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(54) Title: PLATINUM COMPLEXES AS ANTITUMOR AGENTS IN COMBINATION WITH BIOCHEMICAL MODULATION

(57) Abstract: The present invention concerns the use of methods and compositions for the treatment of cancer and other hyperproliferative diseases. In certain embodiments, methods are described for the treatment of cancer and/or hyperproliferative diseases by administration of compositions containing at least one platinum complex alone or in combination with a modulator of glutathione. In particular, the methods may be used to treat cisplatin or carboplatin resistant tumor cells.

## DESCRIPTION

### PLATINUM COMPLEXES AS ANTITUMOR AGENTS IN COMBINATION WITH BIOCHEMICAL MODULATION

5

#### BACKGROUND OF THE INVENTION

The present application claims priority to co-pending U.S. Provisional Patent Application Serial No. 60/409,813 filed September 11, 2002. The entire text of the above-referenced disclosure is specifically incorporated herein by reference without disclaimer. The government may own rights in the present invention pursuant to grant number RO1CA50380 from the National Cancer Institute.

#### 1. Field of the Invention

The present invention relates generally to the field of cancer therapy. More particularly, it concerns formulations and methods for the treatment of cancer patients using compositions including specific platinum complexes and/or inhibitors of glutathione (GSH) synthesis or activity, such as L-buthionine-sulfoximine (BSO).

#### 2. Description of Related Art

Cisplatin is one of the most effective and broadly used anticancer drugs. Apoptosis induced by cisplatin is generally considered to be mediated by the formation of covalent DNA adducts, which block replication and transcription. Cisplatin (cis-diamminedichloroplatinum) has been used as a chemotherapeutic agent for many years. Rosenberg *et al.*, U.S. Patent 4,177,263, describes methods of treating cancer using cisplatin and cisplatin analogs. The compounds were effective for treating leukemia and tumors induced in mice. Cisplatin and an analog, carboplatin, are now among the most widely used anticancer drugs.

Platinum-based antitumor agents (*e.g.*, cisplatin and carboplatin) play critical roles in the treatment of several cancers. One of the major limitations to these treatments is relapse in a majority of patients, which fail subsequent treatment with platinum agents due to drug resistant tumor cells. This limitation has resulted in an effort to identify platinum analogs that are effective against resistant tumors. Indeed several such analogs (*e.g.*, oxaliplatin and JM216) have entered clinical trials. However, little or no knowledge of the effective mode of action of these analogs is known. Although reduced drug accumulation, increased intracellular

glutathione, and increased DNA adduct repair are usually identified as key mechanisms of resistance for cisplatin, satisfactory explanations for reversal of resistance by analogs have not been provided.

5 Attempts have been made to increase the effectiveness or sensitize resistant tumor cells to cisplatin or analogs thereof by administering the drug in combination with sulfoximines, for example D,L-buthionine-S,R-sulfoximine (BSO) or other agents. The effects of BSO on cytotoxicity and DNA cross-linking induced by bifunctional DNA-reactive cytostatic agents in a human melanoma cell line (RPMI 8322) have been investigated. BSO pretreatment enhanced cytotoxicity of melphalan and nitrogen mustard. A small but significant potentiation by BSO of  
10 cisplatin toxicity was also seen (dose modification factor (DMF) of 1.5). The findings supported the hypothesis that the potentiation of the cytotoxicity of bifunctional alkylating agents by BSO is due to increased DNA cross-linking caused by a reduced intracellular conjugation of drug with glutathione.

15 None of the methods for the treatment of cancer, are entirely satisfactory, thus new and improved methods and compositions for the treatment of cancer are needed.

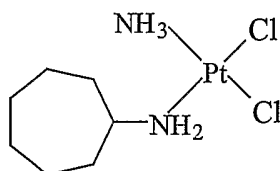
### SUMMARY OF THE INVENTION

20 Platinum complexes, as described herein, alone or in combination with inhibitors of GSH synthesis or activity (*e.g.*, BSO) show an enhancement of antitumor activity and selectivity for cisplatin-resistant cells. In certain embodiments, the activity of platinum complexes of the invention may be greater against resistant cells than against sensitive cells.

25 In certain embodiments of the invention the compounds ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), and/or ammine/hexamethyleneimine-tetrachloro-platinum(IV) may be used alone or in combination with inhibitors of GSH synthesis and/or activity for the treatment of a patient with cancer or a hyperproliferative condition.

In various embodiments, an antitumor formulation or composition may include a compound represented by the structural formula:

5

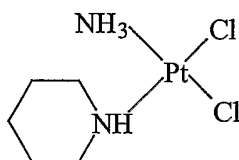


Structural Formula I

10 or salts thereof. The formulation or composition may also include a negative modulator of glutathione. The negative modulator of glutathione may be an inhibitor of glutathione synthesis. The inhibitor of glutathione synthesis may be L-buthionine-sulfoximine (BSO). BSO may include one or more isomer of BSO.

In other embodiments, an antitumor formulation or composition may include a compound represented by the structural formula:

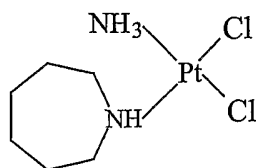
15



Structural Formula II

20 or salts thereof. The formulation or composition may also include a negative modulator of glutathione. The negative modulator of glutathione may be an inhibitor of glutathione synthesis. The inhibitor of glutathione synthesis may be L-buthionine-sulfoximine (BSO). BSO may include one or more isomer of BSO.

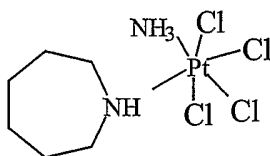
In still other embodiments, an antitumor formulation or composition may include a compound represented by the structural formula:



Structural Formula III

or salts thereof. The formulation or composition may also include a negative modulator of  
5 glutathione. The negative modulator of glutathione may be an inhibitor of glutathione synthesis.  
The inhibitor of glutathione synthesis may be L-buthionine-sulfoximine (BSO). BSO may  
include one or more isomer of BSO.

In still other embodiments, an antitumor formulation or composition may include a  
compound represented by the structural formula IV:



10

Structural Formula IV

or salts thereof. The formulation or composition may also include a negative modulator of  
glutathione. The negative modulator of glutathione may be an inhibitor of glutathione synthesis.  
15 The inhibitor of glutathione synthesis may be L-buthionine-sulfoximine (BSO). BSO may  
include one or more isomer of BSO.

In certain embodiments, a pharmaceutical composition may include one or more  
platinum complex of ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-  
dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), or  
20 ammine/hexamethyleneimine-tetrachloro-platinum(IV).

The pharmaceutical formulations or compositions of the invention may include a  
platinum complex in the approximate range of 0.1, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,  
15 mM to 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 40, 50 mM.  
Pharmaceutical formulations or compositions of the present invention may comprise a biologic  
25 modifier of glutathione. The biologic modifier of glutathione may be an inhibitor of glutathione  
synthesis, such as L-buthionine-sulfoximine. A pharmaceutical composition may include L-  
buthionine-sulfoximine in the approximate range of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15,

16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 75, 80, 85, 90, 95  $\mu\text{M}$ , to 100, 150, 200, 250, 300, 400, 500  $\mu\text{M}$  or more. A pharmaceutical composition of the invention may be administered intravascularly, orally, intraperitoneally, or by other routes of administration known for platinum complexes and the like.

5 In yet other embodiments of the invention, a method of inhibiting the proliferation of a cisplatin-resistant cell comprising providing, contacting or administering to a cell ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), or ammine/hexamethyleneimine-tetrachloro-platinum(IV) is contemplated. The method may also include providing a biologic  
10 modifier of glutathione. The biologic modifier of glutathione may be an inhibitor of glutathione synthesis, such as one or more isomer of L-buthionine-sulfoximine. In particular embodiments of the invention, the cell is located in a subject such as a mammal. The mammal may be a human or a mouse.

Various embodiments include, a method of treating a cancer cell comprising providing,  
15 contacting or administering to the cancer cell ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), or ammine/hexamethyleneimine-tetrachloro-platinum(IV). The method may also include providing a biologic modifier of glutathione. The biologic modifier of glutathione may be an inhibitor of glutathione synthesis, such as one or more isomer of L-buthionine-sulfoximine.

20 Still other embodiments of the invention include, a method of enhancing anti-tumor activity comprising providing, contacting, or administering a composition comprising a platinum complex selected from the group consisting of ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), and ammine/hexamethyleneimine-tetrachloro-platinum(IV) in combination with an inhibitor of  
25 glutathione synthesis. The inhibitor of glutathione synthesis may be further defined as one or more isomer of L-buthionine-sulfoximine. The concentration of L-buthionine-sulfoximine may be in the approximate range of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 75, 80, 85, 90, 95  $\mu\text{M}$ , to 100, 150, 200, 250, 300, 400, 500  $\mu\text{M}$  or more.

30 Additional embodiments of the invention include, a method of making ammine/cycloheptylamine-dichloro-platinum(II) comprising: a) treating an aqueous 20 mmol solution of  $\text{K}_2\text{PtCl}_4$  with 200 mmol KI with stirring for 10 min at room temperature; b) adding two equivalents of cycloheptylamine dropwise and stirring for 30 minutes forming a *cis*-Pt<sup>II</sup>(c-

C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> precipitate; c) filtering and washing the *cis*-Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> precipitate with water; d) recrystallizing the *cis*-Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> precipitate from a DMF/H<sub>2</sub>O mixture and washing with water, methanol, and ethyl ether; e) drying the *cis*-Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> precipitate *in vacuo*; f) suspending the dried *cis*-Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> precipitate in 50 mL of 60 to 70% HClO<sub>4</sub> and adding 150 mL of ethanol to the suspension with stirring at room temperature forming a brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate; g) filtering the brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate and washing the brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate with water; h) drying the washed brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate *in vacuo*; i) mixing 5 mmol of brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate with 5 mL of 1.5M NH<sub>4</sub>OH in 25 mL of water and stirring the mixture at room temperature overnight forming a yellow *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> precipitate; j) filtering the yellow *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> precipitate and washing with water; k) drying the washed yellow *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> precipitate *in vacuo*; l) mixing 4 mmol of *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> with 7.4mmol of AgNO<sub>3</sub> in 200 mL of water and stirring overnight in the dark forming an AgI precipitate; m) removing AgI precipitate by filtration through celite forming a *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)NO<sub>3</sub> filtrate; n) adding 10 mL of concentrated HCl the *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)NO<sub>3</sub> filtrate and stirring the mixture for 3 hours forming a yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate; o) evaporating the mixture to approximately 2 mL under reduced pressure and filtering yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate; p) washing the yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate with water and acetone, and drying the washed yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate *in vacuo*.

