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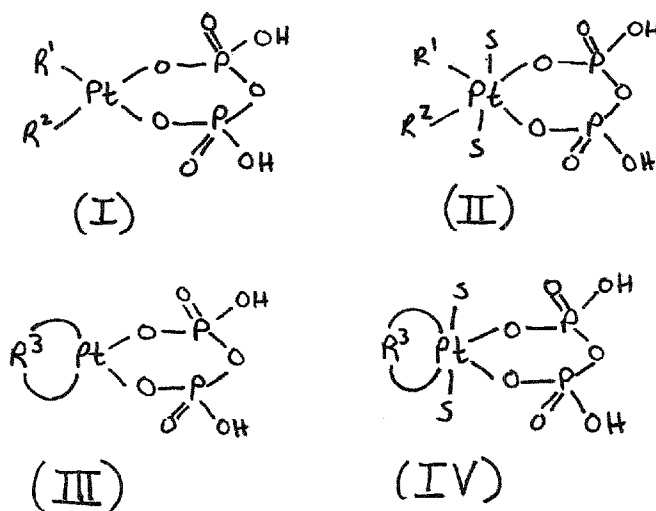


Figure 1

(57) Abstract: The present invention provides phosphaplatins, stable isolated monomeric phosphato complexes of platinum (II) and (IV) and methods of use thereof for treating cancers, including cisplatin - and carboplatin-resistant cancers. Unlike cisplatin, these complexes do not readily undergo hydrolysis and are quite soluble and stable in aqueous solutions. Moreover, these complexes - unlike cisplatin, carboplatin, and related platinum-based anti-cancer agents - do not bind DNA. Rather, data suggests that phosphaplatins trigger overexpression of fas and fas-related transcription factors and some proapoptotic genes such as Bak and Bax. Nevertheless, the complexes exhibit tremendous cytotoxicity towards cancer cells. Thus, the present invention provides novel platinum anticancer agents that have a different molecular target than those in the art.

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PHOSPHAPLATINS AND THEIR USE IN THE TREATMENT OF CANCERS
RESISTANT TO CISPLATIN AND CARBOPLATIN

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. Section 119(e) of United States Provisional Patent Application No. 60/954,126, filed August 6, 2007, and United States Provisional Patent Application No. 60/973,926, filed September 20, 2007, both of which are hereby incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] Platinum diamine complexes are well known in the art because of the tremendous success of cisdiamminedichloroplatinum(II) (cisplatin) for the treatment of ovarian, testicular, head and neck, and other forms of cancer. In addition, cisplatin is used in conjunction with other therapeutic regimens including radiation therapy. This platinum chemotherapeutic mediates apoptosis at the G2 phase of the cell cycle predominantly through transcription inhibition and through replication inhibition processes, especially at high doses. Covalent bonding to DNA through the N7 sites of guanine and adenine bases, both by intra- and inter-strand modes, is generally believed to be the key molecular event in transducing a cascade of cellular responses leading to apoptosis.

[0003] Although cisplatin is highly effective, it exhibits renal, nephro-, and neuro-toxicities. Moreover, many patients develop resistance to cisplatin treatment over time and are therefore not cured by cisplatin treatment. Two other FDA-approved platinum drugs, carboplatin (diammine-1,1-dicarcboxylatocyclobutane-platinum(II)) and oxaliplatin (diammine-oxalatoplatinum(II)), are also believed to function in a similar manner to that of cisplatin. Carboplatin is especially effective towards cisplatin-resistant tumor cells, but relatively high doses are required to effectively treat patients who are resistant to cisplatin. Such high doses also have associated toxicities.

[0004] Many new platinum amine complexes have been synthesized and tested for their anticancer activities. However, only a few of these complexes (some of which are listed in Figure 14) have exhibited promising results. These new complexes contain a variety of replaceable nonamine ligands, as well as nonreplaceable amine ligands that are believed to be important for DNA binding and cellular uptake. Generally, these and other relevant platinum ammine complexes known in the art are synthesized by the process used for preparing cisplatin, namely where tetrachloroplatinate (PtCl_4^{2-}) receives amine ligands to become $\text{PtCl}_2(\text{amine/diamine})$. Starting with the tetrachloro complex generally provides other products, and so PtI_4^{2-} can also be used to ensure high yield and purity of the cis isomer, followed by conversion of PtI_4^{2-} to $\text{PtI}_2(\text{amine/diamine})$ and then into $\text{PtCl}_2(\text{amine/diamine})$. In converting $\text{PtI}_2(\text{amine/diamine})$ to $\text{PtCl}_2(\text{amine/diamine})$, the di-iodo complex is converted to diaqua complex by treating the former with two equivalents of silver nitrate or other soluble silver salts at low pH. The resulting diaqua complex readily reacts with potassium chloride or hydrochloric acid to yield the dichloro complex of interest. In general, the platinum complexes of interest are synthesized from the corresponding diaqua complex at a low pH to introduce the replaceable ligands since dimerization or polymerization of the diaqua complex takes place rapidly at higher pH, yielding undesirable products.

[0005] Instead of replaceable chlorine ligands, platinum amine complexes in the art also have nitrogen, sulfur, carboxylate, and phosphonate as replaceable ligands. However, one characteristic of those complexes showing the most promise for treating cancer is a replaceable hard base ligand coordinated to platinum (a soft acid). Examples of such hard-soft combinations that have displayed excellent anticancer properties are carboxylato, carbonato, phosphonato platinum complexes.

[0006] Despite tremendous efforts to replace cisplatin with more effective chemotherapeutics, platinum (II) and platinum(IV) complexes with phosphates as the replaceable ligands have remained largely unexplored. This is primarily due to the fact that early work on platinum(II) phosphato complexes usually resulted in phosphate-bridged dinuclear complexes. Despite reports of excellent anticancer properties of some dinuclear phosphatoplatinum(II) complexes, further exploration of their applications were limited because of the poor solubility of these complexes in

aqueous solutions. Although certain monomeric pyro- and triphosphate complexes are known in the art, such complexes are not suitable for pharmaceutical compositions because they undergo phosphate hydrolysis in moderately acidic solutions, resulting in insoluble dinuclear products (See US 7,342,122 to Odani et al., describing a dimer of the monomeric complex am-2, which is described herein and in Bose et al., *Inorg. Chem.* 1985, 24, 3989-3996; see also, WO 2005/000858 to Odani et al., describing monomeric am-2 as a potential anticancer drug).

[0007] Therefore, there remains a need in the art for stable and effective alternatives to cisplatin and carboplatin for the treatment of cancers.

SUMMARY OF THE INVENTION

[0008] The present invention provides phosphaplatins, stable monomeric phosphato complexes of platinum (II) and (IV) having the general formulas shown in Figure 1, wherein wherein R^1 , R^2 , and R^3 each is independently selected from substituted or unsubstituted aliphatic or aromatic amines, and wherein when one of R^1 and R^2 is NH_3 , the other of R^1 and R^2 is not NH_3 ; and wherein S is nothing or is independently selected from hydroxide, acetic acid, butyric acid, and alpha-hydroxy acids. Also provided are methods of making and isolating phosphaplatins.

[0009] The present invention further provides methods for treating cancers, including cisplatin- and/or carboplatin-resistant cancers, by administering an effective amount of phosphaplatins, either alone or in combination, with a pharmaceutically acceptable carrier, to a subject in need of such treatment.

BRIEF DESCRIPTION ON THE DRAWINGS

[0010] FIGURE 1 displays structures of the platinum (II) and platinum (IV) complexes of the present invention. R_1 , R_2 , and R_3 each is independently selected from substituted or unsubstituted aliphatic or aromatic amines, wherein when one of R_1 and R_2 is NH_3 , the other of R_1 and R_2 is not NH_3 . In certain embodiments, R_1 and R_2 are selected from amine, methyl amine, ethyl amine, propyl amine, isopropyl amine, butyl amine, cyclohexane amine, aniline, pyridine, and substituted pyridine. In certain embodiments, R_3 is selected from ethylenediamine and cyclohexanediamine. S is independently selected from hydroxide, acetic acid,

butyric acid, and alpha-hydroxy acids. In certain embodiments, pharmaceutically acceptable salts of the compounds are claimed.

[0011] FIGURE 2 displays structures of some isolated complexes of the present invention, namely (A) diammine(dihydrogen pyrophosphato)platinum(II), also known as am-2; (B) *cis*-diammine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV), also known as am-4; (C) 1,2-ethanediamine(dihydrogen pyrophosphato)platinum(II), also known as en-2; (D) 1,2-ethanediamine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV), also known as en-4; (E) (*trans*-1,2-cyclohexanediamine)(dihydrogen pyrophosphato)platinum(II), also known as dach-2; and (F) (*trans*-1,2-cyclohexanediamine)-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum (IV), also known as dach-4.

[0012] FIGURE 3 displays the X-ray crystal structure of am-4 with sodium counter ion.

[0013] FIGURE 4 displays the X-ray crystal structure of en-4 in its different conformations, as viewed from the pyrophosphate side.

[0014] FIGURE 5 displays the extent of protonation of the complexes shown in Figure 2, as measured by ^{31}P chemical shift as a function of pH. The estimated acidity constants are listed in Table 1. These data provide insight into the solubility differences of these complexes between acidic solution and neutral solution. Under the disclosed conditions at pH values below 2, these complexes are completely protonated and hence expected to exhibit reduced solubility.

[0015] FIGURE 6 exhibits the differential stability of dach-2 at (A) pH 4.2 and (B) pH 8. At pH 8, no decomposition of dach-2 was observed as evidenced by the retention of the coordinated pyrophosphate ion to platinum(II) up to six days. In contrast, at pH 4.2, considerable decomposition is evident due to the appearance of the free pyrophosphate signal. Starting with the bottom spectrum in each panel, spectra were recorded at 24 hour time intervals.

[0016] FIGURE 7 is a plot of the comparison of cytotoxic effects of dach-2, cisplatin, and carboplatin as a function of micromolar concentration in cisplatin and carboplatin

resistant human ovarian cell lines (A2780/C30). This cell line is resistant to 30 micromolar cisplatin and 100 micromolar carboplatin.

[0017] FIGURE 8 is a plot comparing the cytotoxic effects of dach-2 with FDA approved cisplatin and carboplatin anticancer drugs towards human ovarian cell line (A2780).

[0018] FIGURE 9 represents cytotoxicity of dach-2 towards (A) cisplatin-sensitive and (B) cisplatin-resistant head and neck cancer cell lines. IC50 values for dach-2 for cisplatin-sensitive cells is below 1 micromolar and for cisplatin-resistant cells, it is below 5 micromolar.

[0019] FIGURE 10 shows that at a given concentration, dach-2 is taken up by cells (as determined by atomic absorption spectroscopy) in reduced quantities compared to cisplatin. For example, at 10 μ M concentration, cisplatin accumulation in A2780 cells was 3.0 ng Pt/ 10^6 cells while dach-2 showed 1.0 ng Pt/ 10^6 cells. A similar trend for platinum accumulations holds for other concentrations.

[0020] FIGURE 11 shows the extent of DNA binding by cisplatin as a function of concentration in human ovarian cell line (A2780) measured by atomic absorption spectroscopy after incubating cisplatin for 2 hours. No DNA-bound platinum was detected by the same technique when A2780 cells were treated with dach-2 up to 50 micromolar concentration, even when the cells were treated for 24 hours.

[0021] FIGURE 12 is a comparison of guanine base binding (the predominant DNA binding site of cisplatin) among cisplatin (bottom), am-2 (middle), and dach-2 (top) by proton NMR spectroscopy. The top spectrum exhibits a signal for the free guanine base at 8.05 ppm for the H8 hydrogen of the purine ring, the bottom spectrum reveals an additional signal at 8.43 ppm for H8 proton due to guanine binding to cisplatin through the N7 site of the purine ring, and the middle spectrum only indicates the unbound guanine H8 signal but not platinum bound signal. The bottom spectrum was recorded after 48 hours. The middle and top spectra were recorded after 96 and 106 hours, respectively. That the complexes of the present invention do not covalently bind guanine bases (the DNA binding site for cisplatin, carboplatin, and oxaliplatin) suggests apoptotic mechanisms that are different from those proposed for cisplatin.

