The present invention relates to a pharmaceutical composition comprising one or more of the following ruthenium oxalato compounds I, II, III and IV as an active ingredient. The pharmaceutical composition can be used for the treatment of viral-infected patients or prophylactic treatment of patients at risk from viral infection.
Fig. 3

Intensity (cps)

two theta (deg)

calculated

experimental
Fig. 6
Fig. 7

% inhibition of HIV-1 replication in HeLa cells (vs vehicle control)

<table>
<thead>
<tr>
<th>Compound</th>
<th>3 days</th>
<th>7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZT (0.5 μM)</td>
<td>97%</td>
<td>99%</td>
</tr>
<tr>
<td>RuCl₃ (50 μM)</td>
<td>65%</td>
<td>99%</td>
</tr>
<tr>
<td>2 (0.5 μM)</td>
<td>98%</td>
<td>42%</td>
</tr>
<tr>
<td>2 (50 μM)</td>
<td>99%</td>
<td>41%</td>
</tr>
<tr>
<td>AZT (0.5 μM)</td>
<td>97%</td>
<td>99%</td>
</tr>
<tr>
<td>RuCl₃ (50 μM)</td>
<td>65%</td>
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</tr>
<tr>
<td>2 (0.5 μM)</td>
<td>98%</td>
<td>42%</td>
</tr>
<tr>
<td>2 (50 μM)</td>
<td>99%</td>
<td>41%</td>
</tr>
</tbody>
</table>
Fig. 8

(a) GHOST/CXCR4 cells

- AZT (0.5 μM) 96%
- 2 (0.5 μM) 23%
- 2 (5 μM) 98%
- 2 (50 μM) 98%

(b) PBMC

- AZT (0.5 μM) 95%
- 2 (0.5 μM) 43%
- 2 (5 μM) 80%
- 2 (50 μM) 90%

% inhibition of HIV-1 replication in cells (vs vehicle control)
Fig. 9

HIV-1 RT activity (%) vs Concentration (M)

IC<sub>50</sub> = 1.98 x 10<sup>-9</sup> M
Fig. 10

- **Vehicle control**: 47%
- **2 (0.5 μM)**: 34%
- **2 (5 μM)**: 15%
Fig. 11

(a) Hut/CCR5  (b) GHOST/CXCR4  (c) PBMC

% cell viability (7 days)

A2T (0.5 μM)  2 (0.5 μM)  2 (5 μM)  A2T (0.5 μM)  2 (0.5 μM)  2 (5 μM)  A2T (0.5 μM)  2 (0.5 μM)  2 (5 μM)

90%  96%  96%  90%  91%  98%  92%  91%  95%  97%  98%
PHARMACEUTICAL COMPOSITION HAVING A RUTHENIUM OXALATO COMPOUND AND METHOD OF USING THE SAME

FIELD OF THE INVENTION

[0001] The present invention relates generally to a pharmaceutical composition having ruthenium oxalate compound. In addition, the present invention relates to the use of ruthenium oxalate compounds as potent anti-viral agents.

BACKGROUND OF THE INVENTION

[0002] Acquired Immunodeficiency Syndrome (AIDS) was first reported in the United States in 1981 and the AIDS epidemic shows great diversity in severity and timing worldwide. Human immunodeficiency virus type 1 (HIV-1), the causative agent of AIDS, is a retrovirus composed of RNA genetic material, which inhibits the human immune system from fighting off infection. Currently known anti-HIV agents fall into four major categories: (1) nucleoside reverse transcriptase inhibitors; (2) non-nucleoside reverse transcriptase inhibitors; (3) protease inhibitors; and (4) ribonucleotide reductase inhibitors (De Clercq et al. Rev. Med. Virol. (2000), 10, 255). The first clinically used drug for the treatment of HIV is azidothymidine (AZT) (Ezzell et al. Nature. (1987), 329, 751). AZT exerts its function by incorporating into the DNA chain, and results in interrupting chain elongation and impeding further replication of the genome (http://www.aidso.org/). Although AZT and itscocktail regimens have shown promising effects on suppression of HIV-1 replication, drug-resistant HIV-1 as well as anti-retroviral toxicity are still causes of growing clinical and public concern (Deeks S. G. Lancet (2003), 362, 2002).


SUMMARY OF THE INVENTION

[0004] The present invention relates to structural characterization of a mixed-valence polyoxomeric ruthenium oxalate cluster that exhibited potent anti-HIV-1 activities by inhibiting HIV-1 (Bal) replication in HUT/CCR5 cells, HIV-1 (IIIB) replication in GHOST/CXCR4 and normal human peripheral blood mononuclear cells (PBMC), and HIV-1 RT activity in vitro studies. This ruthenium oxalate cluster showed low cytotoxicity toward the host cells as revealed by MTT assay. By means of TUNEL assay, this ruthenium oxalate compound was also found to exhibit cytotoxic activity toward HIV-1 (IIIB) infected HUT/CCR5 cells.