Other embodiments include, a method of making ammine/piperidine-dichloro-platinum(II) comprising: a) dissolving 5.5 mmol of K[Pt(NH<sub>3</sub>)Cl<sub>3</sub>] in 50 mL of water; b) adding 55 mmol of KI in 100 mL of water forming a brown solution and stirring for 20 minutes; c) adding 55 mmol of Piperidine in 10 mL of water dropwise to the brown solution until a golden yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)I<sub>2</sub> precipitate is formed and stirring for another hour; d) filtering the golden yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)I<sub>2</sub> precipitate and washing with acetone; e) drying *in vacuo* the washed golden yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)I<sub>2</sub> precipitate; f) suspending 4.24 mmol of Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)I<sub>2</sub> in 100 ml of water; g) adding 8.48 mmol of AgNO<sub>3</sub> in 100 mL of water and stirring for 24 hours in the dark, at room temperature; h) filtering an AgI precipitate; i) evaporating the AgI filtrate to 50 mL; j) adding a 1:1 HCl solution dropwise while stirring forming a bright yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)Cl<sub>2</sub> compound; and k) filtering the bright yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)Cl<sub>2</sub> compound and re-crystallizing the bright yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)Cl<sub>2</sub> compound in hot water and drying the bright yellow Pt(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)Cl<sub>2</sub> crystals under vacuum.

Still other embodiments of the invention include, a method of making ammine/hexamethyleneimine-dichloro-platinum(II) comprising: a) dissolving 5.5 mmol of  $K[Pt(NH_3)Cl_3]$  in 50 mL of water; b) adding 55 mmol of KI in 100 mL of water forming a brown solution and stirring for 20 minutes; c) adding 55 mmol of hexamethylenimine in 10 mL of water dropwise to the brown solution until a golden yellow  $Pt(NH_3)(C_6H_{13}N)_2I_2$  precipitate is formed and stirring for an hour; d) filtering the golden yellow  $Pt(NH_3)(C_6H_{13}N)_2I_2$  precipitate and washing with acetone; e) drying *in vacuo* the washed golden yellow  $Pt(NH_3)(C_6H_{13}N)_2I_2$  precipitate; f) suspending 4.24 mmol of  $Pt(NH_3)(C_6H_{13}N)_2I_2$  in 100 ml of water; g) adding 8.48 mmol of  $AgNO_3$  in 100 mL of water and stirring for 24 hours in the dark, at room temperature; h) filtering an AgI precipitate; i) evaporating the AgI filtrate to 50 mL; j) adding a 1:1 HCl solution dropwise while stirring forming a bright yellow  $Pt(NH_3)(C_6H_{13}N)Cl_2$  compound; and k) filtering the bright yellow  $Pt(NH_3)(C_6H_{13}N)Cl_2$  compound and re-crystallizing the bright yellow  $Pt(NH_3)(C_6H_{13}N)Cl_2$  compound in hot water and drying the bright yellow  $Pt(NH_3)(C_6H_{13}N)Cl_2$  crystals under vacuum.

Additional embodiments include, a method of making ammine/hexamethyleneimine-tetrachloro-platinum(IV) comprising: a) adding 10 milliliters of  $H_2O_2$  to a suspension of 2.61 mmol  $Pt^{II}(NH_3)(C_6H_{13}N)Cl_2$  in 200 mL of water, stirring for 15 hours, filtering the solution, concentrating to a minimum volume; b) precipitating with acetone forming a yellow  $(Pt^{IV}(NH_3)(C_6H_{13}N)trans-(OH)_2Cl_2)$  product; c) drying the yellow  $(Pt^{IV}(NH_3)(C_6H_{13}N)trans-(OH)_2Cl_2)$  *in vacuo*; d) dissolving the yellow 1.64 mmol of  $Pt^{IV}(NH_3)(C_6H_{13}N)trans-(OH)_2Cl_2$  (0.65 g; 1.64 mmol) in 100 mL of water; e) adding 20 mL of concentrated HCl and stirring for 24 hours at room temperature forming a clear yellow solution; f) filtering the clear yellow solution, concentrating the clear yellow solution to a minimum volume to form a yellow crystalline  $Pt^{IV}(NH_3)(C_6H_{13}N)Cl_4$ ; and g) filtering, washing the yellow crystalline  $Pt^{IV}(NH_3)(C_6H_{13}N)Cl_4$  with water, and drying under a vacuum.

All amounts as disclosed herein are approximate and may vary by about 5 to about 10, about 15 to about 20 percent or more. In other embodiments of the present invention, the amount may vary by about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or more millimolars. The amounts as disclosed herein may also vary by about 5 to about 10, about 15 to about 20, about 25 to about 30 or more milliliters.

The use of the word "a" or "an" when used in conjunction with the term "comprising" in the claims and/or the specification may mean "one," but it is also consistent with the meaning of "one or more," "at least one," and "one or more than one."

Other objects, features and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples, while indicating specific embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

**FIG. 1.** List of the chemical identity of exemplary platinum complexes.

**FIG. 2.** Schematic of the structures representing the chemicals described in the application and provided in FIG 1.

### **DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS**

Resistance to platinum complexes may be overcome by the enhanced and/or selective antitumor activity of a specific platinum complex(es) alone or in combination with negative modulators of GSH. In certain embodiments, a negative modulator of GSH may be an inhibitor of GSH synthesis, which includes, but is not limited to, L-buthionine-SR-sulfoximine (BSO), which may include one to more isomers of BSO. Embodiments of the invention result in an increased activity against cisplatin-resistant cells that is greater than the activity against cisplatin-sensitive cells. The combination of a specific platinum analog and an inhibitor of GSH synthesis or activity (*e.g.*, BSO) may be used against refractory cancers, and is independent of the p53 status of the target cells.

The increase in antitumor activity in combination with BSO is usually under 2-fold for cisplatin, although isolated publications have demonstrated increases of up to 4-fold. Moreover, the increased activity of cisplatin is not selective, as both sensitive and resistant cells respond equally well. Other analogs of cisplatin have been demonstrated to behave in a similar manner.

Platinum complexes referred to in the present disclosure are listed by complex number, chemical name, and chemical structures provided in FIG 1 and FIG 2.

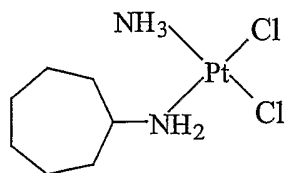
The inventors have identified specific platinum complexes which when administered in combination with an inhibitor of GSH synthesis (*e.g.*, BSO), show (1) substantially greater enhancement in antitumor activity, and (2) selectivity for cisplatin-resistant cells. Thus, in isogenic pairs of sensitive and resistant tumor models, the activity of specific analogs is much greater against resistant cells than against sensitive cells.

The present invention includes formulations and methods for the treatment of cancer and other hyperproliferative diseases using pharmaceutical compositions including platinum complexes and/or a biologic response modifying agent, such agents enhance the activity of an antitumor compound or enhances the sensitivity of a tumor cell to an antitumor compound. In certain embodiments, the platinum complexes may include one or more of ammine/cycloheptylamine-dichloro-platinum(II) (complex No. 7), ammine/piperidine-dichloro-platinum(II) (complex No. 11), ammine/hexamethyleneimine-dichloro-platinum(II) (complex No. 12), and ammine/hexamethyleneimine-tetrachloro-platinum(IV) (complex No. 17), which are represented by the chemical structures described herein.

## I. PLATINUM COMPLEXES

Cisplatin is a clinically very important anticancer/antitumor metal-based drug which coordinates to DNA and distorts its double-helical conformation (Rosenberg, 1999; O'Dwyer *et al.*, 1999; Reedijk, 1996; Lepre and Lippard, 1990; Johnson *et al.*, 1989). The anticancer effects of cisplatin are associated with the capability of these distortions to terminate DNA polymerase (Comess *et al.*, 1992) and to induce apoptosis (Eastman, 1999). In addition, these distortions attract various damaged DNA-binding proteins and the binding of these proteins has been postulated to mediate the antitumor properties of cisplatin (Jamieson and Lippard, 1999; Zamble and Lippard, 1999). The compounds of the invention have antitumor activity comparable to or better than cisplatin and show little or no cross resistance, *i.e.*, resistance to cisplatin does not correspond to resistance to the compounds of the invention. Such compounds are typically more effective than cisplatin against cisplatin-resistant cell lines.

Certain embodiments of the invention may include ammine/cycloheptylamine-dichloro-platinum(II), complex #7, a compound represented by the structure:

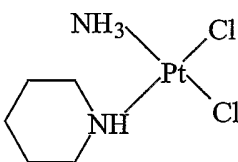


Structural Formula I

5

and salts thereof

Some embodiments of the invention may include ammine/piperidine-dichloro-platinum(II), complex #11, a compound represented by the structure:

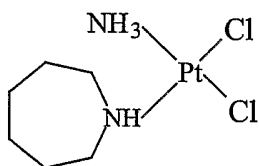


Structural Formula II

10

and salts thereof.

Various embodiments of the invention may include ammine/hexamethyleneimine-dichloro-platinum(II), complex #12, a compound represented by the structure:

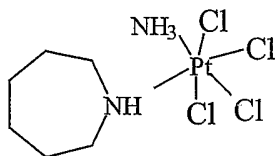


Structural Formula III

15

and salts thereof.

