BENZOQUINOLINE INHIBITORS OF VESICULAR MONOAMINE TRANSPORTER 2

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ABSTRACT

The present invention relates to new benzoquinoline inhibitors of vesicular monoamine transporter 2 (VMAT2), pharmaceutical compositions thereof, and methods of use thereof.
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[0001] This application is a continuation of U.S. patent application Ser. No. 13/934,960, filed Jul. 3, 2013, which is a continuation of U.S. patent application Ser. No. 12/562,621, filed Sep. 18, 2009, issued as U.S. Pat. No. 8,524,733 on Sep. 3, 2013, which claims the benefit of priority of U.S. provisional application No. 61/097,896, filed Sep. 18, 2008, the disclosures of which are hereby incorporated by reference as if written herein in their entireties.

[0002] Disclosed herein are new benzoquinoline compounds, pharmaceutical compositions made thereof, and methods to inhibit vesicular monoamine transporter 2 (VMAT2) activity in a subject are also provided for, for the treatment of chronic hyperkinetic movement disorders.


[0004] In vivo, tetrabenazine is rapidly and extensively metabolized to its reduced form, 3-isobutyl-9,10-dimethoxy-1,3,4,6,7,11b-hexahydro-2H-pyrano[2,1-a]isouquinolino-2-ol, which then binds specifically to VMAT2 (Zhang et al., AAPS Journal, 2006, 8(4), E682-E692). Additional metabolic pathways involve O-demethylation of the methoxy groups, as well as hydroxylation of the isobutyl group (Schwartz et al., Biochem. Pharmacol., 1966, 15, 645-655). Adverse effects associated with the administration of tetrabenazine include neuroleptic malignant syndrome, drowsiness, fatigue, nervousness, anxiety, insomnia, agitation, confusion, orthostatic hypotension, nausea, dizziness, depression, and Parkinsonism.

Deuterium Kinetic Isotope Effect

[0005] In order to eliminate foreign substances such as therapeutic agents, the animal body expresses various enzymes, such as the cytochrome P₄₅₀ enzymes (CYPs), esterases, proteases, reductases, dehydrogenases, and monoamine oxidases, to react with and convert these foreign substances to more polar intermediates or metabolites for renal excretion. Such metabolic reactions frequently involve the oxidation of a carbon-hydrogen (C—H) bond to either a carbon-oxygen (C—O) or a carbon-carbon (C—C) π-bond. The resultant metabolites may be stable or unstable under physiological conditions, and can have substantially different pharmacokinetic, pharmacodynamic, and acute and long-term toxicity profiles relative to the parent compounds. For most drugs, such oxidations are generally rapid and ultimately lead to administration of multiple or high daily doses.

[0006] The relationship between the activation energy and the rate of reaction may be quantified by the Arrhenius equation, k = Ae⁻¹⁰⁻¹⁰¹ₚ. The Arrhenius equation states that, at a given temperature, the rate of a chemical reaction depends exponentially on the activation energy (E_a).

[0007] The transition state in a reaction is a short lived state along the reaction pathway during which the original bonds have stretched to their limit. By definition, the activation energy E_a for a reaction is the energy required to reach the transition state of that reaction. Once the transition state is reached, the molecules can either revert to the original reactants, or form new bonds giving rise to reaction products. A catalyst facilitates a reaction process by lowering the activation energy leading to a transition state. Enzymes are examples of biological catalysts.

[0008] Carbon-hydrogen bond strength is directly proportional to the absolute value of the ground-state vibrational energy of the bond. This vibrational energy depends on the mass of the atoms that form the bond, and increases as the mass of one or both of the atoms making the bond increases. Since deuterium (D) has twice the mass of protium (H), a C-D bond is stronger than the corresponding C—H bond. If a C—H bond is broken during a rate-determining step in a chemical reaction (i.e. the step with the highest transition state energy), then substituting a deuterium for that protium will cause a decrease in the reaction rate. This phenomenon is known as the Deuterium Kinetic Isotope Effect (DKIE). The magnitude of the DKIE can be expressed as the ratio between the rates of a given reaction in which a C—H bond is broken, and the same reaction where deuterium is substituted for protium. The DKIE can range from about 1 (no isotope effect) to very large numbers, such as 50 or more. Substitution of tritium for hydrogen results in yet a stronger bond than deuterium and gives numerically larger isotope effects.