[0022] FIGURE 13 shows ^1H NMR spectroscopy data confirming the lack of DNA binding in human ovarian cells by dach-2. In the associated experiment, dach-2 was allowed to react with double-stranded calf-thymus DNA, a synthetic oligonucleotide (5'-ATGATTTAGGTGACACTATAGCAGT-3'), a dinucleotide (dGpG), and nucleotide monophosphates (5'-dGMP and 5'-dAMP) at concentrations as much as 250-times higher than those of cellular doses. The extent of DNA binding was monitored by ^1H NMR spectroscopy. In parallel, similar reactions with cisplatin were conducted under identical conditions. Results from a typical NMR experiment using a 25-mer oligonucleotide are displayed in the figure, which shows that dach-2 does not exhibit any measurable DNA binding, while cisplatin readily forms covalent adducts with DNA as evidenced by the formation of new signals in the region 8.4 to 8.95 ppm. However, cisplatin readily formed adducts with all the nucleotides stated above while no detectable NMR signals for dach-2 binding to nucleotides were observed even after seven days.

[0023] FIGURE 14 displays structures of some of the active platinum complexes known in the art that are being used as drugs, are being evaluated as potential drugs, or that underwent clinical trials.

[0024] FIGURE 15 displays structures of complexes used to form the phosphaplatin complexes of FIGURE 1; X is halogen, R1, R2 and R3 each is independently selected from substituted or unsubstituted aliphatic or aromatic amines.

DETAILED DESCRIPTION

[0025] Provided herein are stable, monomeric platinum (II) and (IV) pyrophosphate complexes (termed phosphaplatins) for cancer treatment, including treatment of cisplatin- and/or carboplatin-resistant cancers. In general, phosphaplatins do not readily undergo hydrolysis, are soluble in aqueous solution at neutral pH, and are stable in aqueous solution at neutral pH. Furthermore, phosphaplatins show general cytotoxicity in cancer cell lines, and are effective in cell lines that are resistant to one or both cisplatin and carboplatin. Accordingly, the phosphaplatins are effective, and in some cases more effective, in inducing cancer cell death as compared to known platinum cancer drugs, and exhibit desirable stability and solubility in solutions that are suitable for administration to patients. As used herein in reference to the

phosphaplatins of the invention, stable refers to the resistance of the complexes to hydrolysis when maintained in aqueous solution at a pH in the range from 6-8 for a period of time from between 2 and six days.

[0026] It is believed that phosphaplatins, unlike cisplatin, carboplatin, and related platinum-based anti-cancer agents, do not covalently bind DNA. Since cisplatin resistance is believed to originate from the efficient repair of DNA damage by a variety of enzymes including nuclear excision repair enzymes, and since phosphaplatins do not covalently bind DNA, resistance towards phosphaplatins due to the DNA repair mechanism is unlikely. Data suggests that phosphaplatins trigger overexpression of fas and fas-related transcription factors and some proapoptotic genes such as Bak and Bax. In addition, the cellular binding of phosphaplatins is much less than cisplatin, yet the phosphaplatins exhibit tremendous cytotoxicity. Thus, the present invention provides effective platinum anticancer agents that have a different molecular target than those in the art.

[0027] In some embodiments, the complexes have the general formulas shown in Figure 1 wherein R1, R2, and R3 each is independently selected from substituted or unsubstituted aliphatic or aromatic amines, wherein when one of R1 and R2 is NH₃, the other of R1 and R2 is not NH₃. In certain embodiments, R1 and R2 are selected from amine, methyl amine, ethyl amine, propyl amine, isopropyl amine, butyl amine, cyclohexane amine, aniline, pyridine, and substituted pyridine. In certain embodiments, R3 is selected from ethylenediamine and cyclohexanediamine. S is independently selected from hydroxide, acetic acid, butyric acid, and alpha-hydroxy acids. In certain embodiments, pharmaceutically acceptable salts of the compounds are claimed. Thus, the anticancer agents of the present invention include, in certain embodiments, the complexes in Figure 2.

[0028] Also provided herein are methods of synthesizing and isolating stable monomeric platinum (II) and (IV) pyrophosphate complexes. In one example, the method includes forming complexes having the formula of Figure 1 (I) and (III) by maintaining an aqueous reaction mixture comprising excess pyrophosphate and a platinum complex of the formulas shown in Figure 15 wherein R¹, R², and R³ each is independently selected from substituted or unsubstituted aliphatic or aromatic amines, and wherein when one of R¹ and R² is NH₃, the other of R¹ and R² is not

NH₃; and wherein X is independently selected from halogens; at a temperature of about 30 to about 60 degrees Celsius for a period of about 12 to about 18 hours at a pH from about 7 to about 9.

[0029] The complexes shown in Figure 15 may be made in any suitable manner. In some examples as generally described in the art, *cis*-(amine/diamine)dichloroplatinum(II) complexes can be prepared by converting K₂PtCl₄ to K₂PtI₄ by the addition of potassium iodide. This is then reacted with the desired amine ligands. The resulting *cis*-(amine/diamine)diiodoplatinum(II) complexes are then transformed to the corresponding *cis*-(amine/diamine)diaquaplatinum(II) complexes in situ by adding two equivalents of silver nitrate. The *cis*-diaqua species [Pt(amine/diamine)₂(H₂O)₂²⁺] are then converted to the *cis*-dichloro complexes by addition of potassium chloride.

[0030] It will be understood that other suitable reaction conditions may be used. For example, in some embodiments the temperature may be from about 35 to about 45 degrees C. Thus, the reaction temperature can be from about 30-31, 31-32, 32-33, 33-34, 34-35, 35-36, 36-37, 37-38, 38-39, 39-40, 40-41, 41-42, 42-43, 43-44, 44-45, 45-46, 46-47, 47-48, 48-49, 49-50, 50-51, 51-52, 52-53, 53-54, 54-55, 55-56, 56-57, 57-58, 58-59, 59-60 degrees C, and increments therebetween. Good results have been obtained at 40 degrees C. In some examples, the reaction is allowed to proceed from about 13 to about 16 hours. Thus the reaction time can be from about 12-13, 13-14, 14-15, 15-16, 16-17, and 17-18 hours and increments therebetween. Good results have been obtained at reaction times of 15 hours. In some examples, the pH can be from about 6-7, 7-8, and 8-9 and increments therebetween. Good results have been obtained at pH of about 8.

[0031] The method further includes subsequently concentrating the aqueous reaction mixture such that precipitates of pyrophosphate do not form. It will be understood that the aqueous reaction mixture may be concentrated in any suitable manner. For example, the aqueous reaction mixture may be concentrated by rotary evaporation.

[0032] The method further includes rapidly lowering the pH of the reaction mixture to a pH of less than about 2 by addition of a suitable acid. In some examples, nitric

acid may be used to lower the pH. In some embodiments, the pH is in the range between about 1 to about 2. Good results have been obtained at pH 1

[0033] In some examples, the method also includes the reaction mixture to a temperature of between 5 degrees Celsius and ambient temperature after concentrating the reaction mixture. In other examples, the method also includes cooling the reaction mixture to a temperature of between 5 degrees Celsius and ambient temperature after lowering the pH of the reaction mixture.

[0034] In other embodiments, methods of forming complexes according to Figure 1 (II) and (IV) are provided. The methods are as described above, but further comprise adding to the reaction mixture hydrogen peroxide, and optionally a reagent selected from the group acetate salts, butyrate salts, and salts of alpha-hydroxy acids after maintaining the reaction mixture at a temperature of about 30 to about 60 degrees Celsius for a period of about 12 to about 18 hours at a pH from about 7 to about 9.

[0035] In some examples, the optional reagent added together with hydrogen peroxide prior to concentration of the reaction mixture is selected from sodium acetate, sodium butyrate, and sodium salts of alpha-hydroxy acids.. In other examples, the optional reagent added together with hydrogen peroxide prior to concentration of the reaction mixture is selected from potassium acetate, potassium butyrate, and potassium salts of alpha-hydroxy acids.

[0036] The method of synthesis and isolation of monomeric complexes described herein can be distinguished over the art since the novel method does not produce dimeric or oligomeric phosphate compounds. For example, the method reported by Bose et al. in *Inorg. Chem.* 1985, 24, 3989-3996 ("Bose 1985"), which involves isolation of $\text{Pt}(\text{NH}_3)_2(\text{H}_2\text{P}_2\text{O}_7)$ (am-2) from the reaction mixture by absorbing the anionic pyrophosphato complex on an anion-exchange resin at neutral pH and eluting it with a lower pH eluant, was not useful for the synthesis and isolation of am-4, en-2, en-4, dach-2, and dach-4. When the Bose 1985 method was used, these complexes decomposed on the ion-exchange beds when separation was attempted by elution with a lower pH electrolyte. Initially, the complexes turned brownish black, followed by the formation of an insoluble black precipitate inside the ion-exchange

resins. Separation of am-4, en-2, en-4, dach-2, and dach-4 from their respective reaction mixtures was possible only when the Bose 1985 method was modified as described herein. Each reaction mixture was concentrated by vacuum evaporation to the extent that unreacted pyrophosphoric acid would not precipitate out when the pH was lowered in a following step (the solubility of the pyrophosphate ligand varies greatly with pH). To initiate selective precipitation, the final concentrations were between 0.05M to 0.08M since further reduction in volume resulted in coprecipitation of the unreacted pyrophosphate that must be present in excess during the reaction. After concentrating, the reaction mixtures were cooled and the pH was rapidly lowered to 1.0 in order to induce precipitation by taking advantage of the differences in solubility between the protonated and deprotonated forms of the complexes.

[0037] At neutral pH, the isolated monomeric Pt(II) and Pt(IV) complexes of the present invention are stable. As indicated by ^{31}P NMR spectra, in the range of pH 6-8 the complexes did not suffer any deligation due to the loss of either an amine or a pyrophosphate ligand over the time interval of six days at neutral pH in aqueous solution. However, in the same time interval, slow deligation due to the release of the pyrophosphate ligand was evident at pH 4.2 by the appearance of the free pyrophosphate signal at -10.3 ppm. At the same time, an insoluble pyrophosphato-bridged dinuclear platinum(II) product was formed. The data also indicates that acid decomposition is largely dependant on acidity—the higher the acidity, the faster the decomposition (See Figure 5, Table 1, and Table 2).

Table 1. Chemical shifts (d, ppm) for deprotonated platinum(II) and platinum(IV) pyrophosphato-complexes and Pt-P coupling constants

Complex	$\delta\text{-}^{31}\text{P}$, ppm	$\delta\text{-}^{195}\text{Pt}$, ppm	$J_{\text{P-Pt}}$, Hz
am-2	2.12	-1503	23.44
dach-2	1.78	-1729	25.03
en-2	1.93	N/A	29.73
am-4	2.32	1733	15.38
dach-4	2.41	1613	25.91
en-4	2.35	1582	25.91

Table 2. Calculated pKa (-log of acidity constants) values for Pt(II)- and Pt(IV)-pyrophosphato complexes determined from phosphorus-31 chemical shifts

Complex	pKa ₁	pKa ₂
am-2	2.9±0.3 (3.8±0.1)	4.7±0.2
en-2	2.2±0.1	4.4±0.1
dach-2	2.6±0.2 (3.3±0.1)	4.4±0.2
am-4	2.0±0.1	4.7±0.1
en-4	<2	4.3±0.1

[0038] The complexes of the present invention are useful for treating various cancers. Cytotoxic assays in human ovarian cell lines (A2780) and Chinese Ovarian Cells (CHO) demonstrate that these complexes are effective as a first round of treatment, and assays with both cisplatin- and carboplatin resistant Ovarian cells (C30) (See Table 3) show that these complexes are a suitable second round of treatment for resistant cancers. The complexes of the present invention are particularly desirable because they may have reduced toxicity *in vivo*. These complexes are taken up by cells in reduced quantities, as compared with cisplatin, indicating that lower dosage may be needed as compared to dosages for cisplatin and other platinum cancer therapeutics. For example, at 10 μM concentration, cisplatin accumulation in A2780 cells was 3.0 ng Pt/ 10^6 cells while dach-2 showed 1.0 ng Pt/ 10^6 cells, and in the resistant cell lines, dach-2 showed 1.4 ng Pt/ 10^6 cells at its IC₅₀ value while cisplatin showed > 5 ng Pt/ 10^6 cells, yet the IC₅₀ value for the former complex is less than half of the latter complex (See Figure 10 and Table 4).