Other embodiments of the invention may include ammine/hexamethyleneimine-tetrachloro-platinum(IV), complex #17, a compound represented by the structure:



Structural Formula IV

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and salts thereof.

In various embodiments of the invention, a platinum complex of ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), and/or ammine/hexamethyleneimine-tetrachloro-platinum(IV) is administered to a patient in need of treatment for a cancerous or hyperproliferative condition. The complexes may be administered alone or in combination with an inhibitor or inhibitors of GSH synthesis or activity. In certain embodiments, an inhibitor or inhibitors of GSH synthesis is administered before, after or at the same approximate time as ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), ammine/hexamethyleneimine-tetrachloro-platinum(IV) or a combination thereof. In various embodiments, a patient or subject has a tumor, cancer or hyperproliferative cells that are resistant to cisplatin, carboplatin or other therapies. In some embodiments, the platinum complex is selective for cells resistant to cisplatin, carboplatin or other therapies and agents.

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## II. INHIBITORS OF GSH SYNTHESIS OR ACTIVITY

Glutathione (L-glutamyl-L-cysteine-glycine; GSH) is found in almost all cells in relatively high concentrations (1 to 10 mM) (Meister and Anderson, 1983; Anderson and Meister, 1983). GSH has a number of cellular functions. It is an effective intracellular reductant. It also functions in the catalysis, metabolism, transport and protection of cells against foreign compounds, free radicals and reactive oxygen compounds. GSH is an active participant in reactions that destroy H<sub>2</sub>O<sub>2</sub> and organic peroxides.

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GSH is synthesized intracellularly by consecutive actions of  $\gamma$ -glutamylcysteine synthetase (reaction 1) and GSH synthetase (reaction 2) (Anderson, 1997):

L-glutamate + L-cysteine + ATP  $\leftrightarrow$  L- $\gamma$ -glutamyl-L-cysteine + ADP + Pi  
(Meister and Anderson, 1983)

L- $\gamma$ -glutamyl-L-cysteine + glycine + ATP  $\leftrightarrow$  glutathione + ADP + Pi (Anderson  
and Meister; 1983)

5

The synthesis of GSH is limited by the availability of substrates, the limiting substrate is typically cysteine.  $\gamma$ -Glutamylcysteine synthetase is non-allosterically, feedback inhibited by GSH (Richman and Meister, 1973). Glutathione is homeostatically controlled, both inside and outside of the cell. Enzyme systems synthesize it, utilize it, and regenerate it in what is known as the  $\gamma$ -glutamyl cycle.

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In various embodiments of the invention, a combination therapy of a platinum complex and an inhibitor of GSH synthesis may be used as an antitumor formulation or composition and in antitumor methods or treatments.

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#### **A. Inhibitors of $\gamma$ -glutamylcysteine synthetase**

BSO was found to be a specific inhibitor of  $\gamma$ -glutamylcysteine synthetase (Griffith and Meister, 1979, incorporated herein by reference).  $\gamma$ -Glutamylcysteine synthetase catalyzes the reaction of L-glutamate with MgATP to form  $\gamma$ -glutamyl phosphate as an enzyme bound intermediate (Griffith, 1982 and Campbell *et al.*, 1991, each of which is incorporated herein by reference).

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#### **B. Inhibitors of Glutathione transferase (GST).**

Agents that inhibit the conjugation of GSH to other compounds may also be used in combination with one or more platinum complexes of the invention. Various compounds are classified as GST inhibitors. GST inhibitors include but are not limited to peptides, peptide mimetics, small molecules, and the like. Tricyclic antidepressants such as amitriptyline, doxepin, cycloheptadiene, and derivatives thereof are known to inhibit the activity of various GST enzymes. Exemplary inhibitors and methods are described in Tew *et al.*, 1997; Baranczyk *et al.*, 2001; Burg *et al.*, 2002; Tew, 1994; and Kunze, 1996.

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### III. COMBINATION THERAPY

Current treatment for many types of cancer, in particular treatment of gynecologic cancers, is mainly surgery, radiation, or chemotherapies. The present invention includes methods comprising the administration of one or more platinum complexes selected from the group consisting of ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), and ammine/hexamethyleneimine-tetrachloro-platinum(IV). The platinum complex may be administered in combination with inhibitors of glutathione synthesis or activity to patients diagnosed with various cancers and in particular cancers that have demonstrated a resistance to treatment with other platinum based therapies. Additionally, these formulations or compositions and methods may be administered in combination with other conventional and developing therapies.

In many therapies, it will be advantageous to provide more than one functional therapeutic or agent. Such "combined" therapies may have particular import in treating multiple aspects of a condition, disease, or other abnormal physiology, such as resistance to one or more conventional therapies. For example, treating multidrug resistant (MDR) cancers. Thus, one aspect of the present invention utilizes administration of one or more platinum complexes to an appropriate site in a tissue, organ or organism for treatment of diseases, while a second therapy providing therapeutic and/or enhancing or sensitizing effects is also provided.

A sensitizing or enhancing treatment may precede or follow platinum complex treatment(s) by intervals ranging from seconds, minutes up to weeks. In embodiments where the other agent and platinum complexes are administered separately to the site or subject of interest, one would generally ensure that a significant period of time did not expire between the time of each delivery, such that an agent and a platinum complex would still be able to exert an advantageously combined effect on a treatment site. In such instances, it is contemplated that one would contact the cell with both modalities within about 12-24 hours of each other and, more preferably, within about 6-12 hours of each other, with a delay time of only about 12 hours being most preferred. In some situations, it may be desirable to extend the time period for treatment significantly, however, where several days (2, 3, 4, 5, 6 or 7) to several weeks (1, 2, 3, 4, 5, 6, 7 or 8) lapse between the respective administrations.

It also is conceivable that more than one administration of either agent will be desired. Various combinations may be employed, where the platinum complex (ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II),

amine/hexamethyleneimine-dichloro-platinum(II), ammine/hexamethyleneimine-tetrachloro-platinum(IV), or a combination thereof is "A" and the other agent is "B", as exemplified below:

A/B/A B/A/B B/B/A A/A/B B/A/A A/B/B B/B/B/A B/B/A/B

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A/A/B/B A/B/A/B A/B/B/A B/B/A/A B/A/B/A B/A/A/B B/B/B/A

A/A/A/B B/A/A/A A/B/A/A A/A/B/A A/B/B/B B/A/B/B B/B/A/B

10 The other agent may be a therapeutic, enhancing and/or sensitizing agent, such as an inhibitor of GSH synthesis or other cancer therapeutics.

Other combinations are contemplated. For example, in the context of the present invention, it is contemplated that platinum complexes of the present invention could be used in conjunction with other anti-cancer agents, including chemo- or radiotherapeutic intervention. To kill cells, inhibit cell growth, inhibit metastasis, inhibit angiogenesis or otherwise reverse or reduce the malignant phenotype of tumor cells, using the methods and formulations/compositions of the present invention, one would generally contact a "target" cell with a platinum complex, as described herein and at least one other agent, such as a GSH synthesis inhibitor; these formulations/compositions would be provided in a combined amount effective achieve these goals. This process may involve exposing the site(s) targeted for treatment with the platinum complexes and an other agent(s) or factor(s) at the same time. This may be achieved by administering or providing a single composition or pharmacological formulation that includes both agents, or by administering two distinct compositions or formulations, at the same or different time, wherein one composition includes a platinum complex(es) and another includes the sensitizing or enhancing agent. In certain embodiments, the compositions and methods of the invention may be used after or before standard cisplatin therapy.

In other embodiments an agent suitable for use in a combined therapy with the platinum complexes of the invention are any chemical compound or treatment method with therapeutic activity. For example, an "anticancer agent" refers to an agent with anticancer activity. These compounds or methods include other alkylating agents, topoisomerase I inhibitors, topoisomerase II inhibitors, RNA/DNA antimetabolites, DNA antimetabolites, antimitotic agents, as well as DNA damaging agents, which induce DNA damage when applied to a cell.

Examples of alkylating agents include, *inter alia*, chloroambucil, cis-platinum, cyclodisone, flurodopan, methyl CCNU, piperazinedione, teroxirone. Topoisomerase I inhibitors encompass compounds such as camptothecin and camptothecin derivatives, as well as morpholinodoxorubicin. Doxorubicin, pyrazoloacridine, mitoxantrone, and rubidazone are illustrations of topoisomerase II inhibitors. RNA/DNA antimetabolites include L-alanosine, 5-fluorouracil, aminopterin derivatives, methotrexate, and pyrazofurin; while the DNA antimetabolite group encompasses, for example, ara-C, guanazole, hydroxyurea, thiopurine. Typical antimetabolic agents are colchicine, rhizoxin, taxol, and vinblastine sulfate. Other agents and factors include radiation and waves that induce DNA damage such as,  $\gamma$ -irradiation, X-rays, UV-irradiation, microwaves, electronic emissions, and the like. A variety of anti-cancer agents, also described as "chemotherapeutic agents," function to induce DNA damage, all of which are intended to be of use in the combined treatment methods disclosed herein. Chemotherapeutic agents contemplated to be of use, include, *e.g.*, adriamycin, bleomycin, 5-fluorouracil (5FU), etoposide (VP-16), camptothecin, actinomycin-D, mitomycin C, cisplatin (CDDP), podophyllotoxin, verapamil, and even hydrogen peroxide. The invention also encompasses the use of a combination of one or more DNA damaging agents, whether radiation-based or actual compounds, such as the use of X-rays with cisplatin or the use of cisplatin with etoposide.

The skilled artisan is directed to "Remington's Pharmaceutical Sciences" 15th Edition, chapter 33, in particular pages 624-652. Some variation in dosage will necessarily occur depending on the condition of the subject being treated. The person responsible for administration will, in any event, determine the appropriate dose for the individual subject. Moreover, for human administration, preparations should meet sterility, pyrogenicity, general safety and purity standards as required by FDA Office of Biologics standards.