[0005] The present invention provides a novel ruthenium oxalate compound (2) capable of inhibiting HIV-1 (Bal) replication in HUT/CCR5 cells, HIV-1 (IIIB) replication on GHOST/ CXCR4 and PBMC and HIV-1 RT inhibitory activity in vitro studies. This novel metal-based compound exhibited low cytotoxicity to the host cells (as observed by MTT assay) and showed cytotoxic activity toward HIV-1 infected HUT/CCR5 cells (as observed by TUNEL assay). The present invention provides an application of ruthenium oxalate compounds, a unique class of ruthenium-based compound, as anti-HIV agents as evidenced by the potent inhibitory activity on HIV-infected HUT/CCR5, GHOST/ CXCR4, and PBMC cells, and HIV-1 RT by administering to a patient in need thereof a composition comprising an effective amount of ruthenium oxalate compound.

BRIEF DESCRIPTION OF THE FIGURES

[0006] FIG. 1 illustrates a perspective view of Na₃[Ru(ox)₂](1). Thermal ellipsoids are drawn at the 50% probability level.

[0007] FIG. 2 illustrates a perspective view of Na₃[Ru(μ₂-O)(C₂O₄)₂] (2) of this invention. Sodium countercations and water have been omitted for clarity. Thermal ellipsoids are drawn at the 30% probability level.

[0008] FIG. 3 illustrates the simulated and experimental powder X-ray diffraction patterns for Na₃[Ru(μ₂-O)(C₂O₄)₂].

[0009] FIG. 4 illustrates the Q-TOF ESI-MS spectrum of Na₃[Ru(μ₂-O)(C₂O₄)₂] (2) with addition of TFA and negative ion mode.

[0010] FIG. 5 illustrates the temperature-dependent magnetic susceptibility of Na₃[Ru(μ₂-O)(C₂O₄)₂] (2). Temperature dependent χ₋₋ plot of χ₋ vs T and (b) plot of 1/χ vs T.

[0011] FIG. 6 illustrates the UV-Vis spectra of Na₃[Ru(μ₂-O)(C₂O₄)₂] in aqueous solution.

[0012] FIG. 7 illustrates the percentage inhibition of HIV-1 (Bal) replication by Na₃[Ru(μ₂-O)(C₂O₄)₂] (2) in HUT/CCR5 cells in (a) 3-day and (b) 7-day incubation period.

[0013] FIG. 8 illustrates the percentage inhibition of HIV-1 (IIIB) replication by Na₃[Ru(μ₂-O)(C₂O₄)₂] (2) in (a) GHOST cells and (b) PBMC in a 7-day incubation period.

[0014] FIG. 9 illustrates the inhibition of HIV-1 RT activity by Na₃[Ru(μ₂-O)(C₂O₄)₂] (2).

[0015] FIG. 10 illustrates the TUNEL assay showing that Na₃[Ru(μ₂-O)(C₂O₄)₂] (2) exhibits cytotoxic activity toward HIV-1 infected HUT/CCR5 cells in a 7-day incubation period.

[0016] FIG. 11 illustrates the percentage cell viability of (a) HUT/CCR5 cells, (b) GHOST/CXCR4 cells and (c) PBMC in the presence of Na₃[Ru(μ₂-O)(C₂O₄)₂] (2).

DETAILED DESCRIPTION OF THE INVENTION

[0017] The present invention relates to a ruthenium oxalate compound, which can be used as anti-viral agents.
For example, one or more ruthenium oxalato compounds can be provided which can have potent inhibitory effect on HIV-1(Bal) replication in Hut/CCR5 cells, HIV-1 (IIIb) replication on GHOST/CXCR4 and PBMC cells, and HIV-1 RT inhibitory activity in in vitro studies. The ruthenium oxalato compound can have a low cytotoxicity toward the host cells as revealed by MTT assay. By means of TUNEL assay. The ruthenium oxalato compound can also exhibit cytoprotective activity toward HIV-1(IIIb) infected Hut/CCR5 cells.

[0018] The present invention also relates to a method of using one or more of the ruthenium oxalato compounds as antiviral agents. In one embodiment, a method is provided for inhibition of HIV activity by administering, such as to a patient or cell-based assay, a composition comprising an effective amount of a ruthenium oxalato compound. The cell referred to can be that of a kind of animal of the kingdom Animalia. Non-limiting examples of the cell include Hut/CCR5, GHOST/CXCR4 and PBMC.

[0019] The amount of the ruthenium oxalato compound in the composition can vary. In one exemplary embodiment, the effective amount of the ruthenium oxalato compound can be from 100 ng/kg to 100 mg/kg, such as when the composition is used on a patient. For example, the ruthenium oxalato compound can be 190 ng/kg, 50 μg/kg, 500 μg/kg, or 5 mg/kg, such as depending on a patient’s condition. In another exemplary embodiment, the effective amount of the ruthenium oxalato compound can be from 1 nM to 1 mM, such as when the composition is used on a cell-based assay. For example, the ruthenium oxalato compound can be 1.9 nM, 500 nM, 5 μM, and 50 μM.