Table 3. IC₅₀ Values in μM concentrations for Phosphaplatins, cisplatin, and carboplatin in A270 and A2780/C30, CHO cell lines

Complex	A780	A2780/C30	CHO
Cisplatin	7.5 ±1.5	110±11.29	29±3
Carboplatin	90±13	>200	>200
dach-2	20±4	48±5	35±5
dach-4	180±15	155±17	116±17
am-2	100±11	>200	120±30
am-4	175±22	>200	>200
en-4	170±33	>200	>200

Table 4. Comparative Cellular Accumulations (ng/ 10^6 cells) of Platinum for cisplatin and pyrodach-2 in A2780 and A2780/C30 Cell Lines

Concentration (μM)	A2780		A2780/C30	
	Cisplatin	dach-2	Cisplatin	dach-2
10	3.00 ± 0.05	1.00 ± 0.20	1.00 ± 0.10	0.10 ± 0.08
20	5.00 ± 0.06	1.50 ± 0.30	2.00 ± 0.40	1.00 ± 0.02
30	6.00 ± 0.10	3.00 ± 1.00	2.00 ± 0.50	1.00 ± 0.02
50	20.00 ± 1.00	5.00 ± 0.30	5.00 ± 1.00	2.00 ± 0.10

[0039] The data suggests that the complexes of the present invention may induce apoptosis by different molecular and cellular mechanisms than cisplatin and other platinum drugs. First, the absence of covalent linkage (See Figure 12 and Example 13) indicates that the complexes of the invention do not function through the DNA binding pathway. It is generally believed by those skilled in the art that acquired cisplatin resistance is due to the efficient removal of platinum from DNA by the nucleotide excision repair process. Because of the apparent absence of DNA binding, and hence the possibility that DNA repair mechanisms do not operate on the complexes of the invention, cellular resistance to the complexes may be eliminated. This conclusion finds support from the cytotoxicity data showing that dach-2 is active in both cisplatin and carboplatin resistant cell lines (See Table 3).

[0040] Second, evidence that the complexes of the present invention induce apoptosis by different molecular and cellular mechanisms than cisplatin and other platinum drugs comes from experiments where dach-2 was allowed to react with cysteine and glutathione (data not shown). The pyrophosphate ligand of dach-2 was readily replaced with concomitant ligation through the thiol, indicating possible protein anchoring sites of the cellular surface proteins through cysteine or methionine residues.

[0041] Third, evidence that the complexes of the present invention induce apoptosis by different molecular and cellular mechanisms than cisplatin and other platinum drugs also comes from experiments involving the over-expression of fas and its associated members (See Example 11). Such over-expression in response to the complexes of the invention implies that signal transduction pathways other than DNA-damaging pathways are most likely involved in exhibiting the cytotoxic activities of the complexes of the invention. On average, fas was over-expressed by a factor

of six when cells were treated with complexes of the present invention, while no significant over-expression was observed in cells treated with cisplatin.

[0042] As described herein, the complexes of the present invention are as effective or more effective than commonly used cisplatin and carboplatin, thus providing a method of cancer treatment for patients who previously lacked effective alternatives to cisplatin and carboplatin treatment. However, a patient need not have previously been treated with cisplatin or carboplatin in order to be treated with the complexes and methods described herein. Administration of the treatment can be performed in a hospital or other medical facility by medical personnel.

[0043] The complexes of the present invention are administered and dosed in accordance with good medical practice, taking into account the clinical condition of the individual patient, the site and method of administration, scheduling of administration, patient age, sex, body weight and other factors known to medical practitioners. The pharmaceutically "effective amount" for purposes herein is thus determined by such considerations as are known in the art. The amount must be effective to achieve improvement including, but not limited to, improved survival rate or more rapid recovery, or improvement or elimination of symptoms and other indicators as are selected as appropriate measures by those skilled in the art. The complexes of the present invention can be administered to animals, including mammals.

[0044] In the method of treatment of the present invention, the complexes of the present invention can be administered in various ways. It should be noted that they can be administered as the complex and can be administered alone in aqueous solution taking advantage of the excellent solubility of these complexes, or as an active ingredient in combination with pharmaceutically acceptable carriers, diluents, adjuvants and vehicles. The complexes can be administered orally, subcutaneously or parenterally including intravenous, intraarterial, intramuscular, intraperitoneally, intratonsillar, and intranasal administration as well as intrathecal and infusion techniques. Implants of the complexes are also useful. The patient being treated is a warm-blooded animal and, in particular, mammals including man. The pharmaceutically acceptable carriers, diluents, adjuvants and vehicles as well as

implant carriers generally refer to inert, non-toxic solid or liquid fillers, diluents or encapsulating material not reacting with the active ingredients of the invention.

[0045] The doses can be single doses or multiple doses over a period of several days. The treatment generally has a length proportional to the length of the disease process and drug effectiveness and the patient species being treated.

[0046] When administering the complexes of the present invention parenterally, they will generally be formulated in a unit dosage injectable form (solution, suspension, emulsion). The pharmaceutical formulations suitable for injection include sterile aqueous solutions or dispersions and sterile powders for reconstitution into sterile injectable solutions or dispersions. The carrier can be a solvent or dispersing medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, liquid polyethylene glycol, and the like), suitable mixtures thereof, and vegetable oils.

[0047] Proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Nonaqueous vehicles such as cottonseed oil, sesame oil, olive oil, soybean oil, corn oil, sunflower oil, or peanut oil and esters, such as isopropyl myristate, may also be used as solvent systems for the compositions. Additionally, various additives which enhance the stability, sterility, and isotonicity of the compositions, including antimicrobial preservatives, antioxidants, chelating agents, and buffers, can be added. Prevention of the action of microorganisms can be ensured by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, sorbic acid, and the like. In many cases, it will be desirable to include isotonic agents, for example, sugars, sodium chloride, and the like. Prolonged absorption of the injectable pharmaceutical form can be brought about by the use of agents delaying absorption, for example, aluminum monostearate and gelatin. According to the present invention, however, any vehicle, diluent, or additive used would have to be compatible with the complexes.

[0048] Sterile injectable solutions can be prepared by incorporating the complexes utilized in practicing the present invention in the required amount of the appropriate solvent with various of the other ingredients, as desired.

[0049] A pharmacological formulation of the present invention can be administered to the patient in an injectable formulation containing any compatible carrier, such as various vehicle, adjuvants, additives, and diluents; or the complexes utilized in the present invention can be administered parenterally to the patient in the form of slow-release subcutaneous implants or targeted delivery systems such as monoclonal antibodies, vectored delivery, iontophoretic, polymer matrices, liposomes, and microspheres. Many other such implants, delivery systems, and modules are well known to those skilled in the art.

[0050] The invention is further described in detail by reference to the following experimental examples. These examples are provided for the purpose of illustration only, and are not intended to be limiting. Thus, the invention should be construed to encompass any and all variations which become evident as a result of the teaching provided herein.

[0051] The above description and the examples that follow demonstrate synthesis of pyrophosphato platinum complexes in a manner different from previously disclosed methods of synthesis. These complexes have been shown to have anticancer activities, including in cisplatin- and carboplatin-resistant cancers. Unexpectedly, the anticancer activities shown are comparable to and active at relatively lower doses than some currently administered platinum complexes. Also unexpectedly, data suggests that the complexes of the present invention have a different mechanism of action than currently administered platinum complexes, namely that they do not bind DNA during treatment. Thus, the complexes of the present invention represent a novel class of platinum therapeutics useful for treating cancers, including cisplatin- and carboplatin-resistant cancers where effective treatment has previously been hard to obtain.

[0052] The invention is described herein in an illustrative manner, and it is to be understood that the terminology used is intended to be in the nature of words of description rather than of limitation. Obviously, many modifications and variations of the present invention are possible in light of the teachings herein. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

EXAMPLE 1: Diammine(dihydrogen pyrophosphato)platinum(II) (am-2)

[0053] Sodium pyrophosphate decahydrate (0.4 g) and 0.1 g of cisplatin were dissolved in 250 mL of distilled water, pH 8, and incubated at 40 degrees C for 15 hours. Following the incubation period, the solution was concentrated to 5-10 mL by rotary evaporation and filtered to remove any unreacted starting material. Rapidly lowering the pH to approximately 1.0 by addition of 1 N HNO₃ precipitated the product as a light yellow powder. Precipitation was completed by cooling on ice, and the product was isolated by vacuum filtration and washed with cold water and acetone. Yield Pt(NH₃)₂(H₂P₂O₇): 0.04 g (30%). The ³¹P NMR spectrum displays a single peak at 2.12 ppm, pH 7.99 with respect to 85% phosphoric acid as an external reference. ¹⁹⁵Pt NMR resonance is detected at -1503 ppm.

EXAMPLE 2: *Cis*-diammine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum (IV)
(am-4)

[0054] Sodium pyrophosphate decahydrate (0.4 g) and 0.1 g of cisplatin were dissolved in 250 mL of distilled water, pH 8, and incubated at 40 degrees C for 15 hours. Following the incubation period, 1 mL 30% H₂O₂ was added to the reaction mixture, and it was allowed to react for a further 3 hours. The solution was then concentrated to 5-10 mL by rotary evaporation and filtered to remove any unreacted starting material. Rapidly lowering the pH to approximately 1.0 by addition of 1 N HNO₃ precipitated the product as a light yellow powder. Precipitation was completed by cooling on ice, and the product was isolated by vacuum filtration and washed with cold water and acetone. Yield *cis, trans*-Pt(NH₃)₂(OH)₂(H₂P₂O₇): 0.05 g (34%). The ³¹P NMR spectrum displays a single peak at 2.32 ppm, pH 8.11, with a ¹⁹⁵Pt-³¹P coupling constant of 15.4 Hz. The ¹⁹⁵Pt NMR spectrum shows a pentet at 1733 ppm with a ¹⁹⁵Pt-¹⁴N coupling constant of 232 Hz.

EXAMPLE 3: 1,2-Ethanediamine(dihydrogen pyrophosphato)platinum(II) (en-2)

[0055] Sodium pyrophosphate decahydrate (0.4 g) and 0.1 g of dichloro(ethylenediamine)platinum(II) were dissolved in 250 mL of distilled water, pH 8, and incubated at 40 degrees C for 15 hours. Following the incubation period, the solution was concentrated to 5-10 mL by rotary evaporation and filtered to remove any unreacted starting material. Rapidly lowering the pH to approximately 1.0 by addition of 1 N HNO₃ did not precipitate the product. The product was characterized *in situ* by ³¹P NMR. A single peak is observed at 1.93 ppm in the ³¹P NMR spectrum with a ¹⁹⁵Pt-³¹P constant of 29.73 Hz.

EXAMPLE 4: 1,2-Ethanediamine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV) (en-4)

[0056] Sodium pyrophosphate decahydrate (0.4 g) and 0.1 g of dichloro(ethylenediamine)platinum(II) were dissolved in 250 mL of distilled water, pH 8, and incubated at 40 degrees C for 15 hours. Following the incubation period, 1 mL 30% H₂O₂ was added to the reaction mixture, and it was allowed to react for a further 3 hours. The solution was then concentrated to 5-10 mL by rotary evaporation and filtered to remove any unreacted starting material. Rapidly lowering the pH to approximately 1.0 by addition of 1 N HNO₃ precipitated the product as a light yellow powder. Precipitation was completed by cooling on ice, and the product was isolated by vacuum filtration and washed with cold water and acetone. Yield *trans*-Pt(OH)₂(C₂H₈N₂)(H₂P₂O₇): 0.07 g (49%). The ³¹P NMR spectrum displays a single peak at 2.30 ppm, pH 8.13, with a ¹⁹⁵Pt-³¹P coupling constant of 25.9 Hz. The ¹⁹⁵Pt NMR spectrum showed a broad peak at 1582 ppm.

EXAMPLE 5: (*Trans*-1,2-cyclohexamediamine)(dihydrogen pyrophosphato)platinum(II) (dach-2)

[0057] Sodium pyrophosphate decahydrate (0.4 g) and 0.1 g of dichloro(*trans*-1,2-diaminocyclohexyl)platinum(II) were dissolved in 250 mL of distilled water, pH 8, and incubated at 40 degrees C for 15 hours. Following the incubation period, the solution was concentrated to 5-10 mL by rotary evaporation and filtered to remove any unreacted starting material. Rapidly lowering the pH to approximately 1.0 by

addition of 1 N HNO₃ precipitated the product as a light yellow powder. Precipitation was completed by cooling on ice, and the product was isolated by vacuum filtration and washed with cold water and acetone. Yield *trans*-Pt(C₆H₁₄N₂)(H₂P₂O₇): 0.05 g (38%). The ³¹P NMR spectrum displays a single peak at 1.78 ppm, pH 7.93 with a ¹⁹⁵Pt-³¹P constant of 25.03 Hz. ¹⁹⁵Pt NMR signal is recorded at -1729 ppm.

