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**Dosage forms and therapeutic uses of l-4-chlorokynurenine**

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DOSAGE FORMS AND THERAPEUTIC USES OF L-4-CHLOROKYNURENINE

**Abstract**

Compositions of L-4-chlorokynurenine are provided, as are methods for the treatment of neurological dysfunction.

## DOSAGE FORMS AND THERAPEUTIC USES OF L-4-CHLOROKYNURENINE

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is a divisional of Australian Patent Application No 2014209466 which is the Australian national phase entry of PCT/US2014/012598, which claims priority to U.S. provisional patent application serial number 61/849,191, filed January 22, 2013 and titled "DOSAGE FORMS AND THERAPEUTIC USES OF L-4-CHLOROKYNURENINE". Each of these applications is herein incorporated by reference in their entireties.

### STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

**[0002]** The data presented in this application was supported at least in part by Grant Number 2R44DA018515-02 from the U.S. National Institutes of Health. The government has certain rights in the invention.

### FIELD OF THE INVENTION

**[0003]** The present invention relates to compositions of L-4-chlorokynurenine (L-4-Cl-KYN) in unit dose form and to the use of these compositions for the treatment of neurological conditions.

### BACKGROUND OF THE INVENTION

**[0004]** Glutamic acid is a major excitatory neurotransmitter in the mammalian central nervous system, and it is involved in the regulation of several different pathways. Associations have been reported between excessive endogenous glutamic acid and various neurological disorders, both acute and chronic, such as cerebral ischemia, epilepsy, amyotrophic lateral sclerosis, Huntington's disease, Parkinson's disease and Alzheimer's disease.

**[0005]** Overactive glutamatergic transmission via N-methyl-D-aspartate (NMDA) receptors (NMDA-R) is known to play a key role in several neurologic conditions, such as neuropathic pain for example. However, direct acting NMDA-R antagonists produce a number of side effects, such as

psychosis, which have limited their therapeutic utility. Antagonism of NMDA-Rs can also be achieved through blockade of a modulatory site on the NMDA-R, known as the glycine B (GlyB) coagonist site. (Reference 8, and citations for this reference and the others cited in this manner are presented below). When compared with classic NMDA-R antagonists, GlyB antagonists have a much better safety profile and do not cause the adverse side effects that are associated with “classic” NMDA-R antagonists. (References 1, 6 and 10).

**[0006]** GlyB antagonists also have been shown to reduce hyperalgesia and allodynia in *ex vivo* and animal neuropathic pain models, and have fewer side effects than classic NMDA-R antagonists, making them a safer alternative as potential analgesics. See, for example, Reference 2.

**[0007]** One of the most potent and specific GlyB antagonists currently known is 7-chlorokynurenic acid (7-Cl-KYNA), which is a synthetic, chlorinated analogue of an endogenous neuromodulator, kynurenic acid. 7-chlorokynurenic acid has been shown to prevent excitotoxic and ischemic neuronal damage but like most GlyB antagonists does not cross the blood-brain barrier. Thus, its clinical use is limited. (References 4 and 9).

**[0008]** In contrast, L-4-chlorokynurenine, a prodrug of 7-chlorokynurenic acid, readily gains access to the central nervous system (CNS) after administration. (References 3, 5, 11 and 12). L-4-chlorokynurenine is efficiently converted to 7-chlorokynurenic acid within activated astrocytes, (Reference 5) and brain levels of 7-chlorokynurenic acid are increased at sites of neuronal injury or excitotoxic insult as a result of astrocyte activation. (Reference 5)

**[0009]** In preclinical studies, L-4-chlorokynurenine has shown anti-seizure activity in rats. (Reference 11). The compound also was found to increase the firing rate and burst firing activity of dopaminergic neurons in the brains of rats. (Reference 7).

**[0010]** Methods for the synthesis of a class of 4,6-disubstituted kynurenines derivatives, including L-4-chlorokynurenine, and their use as antagonists to the NMDA receptor were described in U.S.

Patent No. 5,547,991 to Palfreyman et al. (1996). Pharmaceutical compositions containing these compounds, and their therapeutic use also were described.

#### SUMMARY OF THE INVENTION

[0011] The invention and various embodiments are set out in the claims that form part of this patent application.