[0020] The ruthenium oxalato compound of the present invention can be represented by structural formula I, II, III, or IV, or a pharmaceutically acceptable salt thereof:

![Structural formula I](image)

[0021] The ruthenium oxalato compound of the present invention affords various antiviral effects. In one exemplary embodiment, the ruthenium oxalato compound I, II, III, or IV, or a pharmaceutically acceptable salt thereof can inhibit HIV-1(Bal) replication in Hut/CCR5 cells in in vitro studies. In another exemplary embodiment, the ruthenium oxalato compound I, II, III, or IV, or a pharmaceutically acceptable salt thereof can inhibit HIV-1(IIIb) replication in GHOST/CXCR4 cells in in vitro studies. In another exemplary embodiment, the ruthenium oxalato compound I, II, III, or IV, or a pharmaceutically acceptable salt thereof can inhibit HIV-1(IIIb) replication in PBMC cells in in vitro studies. In another exemplary embodiment, the ruthenium oxalato compound I, II, III, or IV, or a pharmaceutically acceptable salt thereof can inhibit HIV-1 RT activity in in vitro studies. In another exemplary embodiment, the ruthenium oxalato compound I, II, III, or IV can exhibit low cytotoxicity and have cytoprotective activity toward HIV-1 infected Hut/CCR5 cells.

[0022] Pharmaceutical composition and the use of a ruthenium oxalato compound for combating virus are provided herein. The pharmaceutical composition contains a ruthenium oxalato compound in an amount effective to inhibit the activity of reverse transcriptase and the anti-proliferation of virus.

[0023] It will be understood that the ruthenium oxalato compound will not form a charge neutral complex. For instance, the net positive charge on the cationic metal can be less than the absolute net negative charge of the coordinated
oxalato ligand. In view of this, there will be at least one cation or counter-ion coordinated to the metal compound for charge neutralization. As used herein, the phrase “pharmaceutically acceptable salt” described herein includes salts formed from charged metal complex and the cation or counter-ion.

[0024] As used herein, the term “cation” or “counter-ion” described herein refers to the positively charged group coordinated to the negatively charged oxalate ligand of the ruthenium oxalato compound. Non-limiting examples of cations include Li, Na and K.

[0025] As used herein, the ruthenium oxalato compound can exist as a single molecule or aggregated molecules.

[0026] As used herein, the phrase of “pharmaceutically acceptable carrier” means approved by a regulatory agency of the Federal or a state government or listed in the U.S. Pharmacopoeia or other generally recognized pharmacopeia for use in animals, mammals, and more particularly in humans. Non-limiting examples of pharmaceutically acceptable carriers include liquids, such as water and oils, including those of petroleum, animal, vegetable, or synthetic origin. Water is a preferred vehicle when the compound of the present invention is administered intravenously. Saline solutions and aqueous dextrose and glycerol solutions can also be employed as liquid vehicles, particularly for injectable solutions.

[0027] As used herein, the term “patient” refers to any member of the kingdom Animalia. Non-limiting examples of animals include a cow, monkey, horse, sheep, pig, cat, dog, mouse, rat, rabbit, and guinea pig and most preferably human.

[0028] As noted above, the present invention relates to compositions useful for the inhibition of viral activity in virus-infected cells. Non-limiting examples of virus include human hepatitis A virus (HAV), human hepatitis B virus (HBV), human hepatitis C virus (HCV), severe acute respiratory syndrome associated coronavirus (SARS-CoV), herpes simplex virus, human papillomavirus, human herpesvirus, influenza virus, simian immunodeficiency virus (SIV), and most preferably human immunodeficiency virus (HIV).

[0029] As used herein, the term “PBMC” described herein refers to normal human peripheral blood mononuclear cells.

[0030] As used herein, the term “HIV-1 RT” described herein refers to HIV-1 reverse transcriptase.

[0031] As used herein, the term “TUNEL” described herein refers to Terminal Uridyl-Nucleotide End Labeling.

[0032] As used herein, the term “GSH” described herein refers to reduced glutathione.

[0033] As used herein, the term “MTT assay” described herein refers to (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide) assay.

[0034] As used herein, the term “AZT” described herein refers to azidothymidine.

II. Synthesis of Ruthenium Oxalato Compound

[0035] In general, the ruthenium oxalato compounds of this invention were discovered as a new class of substance that can be made according to a modification of a procedure for preparing Na₃[Ru(ox₃)₃] (1) (Che et al., Inorg. Chem. (1985), 24, 1359). K₂[RuCl₆(OH₂)₂] and oxalic acid were stirred in an aqueous medium for 2 weeks at room temperature. During the course of the reaction, a gradual color change from dark black to deep brown was observed. After 2 weeks, the pH of the reaction mixture was changed to alkaline (ca. pH=10) by adding NaHCO₃.