EXAMPLE 6: (*Trans*-1,2-cyclohexanediamine)-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV) (dach-4)

[0058] Sodium pyrophosphate decahydrate (0.4 g) and 0.1 g of dichloro(*trans*-1,2-diaminocyclohexyl)platinum(II) were dissolved in 250 mL of distilled water, pH 8, and incubated at 40 degrees C for 15 hours. Following the incubation period, 1 mL 30% H₂O₂ was added to the reaction mixture, and it was allowed to react for a further 3 hours. The solution was then concentrated to 5-10 mL by rotary evaporation and filtered to remove any unreacted starting material. Rapidly lowering the pH to approximately 1.0 by addition of 1 N HNO₃ precipitated the product as a light yellow powder. Precipitation was completed by cooling on ice, and the product was isolated by vacuum filtration and washed with cold water and acetone. Yield *trans*-Pt(OH)₂(C₆H₁₄N₂)(H₂P₂O₇): 0.07 g (52%). The ³¹P NMR spectrum displays a single peak at 2.41 ppm, pH 7.95, with a ¹⁹⁵Pt-³¹P coupling constant of 25.9 Hz. The ¹⁹⁵Pt NMR spectrum showed a broad peak at 1613 ppm.

EXAMPLE 7

[0059] ³¹P NMR spectroscopy can be used to confirm that the respective diamine(pyrophosphato)platinum(II) and diamine(dihydroxo)(pyrophosphato)platinum (IV) complexes shown in Figure 2 and described in Examples 1-6 were synthesized and isolated by the novel method described herein.

[0060] Each of the complexes exhibited a single ³¹P NMR resonance with chemical shifts in the range 1.78-2.12 ppm. These chemical shifts are 9-11 ppm downfield compared to the free pyrophosphate ligand, consistent with the observed coordination chemical shifts for phosphate chelates reported in the art. Monodentate pyrophosphato complexes were not detected in the final products, as revealed by the absence of the expected two sets of doublets. The ³¹P NMR data also showed that

the oxidation of Pt(II) complexes to Pt(IV) complexes by H₂O₂ was selective, as evidenced by the formation of a single pyrophosphatoplatinum(IV) complex in each case.

EXAMPLE 8

[0061] Human ovarian cancer cells, A2780, were obtained from Dr. Thomas Hamilton (Fox Chase Cancer Center, Philadelphia, PA). Cells were cultured on monolayer using RPMI 1640 supplemented with 10% fetal bovine serum, 2 mM glutamine, 0.25 units/mL insulin and penicillin/streptomycin in a 37 degrees C incubator continuously gassed with 5% CO₂. Cells were subcultured using 0.0625% trypsin in HBSS to maintain cells in exponential growth.

[0062] IC₅₀ values were determined using a clonogenic assay. Briefly, 500 A2780 cells from a single cell suspension were plated onto 60mm Petri plates 24 hours before drug treatment to permit cell attachment. On the day of drug treatment, the medium was decanted and replaced with the drug and these treated cells were placed back into the 37 degrees C incubator for 1 hour. Triplicate plates were set up for each drug concentration. After the 1 hour drug treatment, the drug containing medium was decanted and replaced with fresh medium. These plates were returned to the 37 degrees C incubator for 1 week for colony formation. Colonies were fixed and stained using 2% crystal violet in absolute methanol. Colonies containing more than 50 cells were scored. The number of scored colonies from the triplicate plates was averaged and this number was divided by the number of cells plated to obtain a value for the fraction of cells forming colonies. These values for fraction of cells forming colonies were then corrected for plating efficiency by dividing it by the number of cells forming colonies in plates that were not treated with drug.

[0063] Table 3 shows the anticancer activity of the complexes described herein, expressed as IC₅₀ values, as compared to cisplatin and carboplatin. As can be seen from the data, dach-2 exhibits better performance than both cisplatin and carboplatin in resistant cell lines. Furthermore, dach-4 shows much superior activity to carboplatin. Data also shows that dach-4 is equally or more effective towards cisplatin/carboplatin resistant cancer cells and cisplatin sensitive cells, further indicating that phosphaplatins may not develop resistance.

[0064] Unlike cisplatin and carboplatin, the phosphato complexes of the present invention are predicted to exhibit less toxicity due to the presence of phosphato ligands which might help efficiently transport these complexes to the cell. Furthermore, unlike cisplatin, these phosphato complexes did not exhibit any measurable binding to DNA within 72 hours, as shown in Figure 12. Cisplatin is believed to function by binding genomic DNA. Thus, the phosphato complexes of the present invention have different cellular targets.

EXAMPLE 9

[0065] A cisplatin-resistant Ovarian cell line (C30) (Hamaguchi, et al., 1993), obtained from Dr. Thomas Hamilton (Fox Chase Cancer Center, Philadelphia, PA), was treated with the monomeric platinum complexes of the present invention (shown in Figure 2). This cell line is also cross resistant to carboplatin. Cells were cultured on monolayer using RPMI 1640 supplemented with 10% fetal bovine serum, 2mM glutamine, 0.25 units/mL insulin and penicillin/streptomycin in a 37 degrees C incubator continuously gassed with 5% CO₂. Cells were subcultured using 0.025% trypsin in HBSS to maintain cells in exponential growth.

[0066] IC₅₀ values were determined using a clonogenic assay. Briefly, 500 C30 cells from a single cell suspension were plated onto 60mm Petri plates 24 hours before drug treatment to permit cell attachment. On the day of drug treatment, the medium was decanted and replaced with the drug and these treated cells were placed back into the 37 degrees C incubator for 1 hour. Triplicate plates were set up for each drug concentration. After the one hour drug treatment, the drug containing medium was decanted and replaced with fresh medium. These plates were returned to the 37 degrees C incubator for 1 week for colony formation. Colonies were fixed and stained using 2% crystal violet in absolute methanol. Colonies containing more than 50 cells were scored. The number of scored colonies from the triplicate plates was averaged and this number was divided by the number of cells plated to obtain a value for the fraction of cells forming colonies. These values for fraction of cells forming colonies were then corrected for plating efficiency by dividing them by the number of cells forming colonies in plates that were not treated with drug.

EXAMPLE 10

[0067] The UMSCC10b (Cisplatin-sensitive) and UMSCC10b/15s (Cisplatin-resistant) cell lines derived from human head and neck squamous cell cancer were lines were obtained from Dr. Stephen B. Howell of the University of California, Dan Diego. Cells were cultured in 1640 RPMI with 10% fetal bovine serum, 100units/ml penicillin and 100µg/ml of streptomycin. Cells were seeded into 24-well plates with approximately 20,000 cells/500 µl of media in each well plate. Cells were exposed to dach-2 with variable concentrations ranging from 1.12 µM to maximum of 72 µM. Stock solutions of dach-2 complex were prepared and aliquots of these solutions were added to make those effective concentrations. Cells were then allowed to grow for 72 hours. Twelve different concentrations were used in this study. Each concentration had one control for a total of 12 controls.

[0068] The IC50 for UMSCC10b (Cisplatin-sensitive) can be estimated to be below 1.0 µM. In comparison, the IC50 value for cisplatin is 17 µM in the same line (See Zheng et al., Clinical Cancer Research, 1997, 3, 1157-1165). The IC50 for UMSCC10b/15s (Cisplatin-resistant) was determined to be 5 µM. Figure 9 shows the cell survival curve for the cisplatin-sensitive and cisplatin-resistant cell lines.

EXAMPLE 11

[0069] Preliminary gene expression experiments involving complexes of the present invention as compared to cisplatin (data not shown) were carried out with an apoptotic array containing 84 genes that includes the BCL2 superfamily, both pro- and anti-apoptotic, caspases, the BIR-family, TNF receptor activator factors, p53 and its congeners, and fas associated members by real-time PCR. A closer look at the two sets of gene expressions clearly indicates a number of differences in the expression patterns. For example, fas and members of the fas superfamily genes were overexpressed in cells treated with dach-2 while the cisplatin influenced marginal changes in the expression of these genes. Specifically, fas was overexpressed by 6-fold compared to the control, and TNFRSF-10B was overexpressed by 2-3 folds over controls. These latter receptor factors

belong to the fas superfamily. It is interesting to note that proapoptotic BCL2 members such as BAK1 and BAX were overexpressed about 2-3 folds by dach-2 while cisplatin did not make significant changes in their expression.

EXAMPLE 12: Cellular accumulation of platinum and estimation of DNA-bound platinum

[0070] Platinum content was quantitatively estimated on a Graphite Furnace Atomic Absorption Spectrometer (Perkin Elmer AA-600) from calibration curves established by using cisplatin or pyrodach-2 in water. Cells (5×10^6) were seeded in T75cm² flasks. After 24h, these cells were then treated with the different concentrations (0, 10, 20, 30 and 50 μ M) of cisplatin and pyrodach-2. After 1hr exposure with the platinum complexes, the drug-containing medium was removed and the cells were washed with ice-cold phosphate-buffered saline (PBS). The cells were then trypsinized and centrifuged into a pellet. Cell pellets were digested in concentrated HNO₃ and H₂O₂ prior to analysis, according to the method of McGahan. Data reported in Table 4 were collected from three independent experiments each was carried out in duplicate. For the cisplatin accumulation, data were obtained from triplicate runs from a single sample at a given concentration.

[0071] For DNA-Pt measurements, 1.0×10^7 cells were seeded in T75cm² flasks. After 24hr, the platinum complexes were added at the different concentrations 0, 10, 20, 30 and 50 μ M. Cells were treated with the platinum complexes for 24 hours. Following treatment, the medium was removed and cells were washed with ice-cold PBS. The cells were trypsinized and centrifuged into a pellet. DNA was extracted using a Wizard[®] SV DNA purification kit (Promega). The DNA was quantitatively estimated from the absorption at 260 nm using a NanoDrop UV-Vis instrument.

EXAMPLE 13: Platinum-DNA Binding by NMR

[0072] Proton NMR spectroscopic experiments were conducted on a Bruker 500 MHz NMR instrument in 99% (atom) D₂O with a water suppression pulse sequence. Samples contained cisplatin (2.0 mM) or pyrodach-2 (2.0 mM) and nucleotides (5'-dGMP, 5'-dAMP, dGpG (5.0 mM)), and single- and double stranded DNA (calf thymus, 5.0 mM) at pH 7.0 maintained by phosphate and carbonate buffers (10-20

mM). Reactions of cisplatin (0.25 mM) and pyrodach-2 (0.25 mM) with a synthetic 25-mer: 5'-ATGATTTAGGTGACACTATAGCAGT-3' (0.25mM) were also performed under identical conditions. Reactions were carried out up to 7 days, and ^1H and ^{31}P NMR spectra were recorded at regular time intervals. Usually, a pulse width of 5 μs with a 1.0 s repetition delay was used for the measurements. Typically, a sweepwidth of 10,000 Hz and 32 K data points were selected to collect the Free Induction Decays. A line broadening factor of 1 Hz was for applied Fourier transformation. The chemical shifts, with reference to H-O-D peak, are at 4.67 ppm.

CLAIMS

What is claimed is:

1. A composition for treating cancer comprising:

one or more isolated monomeric platinum complexes of the formulas I, II, III and IV as set forth in FIGURE 1

wherein R^1 , R^2 , and R^3 each is independently selected from substituted or unsubstituted aliphatic or aromatic amines, and

wherein when one of R^1 and R^2 is NH_3 , the other of R^1 and R^2 is not NH_3 ;

and

wherein S is independently selected from hydroxide, acetic acid, butyric acid, and alpha-hydroxy acids; or

pharmaceutically acceptable salts thereof.

2. The composition of claim 1, wherein R^1 and R^2 are each independently selected from ammine, methyl amine, ethyl amine, propyl amine, isopropyl amine, butyl amine, cyclohexane amine, aniline, pyridine, and substituted pyridine.

3. The composition of claim 1 wherein R^3 is selected from ethylenediamine and cyclohexanediamine.

4. The composition of claim 1, wherein the isolated monomeric platinum complex is 1,2-Ethanediamine(dihydrogen pyrophosphato)platinum(II).