In addition to combining platinum complex therapies with sensitizing, or chemo- and radiotherapies, it also is contemplated that combination with gene therapies will be advantageous. For example, using a combination of p53, p16, p21, Rb, APC, DCC, NF-1, NF-2, BCRA2, p16, FHIT, WT-1, MEN-I, MEN-II, BRCA1, VHL, FCC, or MCC, or antisense versions of the oncogenes ras, myc, neu, raf, erb, src, fms, jun, trk, ret, gsp, hst, bcl, abl, or any of the genes mentioned above are included within the scope of the invention.

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#### IV. DISEASE STATES

The present invention deals with the treatment of disease states that involve hyperproliferative disorders including benign and malignant neoplasias. Such disorders include

hematological malignancies, restenosis, cancer, multi-drug resistant cancer, primary, psoriasis, inflammatory bowel disease, rheumatoid arthritis, osteoarthritis and metastatic tumors.

In particular, the present invention is directed at the treatment of human cancers including cancers of the prostate, lung, brain, skin, liver, breast, lymphoid system, stomach, 5 testicular, ovarian, pancreatic, bone, bone marrow, head and neck, cervical, esophagus, eye, gall bladder, kidney, adrenal glands, heart, colon, rectum and blood, in particular those cancers that have developed or may develop resistance to conventional chemotherapies. Other diseases that may be treated with formulations/compositions or methods of the invention also may include renal cell carcinomas; viral infections such as, hepatitis C (Garini *et al.*, 2001), HIV-1 (Hatzakis 10 *et al.*, 2001); Erdheim-Chester disease (Esmali *et al.*, 2001), thrombocytopenic purpura (Dikici *et al.*, 2001), marburg hemorrhagic fever (Kolokol'tsov *et al.*, 2001) In certain embodiments, methods and formulations/compositions are used to treat a subject with ovarian cancer.

## V. SYNTHESIS OF PLATINUM COMPLEXES

### 15 A. Preparation of Ammine/cyclopentylamine-dichloro-platinum(II) *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)Cl<sub>2</sub> (compound #5)

An aqueous solution of K<sub>2</sub>PtCl<sub>4</sub> (8.30 g; 20 mmol) was treated with KI (33.2 g; 200 mmol) and stirred for 10 minutes at room temperature. Two equivalents of cyclopentylamine were added dropwise to the K<sub>2</sub>PtCl<sub>4</sub> solution. Upon stirring for 30 minutes a yellow precipitate 20 (*cis*-Pt<sup>II</sup>(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub>) was formed. The yellow precipitate was filtered and washed extensively with water. The precipitate was recrystallized from a DMF/H<sub>2</sub>O mixture. After washing with water, methanol, and ethyl ether, the crystallized product (*cis*-Pt<sup>II</sup>(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub>) was dried *in vacuo*.

One hundred fifty milliliters (mL) of ethanol was added to a suspension of *cis*-Pt<sup>II</sup>(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> (6.19 g; 10 mmol) in 50 mL of 60-70% HClO<sub>4</sub>. In the course of the reaction samples were taken for analysis by <sup>195</sup>Pt NMR spectroscopy. At the end of 4 days of stirring at room temperature a brown precipitate ([Pt<sup>II</sup>(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)<sub>2</sub>]I<sub>2</sub>) was filtered, washed with water, and dried *in vacuo*. 25

[Pt<sup>II</sup>(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)<sub>2</sub>]I<sub>2</sub> (5.25 g; 5 mmol) was mixed with 5 mL of 1.5 M NH<sub>4</sub>OH in 25 mL 30 of water. The mixture was stirred at room temperature overnight. Again the completeness of the reaction was monitored by <sup>195</sup>Pt NMR spectroscopy. A yellow precipitate (*cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)I<sub>2</sub>) was filtered, washed with water, and dried *in vacuo*.

*cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>5</sub>H<sub>9</sub>NH<sub>2</sub>)I<sub>2</sub> (2.20 g; 4mmol) was mixed with AgNO<sub>3</sub> (1.25 g; 7.4 mmol) in 200 mL of water and stirred overnight in the dark. After the removal of AgI by filtration

through celite, 10 mL of concentrated HCl was added to the filtrate. The mixture was allowed to stir for 3 hours and then evaporated to approximately 2 mL under reduced pressure. A yellow precipitate ( $cis\text{-Pt}^{\text{II}}(\text{NH}_3)(c\text{-C}_5\text{H}_9\text{NH}_2)\text{Cl}_2$ ) was filtered, washed with water and acetone, and dried *in vacuo*.

5           **B.     Preparation of Ammine/cycloheptylamine-dichloro-platinum(II)**  
                  **[Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub>] (compound #7)**

An aqueous solution of K<sub>2</sub>PtCl<sub>4</sub> (8.30 g; 20 mmol) was treated with KI (33.2 g; 200 mmol) and stirred for 10 minutes at room temperature. Two equivalents of cycloheptylamine were added dropwise to the resulting K<sub>2</sub>PtCl<sub>4</sub> solution. Upon stirring for 30 minutes yellow precipitate ( $cis\text{-Pt}^{\text{II}}(c\text{-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$ ) was formed. The yellow precipitate was filtered and washed extensively with water. The precipitate was recrystallized from a DMF/H<sub>2</sub>O mixture. After washing with water, methanol, and ethyl ether, the product ( $cis\text{-Pt}^{\text{II}}(c\text{-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$ ) was dried *in vacuo*.

One hundred fifty milliliters (mL) of ethanol was added to a suspension of  $cis\text{-Pt}^{\text{II}}(c\text{-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$  (10 mmol) in 50 mL of 60-70% HClO<sub>4</sub>. In the course of reaction samples were taken for analysis by <sup>195</sup>Pt NMR spectroscopy. At the end of 4 days of stirring at room temperature a brown precipitate ([Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub>) was filtered, washed with water, and dried *in vacuo*.

[Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> (5 mmol) was mixed with 5 mL of 1.5M NH<sub>4</sub>OH in 25 mL of water. The mixture was stirred at room temperature overnight. Again the completeness of the reaction was monitored by <sup>195</sup>Pt NMR spectroscopy. A yellow precipitate ( $cis\text{-Pt}^{\text{II}}(\text{NH}_3)(c\text{-C}_7\text{H}_{11}\text{NH}_2)\text{I}_2$ ) was filtered, washed with water, and dried *in vacuo*.

$cis\text{-Pt}^{\text{II}}(\text{NH}_3)(c\text{-C}_7\text{H}_{11}\text{NH}_2)\text{I}_2$  (4 mmol) was mixed with AgNO<sub>3</sub> (1.25 g; 7.4 mmol) in 200 mL of water and stirred overnight in the dark. After the removal of AgI by filtration through celite, 10 mL of concentrated HCl was added to the filtrate, the mixture was allowed to stir for 3 hours and then evaporated to approximately 2 mL under reduced pressure. The yellow precipitate (Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub>) was filtered, washed with water and acetone, and dried *in vacuo*.

30           **C.     Preparation of Ammine/piperidine-dichloro-platinum(II)**  
                  **[Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>5</sub>H<sub>11</sub>N)Cl<sub>2</sub>] (compound #11)**

Cosa salt K[Pt(NH<sub>3</sub>)Cl<sub>3</sub>] (1.98 g; 5.5 mmol) was dissolved in 50 mL of water. KI (9.19 g; 55 mmol) in 100 mL of water was added to the Cosa salt solution. A brown solution was formed upon the addition the KI solution. The reaction mixture was stirred for 20 minutes.

Piperidine (55 mmol) in 10 mL of water was added dropwise to the reaction mixture until a golden yellow precipitate ( $[\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2]$ ) was formed. The reaction mixture was kept stirring for another hour. The precipitate was filtered, washed with acetone, and dried *in vacuo*. A golden yellow compound  $[\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2]$  was obtained.  $[\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2]$  (2.39 g, 4.24 mmol) was suspended in 100 ml of water.  $\text{AgNO}_3$  (1.44 g; 8.48 mmol) in 100 mL was added. The reaction mixture stirred for 24 hours in the dark, at room temperature.  $\text{AgI}$  precipitate was filtered, and the filtrate was evaporated to 50 mL.  $\text{HCl}$  (1:1) was added dropwise while stirring. A bright yellow compound  $[\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{Cl}_2]$  was obtained. It was filtered and re-crystallized with hot water and dried under vacuum.

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**D. Preparation of Ammine/hexamethyleneimine-dichloro-platinum(II) *cis*- $\text{Pt}^{\text{II}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  (compound # 12)**

Cosa salt  $\text{K}[\text{Pt}(\text{NH}_3)\text{Cl}_3]$  (1.98 g; 5.5 mmol) was dissolved in 50 mL of water.  $\text{KI}$  (9.19 g; 55 mmol) in 100 mL of water was added. A brown solution was formed. The reaction mixture was stirred for 20 minutes. Hexamethylenimine (55 mmol) in 10 mL of water was added dropwise to the reaction mixture until a golden yellow precipitate ( $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$ ) was formed. The reaction mixture was kept stirring for another hour. The precipitate was filtered, washed with acetone, and dried in vacuum. A golden yellow compound ( $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$ ) was obtained.  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$  (4.24 mmol) was suspended in 100 ml of water.  $\text{AgNO}_3$  (1.44 g; 8.48 mmol) in 100 mL was added. The reaction mixture stirred for 24 hours in the dark, at room temperature. An  $\text{AgI}$  precipitate was filtered, and the filtrate was evaporated to 50 mL.  $\text{HCl}$  (1:1) was added dropwise while stirring. A bright yellow compound  $[\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2]$  was obtained. It was filtered and re-crystallized with hot water and dried under vacuum.