[0036] In this invention, the compositions described herein are ruthenium oxalato clusters having the following structure IV:

![Diagram of Ruthenium Oxalato Cluster IV]

[0037] An exemplary synthetic ruthenium oxalato cluster of formula IV is given below:

![Diagram of Exemplary Synthetic Ruthenium Oxalato Cluster]

[0038] Ruthenium oxalato cluster Na₃[Ru₂(μ₁-O₂C₂O₄)₃] (2) was obtained as a dark green solid and as the sodium salt in 10% yield. A small amount of Na₃[Ru(ox₃)] (1) afforded as a light brown solid was also obtained. Due to differences in solubility of 1 and 2 in water, the latter cluster preferentially precipitated out by slow diffusion of acetone into a solution of water containing 2. Repeated recrystallization removed undesired 1.

III. Anti-HIV Activity of Ruthenium Oxalato Cluster

[0039] The ruthenium oxalato cluster Na₃[Ru₂(μ₁-O₂C₂O₄)₃] (2) described in this invention exhibited potent
inhibitory effect on HIV-1(BalL) replication in HUT/CCR5 cells, HIV-1(IIIB) replication in GHOST/CXCR4 and PBMC cells, and HIV-1 RT inhibitory activity in in vitro studies. This class of ruthenium-based clusters also exhibited low cytotoxicity and showed cytoprotective activity toward HIV-1 infected HUT/CCR5 cells as observed by TUNEL assay. The present invention describes the first application of a polyatomic ruthenium oxalato cluster, a class of metal-based clusters, as antiviral agents, demonstrating potent anti-HIV inhibitory activity.

[0040] Non-limiting examples of cells for antiviral studies include but not limited to HUT/CCR5, GHOST/CXCR4 and PBMC cells.

[0041] The invention relates to ruthenium oxalato cluster Na2[Ru2(μ3-O)2(C2O4)2]2 (2) demonstrating inhibition of HIV-1(BalL) replication in HUT/CCR5 cells, HIV-1(IIIB) replication in GHOST/CXCR4 and PBMC cells, and HIV-1 RT inhibitory activity in in vitro studies. This class of metal-based clusters also exhibited low cytotoxicity and showed cytoprotective activity toward HIV-1 infected HUT/CCR5 cells as observed by TUNEL assay.

IV. EXAMPLES

[0042] The following examples are set forth to assist in understanding the invention and should not be construed as specifically limiting the invention described and claimed herein. Such variations of the invention, including substitution of all equivalents now known or later developed, which will be within the purview of those skilled in the art, and changes in formulations or minor changes in experimental design, fall within the scope of present invention.

[0043] Instrumentation. All absorption spectra and MTT assays were recorded on a Perkin-Elmer Lambda 900 and Perkin-Elmer Fusion α-FP spectrophotometer. Positive ion FAB and EI mass spectra were recorded on a Finnigan MAT95 mass spectrometer. Electrospray ionization mass spectrometry (ESI-MS) was performed on a Micromass Q-TOF spectrometer. 1H NMR spectra were recorded on Brucker DPX-300 or DPX-400 NMR spectrometers. Magnetic measurements were performed on a Quantum Design SQUID magnetometer. TUNEL flow cytometric analysis was performed with a Coulter EPICS flow cytometer (Coulter, Miami, Fla.) equipped with 480 long, 525 band and 625 long pass mirrors. Samples were excited by 15 mW air-cool argon convergent laser at 488 nm. Fluorescence signal was manipulated with Coulter Elite 4.0 software (Coulter) and were analyzed by Winlist 1.04 and Modfit 5011 software (verity Software House, Topsham, Me.).

[0044] Materials. All chemicals were of analytical grade and purchased from Sigma-Aldrich Chemical Co. unless otherwise noted. Analytical grade organic solvents and Milli-Q water were used throughout the experiments. Ruthenium trichloride was purchased from Strem. Preparation of K2[RuCl4(OH)2] was achieved by a methodology along the lines of that described in Mercer and Buckley Inorg. Chem. (1965), 4, 1692.

[0045] HIV-1(BalL) and HIV-1 (IIIB) stocks (300 ng/mL of p24 protein), HUT/CCR5 and GHOST/CXCR4 cells were gifts from Dr. D. Tao (Institute of Molecular Medicine, University of Oxford, UK). Peripheral blood mononuclear cells (PBMC) were prepared from buffy coat obtained from the Hong Kong Red Cross Blood Transfusion Service.