5. The composition of claim 1, wherein the isolated monomeric platinum complex is (*Trans*-1,2-cyclohexanediamine)(dihydrogen pyrophosphato)platinum(II).

6. The composition of claim 1, wherein the isolated monomeric platinum complex is *cis*-diammine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV).

7. The composition of claim 1, wherein the isolated monomeric platinum complex is 1,2-Ethanediamine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV).
8. The composition of claim 1, wherein the isolated monomeric platinum complex is *Trans*-1,2-cyclohexanediamine)-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV).
9. A composition for treating cancer comprising:
one or more isolated monomeric platinum complexes selected from
 - (i) *cis*-diammine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV); (ii) 1,2-Ethanediamine(dihydrogen pyrophosphato)platinum(II);
 - (iii) 1,2-Ethanediamine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV);
 - (iv) (*Trans*-1,2-cyclohexanediamine)(dihydrogen pyrophosphato)platinum(II);
 - (v) *Trans*-1,2-cyclohexanediamine)-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV); and
 - (vi) pharmaceutically acceptable salts thereof.
10. The composition of claim 9, wherein the isolated monomeric platinum complex is stable in aqueous solution at a pH between about 6 to about 8.
11. The composition of claim 9, wherein the isolated monomeric platinum complex does not bind DNA.
12. The composition of claim 11, wherein the isolated monomeric platinum complex triggers overexpression of fas and fas-related transcription factors.
13. The composition of claim 11, wherein the isolated monomeric platinum complex triggers overexpression of proapoptotic genes.

14. The composition of claim 13, wherein the proapoptotic genes are Bak and Bax.

15. A method of preparing an isolated monomeric platinum (II) complex comprising:

(i) maintaining an aqueous reaction mixture comprising excess pyrophosphate and a platinum complex of the formulas V and VI as set forth in FIGURE 15

wherein R^1 , R^2 , and R^3 each is independently selected from substituted or unsubstituted aliphatic and aromatic amines, and

wherein X is independently selected from halogens;

at a temperature of about 30 to about 60 degrees Celsius for a period of about 12 to about 18 hours at a pH from about 7 to about 9;

(ii) subsequently concentrating the aqueous reaction mixture such that precipitates of pyrophosphates do not form;

(iii) rapidly lowering the pH of the reaction mixture to a pH of less than 2 by addition of an acid;

wherein, the isolated monomeric platinum complex has a formula of I or III as set forth in FIGURE 1

wherein R^1 , R^2 , and R^3 each is independently selected from substituted or unsubstituted aliphatic and aromatic amines; and

wherein the isolated monomeric platinum complex is stable in aqueous solution at a pH between about 6 to about 9.

16. The method of claim 15, wherein the isolated monomeric platinum complex prepared is (*Trans*-1,2-cyclohexanediamine)(dihydrogen pyrophosphato)platinum(II).

17. The method of claim 15, wherein the temperature is 40 degrees Celsius and the reaction time is 15 hours and the pH is between 7 and 8.

18. The method of claim 15, further comprising cooling the reaction mixture to a temperature of between 5 degrees Celsius and ambient temperature after concentrating the reaction mixture.
19. The method of claim 15, further comprising cooling the reaction mixture to a temperature of between 5 degrees Celsius and ambient temperature after lowering the pH of the reaction mixture.
21. A method of preparing an isolated monomeric platinum (IV) complex comprising:
- (i) maintaining an aqueous reaction mixture comprising excess pyrophosphate and a platinum complex of the formulas V and VI as set forth in FIGURE 15
 - wherein R^1 , R^2 , and R^3 each is independently selected from substituted or unsubstituted aliphatic and aromatic amines, and
 - wherein X is independently selected from halogens;
 - at a temperature of about 30 to about 60 degrees Celsius for a period of about 12 to about 18 hours at a pH from about 7 to about 9;
 - (ii) adding to the reaction mixture hydrogen peroxide, and optionally a reagent selected from the group of acetate salts, butyrate salts, and salts of alpha-hydroxy acids, and combinations thereof;
 - (iii) subsequently concentrating the aqueous reaction mixture such that precipitates of pyrophosphate do not form;
 - (iv) rapidly lowering the pH of the reaction mixture to a pH of less than 2 by addition of nitric acid;
- wherein, the isolated monomeric platinum complex has a formula of II or IV as set forth in FIGURE 1;

wherein R¹, R², and R³ each is independently selected from substituted or unsubstituted aliphatic and aromatic amines;

wherein S is independently selected from hydroxide, acetic acid, butyric acid, and alpha-hydroxy acids; and

wherein the isolated monomeric platinum complex is stable in aqueous solution at a pH between about 6 to about 9.

21. The method of claim 20, wherein the temperature is 40 degrees Celsius and the reaction time is 15 hours and the pH is between 7 and 8.
22. The method of claim 20, further comprising cooling the reaction mixture to a temperature of between 5 degrees Celsius and ambient temperature after concentrating the reaction mixture.
23. The method of claim 20, further comprising cooling the reaction mixture to a temperature of between 5 degrees Celsius and ambient temperature after lowering the pH of the reaction mixture.
24. The method of claim 20, wherein the optional reagent added together with hydrogen peroxide prior to concentration of the reaction mixture is selected from sodium acetate, sodium butyrate, and sodium salts of alpha-hydroxy acids.
25. The method of claim 20, wherein the optional reagent added together with hydrogen peroxide prior to concentration of the reaction mixture is selected from potassium acetate, potassium butyrate, and potassium salts of alpha-hydroxy acids.
26. The method of claim 20, wherein the hydrogen peroxide is at an initial vol/vol concentration of 30%.
27. The method of claim 20, wherein the isolated monomeric platinum complex prepared is *cis*-diammine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV).

28. The method of claim 20, wherein the isolated monomeric platinum complex prepared is 1,2-Ethanediamine-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV).
29. The method of claim 20, wherein the isolated monomeric platinum complex prepared is *Trans*-1,2-cyclohexanediamine)-*trans*-dihydroxo(dihydrogen pyrophosphato)platinum(IV).
30. A method of treating cancer comprising: administering a therapeutically effective amount of at least one isolated monomeric platinum complex selected from the complexes of claim 1 and at least one pharmaceutically acceptable carrier, diluent, adjuvant, or vehicle.
31. The method of claim 30, wherein the cancer is selected from ovarian, testicular, small cell lung, and head and neck cancers.
32. A method of treating cancers that are resistant to one or more anticancer agents selected from cisplatin, carboplatin, and oxaliplatin comprising: administering a therapeutically effective amount of at least one isolated monomeric platinum complex selected from diammine(dihydrogen pyrophosphato)platinum(II) and the complexes of claim 1 and at least one pharmaceutically acceptable carrier, diluent, adjuvant, or vehicle.
33. The method of claim 32, wherein the cancer is selected from ovarian, testicular, small cell lung, and head and neck cancers.

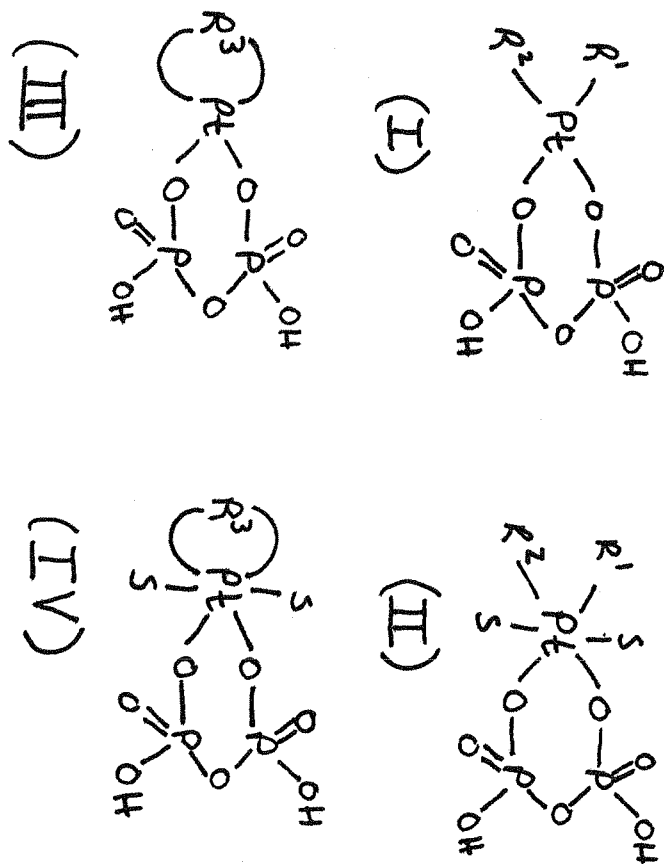


Figure 1

Figure 2

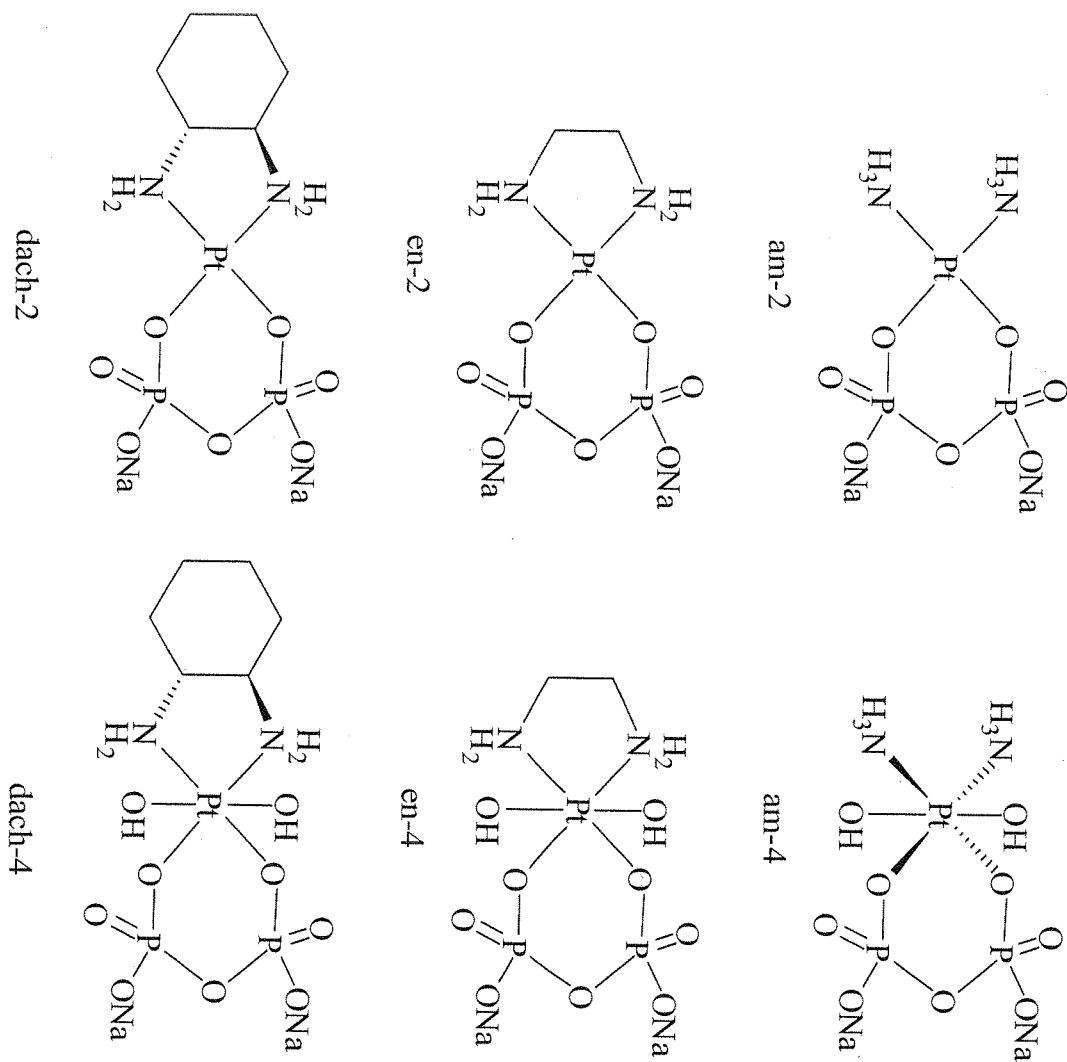
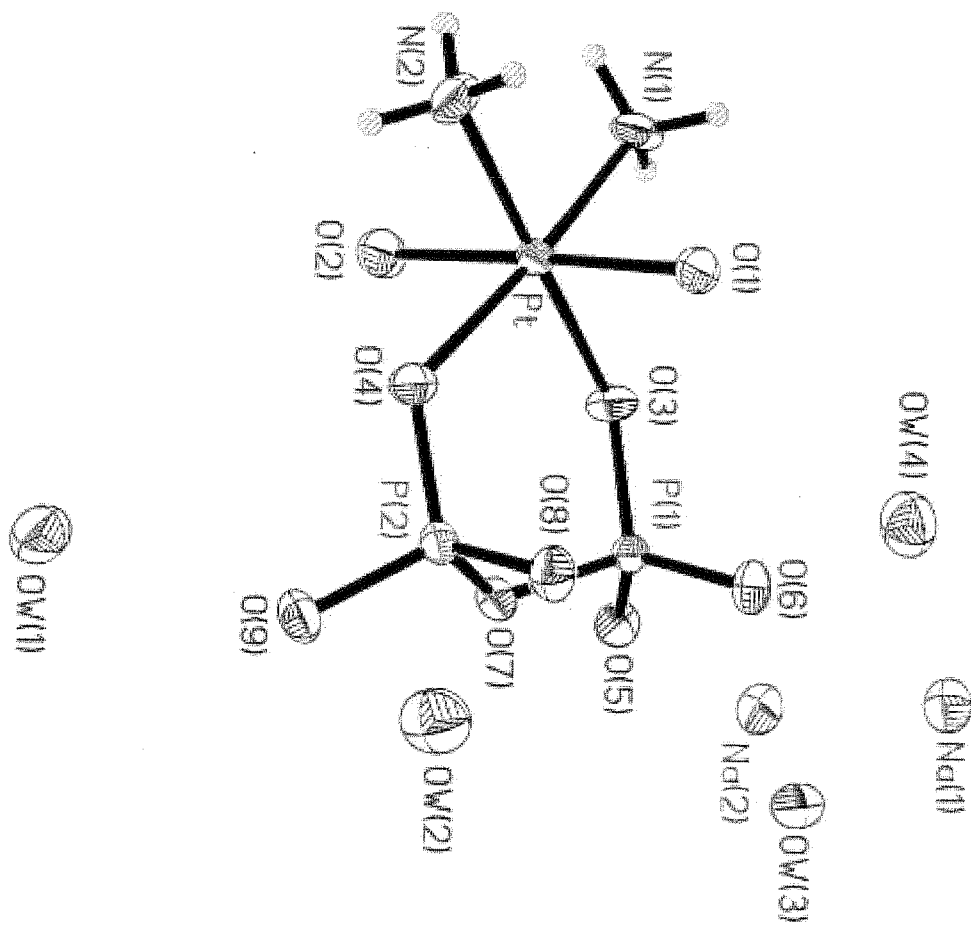


