

METHODS OF OTOPROTECTION AGAINST PLATINUM-BASED ANTINEOPLASTIC AGENTS

FIELD OF THE INVENTION

The present invention provides methods of otoprotection against platinum-based antineoplastic agents.

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BACKGROUND

Platinum-based antineoplastic agents (e.g., cisplatin) are chemotherapeutic agents widely used to treat cancers and tumors. These agents are toxic and are known to induce hearing loss both in human and animal models. Thus, patients undergoing chemotherapy with platinum-based antineoplastic agents can suffer from hearing loss. There is a need for otoprotective compositions and methods to prevent or mitigate hearing loss associated with chemotherapeutic regimens including platinum-based antineoplastic agents.

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SUMMARY OF THE INVENTION

In general, the invention provides methods for mitigating platinum-induced ototoxicity in a subject in need thereof. The method involves administering to the subject an effective amount of a thiosulfate salt.

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In some embodiments, the subject was administered a platinum-based neoplastic agent not more than 7 hours prior administering the thiosulfate salt or is scheduled to be administered a platinum-based antineoplastic agent within 4 hours. In certain embodiments, the subject was administered a platinum-based neoplastic agent not more than 7 hours prior administering the thiosulfate salt. In particular embodiments, the subject is scheduled to be administered a platinum-based antineoplastic agent within 4.5 hours. In further embodiments, the subject was administered a platinum-based neoplastic agent not more than 2.5 hours prior to administering the thiosulfate salt. In yet further embodiments, the subject was administered a platinum-based neoplastic agent not more than 1 hour prior to administering the thiosulfate salt.

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In some embodiments, administration of an effective amount of a thiosulfate salt to the subject produces a plasma thiosulfate C_{max} that is 30 μM or less at the time of administration a platinum-based antineoplastic agent. In certain embodiments, administration of an effective amount of a thiosulfate salt to the subject produces a cochlear thiosulfate C_{max} is at least 30 times greater than a cochlear C_{max} of the platinum-based antineoplastic agent. The cochlear platinum concentrations and the cochlear C_{max} are typically modeled by a pharmacokinetic simulation of intravenous infusion in a two-compartment model. For example, the pharmacokinetic simulation may be conducted using WinNonlin (Phoenix 64) PK simulation model 9 (IV infusion, 2 compartment).

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In still further embodiments, the thiosulfate salt is administered auricularly. In certain embodiments, the thiosulfate salt is administered intratympanically, transtympanically, or by inner ear injection. In particular embodiments, the thiosulfate salt is administered transtympanically or by inner ear injection.

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In some embodiments, the method further includes administering the platinum-based antineoplastic agent.

- In certain embodiments, the thiosulfate salt is an alkaline thiosulfate salt, ammonium thiosulfate salt, or a solvate thereof. In further embodiments, the effective amount of a thiosulfate salt is administered as a hypertonic pharmaceutical composition comprising the effective amount of a thiosulfate salt. In yet further
- 5 embodiments, 200-1,000 μL (e.g., 200-900 μL , 200-800 μL , 200-700 μL , 200-600 μL , 200-500 μL , 200-400 μL , 200-300 μL , 300-900 μL , 300-800 μL , 300-700 μL , 300-600 μL , 300-500 μL , 300-400 μL , 400-900 μL , 400-800 μL , 400-700 μL , 400-600 μL , or 400-500 μL) of the hypertonic pharmaceutical composition are administered to the round window of the subject.
- 10 In still further embodiments, the calculated osmolality of the hypertonic pharmaceutical composition is 500-5,000 mOsm/L (e.g., 600-5,000 mOsm/L, 700-5,000 mOsm/L, 800-5,000 mOsm/L, 900-5,000 mOsm/L, 1,000-5,000 mOsm/L, 1,500-5,000 mOsm/L, 2,000-5,000 mOsm/L, 2,500-5,000 mOsm/L, 3,000-5,000 mOsm/L, 500-4,000 mOsm/L, 600-4,000 mOsm/L, 700-4,000 mOsm/L, 800-4,000 mOsm/L, 900-4,000 mOsm/L, 1,000-4,000 mOsm/L, 1,500-4,000 mOsm/L, 2,000-4,000 mOsm/L, 2,500-4,000
- 15 mOsm/L, 3,000-4,000 mOsm/L, 500-3,000 mOsm/L, 600-3,000 mOsm/L, 700-3,000 mOsm/L, 800-3,000 mOsm/L, 900-3,000 mOsm/L, 1,000-3,000 mOsm/L, 1,500-3,000 mOsm/L, 2,000-3,000 mOsm/L, 2,500-3,000 mOsm/L, 500-2,500 mOsm/L, 600-2,500 mOsm/L, 700-2,500 mOsm/L, 800-2,500 mOsm/L, 900-2,500 mOsm/L, 1,000-2,500 mOsm/L, 1,500-2,500 mOsm/L, 2,000-2,500 mOsm/L, 500-2,000 mOsm/L, 600-2,000 mOsm/L, 700-2,000 mOsm/L, 800-2,000 mOsm/L, 900-2,000 mOsm/L, 1,000-2,000 mOsm/L,
- 20 1,500-2,000 mOsm/L, 500-1,500 mOsm/L, 600-1,500 mOsm/L, 700-1,500 mOsm/L, 800-1,500 mOsm/L, 900-1,500 mOsm/L, or 1,000-1,500 mOsm/L).

- In some embodiments, the concentration of the thiosulfate salt in the hypertonic pharmaceutical composition is 0.5M-2.5M (e.g., about 0.05M to about 1.5 M, about 0.05M to about 0.5M, about 0.05M to about 0.2M, about 0.05M to about 0.1M, about 0.1M to about 1.5M, about 0.1M to about 0.5M, about 0.1M to about 0.2M, about 0.2M to about 1.5M, about 0.2M to about 0.5M, about 0.5M to about 1.5M, 0.05M to about 1.0 M, about 0.05M to about 0.5M, about 0.05M to about 0.2M, about 0.05M to about 0.1M, about 0.1M to about 1.0M, about 0.1M to about 0.5M, about 0.1M to about 0.2M, about 0.2M to about 1.0M, about 0.2M to about 0.5M, about 0.5M to about 1.0M, or about 1.0M to about 1.5M).
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- In certain embodiments, the effective amount is an amount that produces a plasma thiosulfate concentration that is 30 μM or less at the time the platinum-based antineoplastic agent is administered. In certain embodiments, the effective amount is 0.1-2.5 mmol of the thiosulfate salt. In particular
- embodiments, the effective amount is an amount that produces a maximum thiosulfate concentration of
- 35 0.6-10 mmol/L by 1h post administration. In further embodiments, the effective amount is an amount that produces a thiosulfate concentration of 0.1-2 mmol/L by 7 h post administration in the subject's cochlea.

- In some embodiments, the subject is scheduled to be administered a platinum-based antineoplastic agent within about 1 hour to about 6 hours (e.g., within about 1 hour to about 5 hours, about 1 hour to about 4
- 40 hours, about 1 hour to about 3 hours, about 1 hour to about 2 hours, about 2 hours to about 3 hours, about 2 hours to about 4 hours, about 2 hours to about 5 hours, about 2 hours to about 6 hours, about 3 hours to about 4 hours, about 3 hours to about 5 hours, about 3 hours to about 6 hours, about 4 hours to

about 5 hours, about 4 hours to about 6 hours, or about 5 hours to about 6 hours following administration of the thiosulfate salt).

5 In some embodiments, the subject is administered a platinum-based antineoplastic agent within about 1 hour to about 6 hours after administration of the thiosulfate salt (e.g., within about 1 hour to about 5 hours, about 1 hour to about 4 hours, about 1 hour to about 3 hours, about 1 hour to about 2 hours, about 2 hours to about 3 hours, about 2 hours to about 4 hours, about 2 hours to about 5 hours, about 2 hours to about 6 hours, about 3 hours to about 4 hours, about 3 hours to about 5 hours, about 3 hours to about 6 hours, about 4 hours to about 5 hours, about 4 hours to about 6 hours, or about 5 hours to about 6 hours after administration of the thiosulfate salt).

15 In some embodiments, the subject is administered a platinum-based antineoplastic agent within about 1 hour to about 6 hours before administration of the thiosulfate salt (e.g., within about 1 hour to about 5 hours, about 1 hour to about 4 hours, about 1 hour to about 3 hours, about 1 hour to about 2 hours, about 2 hours to about 3 hours, about 2 hours to about 4 hours, about 2 hours to about 5 hours, about 2 hours to about 6 hours, about 3 hours to about 4 hours, about 3 hours to about 5 hours, about 3 hours to about 6 hours, about 4 hours to about 5 hours, about 4 hours to about 6 hours, or about 5 hours to about 6 hours before administration of the thiosulfate salt).

20 In yet further embodiments, the invention is described by the following enumerated items.

1. A method of mitigating platinum-induced ototoxicity in a subject in need thereof, the method comprising administering to the subject an effective amount of a thiosulfate salt, wherein the subject was administered a platinum-based neoplastic agent not more than 7 hours prior to administering the thiosulfate salt or is scheduled to be administered a platinum-based antineoplastic agent within 4 hours.

2. The method of item 1, wherein the effective amount is an amount that produces a plasma thiosulfate concentration that is 30 μM or less at the time the platinum-based antineoplastic agent is administered.

30 3. A method of mitigating platinum-induced ototoxicity in a subject in need thereof, the method comprising administering to the subject an effective amount of a thiosulfate salt to produce (i) a plasma thiosulfate C_{max} that is 30 μM or less at the time of administration a platinum-based antineoplastic agent and (ii) a cochlear thiosulfate C_{max} is at least 30 times greater than a cochlear C_{max} of the platinum-based antineoplastic agent, wherein the cochlear platinum concentrations and the cochlear C_{max} are modeled by a pharmacokinetic simulation of intravenous infusion in a two compartment model.

4. The method of item 2, wherein the subject was administered a platinum-based neoplastic agent not more than 7 hours prior administering the thiosulfate salt or is scheduled to be administered a platinum-based antineoplastic agent within 4 hours

5. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 7 hours prior administering the thiosulfate salt.
6. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 6 hours prior administering the thiosulfate salt.
7. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 5 hours prior administering the thiosulfate salt.
8. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 4 hours prior administering the thiosulfate salt.
9. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 3 hours prior administering the thiosulfate salt.
10. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 2.5 hours prior to administering the thiosulfate salt.
11. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 2 hours prior administering the thiosulfate salt.
12. The method of any one of items 1 to 3, wherein the subject was administered a platinum-based neoplastic agent not more than 1 hour prior administering the thiosulfate salt.
13. The method of any one of items 1 to 3, wherein the subject is scheduled to be administered a platinum-based antineoplastic agent within 4.5 hours.
14. The method of any one of items 1 to 3, wherein the subject is scheduled to be administered a platinum-based antineoplastic agent within 4 hours.
15. The method of any one of items 1 to 3, wherein the subject is scheduled to be administered a platinum-based antineoplastic agent within 3 hours.
16. The method of any one of items 1 to 3, wherein the subject is scheduled to be administered a platinum-based antineoplastic agent within 2 hours.
17. The method of any one of items 1 to 3, wherein the subject is scheduled to be administered a platinum-based antineoplastic agent within 1 hour.
18. The method of any one of items 1 to 16, wherein the thiosulfate salt is administered auricularly.
19. The method of item 17, wherein the thiosulfate salt is administered intratympanically.