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**E. Preparation of Ammine/hexamethyleneimine-tetrachloro-platinum(IV)  $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_4$  (compound # 17)**

Ten milliliters of  $\text{H}_2\text{O}_2$  was added to a suspension of  $\text{Pt}^{\text{II}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  (1.0 g; 2.61 mmol) in 200 mL of water and was stirred for 15 hours. The solution was filtered, concentrated to a minimum volume, and precipitated with acetone. A yellow product ( $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{trans}-(\text{OH})_2\text{Cl}_2$ ) was obtained. ( $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{trans}-(\text{OH})_2\text{Cl}_2$ ) was dried *in vacuo*.  $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{trans}-(\text{OH})_2\text{Cl}_2$  (0.650 g; 1.64 mmol) was dissolved in 100 mL of water and 20 mL of concentrated  $\text{HCl}$  was added. The reaction mixture was kept stirring for 24 hours at room temperature. A clear yellow solution was obtained. It was filtered,

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concentrated to a minimum volume to get a yellow crystalline solid ( $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_4$ ). It was filtered, washed with water, and dried under vacuum.

## VI. PHARMACEUTICAL PREPARATIONS

5           Pharmaceutical formulations/compositions of the present invention comprise an effective amount of platinum complex, as described herein. In various other embodiments, combinations of a platinum complex and a biological modifier agent(s) are dissolved or dispersed in a pharmaceutically acceptable carrier. The phrases "pharmaceutical or pharmacologically acceptable" refers to molecular entities and compositions that do not produce an adverse, allergic  
10 or other untoward reaction when administered to an animal, such as, for example, a human, as appropriate. The preparation of a pharmaceutical composition that contain a platinum complex of the invention and/or in combination with an inhibitor of glutathione synthesis or additional active ingredient will be known to those of skill in the art in light of the present disclosure. Examples and guidance for pharmaceutical composition and methods known to one skilled in the  
15 art may be found in Remington's Pharmaceutical Sciences, 18th Ed. Mack Printing Company, 1990, incorporated herein by reference. Moreover, for animal (*e.g.*, human) administration, it will be understood that preparations should meet sterility, pyrogenicity, general safety and purity standards as required by FDA Office of Biological Standards.

As used herein, "pharmaceutically acceptable carrier" includes any and all solvents,  
20 dispersion media, coatings, surfactants, antioxidants, preservatives (*e.g.*, antibacterial agents, antifungal agents), isotonic agents, absorption delaying agents, salts, preservatives, drugs, drug stabilizers, gels, binders, excipients, disintegration agents, lubricants, sweetening agents, flavoring agents, dyes, such like materials and combinations thereof, as would be known to one of ordinary skill in the art (see, for example, Remington's Pharmaceutical Sciences, 18th Ed.  
25 Mack Printing Company, 1990, pp. 1289-1329, incorporated herein by reference). Except insofar as any conventional carrier is incompatible with the active ingredient, its use in the therapeutic or pharmaceutical compositions is contemplated.

The compositions comprising the platinum complexes of the invention or a combination of the platinum complexes of the invention and inhibitors of glutathione synthesis may comprise  
30 different types of carriers depending on whether it is to be administered in a solid or liquid form, and whether it needs to be sterile for such routes of administration as injection. The present invention can be administered intravenously, intradermally, intraarterially, intramuscularly, intraperitoneally, subcutaneously, orally, by injection, by infusion, by continuous infusion, in lipid compositions (*e.g.*, liposomes), or by other methods or any combination of the foregoing as

would be known to one of ordinary skill in the art (see, for example, Remington's Pharmaceutical Sciences, 18th Ed. Mack Printing Company, 1990, incorporated herein by reference). Compositions contemplated or encompassed by the instant invention include conventional pharmaceutical formulations, including intravenously administered formulation(s) or by any other method or any combination of the foregoing as would be known to one of ordinary skill in the art (see for example, Remington's Pharmaceutical Sciences, 18th Ed., Mack Printing Company, 1990, incorporated herein by reference).

The actual dosage amount of a composition of the present invention administered to a subject can be determined by physical and physiological factors such as body weight, severity of condition, the type of disease being treated, previous or concurrent therapeutic interventions, idiopathy of the patient and on the route of administration. The practitioner responsible for administration will, in any event, determine the concentration of active ingredient(s) in a composition and appropriate dose(s) for the individual subject.

In certain embodiments, pharmaceutical compositions may comprise, for example, at least about 0.1% of an active compound. In other embodiments, the an active compound may comprise between about 2% to about 75% of the weight of the unit, or between about 25% to about 60%, for example, and any range derivable therein. In other non-limiting examples, a dose may also comprise from about 1 microgram/kg/body weight, about 5 microgram/kg/body weight, about 10 microgram/kg/body weight, about 50 microgram/kg/body weight, about 100 microgram/kg/body weight, about 200 microgram/kg/body weight, about 350 microgram/kg/body weight, about 500 microgram/kg/body weight, about 1 milligram/kg/body weight, about 5 milligram/kg/body weight, about 10 milligram/kg/body weight, about 50 milligram/kg/body weight, about 100 milligram/kg/body weight, about 200 milligram/kg/body weight, about 350 milligram/kg/body weight, about 500 milligram/kg/body weight, to about 1000 mg/kg/body weight or more per administration, and any range derivable therein. In non-limiting examples of a derivable range from the numbers listed herein, a range of about 5 mg/kg/body weight to about 100 mg/kg/body weight, about 5 microgram/kg/body weight to about 500 milligram/kg/body weight, *etc.*, can be administered, based on the numbers described above. Also, dosage may be approximately 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 30, 40, 50, 60, 70, 80, 90, 100 or more mg/m<sup>2</sup> including all doses there between.

In various embodiments the concentration of a platinum complex in a pharmaceutical formulation or composition may be in the approximate range of 0.1  $\mu$ M, 0.5  $\mu$ M, 1  $\mu$ M, 2  $\mu$ M, 3  $\mu$ M, 4  $\mu$ M, 5  $\mu$ M, 6  $\mu$ M, 7  $\mu$ M, 8  $\mu$ M, 9  $\mu$ M, 10  $\mu$ M, 25  $\mu$ M, 50  $\mu$ M, 0.1 mM, 0.5 mM, 1 mM to

10  $\mu\text{M}$ , 11  $\mu\text{M}$ , 12  $\mu\text{M}$ , 13  $\mu\text{M}$ , 14  $\mu\text{M}$ , 15  $\mu\text{M}$ , 16  $\mu\text{M}$ , 17  $\mu\text{M}$ , 18  $\mu\text{M}$ , 19  $\mu\text{M}$ , 20 $\mu\text{M}$ , 50  $\mu\text{M}$ ,  
0.1 mM, 1 mM, 2 mM, 3 mM, 4 mM, 5 mM, 6 mM, 7 mM, 8 mM, 9 mM, or 10 mM.

In any case, the formulation or composition may comprise various antioxidants to retard  
oxidation of one or more component. Additionally, the prevention of the action of  
5 microorganisms can be brought about by preservatives such as various antibacterial and  
antifungal agents, including but not limited to parabens (*e.g.*, methylparabens, propylparabens),  
chlorobutanol, phenol, sorbic acid, thimerosal or combinations thereof.

The therapeutic compositions of the present invention may be formulated into a  
composition in a free base, neutral or salt form. Pharmaceutically acceptable salts, include the  
10 acid addition salts, *e.g.*, those formed with the free amino groups of a proteinaceous composition,  
or which are formed with inorganic acids such as for example, hydrochloric or phosphoric acids,  
or such organic acids as acetic, oxalic, tartaric or mandelic acid. Salts formed with the free  
carboxyl groups can also be derived from inorganic bases such as for example, sodium,  
potassium, ammonium, calcium or ferric hydroxides; or such organic bases as isopropylamine,  
15 trimethylamine, histidine or procaine.

In certain embodiments, the therapeutic compositions of the present invention are  
typically prepared for administration by such routes as intravenous injection. In these  
embodiments, the composition may comprise, for example, solutions, suspensions, emulsions, or  
combinations thereof.

20 Sterile injectable solutions are prepared by incorporating the active compounds in the  
required amount in the appropriate solvent with various of the other ingredients enumerated  
above, as required, followed by filtered sterilization. Generally, dispersions are prepared by  
incorporating the various sterilized active ingredients into a sterile vehicle which contains the  
basic dispersion medium and/or the other ingredients. In the case of sterile powders for the  
25 preparation of sterile injectable solutions, suspensions or emulsions, the preferred methods of  
preparation are vacuum-drying or freeze-drying techniques which yield a powder of the active  
ingredient plus any additional desired ingredient from a previously sterile-filtered liquid medium  
thereof. The liquid medium should be suitably buffered if necessary and the liquid diluent first  
rendered isotonic prior to injection with sufficient saline or glucose. The preparation of highly  
30 concentrated compositions for direct injection is also contemplated, where the use of DMSO as a  
solvent is envisioned to result in extremely rapid penetration, delivering high concentrations of  
the active agents to a small area.

The composition must be stable under the conditions of manufacture and storage, and  
preserved against the contaminating action of microorganisms, such as bacteria and fungi. It will

be appreciated that endotoxin contamination should be kept minimally at a safe level, for example, less than 0.5 ng/mg protein.

## VII. EXAMPLES

5           The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventor to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate  
10          that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

### EXAMPLE 1

#### EXPERIMENTAL PROCEDURE

15

          The ovarian A2780 and 2008 cell lines are sensitive to cisplatin, while the corresponding 2780CP and 2008/C13\* cell lines were selected for resistance following *in vitro* exposure to cisplatin. The SKOV-3 cell line was established from a patient who was resistant to cisplatin therapy and is considered a model of cisplatin resistance. The A2780 and 2780CP cells have  
20          wild-type p53 function, while SKOV-3 is devoid of p53 function. The p53 status for the 2008 and 2008/C131 cells is presently not known.