Figure 3



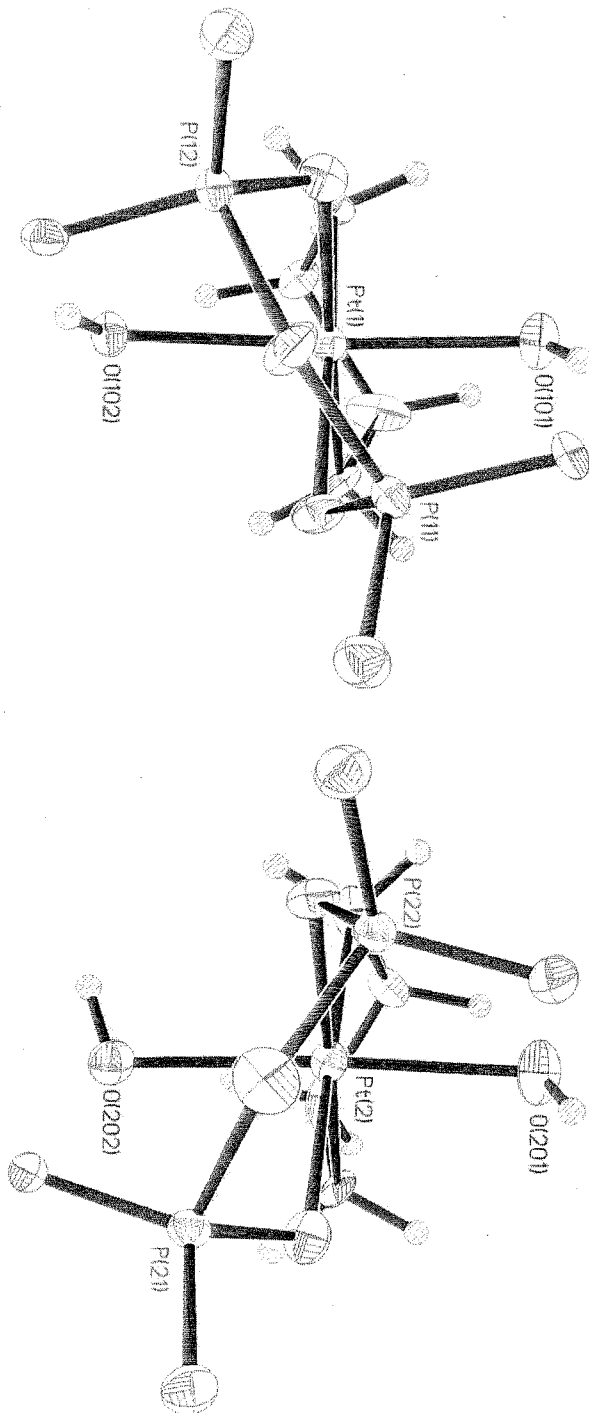


Figure 4

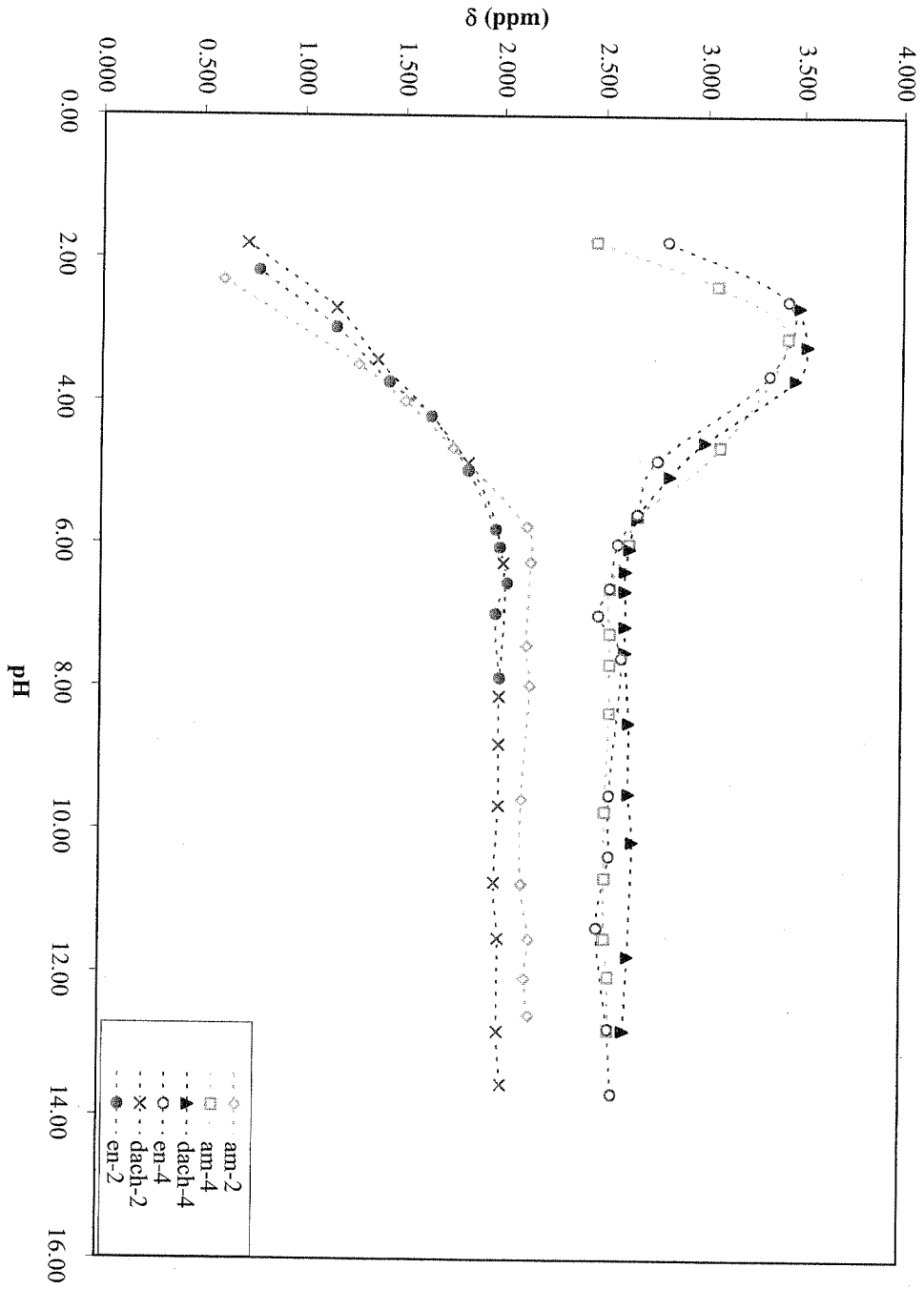


Figure 5

Figure 6

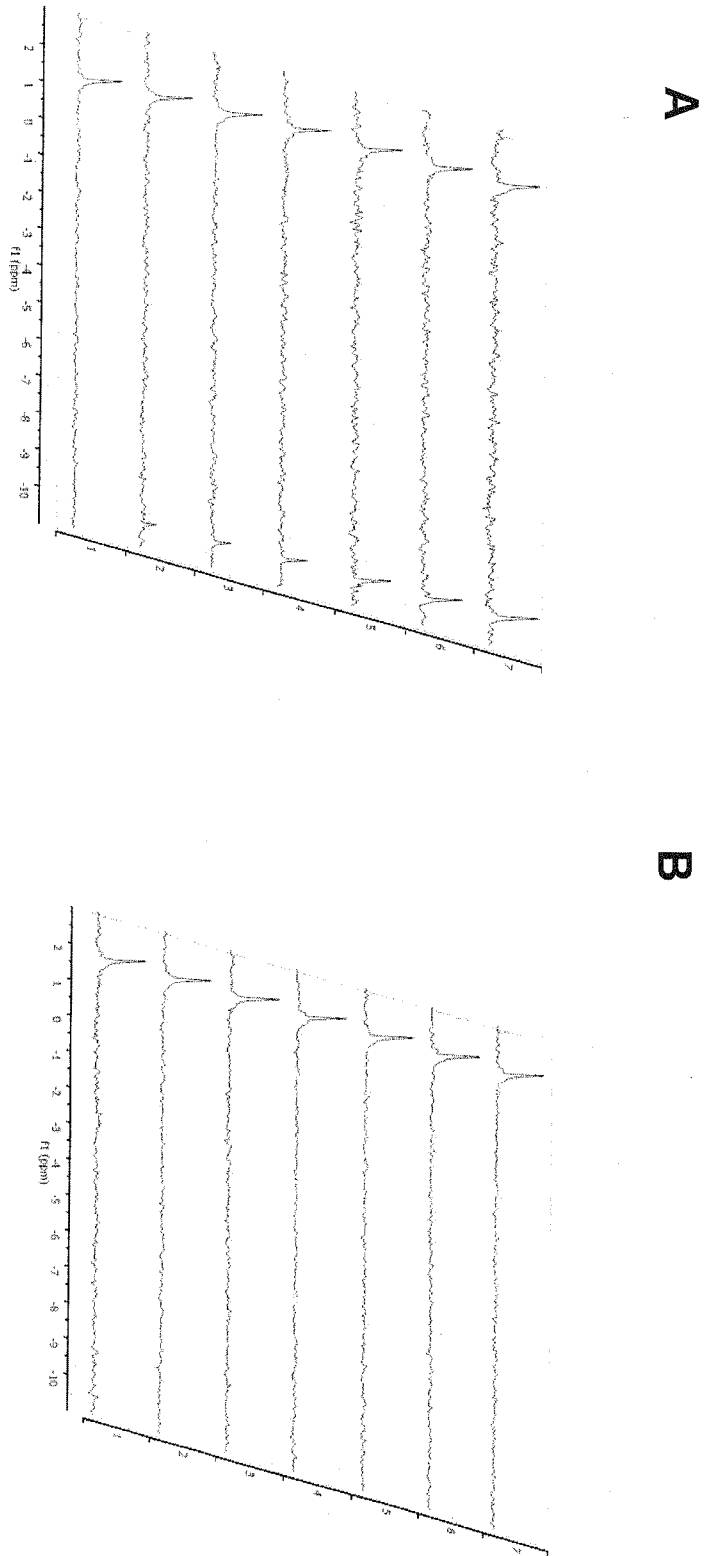
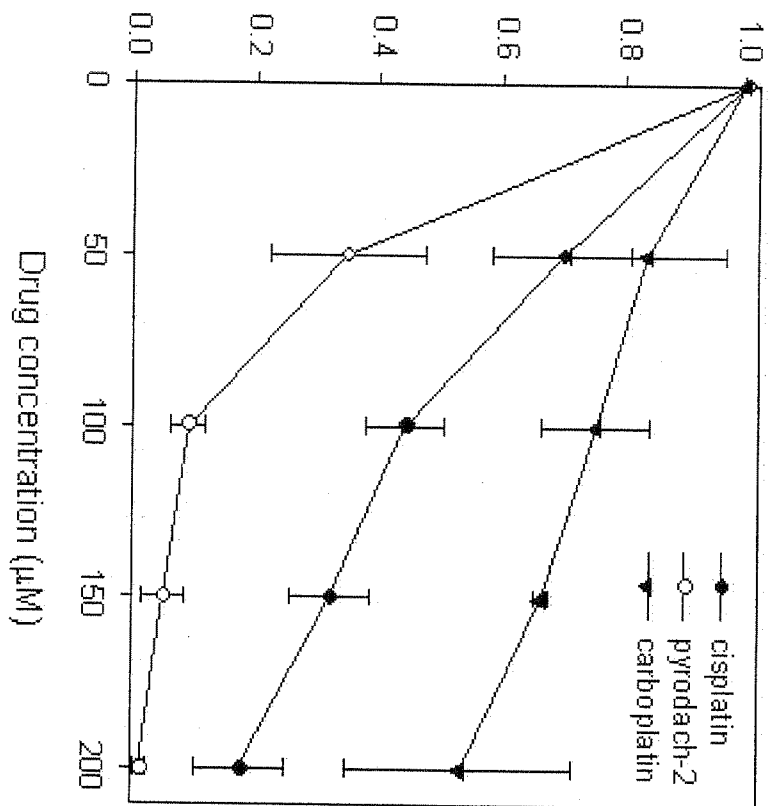


Figure 7