20. The method of item 17, wherein the thiosulfate salt is administered transtympanically.
21. The method of item 17, wherein the thiosulfate salt is administered by inner ear injection.
- 5 22. The method of any one of items 1 to 20, further comprising administering the platinum-based antineoplastic agent.
- 10 23. The method of any one of items 1 to 21, wherein the thiosulfate salt is an alkaline thiosulfate salt, ammonium thiosulfate salt, or a solvate thereof.
- 15 24. The method of any one of items 1 to 22, wherein the effective amount of a thiosulfate salt is administered as a hypertonic pharmaceutical composition comprising the effective amount of a thiosulfate salt.
25. The method of item 23, wherein 200-1,000 μL of the hypertonic pharmaceutical composition are administered to the round window of the subject.
- 20 26. The method of item 23 or 24, wherein the calculated osmolarity of the hypertonic pharmaceutical composition is 500-5,000 mOsm/L.
27. The method of any one of items 23 to 25, wherein the concentration of the thiosulfate salt in the hypertonic pharmaceutical composition is 0.5M-2.5M.
- 25 28. The method of any one of items 23 to 25, wherein the concentration of the thiosulfate salt in the hypertonic pharmaceutical composition is 0.5M-1.5M.
29. The method of any one of items 23 to 25, wherein the concentration of the thiosulfate salt in the hypertonic pharmaceutical composition is 0.5M-1.0M.
- 30 30. The method of any one of items 1 to 28, wherein the effective amount is at least 0.05 mmol of the thiosulfate salt.
- 35 31. The method of any one of items 1 to 28, wherein the effective amount is at least 0.1 mmol of the thiosulfate salt.
32. The method of any one of items 1 to 28, wherein the effective amount is at least 0.2 mmol of the thiosulfate salt.
- 40 33. The method of any one of items 1 to 28, wherein the effective amount is at least 0.3 mmol of the thiosulfate salt.

34. The method of any one of items 1 to 28, wherein the effective amount is at least 0.4 mmol of the thiosulfate salt.

35. The method of any one of items 1 to 33, wherein the effective amount is 2.5 mmol or less of the thiosulfate salt.

36. The method of any one of items 1 to 33, wherein the effective amount is 2.0 mmol or less of the thiosulfate salt.

37. The method of any one of items 1 to 33, wherein the effective amount is 1.5 mmol or less of the thiosulfate salt.

38. The method of any one of items 1 to 33, wherein the effective amount is 1.0 mmol or less of the thiosulfate salt.

39. The method of any one of items 1 to 33, wherein the effective amount is 0.5 mmol or less of the thiosulfate salt.

40. The method of any one of items 1 to 38, wherein the effective amount is an amount that produces a maximum thiosulfate concentration of 0.6-10 mmol/L by 1h post administration.

41. The method of any one of items 1 to 39, wherein the effective amount is an amount that produces a thiosulfate concentration of 0.1-2 mmol/L by 7 h post administration in the subject's cochlea.

Definitions

The term "about," as used herein, represents a value that is in the range of $\pm 10\%$ of the value that follows the term "about."

The term "alkaline salt," as used herein, represents a sodium or potassium salt of a compound. Alkaline salts may be monobasic or, if the number of acidic moieties (e.g., $-\text{COOH}$, $-\text{SO}_3\text{H}$, or $-\text{P}(\text{O})(\text{OH})_n$ moieties) permits, dibasic or tribasic.

The term "ammonium salt," as used herein, represents an NH_4^+ salt of a compound. Ammonium salts may be monobasic or, if the number of acidic moieties (e.g., $-\text{COOH}$, $-\text{SO}_3\text{H}$, or $-\text{P}(\text{O})(\text{OH})_n$ moieties) permits, dibasic or tribasic.

The term "gelling agent," as used herein, refers to pharmaceutically acceptable excipient known in the art to produce a gel upon mixing with a solvent (e.g., an aqueous solvent). Non-limiting examples of gelling agents include hyaluronan, a polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer), poly(lactic-co-glycolic) acid, polylactic acid, polycaprolactone, alginic acid or a salt thereof, polyethylene glycol, a cellulose, a cellulose ether, a carbomer (e.g., Carbopol®), agar-agar, gelatin, glucomannan, galactomannan (e.g., guar gum, locust bean gum, or tara gum), xanthan gum, chitosan, pectin, starch,

tragacanth, carrageenan, polyvinylpyrrolidone, polyvinyl alcohol, paraffin, petrolatum, silicates, fibroin, and combinations thereof.

The term "hypertonic," as used herein in reference to pharmaceutical compositions, represents a pharmaceutical composition having a calculated osmolarity of 300 mOsm/L to 7,000 mOsm/L (e.g., 300 mOsm/L to 2,500 mOsm/L), which corresponds to 300 mmol to 7,000 mmol (e.g., 300 mOsm/L to 2,500 mmol) of ions and/or neutral molecules produced by dissolution of platinum-deactivating agent and any ionic, non-polymeric excipients in 1L of solvent having calculated osmolarity of 0 mOsm/L. For the purpose of the present disclosure, the calculated osmolarity does not include ions and/or neutral molecules produced from polymeric excipients (e.g., from a gelling agent). For the purpose of this disclosure, polymeric excipients (e.g., a gelling agents) are deemed as not contributing to the calculated osmolarity of the compositions disclosed herein.

The term "intratympanic," as used herein in reference to a route of administration, means delivery to the round window by injection or infusion through an ear canal with a temporarily removed or lifted tympanic membrane or through a port created through an auditory bulla into the middle ear of a subject.

The term "pharmaceutical composition," as used herein, represents a composition formulated with a pharmaceutically acceptable excipient, and manufactured or sold with the approval of a governmental regulatory agency as part of a therapeutic regimen for the treatment of disease in a mammal.

The term "pharmaceutical dosage form," as used herein, represents those pharmaceutical compositions intended for administration to a subject as is without further modification (e.g., without dilution with, suspension in, or dissolution in a liquid solvent).

The term "pharmaceutically acceptable excipient," as used herein, refers to any ingredient other than the thiosulfate salts and gelling agents described herein (e.g., a vehicle capable of suspending or dissolving the active compound) and having the properties of being substantially non-toxic and substantially non-inflammatory in a patient. Excipients may include, e.g., antioxidants, disintegrants, dyes (colors), emollients, emulsifiers, fillers (diluents), flavors, fragrances, preservatives, printing inks, sorbents, suspending or dispersing agents, sweeteners, liquid solvents, and buffering agents.

The term "pharmaceutically acceptable salt," as use herein, represents those salts which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of humans and animals without undue toxicity, irritation, allergic response and the like and are commensurate with a reasonable benefit/risk ratio. Pharmaceutically acceptable salts are well known in the art. For example, pharmaceutically acceptable salts are described in: Berge et al., *J. Pharmaceutical Sciences* 66:1-19, 1977 and in *Pharmaceutical Salts: Properties, Selection, and Use*, (Eds. P.H. Stahl and C.G. Wermuth), Wiley-VCH, 2008. The salts can be prepared in situ during the final isolation and purification of the compounds described herein or separately by reacting the free base group with a suitable organic acid. Representative acid addition salts include acetate, adipate, alginate, ascorbate, aspartate, benzenesulfonate, benzoate, bisulfate, borate, butyrate, camphorate, camphorsulfonate, citrate,

cyclopentanepropionate, digluconate, dodecylsulfate, ethanesulfonate, fumarate, glucoheptonate, glycerophosphate, hemisulfate, heptonate, hexanoate, hydrobromide, hydrochloride, hydroiodide, 2-hydroxy-ethanesulfonate, lactobionate, lactate, laurate, lauryl sulfate, malate, maleate, malonate, methanesulfonate, 2-naphthalenesulfonate, nicotinate, nitrate, oleate, oxalate, palmitate, pamoate, pectinate, persulfate, 3-phenylpropionate, phosphate, picrate, pivalate, propionate, stearate, succinate, sulfate, tartrate, thiocyanate, toluenesulfonate, undecanoate, valerate salts, and the like. Representative alkali or alkaline earth metal salts include sodium, lithium, potassium, calcium, magnesium, and the like, as well as nontoxic ammonium, quaternary ammonium, and amine cations, including, but not limited to ammonium, tetramethylammonium, tetraethylammonium, methylamine, dimethylamine, trimethylamine, triethylamine, ethylamine, and the like.

The term "pharmaceutically acceptable solvate" as used herein means a compound as described herein wherein molecules of a suitable solvent are incorporated in the crystal lattice. A suitable solvent is physiologically tolerable at the dosage administered. For example, solvates may be prepared by crystallization, recrystallization, or precipitation from a solution that includes organic solvents, water, or a mixture thereof. Examples of suitable solvents are ethanol, water (for example, mono-, di-, tri-, tetra-, and penta-hydrates), *N*-methylpyrrolidinone (NMP), dimethyl sulfoxide (DMSO), *N,N'*-dimethylformamide (DMF), *N,N'*-dimethylacetamide (DMAC), 1,3-dimethyl-2-imidazolidinone (DMEU), 1,3-dimethyl-3,4,5,6-tetrahydro-2-(1H)-pyrimidinone (DMPU), acetonitrile (ACN), propylene glycol, ethyl acetate, benzyl alcohol, 2-pyrrolidone, benzyl benzoate, and the like. When the solvate is water-based, the solvate is referred to as a hydrate.

The term "platinum-based antineoplastic agent," as used herein, represents a coordination compound of Pt(II) or Pt(IV). Platinum-based antineoplastic agents are known in the art as platins. Typically, platinum-based antineoplastic agents include at least two coordination sites at the platinum center that are occupied by nitrogenous spectator ligand(s). The nitrogenous spectator ligands are monodentate or bidentate ligands, in which the donor atom is an sp³- or sp²-hybridized nitrogen atom within the ligand. Non-limiting examples of nitrogenous spectator ligands are ammonia, 1,2-cyclohexanediamine, a picoline, phenanthrin, or 1,6-hexanediamine. Non-limiting examples of platinum-based antineoplastic agents include cisplatin, carboplatin, oxaliplatin, nedaplatin, triplatin tetranitrate, phenanthriplatin, picoplatin, and satraplatin.

The term "subject," as used herein, refers to an animal (e.g., a mammal, e.g., a human). A subject to be treated according to the methods described herein may be one who is being treated with a therapeutic regimen including a platinum-based antineoplastic agent (e.g., for the treatment of a benign tumor, malignant tumor, or cancer). The subject may have been diagnosed with a benign tumor, malignant tumor, or cancer by any method or technique known in the art. One skilled in the art will understand that a subject to be treated according to the invention may have been subjected to standard tests or may have been identified, without examination, as one at high risk due to receiving a therapeutic regimen including a platinum-based antineoplastic agent.

The term "substantially neutral," used herein, refers to a pH level of 5.5 to about 8.5, as measured at 20 °C.