[0009] Deuterium (²H or D) is a stable and non-radioactive isotope of hydrogen which has approximately twice the mass of protium (¹H), the most common isotope of hydrogen. Deuterium oxide (D₂O or “heavy water”) looks and tastes like H₂O, but has different physical properties.

[0010] When pure D₂O is given to rodents, it is readily absorbed. The quantity of deuterium required to induce toxicity is extremely high. When about 0-15% of the body water has been replaced by D₂O, animals are healthy but are unable to gain weight as fast as the control (untreated) group. When about 15-20% of the body water has been replaced with D₂O, the animals become excitable. When about 20-25% of the body water has been replaced with D₂O, the animals become so excitable that they go into frequent convulsions when stimulated. Skin lesions, ulcers on the paws and muzzles, and necrosis of the tails appear. The animals also become very aggressive. When about 30% of the body water has been replaced with D₂O, the animals refuse to eat and become comatose. Their body weight drops sharply and they have died by about 30 to about 35% replacement with D₂O. The effects are reversible unless more than thirty percent of the previous body weight has been lost due to D₂O. Studies have also
shown that the use of D₂O can delay the growth of cancer cells and enhance the cytotoxicity of certain antineoplastic agents.

[0011] Deuterium enrichment of pharmaceuticals to improve pharmacokinetics (PK), pharmacodynamics (PD), and toxicity profiles has been demonstrated previously with some classes of drugs. For example, the DKIE was used to decrease the hepatotoxicity of halothane, presumably by limiting the production of reactive species such as trifluoroacetyl chloride. However, this method may not be applicable to all drug classes. For example, deuterium incorporation can lead to metabolic switching. Metabolic switching occurs when xenogens, sequestered by Phase I enzymes, bind transiently and re-binding in a variety of conformations prior to the chemical reaction (e.g., oxidation). Metabolic switching is enabled by the relatively vast size of binding pockets in many Phase I enzymes and the promiscuous nature of many metabolic reactions. Metabolic switching can lead to different proportions of known metabolites as well as altogether new metabolites. This new metabolic profile may impart more or less toxicity. Such pitfalls are non-obvious and are not predictable a priori for any drug class.

[0012] Tetrabenazine is a VMAT2 inhibitor. The carbon-hydrogen bonds of tetrabenazine contain a naturally occurring distribution of hydrogen isotopes, namely ¹H or protium (about 99.9844%), ²H or deuterium (about 0.0156%), and ³H or tritium (in the range between about 0.5 and 67 tritium atoms per 10¹⁸ protium atoms). Increased levels of deuterium incorporation may produce a detectable Deuterium Kinetic Isotope Effect (DKIE) that could affect the pharmacokinetic, pharmacologic and/or toxicologic profiles of tetrabenazine in comparison with tetrabenazine having naturally occurring levels of deuterium.

[0013] Based on discoveries made in our laboratory, as well as considering the literature, tetrabenazine is metabolized in humans at the isobutyl and methoxy groups. The current approach has the potential to prevent metabolism at these sites. Other sites on the molecule may undergo transformations leading to metabolites with as-yet-unknown pharmacology/toxicology. Limiting the production of these metabolites has the potential to decrease the danger of the administration of such drugs and may even allow increased dosage and/or increased efficacy. All of these transformations can occur through polymorphically-expressed enzymes, exacerbating interpatient variability. Further, some disorders are best treated when the subject is medicated around the clock or for an extended period of time. For all of the foregoing reasons, a medicine with a longer half-life may result in greater efficacy and cost savings. Various deuteration patterns can be used to (a) reduce or eliminate unwanted metabolites, (b) increase the half-life of the parent drug, (c) decrease the number of doses needed to achieve a desired effect, (d) decrease the amount of a dose needed to achieve a desired effect, (e) increase the formation of active metabolites, if any are formed, (f) decrease the production of deleterious metabolites in specific tissues, and/or (g) create a more effective drug and/or a safer drug for polypharmacy, whether the polypharmacy be intentional or not. The deuteration approach has the strong potential to slow the metabolism of tetrabenazine and attenuate interpatient variability.

