
588	NT	NT	NT	NT
590	NT	NT	NT	NT
591	NT	NT	NT	NT
595	NT	NT	NT	NT
597	NT	NT	NT	NT
598	0.59	NT	NT	NT
599	0.54	NT	NT	NT
600	NT	NT	NT	NT
601	2.1	NT	NT	NT
602	1	NT	NT	NT
603	0.71	NT	NT	NT
604	0.57	NT	NT	NT
605	0.29	NT	NT	NT
607	NT	NT	NT	NT
610	NT	NT	NT	NT
612	NT	NT	NT	NT
613	NT	NT	NT	NT
614	NT	NT	NT	NT
615	NT	NT	NT	NT

NT, not tested.

Statements Regarding Incorporation by Reference and Variations

All references throughout this application, for example patent documents including issued or granted patents or equivalents; patent application publications; and non-patent

literature documents or other source material; are hereby incorporated by reference herein in their entireties, as though individually incorporated by reference, to the extent each reference is at least partially not inconsistent with the disclosure in this application (for example, a reference that is partially inconsistent is incorporated by reference except for the partially inconsistent portion of the reference).

When a group of substituents is disclosed herein, it is understood that all individual members of those groups and all subgroups, including any isomers and enantiomers of the group members, and classes of compounds that can be formed using the substituents are disclosed separately. When a Markush group or other grouping is used herein, all individual members of the group and all combinations and sub-combinations possible of the group are intended to be individually included in the disclosure. When a compound is described herein such that a particular isomer or enantiomer of the compound is not specified, for example, in a formula or in a chemical name, that description is intended to include each isomer and enantiomer of the compound described individually or in any combination. When an atom is described herein, including in a composition, any isotope of such atom is intended to be included. Specific names of compounds are intended to be exemplary, as it is known that one of ordinary skill in the art can name the same compounds differently. Every formulation or combination of components described or exemplified herein can be used to practice the invention, unless otherwise stated. Whenever a range is given in the specification, for example, a temperature range, a time range, or a composition range, all intermediate ranges and sub-ranges, as well as all individual values included in the ranges given are intended to be included in the disclosure.

All patents and publications mentioned in the specification are indicative of the levels of skill of those skilled in the art to which the invention pertains. References cited herein are incorporated by reference herein in their entirety to indicate the state of the art, in some cases as of their filing date, and it is intended that this information can be employed herein, if needed, to exclude (for example, to disclaim) specific embodiments that are in the prior art. For example, when a compound is claimed, it should be understood that compounds known in the prior art, including certain compounds disclosed in the references disclosed herein (particularly in referenced patent documents), are not intended to be included in the claim.

Where the terms "comprise", "comprises", "comprised", or "comprising" are used herein, they are to be interpreted as specifying the presence of the stated features, integers, steps, or components referred to, but not to preclude the presence or addition of one or more other feature, integer, step, component, or group thereof.

The invention has been described with reference to various specific and preferred embodiments and techniques. However, it should be understood that many variations and modifications may be made while remaining within the spirit and scope of the invention. It will be apparent to one of ordinary skill in the art that methods, devices, device elements, materials, procedures and techniques other than those specifically described herein can be applied to the practice of the invention as broadly disclosed herein without resort to undue experimentation. All art-known functional equivalents of methods, devices, device elements, materials, procedures and techniques described herein are intended to be encompassed by this invention. Whenever a range is disclosed, all sub-ranges and individual values are intended to be encompassed. This invention is not to be limited by the embodiments disclosed, including any shown in the drawings or exemplified in

the specification, which are given by way of example or illustration and not of limitation.

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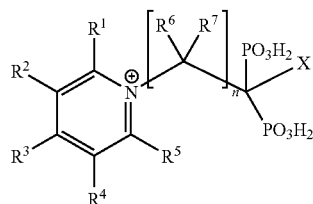
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The invention claimed is:

1. A compound of formula CA1:



or a pharmaceutically acceptable salt thereof; wherein:

X is H

n is 1, 2, or 3;

R¹ and R⁵ are both hydrogens and R², R³ and R⁴ are independently selected from the group consisting of hydro-

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gen, halogen, an optionally substituted alkyl group having 4-20 carbon atoms, an optionally substituted alkenyl group having 2-20 carbon atoms, an —OR group, an optionally substituted aryl group and an optionally substituted arylalkyl group, where R is selected from an optionally substituted alkyl group having 1-20 carbon atoms; and

R⁶ and R⁷, independently, are selected from the group consisting of a hydrogen, a halogen, a —N(R')₂, or —SR' group, an optionally substituted alkyl group, an optionally substituted alkenyl group, an optionally substituted alkoxy group, and an optionally substituted aryl group, where each R', independently, is selected from H, an optionally substituted alkyl group and an optionally substituted aryl group,

wherein at least one of R², R³ or R⁴ is selected from the group consisting of a halogen, an optionally substituted alkyl group having 4-20 carbon atoms, an optionally substituted alkenyl group having 2-20 carbon atoms, an —OR group;

and wherein R is selected from an optionally substituted alkyl group having 1-20 carbon atoms, an optionally substituted aryl group and an optionally substituted aryl alkyl group.