5 The term "tonicity agent," as used herein, refers to a class of pharmaceutically acceptable excipients that are used to control osmolarity of pharmaceutical compositions. Non-limiting examples of a tonicity agent include substantially neutral buffering agents (e.g., phosphate buffered saline, tris buffer, or artificial perilymph), dextrose, mannitol, glycerin, potassium chloride, and sodium chloride (e.g., as a hypertonic, isotonic, or hypotonic saline). Artificial perilymph is an aqueous solution containing NaCl (120-130 mM), KCl (3.5 mM), CaCl₂ (1.3-1.5 mM), MgCl₂ (1.2 mM), glucose (5.0-11 mM), and buffering agents (e.g.,
10 NaHCO₃ (25 mM) and NaH₂PO₄ (0.75 mM), or HEPES (20 mM) and NaOH (adjusted to pH of about 7.5)).

The term "transtympanic," as used herein, in reference to a route of administration, means delivery to the round window by injection or infusion across tympanic membrane. A transtympanic injection may be performed directly through the tympanic membrane or through a tube embedded in the tympanic
15 membrane (e.g., through a tympanostomy tube or grommet).

The term "inner ear injection," as used herein, refers to the direct injection of drug into the inner ear space.

20 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a chart showing the profiles (0-24 h) of mean plasma thiosulfate concentrations over time for each tested human cohort. The X-axis shows time (h), and the Y-axis shows mean plasma thiosulfate concentrations (ng/mL).

25 FIG. 2 is a chart showing the profiles (0-4 h) of mean plasma thiosulfate concentrations over time for each tested human cohort. The error bars shown are standard deviations. The X-axis shows time (h), and the Y-axis shows mean plasma thiosulfate concentrations (ng/mL).

FIG. 3 is a chart showing the profiles (0-672 h) of mean plasma thiosulfate concentrations over time for each tested human cohort. The X-axis shows time (h), and the Y-axis shows mean plasma thiosulfate
30 concentrations (ng/mL).

FIG. 4 is a scheme showing the timing of thiosulfate administration relative to cisplatin.

35 FIG. 5A is a chart showing the average threshold sound pressure levels at 4, 24, and 32 kHz measured during auditory brainstem response (ABR) tests for the control guinea pigs. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve. The X-axis shows sound frequency in kHz, and the Y-axis shows the response threshold in decibel of sound pressure level (dB SPL).

40 FIG. 5B is a chart showing the average threshold sound pressure levels at 4, 24, and 32 kHz measured during auditory brainstem response (ABR) tests for the guinea pigs administered sodium thiosulfate to

one ear each followed by a cisplatin challenge. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve. The X-axis shows sound frequency in kHz, and the Y-axis shows the response threshold in decibel of sound pressure level (dB SPL). The data shown are Mean $\pm$ standard error of the mean (SEM); two way analysis of variance (ANOVA); ** P<0.01; ***P<0.001 Treated ears vs. Untreated ears (compare to FIG. 5A).

FIG. 6 is a chart showing the concentration dependence for thiosulfate (DB-020) in human tumor cell lines treated with cisplatin at 15 μ M. The following tumor cell lines were used; SH-N-AS (brain, neuroblastoma), SNU899 (larynx, squamous cell carcinoma), NCI-H23 (lung, non-small cell), HLF (Liver, undifferentiated hepatocellular carcinoma) and A2780 (Ovary, carcinoma).

FIG. 7 is a chart showing the profiles (0-8 h) of mean thiosulfate concentrations (mM) over time in plasma (human) and perilymph (guinea pig) following administration of Hyaluronan Gel 1 (12% w/v, 0.5M sodium thiosulfate). The horizontal solid line shows the 30 μ M level below which plasma thiosulfate levels should be. The horizontal dotted line shows the 660 μ M (0.66mM) level above which perilymph thiosulfate levels should be.

FIG. 8A is a chart showing the changes in thiosulfate concentrations over time in plasma, perilymph, and cerebrospinal fluid in guinea pigs administered a gel containing 0.1M sodium thiosulfate and 20% (w/v) poloxamer 407.

FIG. 8B is a chart showing the changes in thiosulfate concentrations over time in plasma, perilymph, and cerebrospinal fluid in guinea pigs administered a gel containing 0.5M sodium thiosulfate and 1% (w/v) hyaluronan.

FIG. 9A is a chart showing the changes in thiosulfate concentrations over time in plasma, perilymph, and cerebrospinal fluid in guinea pigs administered a gel containing 0.1M sodium thiosulfate and 2% (w/v) hyaluronan.

FIG. 9B is a chart showing the changes in thiosulfate concentrations over time in plasma, perilymph, and cerebrospinal fluid in guinea pigs administered a gel containing 0.5M sodium thiosulfate and 2% (w/v) hyaluronan.

FIG. 10A is a chart showing the threshold sound pressure levels at 4, 24, and 32 kHz measured across five cohorts of guinea pigs (n = 27 animals) during auditory brainstem response tests. Seven days prior to the auditory brainstem response tests, all guinea pigs were injected intraperitoneally with a bolus of cisplatin. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve.

FIG. 10B is a chart showing the threshold sound pressure levels at 4, 24, and 32 kHz measured during auditory brainstem response tests for the guinea pigs deemed to have hearing loss (n = 18 animals).

Seven days prior to the auditory brainstem response tests, all guinea pigs were injected intraperitoneally with a bolus of cisplatin. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve.

5 FIG. 11A is a chart showing the average threshold sound pressure levels at 4, 24, and 32 kHz measured during auditory brainstem response tests for the guinea pigs deemed to have hearing loss (n = 18 animals). Seven days prior to the auditory brainstem response tests, all guinea pigs were injected intraperitoneally with a bolus of cisplatin. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve.

FIG. 11B is a chart showing the average threshold sound pressure levels at 4, 24, and 32 kHz measured during auditory brainstem response (ABR) tests for the guinea pigs administered vehicle or sodium thiosulfate to one ear each followed by a cisplatin challenge. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve.

FIG. 12 is a figure illustrating the cisplatin challenge test following administration of vehicle or sodium thiosulfate to one ear of a guinea pig.

20 FIG. 13 is a chart showing the average threshold sound pressure levels at 4, 24, and 32 kHz measured during auditory brainstem response (ABR) tests for the guinea pigs administered vehicle or sodium thiosulfate (0.1M, 0.5M, or 1M sodium thiosulfate gel) to one ear each followed by a cisplatin challenge. The baseline thresholds were from historic auditory brainstem response tests on cisplatin-naïve guinea pigs (n = 100 ears). The baseline thresholds are shown as a shaded area curve.

DETAILED DESCRIPTION

In general, the invention provides method of mitigating platinum-induced ototoxicity in a subject by administering to the subject an effective amount of a thiosulfate salt. Preferably, the thiosulfate salt is administered auricularly (e.g., intratympanically or transtympanically).

Typically, the thiosulfate salt is administered to the subject scheduled to be administered a platinum-based antineoplastic agent within 4 hours (e.g., within 3 hours, within 2 hours, or within 1 hour). Alternatively, the thiosulfate salt is administered within 7 hours (e.g., within 6 hours, within 5 hours, within 4 hours, within 3 hours, within 2 hours, or within 1 hour) after the administration of a platinum-based neoplastic agent. Preferably, the thiosulfate salt is administered to the subject scheduled to be administered platinum-based antineoplastic agent within 3 hours. Alternatively, the thiosulfate salt is administered within 4 hours after the administration of a platinum-based neoplastic agent. More preferably, the thiosulfate salt is administered to the subject scheduled to be administered platinum-based antineoplastic agent within 1 hour. Alternatively, the thiosulfate salt is administered within 1 hour after the administration of a platinum-based neoplastic agent.

- An effective amount of a thiosulfate salt typically produces a plasma thiosulfate concentration that is 30 μM or less (e.g., 20 μM or less, 10 μM or less, or near endogenous concentration) at the time of administration a platinum-based antineoplastic agent. Additionally or alternatively, an effective amount of a thiosulfate salt typically produces a cochlear thiosulfate concentration that is at least 30 times greater (e.g., 30 to 1000 times greater, 30 to 500 times greater, or 30 to 150 times greater) than a cochlear C_{max} of the platinum-based antineoplastic agent, wherein the cochlear platinum concentrations and the cochlear C_{max} are modeled by a pharmacokinetic simulation of intravenous infusion in a two compartment model.
- Platinum-induced ototoxicity may occur in subjects receiving a platinum-based antineoplastic agent (e.g., a subject having a tumor or cancer). Non-limiting examples of the platinum-based antineoplastic agents include cisplatin, carboplatin, oxaliplatin, nedaplatin, triplatin tetranitrate, phenanthriplatin, picoplatin, and satraplatin.
- A thiosulfate salt may mitigate (e.g., eliminate) hearing loss in a subject receiving a platinum-based antineoplastic agent, as measured by at least 50% (e.g., at least 60%, at least 70%, or at least 80%) reduction in the sound pressure level threshold elevation in the subject at a frequency 8 kHz or higher (e.g., between 8 kHz and 20 kHz) relative to a reference subject that receives the same platinum-based antineoplastic agent regimen but does not receive the thiosulfate salt.
- Thiosulfate salts may exhibit otoprotective properties against platinum-based antineoplastic agents and may be used in a method of mitigating (e.g., eliminating) platinum-induced ototoxicity in subjects in need thereof. Typically, a thiosulfate salt is administered to a round window of the subject. The subject may be undergoing therapy with a platinum-based antineoplastic agent (e.g., cisplatin, carboplatin, oxaliplatin, nedaplatin, triplatin tetranitrate, phenanthriplatin, picoplatin, or satraplatin).
- A thiosulfate salt may be administered to a subject, e.g., before or after the administration of a platinum-based antineoplastic agent to the subject. Alternatively, a thiosulfate salt may be administered, e.g., at the same time as the administration of a platinum-based antineoplastic agent. A thiosulfate salt may be administered to a subject scheduled to be administered a platinum-based antineoplastic agent within 4 hours, e.g., within 3 hour, within 2 hours, or within 1 hour (e.g., at least 5 minute, at least 15 minutes, or at least 30 minutes prior to platinum-based antineoplastic agent administration). Alternatively, a thiosulfate salt may be administered, e.g., not more than 7 hours (e.g., not more than 6 hours, not more than 5 hours, not more than 4 hours, not more than 3 hours, not more than 2 hours, or not more than 1 hour) after platinum-based antineoplastic agent administration (e.g., at least 5 minutes, at least 15 minutes, or at least 30 minutes after). Administration of a platinum-based antineoplastic agent is typically preceded by administration of a hydration composition (e.g., saline optionally including, e.g., mannitol or furosemide). Further, administration of a platinum-based antineoplastic agent typically lasts for a period of at least 1 hour (e.g., 1 to 24 hours, e.g., 1 to 12 hours, 1 to 6 hours, 1 to 3 hours, or 1 to 2 hours). One of skill in the art would recognize the timing between the administrations of a thiosulfate salt and platinum-based neoplastic agent as being the time between the completion of the administration of one and the commencement of the administration of the other. For example, administration of a platinum-based

neoplastic agent 30 minutes to 4 hours following the step of administration of a thiosulfate salt indicates that 30 minutes to 4 hours separate the end of the thiosulfate salt administration and the commencement of the platinum-based neoplastic agent administration (e.g., infusion of cisplatin).