**Procedure for Cytotoxic Evaluation.** All cell lines are maintained in RPMI 1640 medium supplemented with 10% fetal bovine serum, 50 µg/ml penicillin, 50 µg/ml streptomycin, 100 µg/ml neomycin and 0.3 mg/ml L-glutamine. The ovarian lines also require 2 µg/ml insulin  
25          for maximal growth. Cells are grown as monolayers at 37°C in a humidified atmosphere of 5% CO<sub>2</sub> : 95% air. Cytotoxicity is determined by a standard MTT assay. Briefly, the exponentially-growing cells are trypsinized to dislodge them before use. After diluting the tumor cells to appropriate concentrations (2,000-30,000 cells/ml), 100 µl aliquots of the cell suspensions are added to each well of a 96-well microtiter plate. The cells are allowed to attach overnight, and  
30          then exposed for 24 hr to BSO at a concentration that is equal to or less than maximally tolerated concentration (MTC). At 22 hr after addition of BSO, the platinum complex is added, and 2 hr later the cells are washed and reincubated. After another 5 days, when control cells are in an exponential phase of growth, 50 µl of an MTT solution (3 mg/ml) is added to each well.

Following a 3-hr incubation, the medium is removed and replaced by 50  $\mu$ l of 100% DMSO to dissolve MTT formazan crystals. Plates are agitated on a plate shaker for 5 min, and absorbances are measured at 570 nm in a multiwell scanning spectrophotometer.

5  $IC_{50}$  values, defined as the drug concentration ( $\mu$ M) inhibiting cell growth by 50% compared to control wells, are determined by fitting a sigmoidal curve to the data using a computer program. Resistance factor is calculated as a ratio of the  $IC_{50}$  against resistant cell line to the  $IC_{50}$  against parent cell line. The dose modification factor (DMF) is derived from a ratio of  $IC_{50}$  without BSO to that with BSO.

10

## EXAMPLE 2

### EVALUATION of ANTITUMOR ACTIVITY

15 The inventors have identified specific platinum complexes which when administered in combination with an inhibitor of GSH synthesis (*e.g.*, BSO), show (1) substantially greater enhancement in antitumor activity, and (2) selectivity for cisplatin-resistant cells. The data demonstrates that in isogenic pairs of sensitive and resistant tumor models, the activity of specific analogs is much greater against resistant cells than against sensitive cells (Table 1).

**Table 1. Cytotoxicity of Cisplatin and Analogs Against Human A2780 and 2780CP Cell Lines in Absence or Presence of BSO**

Platinum analog Complex #.	IC <sub>50</sub> (μM) vs. A2780		IC <sub>50</sub> (μM) vs. 2780CP		
	Control (Without BSO)	+10 μM BSO (MTC)	Control (Without BSO)	+10 μM BSO	+ 3mM BSO (MTC)
1 (Cisplatin)	6.75	4.25	100.6	82.0	58.3
2	0.56	0.41	4.61	3.69	2.46
3	3.64	3.46	63.7	62.2	48.8
4	1.03	0.77	16.6	16.0	15.8
5	0.73	0.66	15.2	14.5	9.07
6	0.63	0.50	7.55	6.98	4.19
7	1.23	0.94	12.3	6.92	1.96
8	0.77	0.61	7.41	5.97	2.35
9	4.27	3.02	27.2	18.7	8.20
10	4.08	2.90	37.2	28.2	17.2
11	2.33	1.66	12.2	4.00	0.90
12	2.34	1.56	11.3	3.45	1.03
13	8.48	4.57	44.8	34.9	23.5
14	1.25	1.17	15.8	15.5	9.54
15	0.91	0.72	15.4	10.8	4.34
16	3.55	3.07	23.9	19.6	8.92
17	3.27	1.60	9.54	Nd	0.87

MTC = Maximal tolerated concentration of BSO.

nd = not determined.

5

It is suggested that increased levels of GSH may constitute a mechanism of cisplatin resistance and that GSH inactivates the platinum complex by reducing the amount of the antitumor agent available. More recently, GSH has been implicated in modulation of programmed cell death or apoptosis pathways. Increased levels of GSH may inhibit the apoptotic process and, thereby, increase resistance to anti-tumor therapy or treatment. Thus, the inventors determined whether, reduction in cellular levels of GSH with BSO or other compounds that inhibit the activity or synthesis of GSH, increased the antitumor activity of cisplatin and other platinum complexes or compounds.

Cisplatin and a number of platinum analogs when combined with BSO showed an increase in antitumor activity by a factor less than 2-fold in both sensitive and resistant models (Table 2). Specific analogs, such as complex Nos. 7, 11, 12, and 17 (ammine/cycloheptylaminedichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneiminedichloro-platinum(II), and ammine/hexamethyleneimine-tetrachloro-platinum(IV), respectively) increased activity 5 to 14-fold in GSH-depleted human 2780CP tumor cells. These analogs also demonstrate selectively greater effectiveness against these cisplatin-resistant cells than the

corresponding A2780 cisplatin-sensitive cells. The resistance factor for these analogs was also substantially reduced as demonstrated in Table 3 below. In particular, complex nos. 11, 12 and 17) showed a resistance factor 0.39, 0.44 and 0.27 respectively (Table 3). This increased activity was seen in human tumor cell lines harboring either wild-type or null p53 (Tables 4-6) and was found to be independent of p53 status.

**Table 2. Dose Modification Factor (DMF) for Cisplatin and Analogs in Combination with BSO in Human A2780 and 2780CP Cell Lines**

Platinum analog	DMF vs. A2780		DMF vs. 2780CP		
	Control (Without BSO)	+ 10 $\mu$ M BSO (MTC)	Control (Without BSO)	+ 10 $\mu$ M BSO	+3 mMBSO (MTC)
1 (Cisplatin)	1.00	1.59	1.00	1.23	1.73
2	1.00	1.37	1.00	1.25	1.87
3	1.00	1.05	1.00	1.02	1.31
4	1.00	1.34	1.00	1.04	1.05
5	1.00	1.11	1.00	1.05	1.68
6	1.00	1.26	1.00	1.08	1.80
7	1.00	1.31	1.00	1.78	6.28
8	1.00	1.26	1.00	1.24	3.15
9	1.00	1.41	1.00	1.45	3.32
10	1.00	1.41	1.00	1.32	2.16
11	1.00	1.40	1.00	3.05	13.6
12	1.00	1.50	1.00	3.28	11.0
13	1.00	1.86	1.00	1.28	1.91
14	1.00	1.07	1.00	1.02	1.66
15	1.00	1.26	1.00	1.43	3.55
16	1.00	1.16	1.00	1.22	2.68
17	1.00	2.04	1.00	nd	11.0

DMF determined as the ratio of IC<sub>50</sub> in absence (control) of BSO to IC<sub>50</sub> in presence of BSO.

MTC = Maximal tolerated concentration of BSO

nd = not determined.

10

**Table 3. Resistance Factor for Cisplatin and Analogs in the Human 2780CP Cell Line in Absence or Presence of BSO**

Platinum analog	Resistance Factor vs. 2780CP		
	Control (Without BSO)	+10 $\mu$ M BSO	+3 mM BSO (MTC)
1 (Cisplatin)	14.9	12.1	8.63
2	8.23	6.59	4.39
3	17.5	17.1	13.4
4	16.1	15.5	15.3
5	20.8	19.9	12.4
6	12.0	11.1	6.65
7	10.0	5.63	1.59
8	9.62	7.75	3.05
9	6.37	4.38	1.92
10	9.12	6.91	4.22
11	5.24	1.72	0.39
12	4.83	1.47	0.44
13 (Tetraplatin)	5.28	4.12	2.77
14	12.6	12.4	7.63
15	16.9	11.9	4.77
16	6.73	5.52	2.51
17	2.92	Nd	0.27

Resistance factor was determined as the ratio of  $IC_{50}$  in 2780CP cells with or without BSO to  $IC_{50}$  in A2780 cells without BSO.

- 5 MTC = Maximal tolerated concentration of BSO.  
nd = not determined

**Table 4. Cytotoxicity of Cisplatin and Analogs Against Human Tumor Cell Lines in Absence or Presence of BSO**

10

Cell Line	$IC_{50}$ of Cisplatin ( $\mu$ M)		$IC_{50}$ of complex No. 12		$IC_{50}$ of complex No. 17		$IC_{50}$ of complex No. 18		$IC_{50}$ of complex No. 19	
	Control	+ BSO (MTC)	Control	+BSO (MTC)	Control	+BSO (MTC)	Control	+BSO (MTC)	Control	+BSO (MTC)
A2780	6.75	4.25	2.34	1.56	3.27	1.60	nd	nd	nd	nd
2780CP	100.6	58.3	11.3	1.03	9.54	0.87	nd	nd	Nd	nd
2008	1.42	0.77	3.71	0.82	Nd	nd	nd	nd	Nd	nd
2008/C1	20.8	10.4	11.8	0.77	11.8	0.41	nd	nd	Nd	nd
SKOV-3	33.0	21.1	24.7	1.41	22.1	1.80	140.0	14.2	100.0	21.6

Cytotoxicity of platinum complexes determined in absence (control) or presence of BSO [maximal tolerated concentration (MTC) for all cell lines, except SKOV-3 for which a sub-MTC was used].  
nd = not determined.

15

**Table 5. Dose Modification Factor (DMF) for Cisplatin and Analogs in Human Tumor Cell Lines in Absence or Presence of BSO**

Cell Line	DMF for Cisplatin		DMF for complex No. 12		DMF for complex No. 17		DMF for complex No. 18		DMF for complex No. 19	
	Control	+BSO (MTC)	Control	+BSO (MTC)	Control	+BSO (MTC)	Control	+BSO (MTC)	Control	+BSO (MTC)
A2780	1.00	1.59	1.00	1.50	1.00	2.04	nd	nd	Nd	Nd
2780CP	1.00	1.73	1.00	11.0	1.00	11.0	nd	nd	Nd	Nd
2008	1.00	1.84	1.00	4.52	Nd	nd	nd	nd	Nd	Nd
2008/C13*	1.00	2.00	1.00	15.3	1.00	28.8	nd	nd	Nd	Nd
SKOV-3	1.00	1.56	1.00	17.5	1.00	12.3	1.00	9.86	1.00	4.63

DMF determined as the ratio of IC<sub>50</sub> in absence (control) of BSO to IC<sub>50</sub> in presence of BSO (maximal tolerated concentration (MTC) of BSO used for all cell lines, except SKOV-3 for which a sub-MTC was used).  
 nd = not determined.