2. The compound of claim 1, wherein n is 1.

3. The compound of claim 2, wherein R⁶ and R⁷ are both hydrogens.

4. The compound of claim 1, wherein R¹ and R⁵ are both hydrogens.

5. The compound of claim 1, wherein the alkyl, alkenyl or aryl groups are optionally substituted with one or more halogens, —CN, —COOR", —OR", —COR", —OCOOR", —CON(R'')₂, —OCON(R'')₂, —N(R'')₂, —NO₂, —SR", —SO₂R", —SO₂N(R'')₂, —SOR", alkyl, alkenyl, or aryl groups, where each R", independently, is hydrogen, an alkyl group, alkenyl group or aryl group.

6. The compound of claim 1, wherein at least one of R², R³ or R⁴ is selected from the group consisting of an optionally substituted alkyl group having 4-20 carbon atoms, an optionally substituted alkenyl group having 2-20 carbon atoms, and an —OR group where R is selected from an optionally substituted alkyl group having 1-20 carbon atoms.

7. The compound of claim 6, wherein n is 1 and R⁶ and R⁷ are both hydrogens.

8. The compound of claim 1, wherein at least one of R², R³ or R⁴ is selected from the group consisting of an optionally substituted alkyl group having 4-20 carbon atoms, and an —OR group where R is selected from an optionally substituted alkyl group having 4-20 carbon atoms.

9. The compound of claim 1, wherein at least one of R², R³ or R⁴ is selected from the group consisting of an optionally substituted aryl group and an optionally substituted aryl alkyl group.

10. The compound of claim 9, wherein the aryl groups are optionally substituted with one or more halogens, alkyl groups, alkoxy groups or hydroxy groups.

11. The compound of claim 9, wherein at least one of R², R³ or R⁴ is selected from the group consisting of an optionally substituted phenyl group and an optionally substituted phenylmethyl group.

12. The compound of claim 11, wherein n is 1 and R⁶ and R⁷ are both hydrogen.

13. The compound of claim 1, wherein at least one of R², R³ or R⁴ is selected from the group consisting of an —OR group where R is selected from an optionally substituted alkyl group having 4-20 carbon atoms.

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14. The compound of claim 13, wherein n is 1 and R⁶ and R⁷ are both hydrogen.

15. The compound of claim 1, wherein at least one of R², R³ or R⁴ is selected from the group consisting of an —OR group where R is selected from an alkyl group having 4-20 carbon atoms.

16. The compound of claim 15, wherein n is 1 and R⁶ and R⁷ are both hydrogen.

17. The compound of claim 1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens, and R² is selected from the group consisting of optionally substituted alkyl groups having 4-20 carbon atoms, optionally substituted alkoxy groups having 4-20 carbon atoms and optionally substituted phenyl groups.

18. The compound of claim 17, wherein optional substitution is substitution by one or more halogens, alkyl groups, alkoxy groups or hydroxy groups.

19. The compound of claim 1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens and R² is an optionally substituted alkyl group having 4-20 carbon atoms.

20. The compound of claim 1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens and R² is an alkyl group having 4-20 carbon atoms.

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21. The compound of claim 1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens and R² is an alkyl group having 4-10 carbon atoms.

22. The compound of claim 1, wherein n is 1, all of R¹, R³-R⁷ are hydrogens and R² is an alkyl group having 10-20 carbon atoms.

23. A therapeutic composition comprising a compound of claim 1 and a pharmaceutically acceptable carrier.

24. A pharmaceutical composition comprising a compound of claim 19 and a pharmaceutically acceptable carrier.

25. A method of treating a bone resorption disorder comprising administering to a patient in need thereof, a therapeutically effective amount of a compound of claim 1.

26. A method of treating an infectious disease comprising administering to a patient in need thereof, a therapeutically effective amount of a compound of claim 1 wherein the infection is due to *Trypanosoma* or *Leishmania* parasites.

27. A method for stimulating $\gamma\delta$ T cells which comprises the step of contacting an effective amount of a compound of claim 1 with $\gamma\delta$ T cells.

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