[0012] Without limiting the foregoing, in a preferred aspect, the invention relates to pharmaceutical compositions that per unit dose consist essentially of L-4-chlorokynurenine in an amount of about 360, 1,080 or 1,440 mg, together with pharmaceutically acceptable ingredients such as carriers and excipients. Another aspect of the invention involves the administration of therapeutically effective amounts of these compounds to treat conditions, disorders and diseases caused by neurological dysfunction.

[0013] Another aspect of the invention relates to dosing protocols for the inventive compositions, such as the administration of a daily dose of from 1 to about 14 or from 1 to about 30 days, more preferably from about 7 to about 24 days, and most preferably from about 12 to about 16 days.

[0014] Another preferred aspect of the invention relates to compositions and methods for the treatment of depression and for the treatment of various types of pain, including hyperalgesia, by administering a therapeutically effective amount of L-4-chlorokynurenine.

[0015] In another aspect, the invention relates to pharmaceutical compositions and associated therapeutic methods of administering L-4-chlorokynurenine in an amount that produces plasma levels of 7-chlorokynurenenic acid as described in this application. A preferred aspect of the invention relates to the administration of L-4-chlorokynurenine at a dose sufficient to produce plasma levels of 7-chlorokynurenenic acid are in the range of about 15 ng/mL to 550 ng/mL.

[0016] Another aspect of the invention relates to combination pharmaceutical product and associated methods that comprise formulations including L-DOPA and the pharmaceutical

composition of L-4-chlorokynurenine described in this application, and to their co-administration, either simultaneously or sequentially at dosages described in the application in order to reduce L-DOPA associated dyskinesias.

**[0017]** It is to be noted that, throughout the description and claims of this specification, the word 'comprise' and variations of the word, such as 'comprising' and 'comprises', is not intended to exclude other variants or additional components, integers or steps. Modifications and improvements to the invention will be readily apparent to those skilled in the art. Such modifications and improvements are intended to be within the scope of this invention.

**[0017a]** Any reference to or discussion of any document, act or item of knowledge in this specification is included solely for the purpose of providing a context for the present invention. It is not suggested or represented that any of these matters or any combination thereof formed at the priority date part of the common general knowledge, or was known to be relevant to an attempt to solve any problem with which this specification is concerned.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0018]** The following figures, which are described below and which are incorporated in and constitute a part of the specification, illustrate exemplary embodiments according to the disclosure and are not to be considered limiting of the scope of the invention, for the invention may admit to other equally effective embodiments. The figures are not necessarily to scale, and certain features and certain views of the figures may be shown exaggerated in scale or in schematic in the interest of clarity and conciseness.

**[0019]** Fig. 1 represents the mean (n = 12 or 13) plasma concentrations of L-4-chlorokynurenine on days 1 and 14 after oral administration of once-daily doses of L-4-chlorokynurenine.

**[0020]** Fig. 2 represents the mean (n = 12 or 13) plasma concentrations of 7-chlorokynurenic acid on days 1 and 14 after oral administration of once-daily doses of L-4-chlorokynurenine.

#### DETAILED DESCRIPTION OF THE INVENTION

**[0021]** The invention is described below, with reference to detailed illustrative embodiments. It will be apparent that the invention may be embodied in a wide variety of forms, some of which may be quite different from those of the disclosed embodiments. Consequently, the specific structural and

functional details disclosed below are merely representative and do not limit the scope of the invention.

[0022] In work supported by a grant from the National Institutes of Health, it was shown that L-4-chlorokynurenine (also known as VistaGen AV-101) had potent antihyperalgesic actions in three animal models of peripheral tissue inflammation and nerve injury with no evidence of side effects. Overall, in animal models, L-4-chlorokynurenine was well tolerated, and produced no safety or toxicity at doses that produce antihyperalgesic effects in animal models.

[0023] The present invention is based on the inventors' clinical findings that certain doses of L-4-chlorokynurenine are in fact safe and tolerable in humans without substantial side effects or any significant adverse effects. Moreover, it was surprisingly found that at such dosages, subjects reported relief from neuropathic pain, specifically, hyperalgesia pain. The compound is an antihyperalgesic. It was also surprisingly found that a substantial number of subjects in the clinical study reported positive feelings of "well-being" from the administration of L-4-chlorokynurenine, an indicator of anti-depressive activity, whereas this was not reported by the placebo controls.