- 5 Typically, the pharmaceutical composition of the invention may be administered by a route different from the platinum-based antineoplastic agent. The methods of the invention may utilize a local route of administration, for example, the pharmaceutical composition of the invention may be administered intratympanically or transtympanically. Transtympanic administration may include injection or infusion of an effective amount of the pharmaceutical composition of the invention through the tympanic membrane
10 into the tympanic cavity, thereby providing the anti-platinum chemoprotectant agent to the round window.

In the methods of the invention, typically, a needle is used to pierce the tympanic membrane to instill drug into the middle ear space or traverse an existing PE tube or perforation of the ear drum to instill drug. A separate ventilation hole in the tympanic membrane may or may not be created to allow air to escape the
15 middle ear space. The instilled drug may then target middle ear structures, cells or be designed to enter the inner ear via the round and oval membranes to affect specific targets. This may be accomplished, e.g., by instilling drug through the round window membrane, the oval window, a cochleostomy, or labyrinthotomy approach. These surgical procedures may be accomplished by raising a tympanomeatal flap (lifting up the ear drum) and exposing the round window, stapes/oval window and promontory. A
20 stapedotomy hole may be created in the footplate and the drug instilled into the vestibule by pump, injection, or some other method. Alternatively, the bony lip of the round window (RW) is removed (typically by drill) to expose the RW. The RW may then be pierced with a needle and the drug infused or the RW may be fenestrated and the drug instilled directly through the fenestration. Finally, an entirely separate entrance hole to the cochlea may be opened by drilling a cochleostomy hole into the cochlea
25 and drug instilled.

Alternatively, rather than raising a tympanomeatal flap, a mastoidectomy may be performed and the facial recess opened to provide direct access to the oval and round windows as well as the promontory and the semicircular canals. Via this approach, all three sites can be used as just described. In addition, the
30 labyrinth may be opened, much like a cochleostomy, for the instillation of drug. To dissipate fluid/pressure buildup in the inner ear, a separate opening into the RW or OW may be created to allow for excess perilymph to leak out.

Thiosulfate salts may be provided in a pharmaceutical composition. Pharmaceutical compositions may
35 be, e.g., hypertonic. Without wishing to be bound by theory, the higher tonicity of the pharmaceutical compositions disclosed herein is believed to improve the bioavailability of thiosulfate at the round window of a subject, relative to compositions with lower tonicity (e.g., hypotonic or isotonic). The bioavailability is typically calculated using exposure (AUC) to thiosulfate following its administration to a subject. The calculated osmolarity of the pharmaceutical composition (e.g., pharmaceutical dosage form) may be, e.g.,
40 at least 400 mOsm/L (e.g., at least 500 mOsm/L, at least 600 mOsm/L, at least 700 mOsm/L, at least 800 mOsm/L, at least 900 mOsm/L, at least 1,000 mOsm/L, at least 1,500 mOsm/L, at least 2,000 mOsm/L, at least 2,500 mOsm/L, or at least 3,000 mOsm/L), and/or 5,000 mOsm/L or less (e.g., 4,000 mOsm/L or

- less, 3,000 mOsm/L or less, 2,000 mOsm/L or less, 1,900 mOsm/L or less, 1,800 mOsm/L or less, 1,700 mOsm/L or less, 1,600 mOsm/L or less, or 1,500 mOsm/L or less). The calculated osmolality of the pharmaceutical composition (e.g., pharmaceutical dosage form) may be, e.g., 1,500-4,500 mOsm/L. The calculated osmolality of the pharmaceutical composition (e.g., pharmaceutical dosage forms) may be,
- 5 e.g., 3,000-4,500 mOsm/L. The measured osmolality of the pharmaceutical composition (e.g., pharmaceutical dosage form) may be, e.g., at least 0.3 Osm/kg (e.g., at least 0.5 Osm/kg, at least 0.6 Osm/kg, at least 0.7 Osm/kg, at least 0.8 Osm/kg, at least 0.9 Osm/kg, at least 1.0 Osm/kg, at least 1.2 Osm/kg, at least 1.4 Osm/kg, or at least 1.8 Osm/kg). The measured osmolality of the pharmaceutical composition (e.g., pharmaceutical dosage form) may be, e.g., 2.5 Osm/kg or less (e.g., 2.1 Osm/kg or
- 10 less). The measured osmolality of the pharmaceutical composition (e.g., pharmaceutical dosage form) may be, e.g., 0.3-2.5 Osm/kg (e.g., 0.5-2.5 Osm/kg, 0.6-2.5 Osm/kg, 0.7-2.5 Osm/kg, 0.8-2.5 Osm/kg, 0.9-2.5 Osm/kg, 1.0-2.5 Osm/kg, 1.2-2.5 Osm/kg, 1.4-2.5 Osm/kg, 1.8-2.5 Osm/kg, 0.5-2.1 Osm/kg, 0.6-2.1 Osm/kg, 0.7-2.1 Osm/kg, 0.8-2.1 Osm/kg, 0.9-2.1 Osm/kg, 1.0-2.1 Osm/kg, 1.2-2.1 Osm/kg, 1.4-2.1 Osm/kg, or 1.8-2.1 Osm/kg). "Calculated osmolality" refers to the number of mmoles of ions and/or
- 15 neutral molecules produced by dissolution of one or more compounds in 1L of DI or distilled water; calculated osmolality does not include ions and/or neutral molecules produced from polymeric excipients (e.g., from a gelling agent). "Measured osmolality" refers to the osmolality of a composition, as measured using an osmometer (typically, a membrane osmometer).
- 20 A preferred pharmaceutical dosage form of the invention is a gel.

- In some embodiments, at least 50 μ L (preferably, at least 100 μ L; more preferably, at least 200 μ L) of the pharmaceutical composition are administered to the round window of the subject. In particular
- embodiments, 1 mL or less (e.g., 0.8 mL or less or 0.5 mL or less) of the pharmaceutical composition are
- 25 administered to the round window of the subject. In certain embodiments, 100 μ L to 1 mL (e.g., 200 μ L to 1 mL, 100 μ L to 0.8 mL, 200 μ L to 0.8 mL, 100 μ L to 0.5 mL, 200 μ L to 0.5 mL, 0.5 mL to 1.0 mL, 0.5 mL to 0.8 mL, or 0.8 mL to 1.0 mL) of the pharmaceutical composition are administered to the round window of the subject.
- 30 A thiosulfate salt may be, e.g., the sole compound contributing to osmolality of a pharmaceutical composition. Alternatively, higher osmolalities than those afforded by the desired concentration of a thiosulfate salt may be achieved, e.g., through the use of tonicity agents. A tonicity agent may be present in a hypertonic, isotonic, or hypotonic excipient (e.g., a hypotonic liquid solvent). Non-limiting examples of tonicity agents include substantially neutral buffering agents (e.g., phosphate buffered saline, tris
- 35 buffer, or artificial perilymph), dextrose, mannitol, glycerin, glycerol, potassium chloride, and sodium chloride (e.g., as a hypertonic, isotonic, or hypotonic saline).

Thiosulfate Salts

- Without wishing to be bound by theory, thiosulfate salts are believed to reduce or eliminate the toxicity of
- 40 platinum-based antineoplastic agents by competitively ligating and substantially coordinatively saturating the platinum centers present in the platinum-based antineoplastic agents. The concentration of a thiosulfate salt in a pharmaceutical composition (e.g., a pharmaceutical dosage form) may be, e.g., at

least about 0.05M (e.g., at least about 0.1M, at least about 0.2M, at least about 0.3M, at least about 0.4M, at least about 0.5M, or at least about 1M). The concentration of a thiosulfate salt in a pharmaceutical composition (e.g., a pharmaceutical dosage form) may be, e.g., about 2.5M or less (e.g., 2.0M or less, 1.5M or less, 1.0M or less, 0.5M or less, about 0.3M or less, or about 0.2M or less). Non-limiting

5 examples of the concentrations of a thiosulfate salt in a pharmaceutical composition (e.g., a pharmaceutical dosage form) may be, e.g., about 0.05M to about 1.5 M, about 0.05M to about 0.5M, about 0.05M to about 0.2M, about 0.05M to about 0.1M, about 0.1M to about 1.5M, about 0.1M to about 0.5M, about 0.1M to about 0.2M, about 0.2M to about 1.5M, about 0.2M to about 0.5M, about 0.5M to about 1.5M, 0.05M to about 1.0 M, about 0.05M to about 0.5M, about 0.05M to about 0.2M, about 0.05M

10 to about 0.1M, about 0.1M to about 1.0M, about 0.1M to about 0.5M, about 0.1M to about 0.2M, about 0.2M to about 1.0M, about 0.2M to about 0.5M, or about 0.5M to about 1.0M, or about 1.0M to about 1.5M. Preferably, the concentration of a thiosulfate salt agent in a pharmaceutical composition (e.g., a pharmaceutical dosage form) is about 0.5M to about 1.5M. More preferably, the concentration of a thiosulfate salt agent in a pharmaceutical composition (e.g., a pharmaceutical dosage form) is about 0.5M

15 to about 1.0M.

Preferably, the thiosulfate salt is an alkaline or ammonium thiosulfate salt. More preferably, the thiosulfate salt is sodium thiosulfate.

20 *Gelling Agents*

Pharmaceutical compositions disclosed herein include a gelling agent. Gelling agents may be used to increase the viscosity of the pharmaceutical composition, thereby improving the retention of the pharmaceutical composition at the targeted site. Pharmaceutical compositions (e.g., pharmaceutical dosage forms) may contain, e.g., about 0.1% to about 25% (w/v) (e.g., about 0.1% to about 20% (w/v),

25 about 0.1% to about 10% (w/v), about 0.1% to about 2% (w/v), about 0.5% to about 25% (w/v), about 0.5% to about 20% (w/v), about 0.5% to about 10% (w/v), about 0.5% to about 2% (w/v), about 1% to about 20% (w/v), about 1% to about 10% (w/v), about 1% to about 2% (w/v), about 5% to about 20% (w/v), about 5% to about 10% (w/v), or about 7% to about 10% (w/v)) of a gelling agent relative to solvent. Preferably, pharmaceutical compositions (e.g., pharmaceutical dosage forms) may contain, e.g., about

30 0.5% to about 25% (w/v) (e.g., about 0.5% to about 20% (w/v), about 0.5% to about 10% (w/v), about 0.5% to about 2% (w/v), about 1% to about 20% (w/v), about 1% to about 10% (w/v), about 1% to about 2% (w/v), about 5% to about 20% (w/v), about 5% to about 10% (w/v), or about 7% to about 10% (w/v)) of a gelling agent relative to solvent.

35 Gelling agents that may be used in the pharmaceutical compositions disclosed herein are known in the art. Non-limiting examples of gelling agents include hyaluronan, a polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer), poly(lactic-co-glycolic) acid, polylactic acid, polycaprolactone, alginic acid or a salt thereof, polyethylene glycol, a cellulose, a cellulose ether, a carbomer (e.g., Carbopol®), agar-agar, gelatin, glucomannan, galactomannan (e.g., guar gum, locust bean gum, or tara gum),

40 xanthan gum, chitosan, pectin, starch, tragacanth, carrageenan, polyvinylpyrrolidone, polyvinyl alcohol, paraffin, petrolatum, silicates, fibroin, and combinations thereof. The gelling agents described herein are known in the art. Preferably, the gelling agent is hyaluronan.