[0046] Each unit of the buffy coat prepared from whole blood (450 mL) contained approximately 5×10⁷ cells. To isolate the PBMC, the buffy coat (15 mL) was transferred to a centrifuge tube (50 mL) under sterile conditions and diluted with RPMI culture medium in a 1:1 (v/v) ratio. Ficoll® solution (15 mL) was slowly added to the diluted blood and the mixture was centrifuged at 800 rpm for 25 min. at room temperature. The PBMC at the interface were washed five times with cold RPMI culture medium. The washed PBMC were spun first at 500 rpm for 7 min., followed at 250 rpm for 7 min. and finally at 200 rpm to obtain a cell pellet. The PBMC were re-suspended in ammonium chloride lysis buffer (ACK buffer) and incubated at room temperature for 5 min. to lyse the remaining red blood cells. HUT/CCR5 cells, GHOST/CXCR4 cells and PBMC were maintained in RPMI 1640 medium (Life Technologies, Inc.) supplemented with fetal bovine serum (10%, v/v) and L-glutamine (2 mM). Penicillin (100 U/mL) and streptomycin (100 μg/mL) were added to all media, except for PBMC. The whole cell cultures were incubated at 37°C in a 5% CO2/95% air humidified atmosphere and sub-cultured twice weekly (except for PBMC).

[0047] The identity of complexes 1 and 2 were characterized by microanalysis (elemental analyses), X-ray crystallography, FAB-MS, UV-visible spectroscopy (see FIGS. 1-6).

Example 1

Procedure for Preparation of Ruthenium Oxalato Cluster Na2[Ru2(μ3-O)2(C2O4)2]2 (2)

[0048] Example 1 describes the preparation and characterization of illustrative ruthenium oxalato cluster Na2[Ru2(μ3-O)2(C2O4)2]2 (2).

[0049] K2[RuCl4(OH)2] (1 g, 2.7 mmol) and oxalic acid (1.15 g, 12.8 mmol) were stirred in deionized water (10 mL). Slow warming was required to completely dissolve oxalic acid in the aqueous solution. The reaction mixture was stirred at room temperature for 2 weeks, in which a color change from dark black to deep brown was observed. On completion, the reaction mixture was heated to reflux for 2 h and NaHCO3 was added in small aliquots. Addition of NaHCO3 (ca. 2-3 g) was stopped when no more bubbles were observed. The mixture was continuously refluxed for 3 h and cooled to room temperature. Dark green crystals of 2 were obtained by slow diffusion of acetone to the aqueous reaction mixture. Under light microscope, a small amount of a light brown crystalline solid in addition to dark green crystals of 2, which was characterized as Na3[Ru2(μ3-O)2] (1) by X-ray crystallography was obtained. Contaminant 1 was removed by repeated recrystallization.

[0050] Na2[Ru2(μ3-O)2(C2O4)2]2 (2); Yield: 10%, UV-vis (H2O): λmax (nm): 328 (37600), 400 (1300). ESI-MS -ve (O-TOF): m/z 1003.42 [Ru2O6(C2O4)2(H2)2]2+. 1025.43 [Ru2O6(C2O4)2(H2)2Na]2+; 1047.40 [Ru2O6(C2O4)2(H2)2Na2]2+; 1069.42 [Ru2O6(C2O4)2(H2)22Na]2+; 1091.40 [Ru2O6(C2O4)2(H2)22Na2]2+; 1113.41 [Ru2O6(C2O4)2(H2)22Na3]2+; 1135.40 [Ru2O6(C2O4)2(H2)22Na4]2+.

[0051] X-ray Crystallography. Crystals of 1 and 2 were obtained from diffusion of acetone to the aqueous reaction
mixture containing 1 and 2 at room temperature (see FIGS. 1-2). A brown crystal of dimensions 0.4 x 0.25 x 0.2 mm of 1 and a deep green crystal of dimensions 0.25 x 0.2 x 0.1 mm of 2 were mounted in a glass capillary used for data collection at -20°C on a MAR diffractometer with a 300 mm image plate detector using graphite monochromatized Mo-Kα radiation (λ=0.71073 Å).

[0052] Data collection was made with 2° oscillation step of 0.480 seconds exposure time and scanner distance at 120 mm, 100 images were collected. The images were interpreted and intensities integrated using program DENZO (Otwinowski and Minor, In Processing of X-ray Diffract Data Collected in Oscillation Mode, Methods in Enzymology, C. W. Carter, Sweet Jr. & R. M., Eds., Academic Press: (1997); Vol. 276, pp. 307). The structure was solved by direct methods employing SHELXS-97 program (Sheldrick, SHELXS97. Programs for Crystal Structure Analysis (Release 97-2), University of Goettingen, Germany, (1997)) on a PC. Step-scanned X-ray powder diffraction data of 2 was collected on a Phillips PW3710 powder diffractometer by using graphite-monochromatized CuKα (λ=1.5406 Å, Ni-filter) radiation, operated at 40 kV and 30 mA (see FIG. 3).

[0053] An example of the use of the system is described in Example 2. The sample was unpacked and reloaded onto the sample holder for replication data collections to minimize the systematic errors from particle statistics and preferred orientation of the samples. All samples were free of known oxides and metal impurities checked by ICCD database match search. Data collection parameters of 2-50° (2θ), step size=0.02°, and scan speed=0.0094° s⁻¹ were used to optimize the count statistics and peak shape profiles.

Example 2

Magnetic Measurements of Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2)

[0054] Example 2 describes magnetic properties and mixed-valence oxidation state of Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2).