A2780/C30 cells



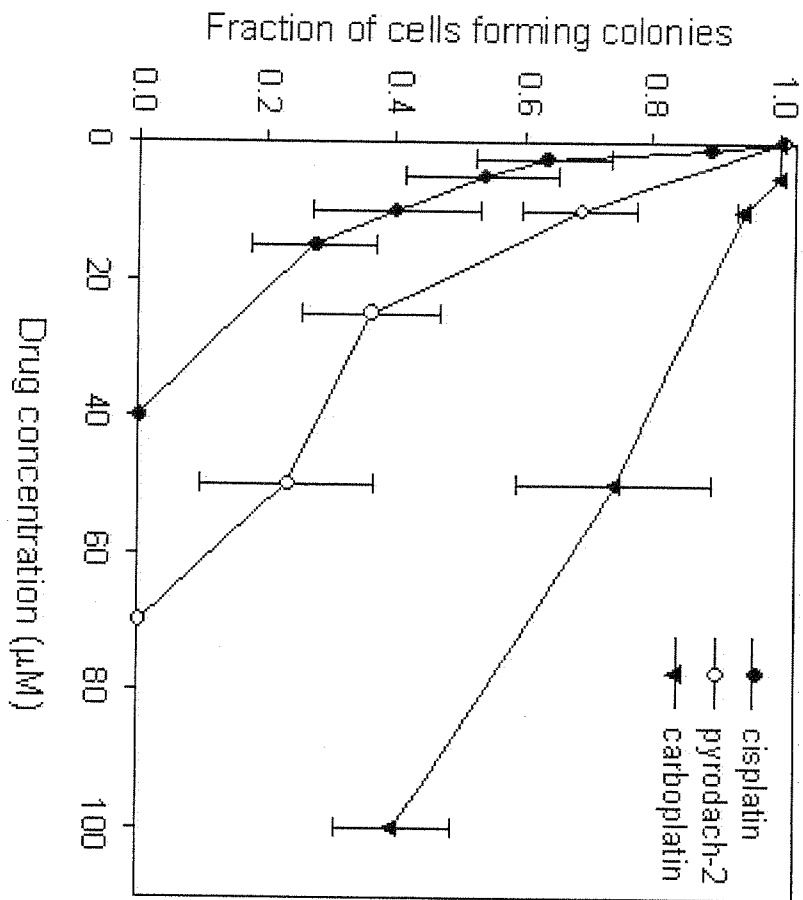


Figure 8
A2780 cells

Figure 9

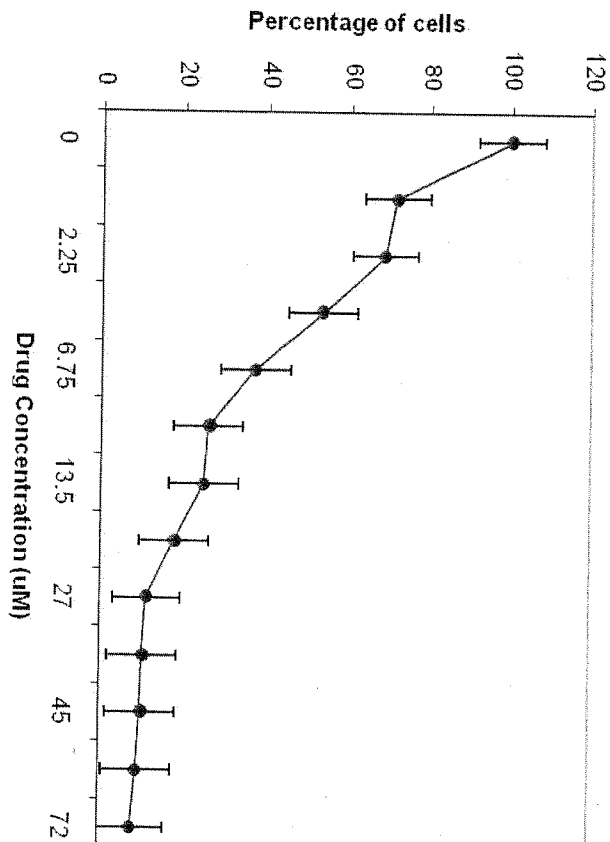
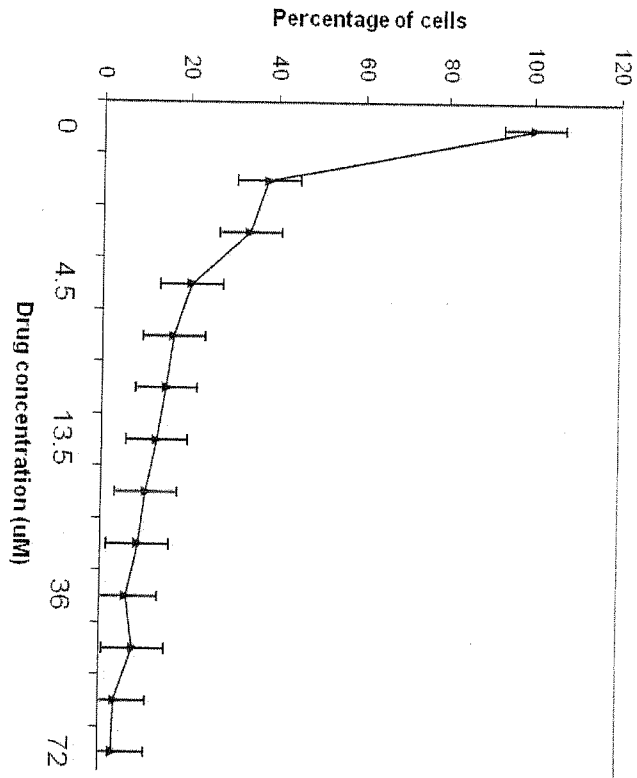
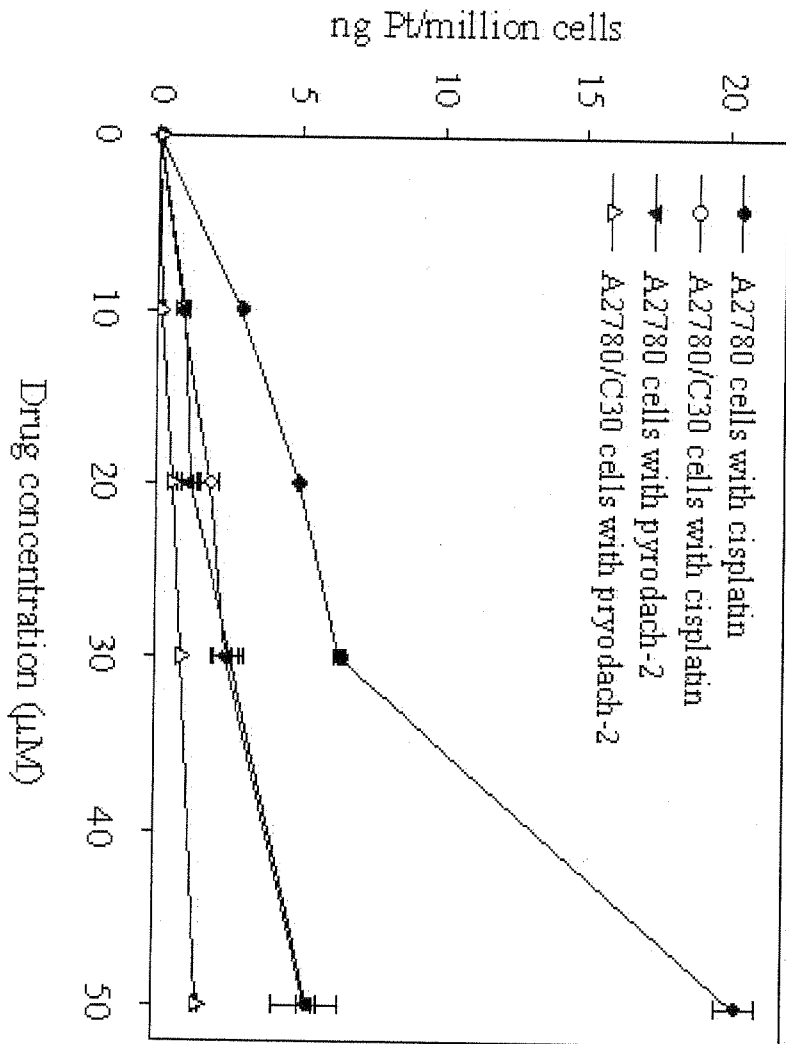