A pharmaceutical composition may contain, e.g., about 0.5% to about 2% (w/v) (e.g., about 1% to about 2% (w/v)) of hyaluronan relative to solvent. A pharmaceutical composition may contain, e.g., about 5% to about 10% (w/v) (e.g., about 6% to about 8% (w/v)) of methylcellulose relative to solvent. A pharmaceutical composition may contain, e.g., hyaluronan and methylcellulose as a gelling agent (e.g., about 0.5% to about 2% (w/v) of hyaluronan and about 5% to about 10% (w/v) of methylcellulose relative to solvent). A pharmaceutical composition may contain, e.g., a polyoxyethylene-polyoxypropylene block copolymer (e.g., poloxamer) as a gelling agent. A pharmaceutical composition may contain, e.g., about 1% to about 20% (w/v) (e.g., about 1% to about 15% (w/v), about 1% to about 10% (w/v), about 5% to about 20% (w/v), about 5% to about 15% (w/v), about 5% to about 10% (w/v), about 10% to about 20% (w/v), or about 10% to about 15% (w/v)) of a polyoxyethylene-polyoxypropylene block copolymer (e.g., poloxamer) relative to solvent. The poloxamer may be poloxamer 407, poloxamer 188, or a combination thereof. A pharmaceutical composition may contain, e.g., about 0.5% (w/v) to about 20% (w/v) of fibroin as a gelling agent relative to solvent.

Hyaluronan is a hyaluronic acid or a salt thereof (e.g., sodium hyaluronate). Hyaluronans are known in the art and are typically isolated from various bacteria (e.g., *Streptococcus zooepidemicus*, *Streptococcus equi*, or *Streptococcus pyrogenes*) or other sources, e.g., bovine vitreous humor or rooster combs. The weight-averaged molecular weight (M_w) of hyaluronan is typically about 50 kDa to about 10 MDa. Preferably, M_w of a hyaluronan (e.g., sodium hyaluronate) is about 500 kDa to 6 MDa (e.g., about 500 kDa to about 750 kDa, about 600 kDa to about 1.1 MDa, about 750 kDa to about 1 MDa, about 1MDa to about 1.25 MDa, about 1.25 to about 1.5 MDa, about 1.5 MDa to about 1.75 MDa, about 1.75 MDa to about 2 MDa, about 2 MDa to about 2.2 MDa, about 2 MDa to about 2.4 MDa). More preferably, the M_w of a hyaluronan (e.g., sodium hyaluronate) is about 620 kDa to about 1.2 MDa or about 1.2 MDa to about 1.9 MDa. Other preferred molecular weight ranges for a hyaluronan include, e.g., about 600 kDa to about 1.2 MDa.

Polyoxyethylene-polyoxypropylene block copolymers are known in the art. A non-limiting example of polyoxyethylene-polyoxypropylene block copolymers is a poloxamer, in which a single polyoxypropylene block is flanked by two polyoxyethylene blocks. Poloxamers are commercially available under various trade names, e.g., Synperonic®, Pluronic®, Kolliphor®, and Lutrol®. A pharmaceutical composition may contain, e.g., a polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer) includes a polyoxypropylene block with a number average molecular weight (M_n) of, e.g., about 1,100 g/mol to about 17,400 g/mol (e.g., about 2,090 g/mol to about 2,360 g/mol, about 7,680 g/mol to about 9,510 g/mol, about 6,830 g/mol to about 8,830 g/mol, about 9,840 g/mol to about 14,600 g/mol, or about 12,700 g/mol to about 17,400 g/mol). A polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer) may include a polyoxypropylene block with a number average molecular weight (M_n) of about 1,100 g/mol to about 4,000 g/mol and a calculated polyoxyethylene content of about 30% to about 85% (w/w). Preferably, a polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer) may include a polyoxypropylene block with a calculated molecular weight of, e.g., about 1,800 g/mol to about 4,000 g/mol. Preferably, the calculated polyoxyethylene content a polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer) may be, e.g., about 70% to about 80% (w/w). Preferably, a

polyoxyethylene-polyoxypropylene block copolymer (e.g., a poloxamer) may have a number average molecular weight of, e.g., about 7,680 g/mol to about 14,600 g/mol. Non-limiting examples of poloxamers are poloxamer 407 and poloxamer 188.

- 5 Celluloses and cellulose ethers are known in the art. Celluloses and cellulose ethers are commercially available under various tradenames, e.g., Avicel®, Methocel™, Natrosol®, and Tylose®. Non-limiting examples of cellulose ethers include methylcellulose, carboxymethylcellulose, ethylcellulose, hydroxyethylcellulose, methyl hydroxyethylcellulose, hydroxypropyl methylcellulose, or hydroxypropylcellulose. A cellulose ether (e.g., methylcellulose) may have a number average molecular weight (M_n) of, e.g., about 5 kDa to about 300 kDa. Methyl-substituted celluloses (e.g., methylcellulose, hydroxypropyl methyl cellulose, or methyl hydroxyethylcellulose) may have methyl content of, e.g., 19% to 35% (e.g., 19% to 30%).

- 15 Fibroin is a protein present in silk created by numerous insects. Fibroins are known in the art and are commercially available from various vendors, e.g., Jiangsu SOHO International Group; Simatech, Suzhou, China; Xi'an Lyphar Biotech, Ltd.; Xi'an Rongsheng Biotechnology; Mulberry Farms, Treenway Silks, Sharda Group, Maniar Enterprises, and Wild Fibres. The molecular weight of silk fibroin is typically about 10 kDa to about 500 kDa. Fibroins are described in WO 2017/139684, the disclosure of which is incorporated herein by reference.

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Cross-Linked Gelling Agents

- Pharmaceutical compositions may contain non-cross-linked or cross-linked gelling agents. Gelling agents may be cross-linked using cross-linking agents known in the art. Preferably, the cross-linked gelling agent is covalently crosslinked. Pharmaceutical compositions (e.g., pharmaceutical dosage forms) including cross-linked gelling agents may be used to control the release profile of an anti-platinum chemoprotectant agent. For example, the release of an anti-platinum chemoprotectant agent from a pharmaceutical composition (e.g., a pharmaceutical dosage form) containing a cross-linked gelling agent may be extended release relative to a reference composition that differs from the pharmaceutical composition only by the lack of cross-linking in the gelling agent in the reference composition. The extension of the release of an anti-platinum chemoprotectant agent may be assessed by comparing T_{max} values for the pharmaceutical composition and the reference composition.

- 35 Certain gelling agents, e.g., those having carboxylate moieties (e.g., hyaluronan, alginic acid, and carboxymethylcellulose), can be cross-linked ionically using ionic cross-linking agents (e.g., a multivalent metal ion, e.g., Mg^{2+} , Ca^{2+} , or Al^{3+}). Techniques for ionic cross-linking of gelling agents are known in the art (see, e.g., U.S. Patent No. 6,497,902 and 7,790,699, the disclosures of which are incorporated herein by reference). Typically, gelling agents can be ionically cross-linked in an aqueous solution using multivalent metal ions, e.g., Mg^{2+} , Ca^{2+} , or Al^{3+} , as ionic cross-linking agents. Without wishing to be bound by theory, the metal ions are believed to coordinate to different molecules of the gelling agent (e.g., to pendant carboxylates residing on different molecules of the gelling agent), thereby forming a linkage between these different molecules of the gelling agent.

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Certain gelling agents having reactive functional groups, e.g., $-OH$, $-COOH$, or $-NH_2$, may be covalently cross-linked. Techniques for covalent cross-linking of gelling agents are known in the art (see, e.g., Khunmanee et al., *J. Tissue Eng.*, 8: 2041731417726464, 2017, the disclosure of which is incorporated herein by reference). Non-limiting examples of covalent cross-linking agents include: 1,4-butanediol diglycidyl ether (BDDE), divinyl sulfone, glutaraldehyde, cyanogen bromide, octeysuccinic anhydride, acid chlorides, diisocyanates, methacrylic anhydride, boric acid, and sodium periodate/adipic acid dihydrazide.

Other Excipients

Pharmaceutical compositions may contain pharmaceutically excipients other than gelling agents. For example, pharmaceutical compositions may contain, e.g., liquid solvents, tonicity agents, buffering agents, and/or coloring agents. Certain excipients may perform multiple roles. For example, a liquid solvent in addition to its function as a carrier may be used as a tonicity agent and/or buffering agent. Such solvents are known in the art, e.g., salines (e.g., hypertonic saline, hypotonic saline, isotonic saline, or phosphate-buffered saline) and artificial perilymph.

Liquid solvents may be used in pharmaceutical compositions (e.g., pharmaceutical dosage forms) as a vehicle. Liquid solvents are known in the art. Non-limiting examples of liquid solvents include water, salines (e.g., hypertonic saline, hypotonic saline, isotonic saline, or phosphate-buffered saline), artificial perilymph, and tris buffer. Artificial perilymph is an aqueous solution containing NaCl (120-130 mM), KCl (3.5 mM), $CaCl_2$ (1.3-1.5 mM), $MgCl_2$ (1.2 mM), glucose (5.0-11 mM), and buffering agents (e.g., $NaHCO_3$ (25 mM) and NaH_2PO_4 (0.75 mM), or HEPES (20 mM) and NaOH (adjusted to pH of about 7.5)).

Tonicity agents may be included in pharmaceutical compositions (e.g., pharmaceutical dosage forms) to increase osmolarity relative to that which is afforded by an anti-platinum chemoprotectant agent. Tonicity agents are known in the art. Non-limiting examples of tonicity agents include substantially neutral buffering agents (e.g., phosphate buffered saline, tris buffer, or artificial perilymph), dextrose, mannitol, glycerin, potassium chloride, and sodium chloride (e.g., as a hypertonic, isotonic, or hypotonic saline). Pharmaceutical compositions (e.g., pharmaceutical dosage forms) include sufficient amount of tonicity agents to provide for administration to a subject a hypertonic pharmaceutical dosage form (e.g., a pharmaceutical dosage form having a calculated osmolarity of at least 400 mOsm/L (e.g., at least 500 mOsm/L, at least 600 mOsm/L, or at least 700 mOsm/L), and/or 2,500 mOsm/L or less (e.g., 2,000 mOsm/L, 1,900 mOsm/L or less, 1,800 mOsm/L or less, 1,700 mOsm/L or less, 1,600 mOsm/L or less, or 1,500 mOsm/L or less)). For example, the targeted concentration of a tonicity agent in a pharmaceutical composition (e.g., pharmaceutical dosage form) can be determined, e.g., by (i) subtracting the calculated osmolarity contributions of an anti-platinum chemoprotectant agent and other non-polymeric excipients from the total targeted calculated osmolarity to obtain the targeted calculated osmolarity contribution from the tonicity agent, and (ii) determining the concentration of the tonicity agent by dividing the targeted calculated osmolarity contribution from the tonicity agent by the number of ions and/or molecules produced upon dissolution of the tonicity agent in a liquid solvent. An appropriate amount of the tonicity agent thus can be included in the pharmaceutical composition (e.g., pharmaceutical dosage form).