**Table 6. Resistance Factor (RF) for Cisplatin and Analogs in Human Tumor Cell Lines in Absence or Presence of BSO**

Cell Line	RF for Cisplatin		RF for complex No. 12		RF for complex No. 17		Rf for complex No. 18		RF for complex No. 19	
	Control	+ BSO (MTC)	Control	+ BSO (MTC)	Control	+ BSO (MTC)	Control	+ BSO (MTC)	Control	+BSO (MTC)
A2780	1.00	--	1.00	--	1.00	--	nd		nd	--
2780CP	14.9	8.63	4.83	0.44	2.92	0.27	nd		Nd	nd
2008	1.00	--	1.00	--	Nd	--	nd	nd	Nd	--
2008/C13*	14.6	7.32	3.18	0.21	Nd	Nd	nd	nd	Nd	nd
SKOV-3	23.2	14.9	6.66	0.38	Nd	Nd	nd	nd	Nd	nd

Resistance factor was determined either as (1) the ratio of IC<sub>50</sub> in 2780CP cells with or without BSO to IC<sub>50</sub> in A2780 cells without BSO, or (2) the ratio of IC<sub>50</sub> in 2008/C13\* and SKOV-3 cell lines with or without BSO to IC<sub>50</sub> in 2008 cells without BSO.

MTC = Maximal tolerated concentration of BSO.  
 nd = not determined.

\*\*\*\*\*

All of the compositions and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents that are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved.

All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

### REFERENCES

The following references, to the extent that they provide exemplary procedural or other details supplementary to those set forth herein, are specifically incorporated herein by reference.

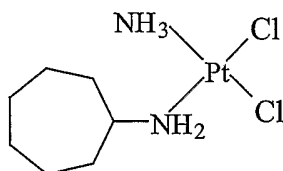
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CLAIMS

1. An antitumor formulation comprising a compound represented by the structural formula



5

or salts thereof.

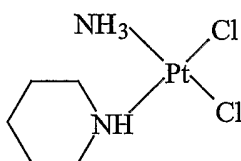
2. The formulation of claim 1, further comprising an negative modulator of glutathione.

- 10 3. The formulation of claim 2, wherein the negative modulator of glutathione is an inhibitor of glutathione synthesis.

4. The formulation of claim 3, wherein the inhibitor of glutathione synthesis is L-buthionine-sulfoximine.

15

5. An antitumor formulation comprising a compound represented by the structural formula



or salts thereof.

20

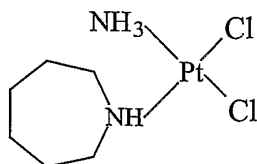
6. The formulation of claim 5, further comprising an negative modulator of glutathione.

7. The formulation of claim 6, wherein the negative modulator of glutathione is an inhibitor of glutathione synthesis.

25

8. The formulation of claim 7, wherein the inhibitor of glutathione synthesis is L-buthionine-sulfoximine.
9. An antitumor formulation comprising a compound represented by the structural formula

5



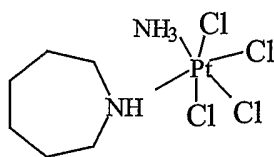
or salts thereof.

10. The formulation of claim 9, further comprising an negative modulator of glutathione.
11. The formulation of claim 10, wherein the negative modulator of glutathione is an inhibitor of glutathione synthesis.
12. The formulation of claim 11, wherein the inhibitor of glutathione synthesis is L-buthionine-sulfoximine.

10

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13. An antitumor formulation comprising a compound represented by the structural formula



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or salts thereof

14. The formulation of claim 13, further comprising an negative modulator of glutathione.

25

15. The formulation of claim 14, wherein the negative modulator of glutathione is an inhibitor of glutathione synthesis.
- 5 16. The formulation of claim 15, wherein the inhibitor of glutathione synthesis is L-buthionine-sulfoximine.
- 10 17. A pharmaceutical formulation comprising a platinum complex selected from the group consisting of ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), and ammine/hexamethyleneimine-tetrachloro-platinum(IV).
18. The pharmaceutical formulation of claim 17, wherein the concentration of a selected platinum complex is in the approximate range of 0.1 mM to 20 mM.
- 15 19. The pharmaceutical formulation of claim 17, wherein the concentration of a selected platinum complex is in the approximate range of 1 mM to 10 mM.
- 20 20. The pharmaceutical formulation of claim 17, wherein the concentration of a selected platinum complex is in the approximate range of 1 mM to 5 mM.
21. The pharmaceutical formulation of claim 17, further comprising a biologic modifier of glutathione.
- 25 22. The pharmaceutical formulation of claim 21, wherein the biologic modifier of glutathione is an inhibitor of glutathione synthesis.
23. The pharmaceutical formulation of claim 22, wherein the inhibitor of glutathione synthesis is L-buthionine-sulfoximine.
- 30 24. The pharmaceutical formulation of claim 17, wherein the concentration of L-buthionine-sulfoximine is in the approximate range of 1  $\mu$ M to 300  $\mu$ M.
25. The pharmaceutical formulation of claim 17, wherein the concentration of L-buthionine-sulfoximine is in the approximate range of 10  $\mu$ M to 200  $\mu$ M.

26. The pharmaceutical formulation of claim 17, wherein the concentration of L-buthionine-sulfoximine is in the approximate range of 20  $\mu$ M to 100  $\mu$ M.
- 5 27. The pharmaceutical formulation of claim 17, further defined as an intravenous pharmaceutical formulation.
28. A method of inhibiting the proliferation of a cisplatin-resistant cell comprising providing to the cell ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-  
10 platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), or ammine/hexamethyleneimine-tetrachloro-platinum(IV).
29. The method of claim 28, wherein the cisplatin-resistant cell is located in a subject.
- 15 30. The method of claim 29, wherein the subject is a mammal.
31. The method of claim 30, wherein the mammal is a human or mouse.
32. The method of claim 28, further comprising providing a biologic modifier of glutathione.  
20
33. The method of claim 32, wherein the biologic modifier of glutathione is an inhibitor of glutathione synthesis.
34. The method of claim 33, wherein the inhibitor of glutathione synthesis is L-buthionine-  
25 sulfoximine.
35. A method of treating a cancer cell comprising providing to the cell ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-  
30 platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), or ammine/hexamethyleneimine-tetrachloro-platinum(IV).
36. The method of claim 35, wherein the cancer cell is located in a subject.
37. The method of claim 35, wherein the subject is a mammal.

38. The method of claim 37, wherein the mammal is a human or mouse.
39. The method of claim 35, further comprising providing a biologic modifier of glutathione.
- 5 40. A method of enhancing anti-tumor activity of a cell comprising providing a formulation comprising a platinum complex selected from the group consisting of ammine/cycloheptylamine-dichloro-platinum(II), ammine/piperidine-dichloro-platinum(II), ammine/hexamethyleneimine-dichloro-platinum(II), and
- 10 ammine/hexamethyleneimine-tetrachloro-platinum(IV) in combination with an inhibitor of glutathione synthesis.
41. The method of claim 40, wherein the inhibitor of glutathione synthesis is further defined as L-buthionine-sulfoximine.
- 15 42. The method of claim 41, wherein the concentration of L-buthionine-sulfoximine is in the approximate range of 1  $\mu\text{M}$  to 300  $\mu\text{M}$ .
43. The method of claim 41, wherein the concentration of L-buthionine-sulfoximine is in the
- 20 approximate range of 10  $\mu\text{M}$  to 200  $\mu\text{M}$ .
44. The method of claim 41, wherein the concentration of L-buthionine-sulfoximine is in the approximate range of 20  $\mu\text{M}$  to 100  $\mu\text{M}$ .
- 25 45. A method of making ammine/cycloheptylamine-dichloro-platinum(II) comprising:
- a) treating an aqueous 20 mmol solution of  $\text{K}_2\text{PtCl}_4$  with 200 mmol KI with stirring for 10 minutes at room temperature;
  - b) adding two equivalents of cycloheptylamine dropwise and stirring for 30 minutes forming a *cis*- $\text{Pt}^{\text{II}}(\text{c-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$  precipitate;
  - 30 c) filtering and washing the *cis*- $\text{Pt}^{\text{II}}(\text{c-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$  precipitate with water;
  - d) recrystallizing the *cis*- $\text{Pt}^{\text{II}}(\text{c-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$  precipitate from a DMF/ $\text{H}_2\text{O}$  mixture and washing with water, methanol, and ethyl ether;
  - e) drying the *cis*- $\text{Pt}^{\text{II}}(\text{c-C}_7\text{H}_{11}\text{NH}_2)_2\text{I}_2$  precipitate *in vacuo*;

- f) suspending the dried *cis*-Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)<sub>2</sub>I<sub>2</sub> precipitate in 50 mL of 60 to 70% HClO<sub>4</sub> and adding 150 mL of ethanol to the suspension with stirring at room temperature forming a brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate;
- g) filtering the brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate and washing the brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate with water;
- h) drying the washed brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate *in vacuo*;
- i) mixing 5 mmol of brown [Pt<sup>II</sup>(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub>]<sub>2</sub> precipitate with 5 mL of 1.5M NH<sub>4</sub>OH in 25 mL of water and stirring the mixture at room temperature overnight forming a yellow *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> precipitate;
- j) filtering the yellow *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> precipitate and washing with water;
- k) drying the washed yellow *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> precipitate *in vacuo*;
- l) mixing 4 mmol of *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)I<sub>2</sub> with 7.4 mmol of AgNO<sub>3</sub> in 200 mL of water and stirring overnight in the dark forming an AgI precipitate;
- m) removing AgI precipitate by filtration through celite forming a *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)NO<sub>3</sub> filtrate;
- n) adding 10 mL of concentrated HCl the *cis*-Pt<sup>II</sup>(NH<sub>3</sub>)(c-C<sub>7</sub>H<sub>11</sub>NH<sub>2</sub>)NO<sub>3</sub> filtrate and stirring the mixture for 3h forming a yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate;
- o) evaporating the mixture to approximately 2 mL under reduced pressure and filtering yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate;
- p) washing the yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate with water and acetone, and drying the washed yellow Pt<sup>II</sup>(NH<sub>3</sub>)(C<sub>7</sub>H<sub>11</sub>N)Cl<sub>2</sub> precipitate *in vacuo*.
46. A method of making ammine/piperidine-dichloro-platinum(II) comprising:
- a) dissolving 5.5 mmol of K[Pt(NH<sub>3</sub>)Cl<sub>3</sub>] in 50 mL of water;
- b) adding 55 mmol of KI in 100 mL of water forming a brown solution and stirring for 20 minutes;