[0024] The present invention relates to compositions and therapeutic methods to treat various types of neurological disorders, neuropathies (both central and peripheral) and dysfunction such as those caused by: (a) injury and drug toxicities such as result from chemotherapy and anti-viral drugs; (b) diseases and neurodegenerative disorders such as diabetes, cancer, viral infection, Multiple Sclerosis, spondylitis, polyneuritis, surgery, amputation, epilepsy, convulsions, Parkinson's disease, Huntington's disease, and Alzheimer's disease and those diseases and conditions involving overactive glutamatergic transmission via N-methyl-D-aspartate receptors; and (c) imbalances in neurotransmitters, receptors and signaling pathways associated with depression and other psychiatric disorders. The treatment of pain is expressly contemplated, including but not limited to neurogenic pain, spontaneous pain, allodynia hyperalgesia pain, mechanical hyperalgesia pain and heat

hyperalgesia pain. Moreover, the treatment of depression is also explicitly contemplated as an aspect of the present invention.

Definitions:

**[0025]** "Consisting essentially of" a specified amount of a pharmaceutically active agent means that there is no additional amount of that agent. The presence of other ingredients, for example, excipients and/or lubricants, and the like, or different pharmaceutically active ingredients in combination is not precluded. For example, the combination of L-DOPA with 4-chlorokynurenine is expressly contemplated, as are other compositions and methods for their administration that include 4-chlorokynurenine plus another active ingredient that are given either simultaneously or sequentially but in a time frame in which they have substantially the same therapeutic effect as if they had been administered in a single combination pharmaceutical product.

**[0026]** "Pharmaceutical unit dose," "unit dose" or "unit dose form" means a single dose of L-4-chlorokynurenine, which is capable of being administered to a subject, and which can be readily handled and packaged, remaining as a physically and chemically stable unit dose.

**[0027]** "Therapeutically effective" means that the amount of L-4-chlorokynurenine administered and converted to 7-chlorokinurenic acid acts to down-regulate NMDA-R mediated signal transmission that is sufficient to produce a clinical improvement in neurological function, such as a decrease in neuropathic pain, or an increase in feelings of well-being.

**[0028]** "Without significant adverse effect" means that substantially all patients to whom L-4-chlorokynurenine is administered will have no more than a "mild" adverse event as defined by the U.S. Food and Drug Administration (FDA). The FDA defines a "mild adverse event" as an event that is easily tolerated by the subject, causing minimal discomfort and not interfering with everyday activities. In contrast, a "moderate adverse event" is an event that is sufficiently discomforting causing it to interfere with normal everyday activities.



Pharmaceutical Compositions:

[0029] L-4-chlorokynurenine has been synthesized by the methods of Palfreyman et al, U.S. Patent No. 5,547,991. More recent synthesis processes also have been reported in the medical literature, such as Salituro et al. "Enzyme-Activated Antagonists of the Strychnine-Insensitive Glycine/NMDA Receptor, J. Med. Chem. 1994;37:334,336. L-4-chlorokynurenine also is available commercially from various sources, including BOC Sciences (Shirley, NY, USA) and Advanced Technology & Industrial Co., Ltd. (Hong Kong, China). Cambridge Major Laboratories (Germantown, WI, USA) manufactured the L-4-chlorokynurenine used in the clinical study discussed in this patent application.

[0030] A preferred embodiment of the invention relates to pharmaceutical compositions comprising a unit dose of a therapeutically effective amount of L-4-chlorokynurenine that is formulated for oral administration, together with pharmaceutically acceptable carriers and excipients.