Buffering agents may be used to adjust the pH of a pharmaceutical composition (e.g., a pharmaceutical dosage form) a substantially neutral pH level. Buffering agents are known in the art. Non-limiting examples of buffering agents include, e.g., phosphate buffers and Good's buffers (e.g., tris, MES, MOPS, TES, HEPES, HEPPS, tricine, and bicine). In addition to the pH control, buffering agents may be used to control osmolarity of the pharmaceutical composition (e.g., pharmaceutical dosage form).

Methods of Preparation

A pharmaceutical composition (e.g., a pharmaceutical dosage form) of the invention may be prepared from an anti-platinum chemoprotectant agent, a gelling agent, and a liquid solvent. A method of preparing a pharmaceutical composition (e.g., a pharmaceutical dosage form) of the invention includes (i) providing the anti-platinum chemoprotectant agent and the gelling agent, and (ii) mixing the anti-platinum chemoprotectant agent and the gelling agent with the liquid solvent to produce the pharmaceutical composition.

The anti-platinum chemoprotectant agent and the gelling agent may be provided, e.g., as a mixture or as separate ingredients. When the anti-platinum chemoprotectant agent and the gelling agent are provided separately, the step (ii) may include, e.g.:

- (a) mixing the liquid solvent first with the gelling agent to produce an intermediate mixture and thereafter mixing the intermediate mixture with the anti-platinum chemoprotectant agent;
- (b) mixing the liquid solvent first with the anti-platinum chemoprotectant agent to produce an intermediate mixture and thereafter mixing the intermediate mixture with the gelling agent; or
- (c) mixing a portion of the liquid solvent with the anti-platinum chemoprotectant agent to produce a first mixture, mixing another portion of the liquid solvent with the gelling agent to produce a second mixture, and combining the first and second mixtures.

The following examples are meant to illustrate the invention. They are not meant to limit the invention in any way.

EXAMPLES

Example 1. Preparation of Thiosulfate Salt Formulations

Hyaluronan Gel 1 (0.5M STS, 1% (w/v) hyaluronan)

Sodium thiosulfate pentahydrate (619.75 mg) was dissolved in sterile, distilled water (5 mL) in a sterile vial to produce a clear solution. Hyaluronan (50.30 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to the solution, and the resulting mixture was stirred for 8-10 min at 4°C. The resulting solution was filtered through 0.22 µm Millex-GV sterile filter.

Hyaluronan Gel 2 (0.1M STS, 2% (w/v) hyaluronan)

Sodium thiosulfate pentahydrate (124.87 mg) was dissolved in sterile, distilled water (3.031 mL). Methylcellulose (351.01 mg; Methocel® A15 Premium LV, Dow Chemical Company) was dissolved in sterile, distilled water (2.0 mL), and the resulting solution was mixed with the sodium thiosulfate solution. Hyaluronan (100.10 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to the resulting mixture and mixed at 4°C for 10-15 min.

Hyaluronan Gel 3 (0.5M STS, 2% (w/v) hyaluronan)

Sodium thiosulfate pentahydrate (620.35 mg) was dissolved in sterile, distilled water (3 mL).

Methylcellulose (350.23 mg; Methocel® A15 Premium LV, Dow Chemical Company) was dissolved in

- 5 sterile, distilled water (2.0 mL), and the resulting solution was mixed with the sodium thiosulfate solution. Hyaluronan (100.65 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to the resulting mixture and mixed at 4°C for 10-15 min.

Hyaluronan Gel 4 (0.1M STS, 1% (w/v) hyaluronan, manitol)

- 10 Hyaluronan (50.09 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to water (5 mL). Sodium thiosulfate pentahydrate (124.9mgs) was added. The pH of the resulting mixture was adjusted to pH7.12 by addition of sodium hydroxide (1N, ca. 0.5 µL). Add appropriate amount of mannitol into the vial to adjust the osmolarity to 1.046 Osm/kg. The viscous solution was filtered through 0.22 µm Millex-GV filter.

15

Hyaluronan Gel 5 (0.1M STS, 1% (w/v) hyaluronan)

Hyaluronan Gel 5 was prepared according to the procedure described for Hyaluronan Gel 1 with the exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 0.1M concentration of sodium thiosulfate.

20

Hyaluronan Gel 6 (0.2M STS, 1% (w/v) hyaluronan)

Hyaluronan Gel 6 was prepared according to the procedure described for Hyaluronan Gel 1 with the exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 0.2M concentration of sodium thiosulfate.

25

Hyaluronan Gel 7 (0.3M STS, 1% (w/v) hyaluronan)

Hyaluronan Gel 7 was prepared according to the procedure described for Hyaluronan Gel 1 with the exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 0.3M concentration of sodium thiosulfate.

30

Hyaluronan Gel 8 (0.4M STS, 1% (w/v) hyaluronan)

Hyaluronan Gel 8 was prepared according to the procedure described for Hyaluronan Gel 1 with the exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 0.4M concentration of sodium thiosulfate.

35

Hyaluronan Gel 9 (0.5M STS, 1% (w/v) hyaluronan, Tris (5x))

Hyaluronan (79.99 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to Tris buffer (8 mL, AMRESCO-0497-500G). The pH of the resulting mixture was adjusted to pH7.13 by addition of HCl (5N). Sodium thiosulfate pentahydrate (992.60 mg) was added to the above solution. The

40 viscous solution was filtered through 0.22 µm Millex-GV filter.

Hyaluronan Gel 10 (0.5M STS, 1% (w/v) hyaluronan, phosphate buffered saline (5x))
Hyaluronan (70.38 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to
PBS buffer (7 mL, 5x). Sodium thiosulfate pentahydrate (868.46 mg) was added. The pH of the resulting
mixture was adjusted to pH6.99 by addition of NaOH (1N). The viscous solution was filtered through 0.22
5 µM Millex-GV filter.

Hyaluronan Gel 11 (0.8M STS, 1% (w/v) hyaluronan)
Hyaluronan Gel 11 was prepared according to the procedure described for Hyaluronan Gel 1 with the
exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 0.8M
10 concentration of sodium thiosulfate.

Hyaluronan Gel 12 (1M STS, 0.8% (w/v) hyaluronan)
Hyaluronan Gel 12 was prepared according to the procedure described for Hyaluronan Gel 1 with the
exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 1M concentration
15 of sodium thiosulfate, and the amount of hyaluronan was adjusted to provide a 0.8% (w/v) concentration
of hyaluronan.

Hyaluronan Gel 13 (0.5M STS, 0.82% (w/v) hyaluronan (HYALGAN))
Hyaluronan Gel 13 was prepared by mixing of sodium thiosulfate pentahydrate with hyaluronan
20 (HYALGAN, Fidia Pharma USA, Florham Park, NJ) to afford the final preparation with 0.82% (w/v)
concentration of hyaluronan.

Hyaluronan Gel 14 (0.5M STS, 1% (w/v) hyaluronan (SINGCLEAN))
Hyaluronan Gel 14 was prepared according to the procedure described for Hyaluronan Gel 13 with the
25 exception that hyaluronan (SINGCLEAN, Hangzhouh Singclean Medical Products Co., Ltd., Hangzhou,
China) was used in the preparation of this gel.

Hyaluronan Gel 15 (0.5M STS, 1% (w/v) hyaluronan (EUFLEXXA))
Hyaluronan Gel 15 was prepared according to the procedure described for Hyaluronan Gel 13 with the
30 exception that hyaluronan (EUFLEXXA, Ferring Pharmaceuticals Inc., Parsippany, NJ) was used in the
preparation of this gel.

Hyaluronan Gel 16 (0.5M STS, 1% (w/v) hyaluronan (HEALON))
Hyaluronan Gel 16 was prepared according to the procedure described for Hyaluronan Gel 13 with the
35 exception that hyaluronan (HEALON, Johnson & Johnson, New Brunswick, NJ) was used in the
preparation of this gel.

Hyaluronan Gel 17 (1M STS, 1% (w/v) hyaluronan)
Hyaluronan Gel 17 was prepared according to the procedure described for Hyaluronan Gel 1 with the
40 exception that the amount of sodium thiosulfate pentahydrate was adjusted to provide a 1M concentration
of sodium thiosulfate.

Hyaluronan Gel 18 (10% (w/v) N-Acetyl-L-cysteine, 1% (w/v) hyaluronan)
Hyaluronan (39.38 mg; Pharma Grade 80, Kikkoman Biochemifa company; 0.6-1.2 mDa) was added to
water (4 mL). N-Acetyl-L-cysteine (399.14 mg) was added. The pH of the resulting mixture was adjusted
to pH 7.21 by addition of NaOH (10N, 240 µL). The viscous solution was filtered through 0.22 µm Millex-
5 GV filter. The osmotic pressure was measured as 1.107 Osm/kg.

Other hyaluronan gels may be prepared using the procedures described herein. For example, 1M and
1.5M hyaluronan gels may be prepared according to the same procedure as described for, e.g.,
Hyaluronan Gel 1 and Hyaluronan Gel 12. Additionally, pH levels of the gels may be adjusted to pH 6.5
10 to 8.5 using Brønsted acids (e.g., hydrochloric acid) and bases (e.g., sodium hydroxide).

Example 2. Pharmacokinetic Modelling of Perilymph Concentrations

Maximum cochlear platinum levels in humans following high dose cisplatin treatment (100 mg/m²) were
modeled through the use of pharmacokinetic (PK) simulations of cisplatin distribution in a human. Kinetic
15 parameters used for simulations were obtained from literature reports on cisplatin population PK (Urien et
al, *Br. J. Clin. Pharmacol.*, 57:756-63, 2004) and PK following high dose cisplatin treatment (Andersson et
al, *J. Pharm. Sci.*, 85:824-27, 1996). The PK simulations were conducted using WinNonlin (Phoenix 64)
PK simulation model 9 (IV infusion, 2 compartment). A plasma-to-cochlea concentration ratio of 1:1 was
assumed based on previous results from animal studies, and this assumption is further supported by
20 literature reports showing tissue distribution characteristics of cisplatin (Johnsson et al, *Cancer
Chemother. Pharmacol.*, 37:23-31, 1995).

The predicted maximal plasma platinum concentration following cisplatin treatment was determined to be
approximately 22 µM. Applying a 30-fold molar stoichiometric ratio results in a concentration of 660 µM
25 (0.66 mM) which, when the molecular weight of thiosulfate is used, results in thiosulfate concentration of
74 µg/mL. Achieving this level of thiosulfate in the human cochlea is expected to provide complete
(maximum) protection against cisplatin induced ototoxicity following high dose (e.g., 100 mg/m²) cisplatin
treatment.

30 Example 3. Pharmacokinetic Studies *In Vivo*

Hyaluronan Gel #1 was administered to male Hartley guinea pigs at a dose of 12% w/v (0.5M, 6.2 mg).
The dose volume was fixed (10 µL). Perilymph was sampled at each timepoint (n=5 animals/timepoint)
and the concentration of thiosulfate was quantified using a liquid chromatography with tandem mass
spectrometry (LC-MS/MS) method.