- 5
- c) adding 55 mmol of Piperidine in 10 mL of water dropwise to the brown solution until a golden yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2$  precipitate is formed and stirring for another 1h;
- d) filtering the golden yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2$  precipitate and washing with acetone;
- e) drying *in vacuo* the washed golden yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2$  precipitate;
- f) suspending 4.24 mmol of  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{I}_2$  in 100 ml of water;
- g) adding 8.48 mmol of  $\text{AgNO}_3$  in 100 mL of water and stirring for 24 hours in the dark, at room temperature;
- 10 h) filtering an AgI precipitate;
- i) evaporating the AgI filtrate to 50 mL;
- j) adding a 1:1 HCl solution dropwise while stirring forming a bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{Cl}_2$  compound; and
- k) filtering the bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{Cl}_2$  compound and re-crystallizing the bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{Cl}_2$  compound in hot water and drying the bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_5\text{H}_{11}\text{N})\text{Cl}_2$  crystals under vacuum.
- 15

47. A method of making ammine/hexamethyleneimine-dichloro-platinum(II) comprising:

- 20 a) dissolving 5.5 mmol of  $\text{K}[\text{Pt}(\text{NH}_3)\text{Cl}_3]$  in 50 mL of water;
- b) adding 55 mmol of KI in 100 mL of water forming a brown solution and stirring for 20 minutes;
- c) adding 55 mmol of hexamethylenimine in 10 mL of water dropwise to the brown solution until a golden yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$  precipitate is formed and stirring for an hour;
- 25 d) filtering the golden yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$  precipitate and washing with acetone;
- e) drying *in vacuo* the washed golden yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$  precipitate;
- f) suspending 4.24 mmol of  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{I}_2$  in 100 ml of water;
- 30 g) adding 8.48 mmol of  $\text{AgNO}_3$  in 100 mL of water and stirring for 24hours in the dark, at room temperature;
- h) filtering an AgI precipitate;
- i) evaporating the AgI filtrate to 50 mL;

- j) adding a 1:1 HCl solution dropwise while stirring forming a bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  compound; and
- k) filtering the bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  compound and re-crystallizing the bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  compound in hot water and drying the bright yellow  $\text{Pt}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  crystals under vacuum.
- 5
48. A method of making ammine/hexamethyleneimine-tetrachloro-platinum(IV) comprising:
- a) adding 10 milliliters of  $\text{H}_2\text{O}_2$  to a suspension of 2.61 mmol  $\text{Pt}^{\text{II}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_2$  in 200 mL of water, stirring for 15 hours, filtering the solution, concentrating to a minimum volume
- 10
- b) precipitating with acetone forming a yellow  $(\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{trans}-(\text{OH})_2\text{Cl}_2)$  product;
- c) drying the yellow  $(\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{trans}-(\text{OH})_2\text{Cl}_2)$  *in vacuo*.
- 15
- d) dissolving the yellow 1.64 mmol of  $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{trans}-(\text{OH})_2\text{Cl}_2$  (0.650 g; 1.64 mmol) in 100 mL of water;
- e) adding 20 mL of concentrated HCl and stirring for 24 hours at room temperature forming a clear yellow solution;
- f) filtering the clear yellow solution, concentrating the clear yellow solution to a minimum volume to form a yellow crystalline  $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_4$ ; and
- 20
- g) filtering, washing the yellow crystalline  $\text{Pt}^{\text{IV}}(\text{NH}_3)(\text{C}_6\text{H}_{13}\text{N})\text{Cl}_4$  with water, and drying under a vacuum.
- 25

**Chemical Identity of Platinum Complexes**

<u>Complex #</u>	<u>Chemical Name</u>
1	<i>cis</i> -diamino-dichloro-platinum(II) (cisplatin)
2	<i>trans</i> -1R,2R-diaminocyclohexane-dichloro-platinum(II)
3	Ammine/cyclopropylamine-dichloro-platinum(II)
4	Ammine/cyclobutylamine-dichloro-platinum(II)
5	Ammine/cyclopentylamine-dichloro-platinum(II)
6	Ammine/cyclohexylamine-dichloro-platinum(II)
7	Ammine/cycloheptylamine-dichloro-platinum(II)
8	Ammine/cyclooctylamine-dichloro-platinum(II)
9	Ammine/azetidine-dichloro-platinum(II)
10	Ammine/pyrrolidine-dichloro-platinum(II)
11	Ammine/piperidine-dichloro-platinum(II)
12	Ammine/hexamethyleneimine-dichloro-platinum(II)
13	<i>trans</i> -1R,2R-1S,2S-diaminocyclohexane-tetrachloro-platinum(IV) (tetraplatin)
14	<i>trans</i> -dihydroxo- <i>trans</i> -1R,2R-diaminocyclohexane-dichloro-platinum(IV)
15	Ammine/cyclohexylamine-tetrachloro-platinum(IV)
16	<i>trans</i> -dihydroxo-ammine/cyclohexylamine-dichloro-platinum(IV)
17	Ammine/hexamethyleneimine-tetrachloro-platinum(IV)
18	<i>trans</i> -dihydroxo-ammine/hexamethyleneimine-dichloro-platinum(IV)
19	<i>trans</i> -diacetato-ammine/hexamethyleneimine-dichloro-platinum(IV)

FIG. 1

Structures of Cisplatin and Platinum Analogs

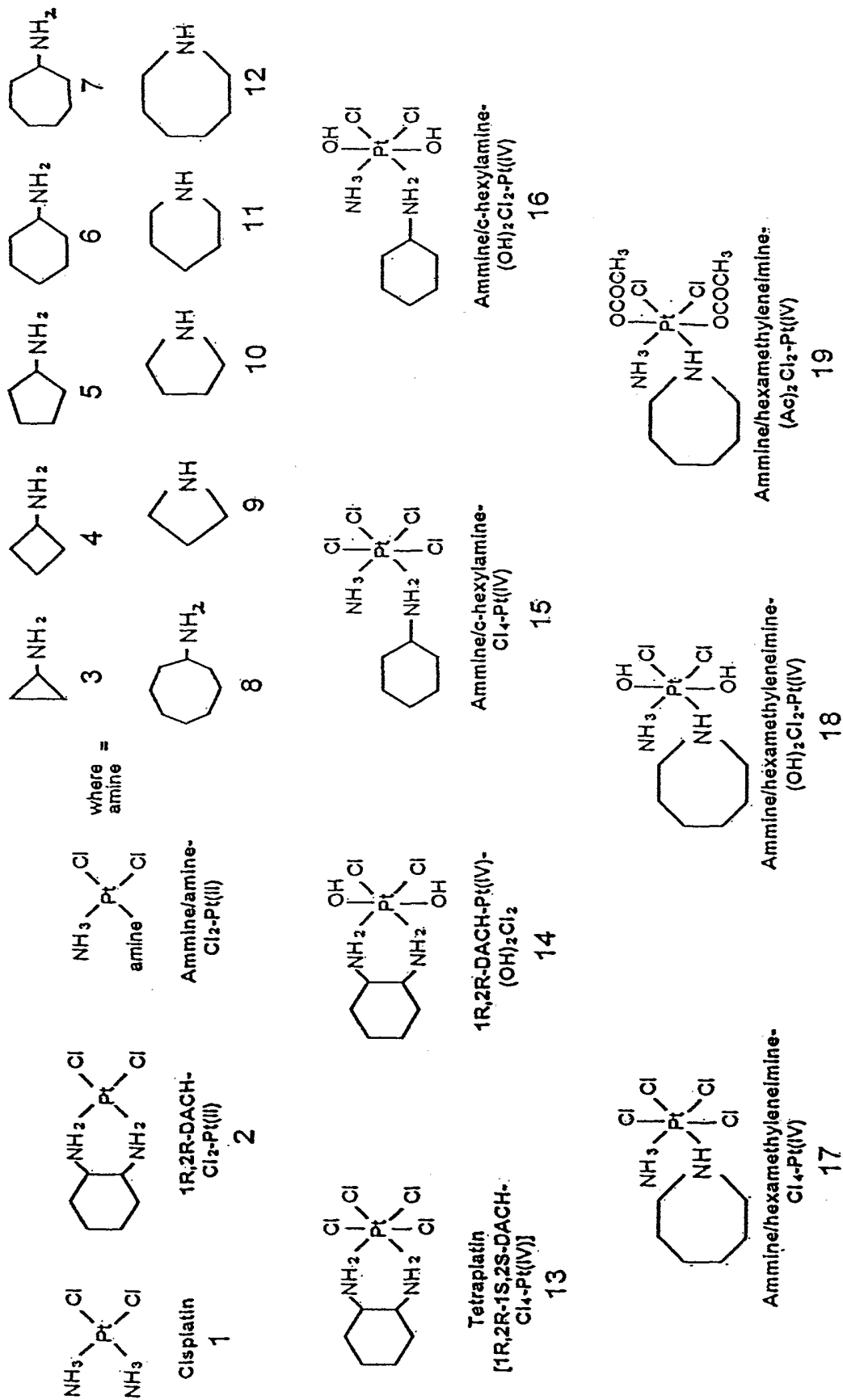


FIG. 2