Figure 10

Platinum cellular accumulation



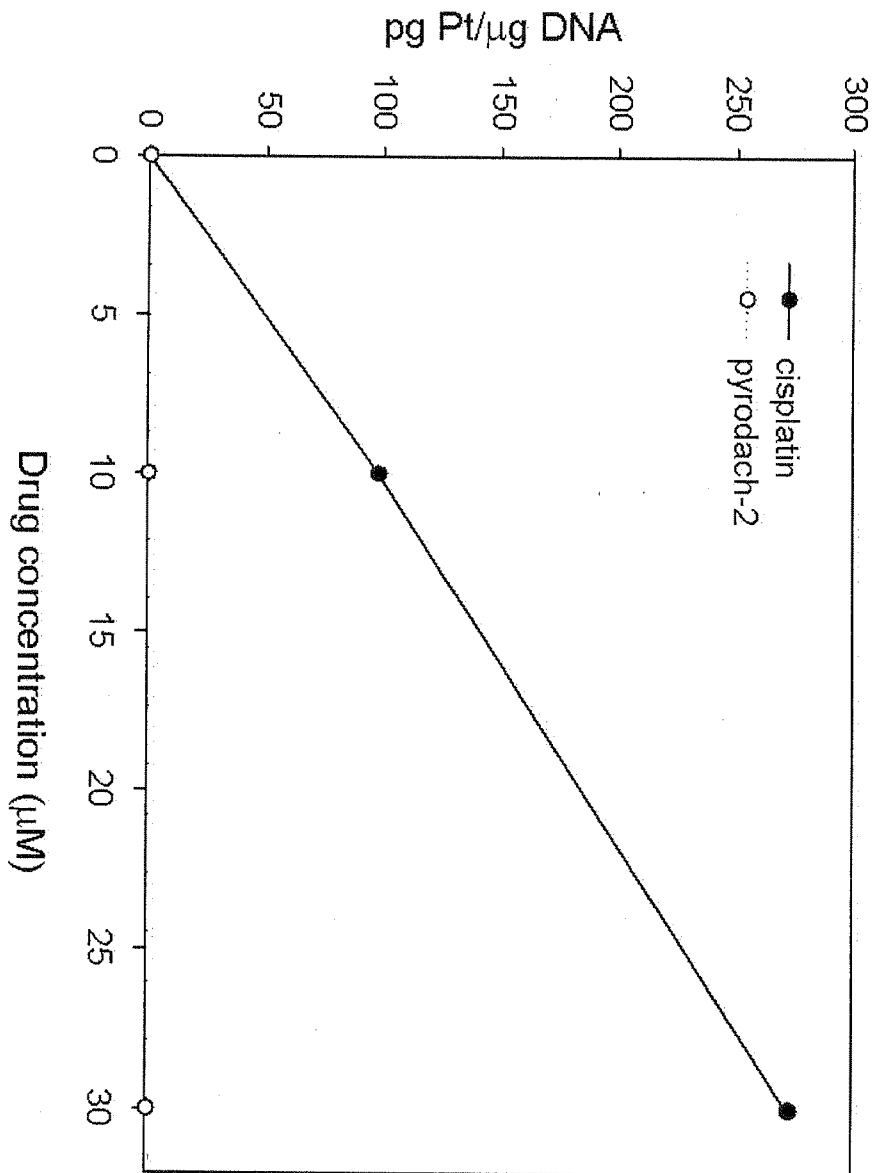
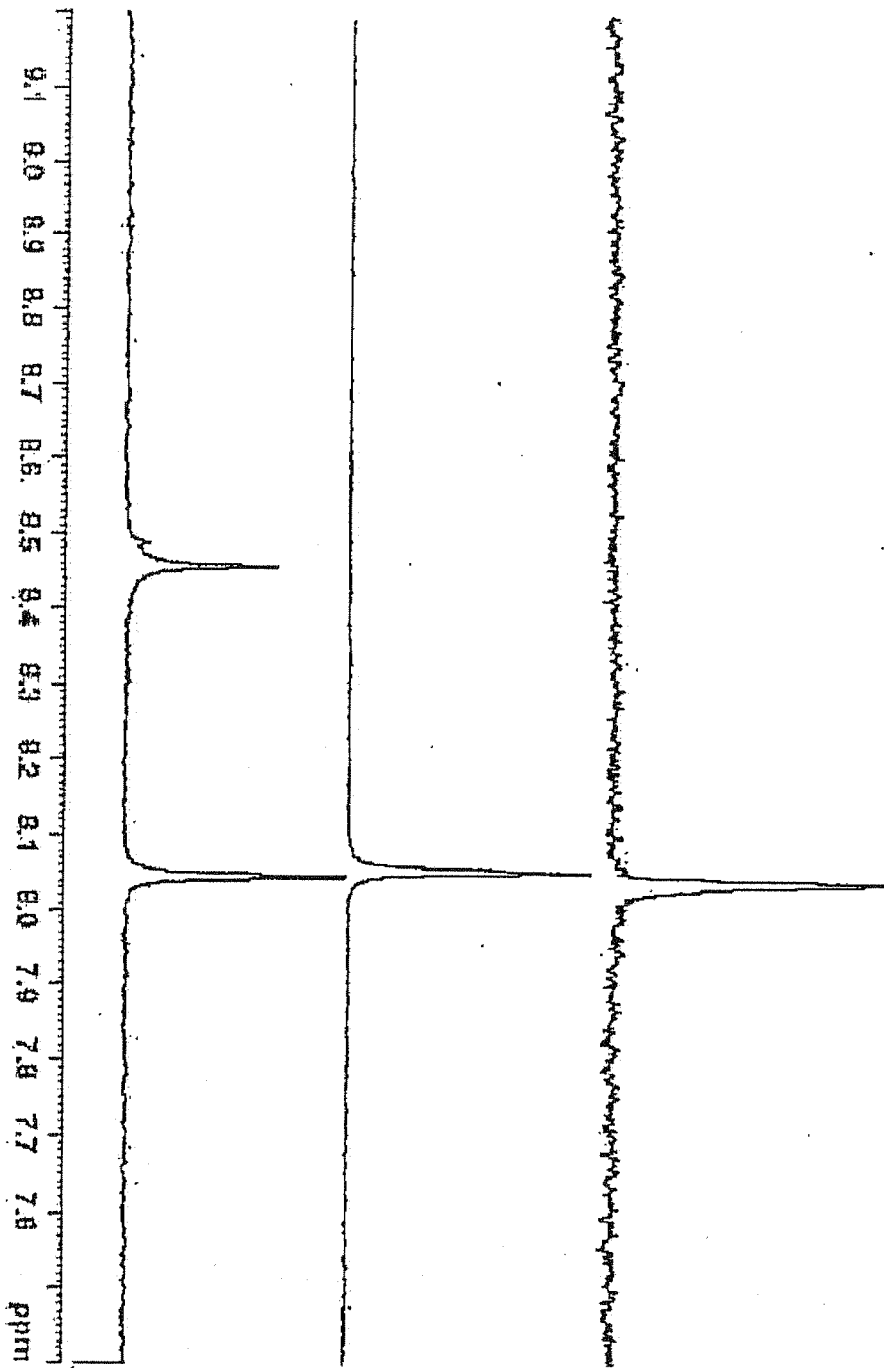


Figure 11

Figure 12



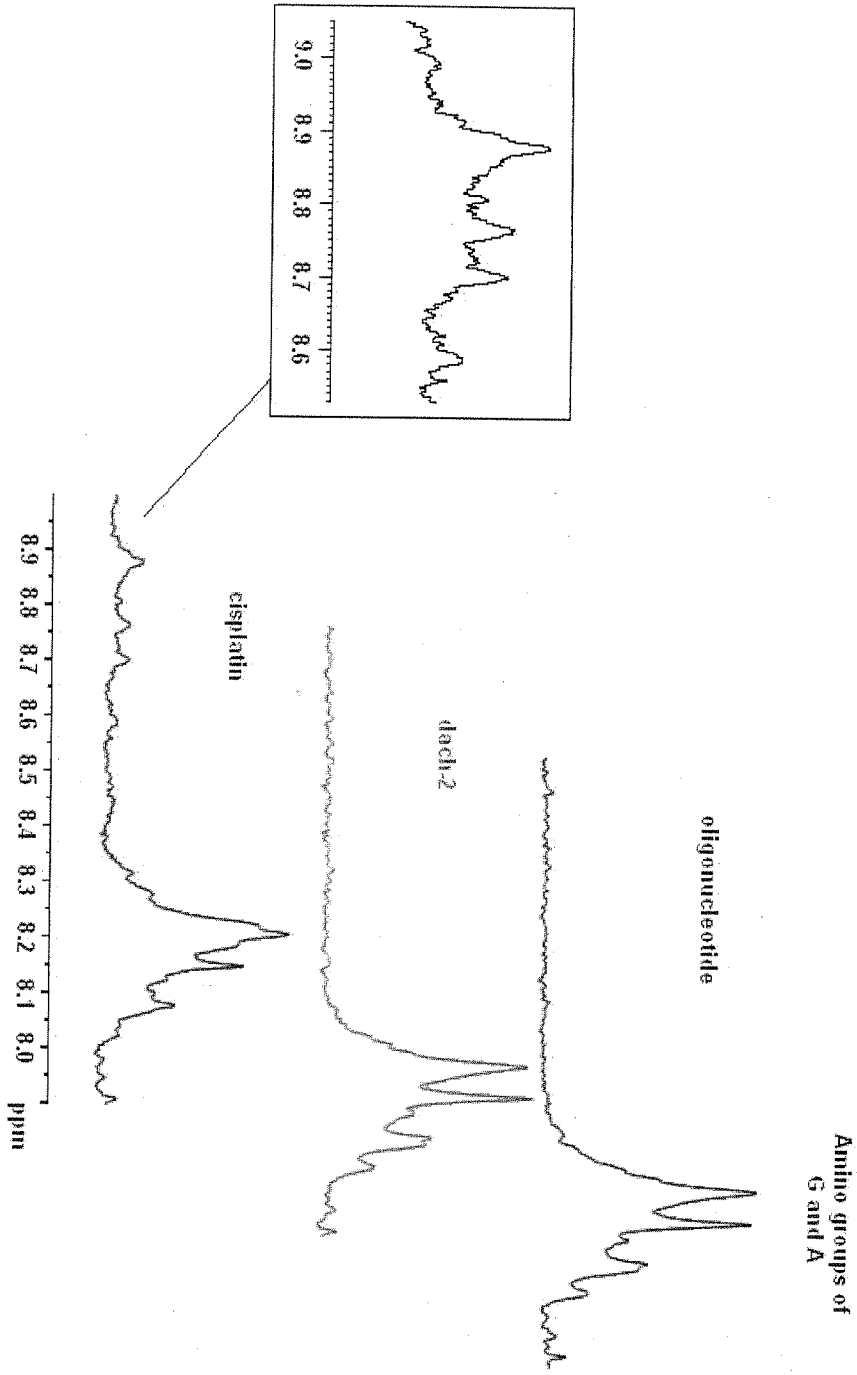
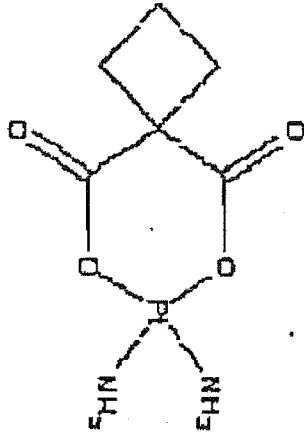
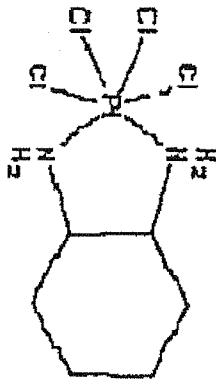


Figure 13

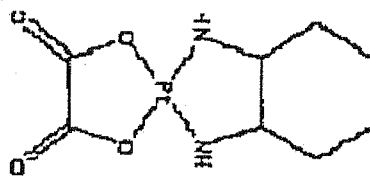
Figure 14



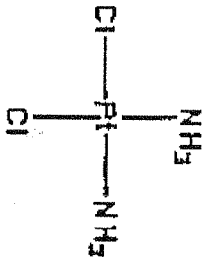
carboplatin



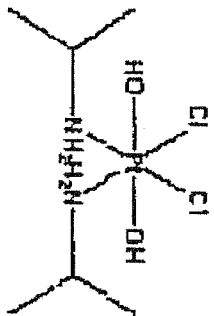
ormaplatin
tetraplatin



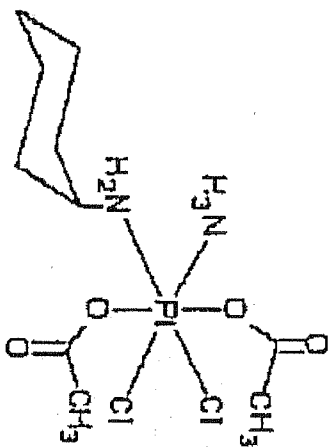
oxaliplatin



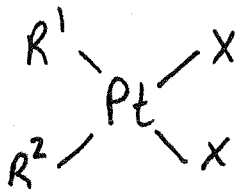
cisplatin
cis-DDP



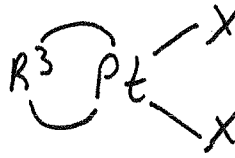
iproplatin
CHIP



satraplatin
JM216



(V)



(VI)

Figure 15