35 Hyaluronan Gel 1 achieved maximal perilymph concentration, 868.5 µg/mL (approximately 7.8 mM) at the
first time-point sampled (1h). This maximum perilymph concentration is approximately 10-fold greater
than the Hyaluronan Gel 1 concentration predicted to provide 100% protection (minimal efficacious
concentration; 74 µg/mL, 0.66 mM) from cisplatin induced ototoxicity. The perilymph t_{1/2} ranged from 2.7
40 to 6.4 hours. The high perilymph Hyaluronan Gel 1 concentration combined with the relatively long half-
life provide a treatment window of 3 h pre to 4 h post cisplatin treatment. In another pharmacokinetic
study, healthy human subjects were divided into 4 dose cohorts: Cohort 1, Cohort 2, Cohort 3, and Cohort

4. Each dose cohort contained 8 human subjects randomized to receive either DB-020 or placebo (6/2 randomization; 6 subjects received DB-020, 2 subjects received placebo). Cohort 1 was administered unilaterally, intratympanically 19 mg of sodium thiosulfate as a 0.15M sodium thiosulfate/hyaluronan gel, prepared as described for Hyaluronan Gel 1. Cohort 2 was administered unilaterally, intratympanically 62 mg of sodium thiosulfate as Hyaluronan Gel 1. Cohort 3 was administered unilaterally, intratympanically 124 mg of sodium thiosulfate as Hyaluronan Gel 17. Cohort 4 was administered unilaterally, intratympanically 186 mg of sodium thiosulfate as a 1.5M sodium thiosulfate/hyaluronan gel, prepared as described for Hyaluronan Gel 1. The Placebo subjects were administered 1% w/v aqueous hyaluronan.
- 10 The results of the studies are shown in Table 1 and 2 and in FIGS. 1-3.

Table 1

Dose	C _{max, 0-24} (ng/mL)	t _{max} (h)	t _{1/2} (h)	AUC ₀₋₂₄ (ng·h/mL)
Placebo	37.51 ± 8.59	9.06 ± 6.31	ND	684.85 ± 105.12
Cohort 1	38.42 ± 7.47	11.33 ± 2.73	ND	685.99 ± 97.86
Cohort 2	130.32 ± 60.26	0.42 ± 0.13	1.11	1011.74 ± 257.25
Cohort 3	180.00 ± 36.59	0.50 ± 0.00	0.87	860.90 ± 219.42
Cohort 4	264.00 ± 68.81	0.46 ± 0.10	0.63	1167.48 ± 204.93

Table 2

Cohort	C _{max}	Increase to endogenous ^a		
	Mean ± SD (ng/mL)	Mean ± SD (μM) ^b	Mean (μM)	Range (μM)
2 (12% w/v)	130.32 ± 60.26	1.16 ± 0.54	0.83	0.04 – 1.20
3 (25% w/v)	180.00 ± 36.59	1.61 ± 0.33	1.28	0.36 – 1.70
4 (37% w/v)	264.00 ± 68.81	2.36 ± 0.61	2.03	0.49 – 2.65

- 15 ^a increase to endogenous = (mean thiosulfate C_{max}) – (mean thiosulfate Placebo levels)

^b MW thiosulfate = 112 g/mol

Example 4. Pharmacodynamic Studies *In Vivo*

- To assess the treatment window for a sodium thiosulfate gel in relation to cisplatin administration, a single dose of 1.24 mg Hyaluronan Gel 1 was administered intratympanically (IT) to the left ear of guinea pigs either 24 hours, 6 hours, 3 hours, or 1 hour prior to, or 1 hour, 4 hours or 24 hours following cisplatin (single 10 mg/kg IV bolus; FIG. 4). All right control ears that were not treated with Hyaluronan Gel 1 demonstrated significant threshold shifts (i.e., hearing loss) compared to naïve animals (FIG. 5A). Hyaluronan Gel 1 dosed from 3 hours prior to 4 hours post cisplatin administration, provided protection from cisplatin-induced hearing loss relative to control ears untreated by Hyaluronan Gel 1 (FIG. 5B). Hyaluronan Gel 1 was moderately less effective at protecting from cisplatin-induced hearing loss when administered more distally to cisplatin treatment (e.g., > 6 h prior or 24 h post cisplatin dose). Maximum protection was observed when Hyaluronan Gel 1 was dosed 1 h prior to cisplatin administration indicating the highest level of protection can be achieved when Hyaluronan Gel 1 is administered prior to and, preferably, proximally to cisplatin treatment.

Example 5. Pharmacokinetic Performance of Exemplary Hydrogels

Guinea Pigs, Study 1

Albino guinea pigs (Hartley), body weight at 250-350 g, were used for the studies. For dosing, the animal was placed on its shoulder with the surgery ear up and auditory bulla was first exposed using retroauricular approach. A hole of 2-3 mm in diameter was drilled on the bulla to provide direct visualization of the round window niche. Then, 10 μ L of an aqueous composition of 0.5M sodium thiosulfate / 2% (w/v) hyaluronan (STS Composition) were applied onto the RWM using a 10 μ L Hamilton syringe and a 26-gauge needle. After application, guinea pigs remained at this position for 30 min to allow compound to diffuse into the cochlea. The bulla opening was sealed with a muscle graft and the incision closed with sutures.

Sampling procedures are as follows, in brief. All sampling procedures are terminal. Animals were euthanized with CO₂. 0.5 mL samples of blood were collected by cardiac puncture. Plasma was separated by centrifugation at 5,000 rpm at 4°C for 10 min and collected in a separate tube. 50 μ L of cerebrospinal fluid were collected through the cisterna magna. Perilymph was collected *ex vivo* to avoid contamination from the cerebrospinal fluid influx via the cochlear aqueduct. The temporal bone was rapidly isolated, and the bulla was removed to expose the cochlea. Any visible remaining dosed compositions were carefully removed with absorbent points under the surgical microscope before perilymph sampling. A small hole was made at the apex, and then 5–7 μ L of perilymph was sampled using a pulled glass pipette. All samples were frozen immediately on dry ice and stored in -80°C until analysis. The concentrations of thiosulfate in the samples were measured using the method disclosed in Togawa et al. *Chem. Pharm. Bull.*, 40:3000-3004, 1992, the disclosure of which is incorporated herein by reference. The results of this study are shown in FIGs. 8A, 8B, 9A, 9B, and in Table 3.

Cynomolgus Monkey

Cynomolgus monkey was administered tolfedine (4 mg/kg) subcutaneously. After 30 minutes, the animal was anesthetized via intravenous bolus of propofol (5.5 mg/kg). 2-3% isoflurane inhalation was then used to maintain the animal in anesthetized state. The animal was then immobilized and placed laterally in reverse Trendelenburg position to ensure the access to the round window. During the surgery process, the animal was kept on a warm blanket.

Intratympanic injection in right ear was conducted when the animal reaches the anesthetized state. 1.1 mL of epinephrine hydrochloride-saline (0.1 mg in 10 mL saline) and 0.5 mL of lidocaine hydrochloride (20 mg/mL) were injected subcutaneously into the skin of ear canal posterior wall of each ear respectively as local anesthetics. An incision was then made in the post-auricular skin, and part of the temporal bone was drilled to expose middle ear. 50 μ L of the STS composition were injected into the round window membrane using a 25G needle. After dosing, the animal was left on a line with its head up to allow the dosing solution to settle into the tympanic cavity for 30 mins. The same procedure was then repeated for the opposite ear.

Plasma and CSF were collected ca. 2 h after dosing the 1st ear (right). Right ear cochlea perilymph sampling was conducted ca. 3 h after the right ear dosing. The animal was euthanized by IV administration of propofol at 11 mg/kg and then exsanguinated via femoral artery. Animal was then placed in lateral recumbent. A post-auricular skin incision was made and the external ear canal was extracted to expose middle ear. Part of the temporal bone was then drilled to expose the basal turn of the cochlea. The remaining dose in the middle ear (if visible) was cleaned with cotton tips. A drop of tissue glue was spread at the base of the cochlea to minimize the contamination from the dosed compositions.

Using a 0.5-1 mm round-tipped burr or sharpened crochet, a hole was made at the basal turn of cochlea. Perilymph (ca. 10 µL) was then collected using the capillary tube inserted into the cochlear scala tympani. The same procedure was repeated for the left ear cochlea perilymph sampling ca. 2 h after the left ear dosing. The results of this study are shown in Table 3.

Table 3

	Poloxamer 407 gel 1	Hyaluronan Gel 2	Hyaluronan Gel 3	Hyaluronan Gel 1	Hyaluronan Gel 1	Hyaluronan Gel 1
Species	Guinea Pig	Guinea Pig	Guinea Pig	Guinea Pig	Guinea Pig	Cynomolgus Monkey
Dose	10 µL (IT)	10 µL (IT)	10 µL (IT)	10 µL (IT)	50 µL (TT)	50 µL (IT)
Total Dose (mg)	0.11	0.11	0.56	0.56	2.8	2.8
Tmax (est.) (h)	1	1	3	1.8	1	
Cmax (ng/mL)	59000	104040	712800	1686200	1930000	688500 @ 2 h
Terminal t _{1/2} (h)	2.38	1.53	2.66	2.01	2.73	
AUC last (h·ng/mL)	212523	327512	4634845	9069083	10498230	
AUC inf (h·ng/mL)	255707	377265	4724413	10418954	10703165	
Plasma* (ng/mL)					2390	766

In the above table, IT is intratympanic administration, and TT is transtympanic administration.

* concentration of thiosulfate as measured in plasma samples from the tested animals.

Guinea Pigs, Study 2

Male guinea pigs weighing 200-300 g of approximately 5-7 weeks of age served as subjects (N = 5 per group). Prior to any procedures, animals were anesthetized using zolazepam hydrochloride (Zoletil 50;

20 mg/kg) 10 minutes before surgery via the intramuscular route. If needed, an intraoperative booster was administered intraperitoneally representing a one-tenth of the original dose.

Intratympanic injection:

- 5 1. Under microscopic magnification, sharp scissors were used to create a 0.5-1.5 cm postauricular skin incision, approximately 6-8 mm caudal to the auriculo-cephalic crease. Care was exercised to avoid cutting deeply to preserve underlying vascular structures.
2. Careful blunt dissection through the subcutaneous fat layer, muscles and tissues was performed with forceps. The cleidomastoideus muscle body was gently retracted until the shiny dome of the tympanic
- 10 bulla periosteum came into view. At the caudal aspect of the bulla, the insertion of a deeper cervical muscle, the sternomastoideus came into view. The facial nerve, which becomes visible at the dorsal and rostral aspect of the bulla dome, was preserved during the operation.
3. A self-retaining retractor was placed prior to creating a small hole (0.5mm diameter) either with a drilling in the posterior part of the bulla. The bulla bone was uncapped in a dorsal and caudal
- 15 direction using a pair of jeweler's tip forceps. The bone was removed in a piecemeal fashion under high magnification. Care was exercised not to puncture the stapedial artery, which lies directly beneath the bulla cap, as bleeding from this artery may compromise the procedure. The amount of bone removed was kept to a minimum to prevent excessive fluid entry to the middle ear while still allowing excellent visualization and access to the round window niche.
- 20 4. 10 or 90 μ L of a gel formulation was delivered to the round window niche using a sterile glass Hamilton syringe with 25-26 G blunt needle.
5. The delivered agent was allowed to rest within the round window niche for up to 30 min. The small hole was covered with muscular tissue and tissue glue.
6. The incision was closed with sutures (4-0 non-absorbable monofilament or 5-0 non-absorbable
- 25 nylon) and tissue glue or wound clips. The entire procedure took approximately 3-5 minutes depending on agent specifications.
7. During the procedure and until recovery, animals were placed on a temperature controlled (38 °C) heating pad until consciousness was regained, at which time they were returned to the home-cage.
- 30 Alternatively, the animals were administered the gel formulations transtympanically.