[0055] The magnetic properties and temperature magnetic susceptibility of 2 were performed on Quantum Design SQUID Magnetometer. The Quantum Design magnetometer (MPMS-5s) is equipped with a superconducting magnet (5 Tesla), AC susceptibility measurement and Reciprocal Sample Option (RSO). The temperature range is 1.8K<T<400K, with a furnace of 300K<T<800K. Magnetic measurements' Magnetization as a function of temperature and magnetic field. The sample crystals were grinded to powder and located in a holder for measurement.

[0056] Na₂[Ru₂(μ₂-O)(C₅O₄)₆] (2) of this invention shows no ferromagnetic or antiferromagnetic behavior. Using the Curie Law, the Curie constant for 2 is 0.347 cm³ K mol⁻¹ and magnetic moment of 1.67 μₜ. This corresponds to 1 unpaired electron (calculated S=3/2, μₑₐ=1.75 μₜ), and suggests that the four ruthenium atoms do not have the same oxidation state. In conjunction with X-ray analysis, the mixed-valence oxidation state of (III, III, III, IV) for 2 is deduced (see FIG. 5). Mixed valency in 2 is also supported by a broad absorption band observed in the UV-vis spectrum of 2 at around 800 nm (e=1300 dm³ mol⁻¹ cm⁻¹) in H₂O that is attributed to the intercalation band (see FIG. 6). Such intercalation band has also been observed in other ruthenium systems with oxo bridges or carboxylate ligands. (Shepherd Inorg. Chem. (1994), 33, 5262).

Example 3

Stability Studies of Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2)

[0057] Example 3 describes the results of stability studies for Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2).

[0058] The UV-vis absorption spectra of 2 were monitored over 7 days in aqueous solution. Its stability in physiological relevant medium (in the presence of 2 mM GSH aqueous solution) was also monitored by UV-vis spectroscopy.

[0059] No observable changes in the spectra were observed for 2 when upon standing in H₂O and 2 mM GSH aqueous solution for 7 days. This shows that 2 is stable in both H₂O and physiological medium and that the cluster framework is intact in solution. This provides the opportunity to understand its mode of action in biological systems.

Example 4

Inhibition of HIV-1(BaL) Replication in HutCCR5 Cells

[0060] Example 4 describes the procedure employed to examine the inhibitory effects of Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2) on HIV-1(BaL) replication in HutCCR5 cells and the results of these studies.

[0061] Stock solutions (10 mM) of Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2) were prepared in sterile water and diluted to desired concentration in growth medium. HutCCR5 cells in 24-well plate (5x10⁵ cells/well) were pretreated with compounds (400 μL) for an hour at 37°C. C and subsequently infected in triplicate with a panel of CCR5-tropic HIV-1 isolates (with the addition of 5 μL of HIV-1 stock to each well, total p24 content=1500 pg) for 3 h. Following infection, the cells were washed to remove residual viral inoculum and cultured in the presence of compounds (400 μL) for 3 or 7 days. Culture supernatants were harvested and viral replication was measured by determination of viral p24 antigen concentration by ELISA (HIV-1 p24 antigen Kit, Beckman Coulter). Compounds were tested in triplicate at 3 concentrations ranging from 0.5-50 μM. AZT and RuCl₃ were also examined as reference standards.

[0062] Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2) of this invention inhibited HIV-1(BaL) replication in HutCCR5 cells (see FIG. 7).

Example 5

Inhibition of HIV-1 (IIIₙ) Replication in GHOST/CXCR4 and PBMC Cells

[0063] Example 5 describes the procedures employed to examine the inhibitory effects of Na₂[Ru₂(μ₁-O)(C₅O₄)₆] (2) on HIV-1(IIIₙ) replication in GHOST/CXCR4 and PBMC cells and the results of these studies.

[0064] Stock solutions (10 mM) of 2 were prepared in sterile water and diluted to desired concentration in growth medium. GHOST/CXCR4 and PBMC cells in 24-well plate (5x10⁵ cells/well) were pretreated with compounds (400 μL) for an hour at 37°C. C and subsequently infected in triplicate...
with a panel of CCR5-tropic HIV-1 isolates (with the addition of 5 μL of HIV-1 stock to each well, total p24 content=1500 pg) for 3 h. Following infection, the cells were washed to remove residual viral inoculums and cultured in the presence of compounds (400 μL) for 3 or 7 days. Culture supernatants were harvested and viral replication was measured by determination of viral p24 antigen concentration by ELISA (HIV-1 p24 antigen Kit, Beckman Coulter). Compounds were tested in triplicate at 3 concentrations ranging from 0.5-50 μM. AZT was also examined as a reference standard.

Inhibition of HIV-1 RT Activity

Example 6

Example 6 describes the procedures employed to examine the inhibitory effect of Na4[Ru(μ3-O)-]2(C2O4)2]2- (2) on HIV-1 RT activity and the results of these studies.