[0031] A pharmaceutical composition of the invention may be formulated in any pharmaceutical form that contains L-4-chlorokynurenine according to the invention and that produces a blood plasma level of 7-chlorokynurenenic acid as described in this application. It is contemplated that the exact dosages of L-4-chlorokynurenine to be administered within the ranges described for the present invention are to be safe and effective, and that they produce plasma levels of 7-chlorokynurenenic acid resulting from the administration of L-4-chlorokynurenine as described in this patent application at Fig. 2 and in other places. Thus, plasma ranges of 7-chlorokynurenenic acid from about 15 ng/mL to about 65 ng/m, from about 65 ng/mL to about 300 ng/mL and from about 300 ng/mL to about 550 ng/mL are expressly contemplated. It is also contemplated that the unit dose formulation of the present invention may be administered one or more times per day, in order to extend the time period in which 4-cholokynurenine levels are elevated to a therapeutically effective amount of 7-cholokynurenenic acid.

[0032] The unit dose pharmaceutical compositions of L-4-chlorokynurenine for oral administration preferably contain about 50 mg to about 1,800 mg, more preferably about 260 mg to about 1,540 mg, more preferably either about 260 mg to about 460 mg, about 310 mg to about 410 mg, about 980 mg to about 1,180 mg, about 1,030 mg to about 1,130 mg, about 1,340 to about 1,540 mg, about 1,390 mg to about 1,490 mg and most preferably about 360, 1,080 or 1,440 mg.

[0033] It is contemplated that the dosing regimens for the compositions of the present invention are therapeutically effective. While a daily dosing regimen is contemplated, as described above, this would preferably be from about 5 to about 30 days, including shorter and longer dosing regimes as determined by a patient's physician. In particular, dosing regimes of about 7 to about 24 days, and about 12 to about 16 days are expressly contemplated.

[0034] A preferred aspect of the present invention involves the administration of 4-chlorokynurenine in conjunction with L-DOPA to reduce the dyskinesia associated with maintenance doses (typically, determined empirically for each patient by the physician) of L-DOPA; or to reduce the minimum effective dose of L-DOPA, thereby delaying the onset and/or reducing the severity of the dyskinesia. Pharmaceutical compositions according to the present invention may be administered in combination with L-DOPA, concurrently or closely enough in temporal proximity to ameliorate the side effects of L-DOPA administration. Protocols for the administration of L-DOPA are well known as are associated dyskinesias. See, for example, Tambasco, N. et al "Clinical Aspects and Management of Levodopa-Induces Dyskinesia," *Parkinson's Disease* 2012, Article ID 745947, doi:10.1155/2012/745947.

[0035] The pharmaceutical composition according to the present invention may be, for example, a tablet, capsule, liquid suspension, solid solution, softgel, injectable, topical, or transdermal, or suppository and nasal delivery. Additionally, a pharmaceutical composition of the present invention can also be a modified release form such as, but not limited to, a bi-modal or extended release form.

[0036] In general, the pharmaceutical compositions of the invention may be prepared by conventional methods known in the art of pharmaceutical formulations. For example, see Remington's Pharmaceutical Sciences, 18th Ed., (Mack Publishing Company, Easton, Pa., 1990), which is incorporated herein by reference. In a solid dosage form, L-4-chlorokynurenine may be admixed with at least one pharmaceutically acceptable excipient such as, for example, sodium citrate or dicalcium phosphate or (a) fillers or extenders, such as, for example, starches, lactose, sucrose, glucose, mannitol, and silicic acid, (b) binders, such as, for example, cellulose derivatives, starch, alginates, gelatin, polyvinylpyrrolidone, sucrose, and gum acacia, (c) humectants, such as, for example, glycerol, (d) disintegrating agents, such as, for example, agar-agar, calcium carbonate, potato or tapioca starch, alginic acid, croscarmellose sodium, complex silicates, and sodium carbonate, (e) solution retarders, such as, for example, paraffin, (f) absorption accelerators, such as, for example, quaternary ammonium compounds, (g) wetting agents, such as, for example, cetyl alcohol, and glycerol monostearate, magnesium stearate and the like (h) adsorbents, such as, for example, kaolin and bentonite, and (i) lubricants, such as, for example, talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate, or mixtures thereof. In the case of capsules, tablets, and pills, the dosage forms may also comprise buffering agents.