Sampling collection:

Blood collection:

- 35 1. Without preinflating in the euthanasia box, the guinea pig was placed in a box, and 100% carbon dioxide was introduced to cause the animal unconsciousness and to reduce animal suffering. Carbon dioxide flow was maintained for a minimum of 1 minute after the breath has stopped. The guinea pig was removed from the euthanasia box after death was confirmed.
2. Blood was collected immediately after euthanasia.
3. After the operator fixed the animal's back position, the needle was inserted at the front of the sternal
- 40 ridge at 4-6 or slightly forward.
4. The needle was pulled back, and the blood was returned.
5. Volume: for each blood collection, ca. 1 mL of blood was collected.

CSF collection:

CSF was collected after euthanasia. A 0.5*20 intravenous infusion needle was slowly lowered from 90° to the foramen magnum. The needle reached a distance of 4.5-5 mm under the skin, and 50-200 µl of clear tissue fluid were withdrawn.

Perilymph collection:

After euthanasia, the animal was stripped excess skin and muscle tissue to obtain a complete auditory bulla, and the bulla wall was cut with small forceps to expose the cochlea. The basal turn of bulla was cleaned by using small cotton ball. The cochlear bottom circle and the round window were coated with bio glue. After drying, a unique microhole was hand-drilled in the top circle of the cochlea. A 2µL volume of perilymph was then collected using a microcapillary inserted into the cochlear top circle. Perilymph samples were added to a vial containing 18 µL of bovine serum albumin (BSA, 1M) stored at -80 °C until analysis.

The results of the Guinea Pig, Study 2 are provided in Tables 4 and 5.

Table 4

Formulation	Route	T _{max} (h)	C _{max} (ng/mL)	terminal T _{1/2} (h)	AUC _{INF} (h×ng/g)	AUC _{last} (h×ng/g)	Osmol. (Osm/kg)
Hyaluronan Gel 1	TT (50 µL)	1	872360	2.73	4837831	4745200	
Hyaluronan Gel 4	TT (50 µL)	3	115300	2.3	608881	601694	1.046
Hyaluronan Gel 5	TT (50 µL)	1	391432	6.42	4084991	3529898	0.267
Hyaluronan Gel 6	TT (50 µL)	1	1069794	8.89	5727631	4150041	
Hyaluronan Gel 6*	TT (50 µL)	3	500900	N/A	N/A	3817583	0.491
Hyaluronan Gel 7	TT (50 µL)	7	210933	N/A		2357105	0.657
Hyaluronan Gel 7*	TT (50 µL)	3	600420	N/A	N/A	3281800	0.66
Hyaluronan Gel 8	TT (50 µL)	1	508500	3.48	4014647	3887550	0.838
Hyaluronan Gel 9	TT (50 µL)	1	1602936	2.11	7029505	6990442	2.048
Hyaluronan Gel 10	TT (50 µL)	1	1293624	2.2	5866461	5825930	
Hyaluronan Gel 11	TT (50 µL)	1	1371800	2.99	5863793	5714356	1.494
Hyaluronan Gel 12	TT (50 µL)	1	1892000	2.57	7744025	7644025	1.860
Hyaluronan Gel 17	TT (50 µL)	1	1044400	2.47	5918627	5843593	
Hyaluronan Gel 18	TT (50 µL)	1	705600	5.53	4887980	4876589	1.107

In this table, TT is transtympanic administration,

* This test was a duplicate of the preceding test.

Table 5

Formulation	MW (mDa)	Route	T _{max} (h)	C _{max} (ng/mL)	terminal T _{1/2}	AUC _{INF} (h×ng/g)	AUC _{last} (h×ng/g)
Hyaluronan Gel 1	0.6-1.2	IT (10 µL)	1	625297	1.88	4112197	4099226
Hyaluronan Gel 13	0.5-0.73	TT (50 µL)	1	815408	2.82	4868652	4754315
Hyaluronan Gel 14	unknown	TT (50 µL)	1	851568	3.27	5178077	4992602
Hyaluronan Gel 15	2.4-3.6	TT (50 µL)	1	628200	3.41	3908302	3761700
Hyaluronan Gel 16	ca. 4	TT (50 µL)	1	919097	5.42	5033151	4407366

In this table, IT is intratympanic administration, and TT is transtympanic administration.

Example 6. Pharmacodynamic Performance of Exemplary Hydrogels

- 5 Cisplatin was diluted with 0.9% (w/v) saline to a final concentration of 5 mg/mL. Albino guinea pigs (Hartley), body weight at 250-350 g were used in the study. After a minimal 3 days acclimation, 28 animals were enrolled into the study. Under aseptic condition, cisplatin was administered intraperitoneally with a bolus injection. The five cohorts were staggered with different starting dates for the study.
- 10 Seven days after the cisplatin administration, the animals were recorded for their auditory brainstem responses (ABR) response using TDT RZ6 Multi-I/O processor. Historical ABR data were used to define a baseline. The animals were anesthetized with tiletamine hydrochloride and zolazepam hydrochloride (Zoletil). Acoustic stimuli were delivered via an earphone. Needle electrodes were placed near the ear
- 15 canal at the caudoventral position, the vertex of the skull, and a ground at the lower leg. The stimulus level was from 10 to 90 dB in 5 dB steps, and the tone-pip frequencies were 4, 24, and 32 kHz. The ceiling sound pressure level was 90 dB. ABR threshold was observed by visual inspection of stacked waveforms as the lowest sound pressure level, at which the waveform was above the noise floor.
- 20 Prior to the cisplatin study, ABR data from 50 animals were recorded for both ears of each animal (Naïve n=100). The threshold at 32 kHz in naïve animals was 39.8 dB. The range of normal hearing was defined as a mean $\pm$ 2SD, 27.9 to 51.6 dB. Cisplatin primarily induces hearing loss at high frequencies. A clear pattern of hearing loss after cisplatin is defined as a threshold of 60 dB and above at 32 kHz.
- 25 In this study, 1 out of 28 animals died before the day 7 measurement. In the remaining 27 animals, 18 animals had hearing loss with threshold >60 dB at 32 kHz (FIG. 10A). The range of hearing loss at 32 kHz was the thresholds from 65 dB to 90 dB (FIG. 10B). 90 dB is the measurement ceiling. Note when no waveform or waveform only seen at 90 dB, the threshold was defined both as 90 dB. The average threshold at 32 kHz was 82 dB, which corresponds to an average 42.2 dB shift from the naïve threshold
- 30 of 39.8 dB (FIG. 11A).

Local Intratympanic Dosing and Cochlear Sampling

Local intratympanic dosing and cochlear sampling were conducted as described in Example 5.

Locally Delivered Anti-platinum Chemoprotectant Agent Provides Hearing Protection
from Platinum-based Antineoplastic Agent

Evaluation of the effect of a locally delivered anti-platinum chemoprotectant agent on hearing protection from a platinum-based antineoplastic agent was conducted as follows.

5

An aqueous composition of 0.5M sodium thiosulfate / 2% (w/v) hyaluronan (STS Composition) or vehicle was dosed intratympanically onto the round window in the left ear (LE) as described above, and the right ear (RE) was left untreated in the guinea pigs (FIG. 12). 60 min after STS Composition or vehicle dosing, the animals were injected with cisplatin at 10 mg/kg intraperitoneally. ABR at 4, 24, and 32 kHz was measured in both ears 7 days after cisplatin administration.

10

Because of heterogeneity of hearing loss after cisplatin challenge, the untreated right ears was used to select the animals with hearing loss. There were 21 animals with right ear threshold >60 dB at 32 kHz. Of these 21 animals, 3 with otitis media were excluded, leaving 18 animals for the final analysis. 10 animals were dosed with vehicle and 8 animals were dosed with STS Composition (FIG. 11B). In the untreated right ears of both the STS Composition and vehicle groups, there is no difference in the ABR thresholds with an average threshold 73 dB at 4 kHz, 71 dB at 24 kHz, and 80 dB at 32 kHz. The vehicle-treated left ears had no significant difference in comparison to their untreated right ears, showing thresholds 74 dB at 4 kHz, 70 dB at 24 kHz, and 74 dB at 32 kHz.

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The STS Composition-treated ears had significantly lower thresholds at both 32 kHz and 24 kHz compared to the vehicle-treated ears and untreated right ears ($***P<0.001$, two way ANOVA). At 4 kHz an average threshold was 61 dB in the STS Composition treated ears and 75 dB in their untreated contralateral right ears; the protection was not statistically significant ($P=0.089$). The average thresholds in the STS Composition treated ears were 40 dB and 48 dB at 24 kHz and 32 kHz, respectively, in contrast to 69 dB and 80 dB in their contralateral untreated right ears. The normal hearing thresholds were 35 dB and 40 dB at 24 kHz and at 32 kHz, respectively, in the naïve animals. To the naïve ears, the untreated ears after cisplatin had an average of 34 dB and 40 dB threshold elevation at 24 kHz and 32 kHz, respectively, but STS Composition treated ears only had 5 dB and 8 dB shift. Therefore, sodium thiosulfate provided, on average, 80% protection at both 24 kHz and 32 kHz.

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In a similarly designed study as described hereinabove, sound pressure levels at 4, 24, and 32 kHz were measured during ABR tests for the guinea pigs administered vehicle or sodium thiosulfate (0.1M, 0.5M, or 1M sodium thiosulfate gel) to one ear each followed by a cisplatin challenge (Cisplatin 10MPK, intravenous injection). Different doses of hyaluronan gels were administered as a 10 μ L IT injection into the left ear one hour prior to cisplatin administration. The contralateral ear (right ear) of the animal was untreated. Hyaluronan Gel 5 (0.1M), Hyaluronan Gel 1 (0.5M), and Hyaluronan Gel 17 (1M) was tested. The untreated ears demonstrated significant threshold shifts compared to naïve animals (gray shaded areas). The groups treated with Hyaluronan Gel 1 (0.5M) and Hyaluronan Gel 17 (1M) showed hearing protection compared to the untreated contralateral control ears at all tested frequencies. No protection was seen with the vehicle treated ears. The results are summarized in FIG. 13.

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OTHER EMBODIMENTS

- Various modifications and variations of the described invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. Indeed, various modifications of the described modes for carrying out the invention that are obvious to those skilled in the art are intended to be within the scope of the invention.
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- 10 Other embodiments are in the claims.