Example 7

The inhibitory effect of different compounds on HIV-1 RT activities were assayed using a commercial assay kit (Reverse Transcriptase Assay, Chemiluminescent, Roche). Complex 2 and AZT-TP were first dissolved in PBS (1.3 μL) and mixed with a set of HIV-1 RT in lysis buffer (2 ng, 128.7 μL) at 37°C (30 min.). The ELISA assays were conducted by following the manufacturer’s instructions (Eberle and Stiehl J. Virol. Methods (1992), 40, 347). In general, the indicated compounds were added to the corresponding well of the microtiter plate from the kit and incubated for 1 h at 37°C. The solution in each well was then completely removed and the wells were rinsed five times with 250 μL of washing buffer per well. During each washing step, the washing buffer was left in the wells for a minimum of 30 seconds. The microtiter plate was covered and dried with a blotting paper, followed by the incubation with anti-DIG-POD working dilution was added (200 μL per well) for 1 h at 37°C. The solution was discarded followed by the washing and drying steps as described above. The POD substrate was added (200 μL per well) and was incubated at room temperature for 15 min. The chemiluminescence signal was measured and quantified using a microtiter plate chemiluminescence reader. The HIV-1 RT activities were evaluated based on percentage luminescence of the solutions relative to the negative control (untreated population).

Example 8

Percentage Cell Viability of HIV-infected Hut/CRC5, GHOST/CXCR4 and PBMC Cells in the Presence of Na4[Ru(μ3-O)-]2(C2O4)2]2- (2)

Example 8 describes the procedures employed to examine the percentage cell viability of HIV-infected Hut/CRC5, GHOST/CXCR4 and PBMC cells in the presence of Na4[Ru(μ3-O)-]2(C2O4)2]2- (2) and the results of these studies.

Assays on the cell viability of Hut/CRC5, GHOST/CXCR4 and PBMC were conducted in 96-well flat-bottom microtiter plates. The supplemented culture medium (90 μL), with fetal bovine serum (10%, v/v), L-glutamine (2 mM), penicillin (100 U/mL) and streptomycin (100 μg/mL) with cells (1×10^6 cells per mL) was added into a 96-well plate. Complex 2 with concentrations ranging from 0.5-100 μM dissolved in culture medium (10 μL) were subsequently added into each of the 96 wells. Control wells contained only supplemented media (100 μL). Microtiter plates were incubated at 37°C, a 5% CO2/95% air humidified atmosphere for 7 days. All the assays were run in parallel with a negative control (i.e., vehicle control) and a positive control with cisplatin as a cytotoxic agent.

Assessment of the cell viability was carried out using a modified method of Mosman based MTT assay. 10 μL of MTT solution (5 mg MTT/mL in 1×PBS) was added to each well and incubated for 4 h. This was followed by adding 100 μL solubilization buffer (10% SDS in 0.01 M HCl) to each well to lyse the cells and solubilize the blue formazan complex formed. After overnight incubation, the formation of formazan was measured by a microtiter plate reader (Perkin-Elmer FusionTM Alpha-FP) using an absorbance 590 nm filter. IC50 of the complex was calculated as cell survival in a range of complex concentration relative to the untreated control.

The TUNEL reaction preferentially labels DNA strand breaks generated during apoptosis. This is done by labeling DNA strand breaks by terminal desoxynucleotidyl transferase (TdT), which catalyzes polymerization of labeled nucleotides to free 3′-OH DNA ends in a template-independent manner (TUNEL reaction). The TUNEL method (In Situ Cell Death Detection Kit, Fluorescein, Roche) combined with flow cytometry was used for the measurement of apoptosis (Goreczyca et al. Cancer Res. (1993), 53, 1945). The quantitative analysis of 3′-OH ends was performed using the MDADS analysis program (Beckman Coulter).

0071 HIV-1 infected Hut/CRC5 cells were treated with 2 (0.5, 5, and 50 μM) for 3 days. The cells were fixed (in 4% paraformaldehyde in PBS, pH 7.4) and permeabilised (0.1% Triton X-100 in 0.1% sodium citrate). The cells were then rinsed twice with PBS and labeled with 50 μL TUNEL reaction mixture (50 μL Enzyme solution +450 μL Label solution) for 60 min at 37°C in a humidified atmosphere in dark. The samples were rinsed with PBS three times and resuspended in 1 mL PBS containing 5 μg/mL of PI and 0.1% RNase. Flow cytometry was performed on a FACScan cytometer. The red (PI) and green (fluorescein) fluorescence emissions from each cell were measured.

0072 Na4[Ru(μ3-O)-]2(C2O4)2]2- (2) this invention showed c[text missing or illegible when filed]ective activity in HIV-1 Infected Hut/CRC5 cells (see FIG. 10).

Example 9

Cytotoxicity Activity of Na4[Ru(μ3-O)-]2(C2O4)2]2- (2) in HIV-1 Infected Hut/CRC5 Cells

Example 9 describes the procedures employed to examine the cytotoxic effects of Na4[Ru(μ3-O)-]2(C2O4)2]2- (2) on HIV-1 infected Hut/CRC5 cells and the results of these studies.