[0037] Pharmaceutically acceptable adjuvants known in the pharmaceutical formulation art may also be used in the pharmaceutical compositions of the invention. These include, but are not limited to, preserving, wetting, suspending, sweetening, flavoring, perfuming, emulsifying, and dispensing agents. Prevention of the action of microorganisms may be ensured by inclusion of various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, sorbic acid, and the like. It may also be desirable to include isotonic agents, for example, sugars, sodium chloride, and the like. If desired, a pharmaceutical composition of the invention may also contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents, antioxidants, and the

like, such as, for example, citric acid, sorbitan monolaurate, triethanolamine oleate, butylated hydroxytoluene, etc.

**[0038]** Solid dosage forms as described above may be prepared with coatings and shells, such as enteric coatings and others well known in the art. They may contain pacifying agents, and can also be of such composition that they release the active compound or compounds in a certain part of the intestinal tract in a delayed manner. Non-limiting examples of embedded compositions that may be used are polymeric substances and waxes. The active compounds may also be in microencapsulated form, if appropriate, with one or more of the above-mentioned excipients.

**[0039]** Suspensions, in addition to the active compounds, may contain suspending agents, such as, for example, ethoxylated isostearyl alcohols, polyoxyethylene sorbitol and sorbitan esters, microcrystalline cellulose, aluminum metahydroxide, bentonite, agar-agar and tragacanth, or mixtures of these substances, and the like.

**[0040]** Compositions for rectal administrations are, for example, suppositories that may be prepared by mixing the crystalline genistein sodium salt dihydrate according to the invention with, for example, suitable non-irritating excipients or carriers such as cocoa butter, polyethylene glycol or a suppository wax, which may be solid at ordinary temperatures but may be liquid at body temperature and, therefore, melt while in a suitable body cavity and release the active component therein.

#### Clinical Study:

**[0041]** A Phase 1b, single-site, randomized, double-blind, placebo-controlled, study was conducted involving multiple oral doses of AV-101 in healthy male and female subjects. Subjects were randomized into one of three cohorts (360, 1,080, and 1,440 mg) and received a daily oral dose for 14 consecutive days. Each cohort originally included 12 subjects on active drug and 4 subjects on placebo. The safety, pharmacokinetics (PK), tolerability of treatment, and antihyperalgesic effect of AV-101 on capsaicin-induced hyperalgesia were assessed.

[0042] The following PK parameters were derived from the plasma concentration versus time profiles to determine the single-dose and multiple-dose PK profile of AV-101 (L-4-chlorokynurenine) and the active metabolite, 7-chlorokynurenic acid: Maximum concentration ( $C_{max}$ ), Terminal elimination half-life ( $t_{1/2}$ ), Time to maximum concentration ( $T_{max}$ ), Area under the plasma study drug concentration versus time curve from Time 0 to time of last measurable concentration ( $AUC_{0-t}$ ) and Area under the plasma study drug concentration versus time curve from Time 0 extrapolated to infinity ( $AUC_{0-\infty}$ ).

[0043] Blood was collected in 6-mL lithium heparin Vacutainer tubes. Samples were centrifuged, and the plasma was separated from the cells and frozen within 30 minutes after centrifugation. Centrifuged samples were placed on ice until they were placed in the freezer. Plasma samples were stored frozen at approximately  $-20^{\circ}\text{C}$  until their shipment to a contractor for analysis.

[0044] Baseline samples (0 minutes) were collected before the drug was administered on Day 1 and on Day 14. Samples were then collected at 0.5, 1, 1.5, 2, 4, 6, 8, 12, and 24 hours after dosing on Day 1 and Day 14.

[0045] A liquid chromatography with tandem mass spectrometry assay was used for the determination of 7-chlorokynurenic acid and L-4-chlorokynurenine in human plasma. The standard curve range was from 2.00 to 1,000 ng/mL for 7-chlorokynurenic acid, with a lower limit of quantification of 2.00 ng/mL. The standard curve range was from 0.05 to 50  $\mu\text{g/mL}$  for L-4-Cl-KYN with a lower limit of quantification of 0.05  $\mu\text{g/mL}$ . Both assays used a plasma sample volume of 50.0  $\mu\text{L}$ .