The TUNEL reaction preferentially labels DNA strand breaks generated during apoptosis. This is done by labeling DNA strand breaks by terminal desoxynucleotidyl transferase (TdT), which catalyzes polymerization of labeled nucleotides to free 3′-OH DNA ends in a template-independent manner (TUNEL reaction). The TUNEL method (In Situ Cell Death Detection Kit, Fluorescein, Roche) combined with flow cytometry was used for the measurement of apoptosis (Goreczyca et al. Cancer Res. (1993), 53, 1945). The quantitative analysis of 3′-OH ends was performed using the MDADS analysis program (Beckman Coulter).

0076 Na4[Ru(μ3-O)-]2(C2O4)2]2- (2) of this invention showed an increase in cell viability/membrane rigidity of the HIV-1 infected Hut/CRC5, GHOST/CXCR4 and PBMC cells (see FIG. 11).
What is claimed is:

1. A pharmaceutical composition comprising an effective amount of ruthenium oxalato compound for the treatment or prophylaxis of a virus-associated infection, the ruthenium oxalato compound being of formula I, II or III:

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[Diagram of formula I, II, and III]
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or a pharmaceutically acceptable salt thereof, wherein:

- $R_1, R_2, R_3, R_4$, and $R_5$ are each independently oxalate, oxalic acid, hydroxyl, or repeating unit(s) of formula I or II bridged by oxygen atom(s);
- each $X^p$ is independently a pharmaceutically acceptable counter-ion;
- $m$ is an integer ranging from 7 to 0;
- $P$ is an integer ranging from 0 to 3;
- $n$ is equal to the absolute value of $m/P$; and

2. The pharmaceutical composition according to claim 1, wherein one or more than one types of the pharmaceutically acceptable counter-ions are presented in the formula I, II or III.

3. A method for the treatment or prophylaxis of a virus-associated infection comprising administering to a patient in need thereof, or cell-based assay a composition comprising an effective amount of ruthenium oxalato compound of claim 1.

4. The method according to claim 3, wherein the virus is human immunodeficiency virus (HIV).

5. The method according to claim 3, wherein the virus is human hepatitis B virus (HBV).

6. The method according to claim 3, wherein the virus is human hepatitis A virus (HAV), human hepatitis C virus (HCV), severe acute respiratory syndrome associated coronavirus (SARS-CoV), herpes simplex virus, human papillomavirus, human herpesvirus, influenza virus, or simian immunodeficiency virus (SIV).

7. The method according to claim 3, wherein the ruthenium oxalato compound shows anti-viral activity in the virus-infected cells comprising administering to a patient in need thereof, or cell-based assay a composition containing an effective amount of one or more than one types of the said ruthenium oxalato compounds.

8. The method according to claim 3, wherein the patient is any member of the kingdom Animalia.

9. The method according to claim 3, wherein the ruthenium oxalato compound shows anti-viral activity in the virus-infected cells comprising administering an effective amount of one or more than one types of the said ruthenium oxalato compounds to cell-based assays.

10. The method according to claim 3, wherein the cell is referred to that of a kind of animal of the kingdom Animalia.

11. The method according to claim 3, wherein the said ruthenium oxalato compound inhibits HIV-1 reverse transcriptase activity.

12. A pharmaceutical composition comprising an effective amount of ruthenium oxalato cluster for the treatment or prophylaxis of a virus-associated infection, the ruthenium oxalato cluster being of formula IV:

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[Diagram of formula IV]
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or a pharmaceutically acceptable salt thereof, wherein:

- each $X^p$ is independently a pharmaceutically acceptable counter-ion;
- $m$ is an integer ranging from 7 to 0;
- $P$ is an integer ranging from 0 to 3;
- $n$ is equal to the absolute value of $m/P$; and

13. The pharmaceutical composition according to claim 12, wherein one or more types of the pharmaceutically acceptable counter-ions are presented in the formula IV.

14. A method for the treatment or prophylaxis of a virus-associated infection comprising administering to a
24. The method according to claim 14, wherein the said ruthenium oxalato cluster shows potent inhibitory effect on HIV-1(IIIb) replication on PBMCI cells.

25. The method according to claim 14, wherein the said ruthenium oxalato cluster shows cytoprotective activity toward HIV-1 infected HUT/CCR5 cells.

26. The method according to claim 14, wherein the said ruthenium oxalato cluster shows inhibition of HIV-1 reverse transcriptase activity.

27. The method according to claim 14, wherein m is 7-, n is 7, X is Na, and P is 1+ (2):

![Diagram of ruthenium oxalato cluster]

28. The method according to claim 14, wherein the cell is referred to that of a kind of animal of the kingdom Animalia.

29. The method according to claim 14, wherein the said ruthenium oxalato cluster shows potent inhibitory effect on HIV-1(IIIb) replication on GHOST/CXCR4 cells.