[0046] The PK of AV-101 were fully characterized across the range of doses in the study. Plasma concentration-time profiles obtained for L-4-chlorokynurenine and 7-chlorokynurenic acid after administration of a single and multiple, once daily oral doses of 360, 1,080, or 1,440 mg were consistent with rapid absorption of the oral dose and first-order elimination of both analytes, with evidence of multicompartment kinetics, particularly for the metabolite 7-chlorokynurenic acid. Mean

L-4-chlorokynurenine  $T_{max}$  values increased with increasing dose level, reaching nearly 2 hours for the highest dose group. Mean  $t_{1/2}$  values were fairly consistent across doses, ranging from 1.64 to 1.82 hours. Mean L-4-chlorokynurenine  $C_{max}$  and  $AUC_{0-\infty}$  values appeared to be approximately dose linear, although not proportional. Mean  $C_{max}$  values on Day 1 ranged from 27.7  $\mu\text{g/mL}$  after the 360-mg dose to 64.4  $\mu\text{g/mL}$  after the 1,440-mg dose. Mean  $AUC_{0-t}$  values on Day 1 ranged from 64  $\mu\text{g}\cdot\text{h/mL}$  after the lowest dose to 196  $\mu\text{g}\cdot\text{h/mL}$  after the 1,440-mg dose. Mean  $C_{max}$  and  $AUC_{0-t}$  values the majority of the times were slightly lower on Day 14 than those on Day 1.

[0047] In general, as expected for a metabolite, 7-chlorokynurenic acid maximum concentrations occurred at the same time or later than those for L-4-chlorokynurenine, with mean  $T_{max}$  values ranging from 1.67 to 2.34 hours. This is shown in Figs. 1 and 2. Mean  $t_{1/2}$  values, ranging from 2.52 to 3.23 hours, were slightly more variable across doses than those for L-4-chlorokynurenine. Mean  $t_{1/2}$  values did not appear to be dose related. Mean 7-chlorokynurenic acid  $C_{max}$  and  $AUC_{0-t}$  values also appeared to be approximately dose linear. Mean  $C_{max}$  values on Day 1 ranged from 42.7  $\text{ng/mL}$  after the 360-mg dose to 314  $\text{ng/mL}$  after the 1,440-mg dose. Mean  $AUC_{0-t}$  values on Day 1 ranged from 156  $\text{ng}\cdot\text{h/mL}$  after the lowest dose to 985  $\text{ng}\cdot\text{h/mL}$  after the 1,440-mg dose. Similar to the parent compound, mean  $C_{max}$  and  $AUC_{0-t}$  values for 7-chlorokynurenic acid generally were slightly lower on Day 14 than those on Day 1.

EXAMPLE 1: Antihyperalgesic effect of L-4-chlorokynurenine on capsaicin-induced hyperalgesia.

[0048] On Day 1 and Day 14 of the clinical study, two intradermal injections of 250  $\mu\text{g}$  of capsaicin were injected sequentially into the volar aspect of alternate forearms to produce burning pain, secondary hyperalgesia, and a flare. The capsaicin USP (United States Pharmacopeia) was prepared according to the site's standard procedure and dissolved in 20% cyclodextrin at a concentration of 10  $\text{mg/mL}$ .

[0049] The first capsaicin injection in one forearm was given 1 hour after oral administration of AV-101 or placebo, and the second capsaicin injection was given in the other forearm 2 hours after

the administration of AV-101 or placebo. The neurosensory testing began immediately at each capsaicin injection. The serial pain assessments using a 100-mm visual analog scale (VAS) occurred at preinjection and 0, 5, 10, 15, 30, 45, and 60 minutes after each capsaicin injection. The examiner asked the subject to rate the intensity by using the VAS of the spontaneous pain and elicited pain from the application of a 5.18 von Frey hair, 40°C probe, and gentle stroking with a 1-inch foam brush. The VAS consisted of a 100-mm line with “no pain” written at the 0-mm end and the “worst imaginable pain” written at the 100-mm end. The distance in millimeters provided the pain measurement.

**[0050]** The borders of the hyperalgesic area to a 5.18 von Frey hair were determined by moving from an area of the skin that did not produce pain tangentially toward the center of the painful area at a progressively closer radius until the subject reported pain or tenderness. At least eight determinations of the hyperalgesic area borders were made using the same assessments and starting at different angles. Additionally, subjects were asked to rate the pain intensity of a 1-minute 45°C heat stimulus (brief thermal stimulation) applied to the anterior thigh at 4.5 hours ( $\pm 5$  minutes) after study drug administration, then every 30 minutes ( $\pm 5$  minutes) through 6 hours after study drug administration. A radiant temperature probe was applied to fix the skin temperature at 36°C during the pain assessments. Subjects used the VAS for all pain assessments.

**[0051]** All study assessment time points were anchored to Time 0, the time of study drug administration. For the capsaicin injection at 1 hour after dosing, the assessment interval (i.e., time after dosing of the study drug) was 60 to 120 minutes, during which time assessments occurred at approximately 60, 65, 70, and 75 minutes and then every 15 minutes through the 120-minute time point (i.e., 0, 5, 10, 15, 30, 45, and 60 minutes after capsaicin injection). The second injection of capsaicin was administered approximately 2 hours after dosing of the clinical trial material (CTM), and the assessment interval (i.e., time after dosing of the CTM) was 120 to 180 minutes. The serial pain assessments followed the same schedule, as described after the first capsaicin injection.

[0052] The primary efficacy endpoint was the analgesic response to spontaneous pain at each dose level of AV-101 120 to 180 minutes after dosing on Day 14. There was no significant change in the area under the pain time curve (AUPC) for the spontaneous pain assessment between the treatment and the placebo groups. Likewise, there were no significant changes between the treatment and the placebo groups for any of the secondary efficacy endpoints (AUPC for spontaneous pain for the time interval of 120 to 180 minutes after dosing on Day 1; and AUPC for spontaneous pain, elicited pain from the von Frey hair, and elicited pain from the 40°C probe for the time interval of 60 to 180 minutes after dosing on Days 1 and 14). However, the present inventors found a consistent decrease in the least squares means of the AUPC for allodynia pain, mechanical hyperalgesia pain, and heat hyperalgesia pain between subjects that received 1,080 mg AV-101 (Cohort 2) and subjects that received placebo. These data are shown in Table 1.

Table 1: Pain evaluation scores

<b>Heat Allodynia</b>			
	n	MAXPAIN	MP StdDiv
placebo	4	84.75	5.74
1080 mg	13	78.85	16.22
<b>Mechanical Allodynia</b>			
	n	MAXPAIN	MP StdDiv
placebo	4	79.75	7.93
1080 mg	13	66.23	25.60
<b>Allodynia Pain (foam brush)</b>			
	n	MAXPAIN	MP StdDiv
placebo	4	79.50	9.68
1080 mg	13	70.92	21.63
<b>Spontaneous Pain</b>			
	n	MAXPAIN	MP StdDiv
placebo	4	77.00	10.23
1080 mg	13	75.08	23.33



EXAMPLE 2: Anti-Depressive Activity of L-4-chlorokynurenine

[0053] The present inventors surprisingly also found a mood enhancing or anti-depressive activity of L-4-chlorokynurenine. In the clinical study described in this application, 5 out of 26 subjects (as contrasted with zero subjects in the placebo group) affirmatively reported feelings of well being. This is consistent with reports that the glutamatergic system contributes to the pathophysiology of depression and that stress can induce changes in NMDA receptors. See, for example, Calabrese et al. "Stress-Induced Changes of Hippocampal NMDA Receptors; Modulation by Duloxetine Treatment," PLoS ONE 2012, 7(5): e37916. doi:10.1371/journal.pone.0037916.

[0054] In summary, the invention described in this application generally relates to dosage forms of L-4-chlorokynurenine and methods for treating neurological conditions characterized by overactive glutamatergic transmission mediated by N-methyl-D-aspartate receptors, as described above. While certain exemplary embodiments have been described above in detail and shown in the accompanying drawing figures, it is to be understood that such embodiments are merely illustrative of and not restrictive of the broad invention. In particular, it should be recognized that the teachings of the invention apply to a wide variety of diseases. Persons of skill in the art will recognize that various modifications may be made to the illustrated and other embodiments of the invention described above, without departing from its broad inventive scope. Thus, it will be understood that the invention is not limited to the particular embodiments or arrangements disclosed, but is rather intended to cover any changes, adaptations or modifications which are within the scope and spirit of the invention as defined by the appended claims.

## References:

The following journal articles and all other publications, patents and texts mentioned in this application are incorporated by reference in their entireties.

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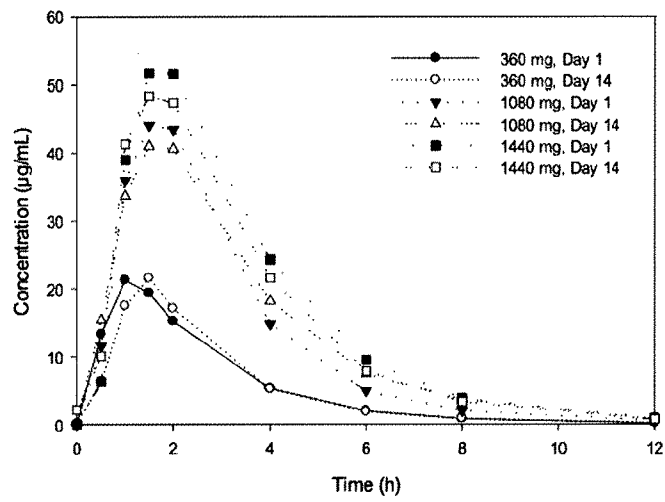
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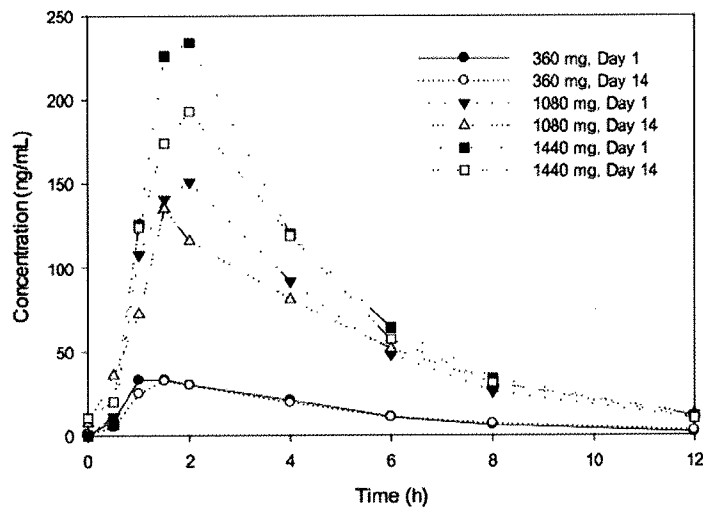
## CLAIMS

We claim:

1. A pharmaceutical composition that per unit dose consists essentially of L-4-chlorokynurenine in an amount of about 360, 1,080 or 1,440 mg, together with pharmaceutically acceptable ingredients such as carriers and excipients.
2. A method of treating conditions caused by neurological dysfunction comprising the administration of a pharmaceutical composition according to claim 1.
3. The method of claim 2, wherein the pharmaceutical composition is administered in a daily dose of from one to about 30 days.
4. A method of treating depression by administering a therapeutically effective amount of L-4-chlorokynurenine.
5. The method of claim 4 comprising the administration of a pharmaceutical composition according to claim 1.
6. A method of treating hyperalgesia by administering a therapeutically effective amount of L-4-chlorokynurenine.
7. The method of claim 6 comprising the administration of a pharmaceutical composition according to claim 1.
8. A pharmaceutical formulation that per unit dose consists essentially of L-4-chlorokynurenine in an amount that produces plasma levels of 7-chlorokynurenic acid consistent with the pharmaceutical composition of claim 1.
9. The pharmaceutical formulation of claim 8 wherein the plasma levels of 7-chlorokynurenic acid are in the range of about 15 ng/mL to 550 ng/mL.
10. A combination pharmaceutical product that comprises L-DOPA and the pharmaceutical composition of claim 1.
11. A method for reducing L-DOPA associated dyskinesias comprising the administration of a therapeutically effective amount of 7-chlorokynurenine.



**Figure 1.** Mean (n = 12 or 13) plasma concentrations of L-4-chlorokynurenine on Days 1 and 14 after oral administration of once-daily doses of AV-101.



**Figure 2.** Mean (n = 12 or 13) plasma concentrations of 7-chlorokynurenic acid on Days 1 and 14 after oral administration of once-daily doses of AV-101.