[0014] Novel compounds and pharmaceutical compositions, certain of which have been found to inhibit VMAT2 have been discovered, together with methods of synthesizing and using the compounds, including methods for the treatment of VMAT2-mediated disorders in a patient by administering the compounds as disclosed herein.

[0015] In certain embodiments of the present invention, compounds have structural formula 1:

![](image)

wherein:

- R₁-R₇ are independently selected from the group consisting of hydrogen and deuterium; and
- at least one of R₁-R₇ is deuterium.

[0016] R₁-R₇ are independently selected from the group consisting of hydrogen and deuterium; and

[0017] at least one of R₁-R₇ is deuterium.

[0018] In certain embodiments, Formula 1 can include a single enantiomer, a mixture of the (+)-enantiomer and the (-)-enantiomer, a mixture of about 90% or more by weight of the (+)-enantiomer and about 10% or less by weight of the (+)-enantiomer, a mixture of about 90% or more by weight of the (+)-enantiomer and about 10% or less by weight of the (-)-enantiomer, or a mixture of diastereomers thereof.

[0019] Certain compounds disclosed herein may possess useful VMAT2 inhibiting activity, and may be used in the treatment or prophylaxis of a disorder in which VMAT2 plays an active role. Thus, certain embodiments also provide pharmaceutical compositions comprising one or more compounds disclosed herein either with a pharmaceutically acceptable carrier, as well as methods of making and using the compounds and compositions. Certain embodiments provide methods for inhibiting VMAT2. Other embodiments provide methods for treating a VMAT2-mediated disorder in a patient in need of such treatment, comprising administering to said patient a therapeutically effective amount of a compound or composition according to the present invention. Also provided is the use of certain compounds disclosed herein for use in the manufacture of a medicament for the prevention or treatment of a disorder ameliorated by the inhibition of VMAT2.

[0020] The compounds as disclosed herein may also contain less prevalent isotopes for other elements, including, but not limited to, ¹³C or ¹⁴C for carbon, ³²S, ³⁴S, or ³⁵S for sulfur, ¹⁵N for nitrogen, and ¹⁷O or ¹⁸O for oxygen.

[0021] In certain embodiments, the compound disclosed herein may expose a patient to a maximum of about 0.000005% D₂O or about 0.00001% DHO, assuming that all of the C-D bonds in the compound as disclosed herein are metabolized and released as D₂O or DHO. In certain embodiments, the levels of D₂O shown to cause toxicity in animals is much greater than even the maximum limit of exposure caused by administration of the deuterium enriched compound as disclosed herein. Thus, in certain embodiments, the
deuterium-enriched compound disclosed herein should not cause any additional toxicity due to the formation of D₂O or DHO upon drug metabolism.  

[0022] In certain embodiments, the deuterated compounds disclosed herein maintain the beneficial aspects of the corresponding non-isotopically enriched molecules while substantially increasing the maximum tolerated dose, decreasing toxicity, increasing the half-life (T₁/₂), lowering the maximum plasma concentration (C₉₀), of the minimum efficacious dose (MED), lowering the efficacious dose and thus decreasing the non-mechanism-related toxicity, and/or lowering the probability of drug-drug interactions.  

[0023] All publications and references cited herein are expressly incorporated herein by reference in their entirety. However, with respect to any similar or identical terms found in both the incorporated publications or references and those explicitly put forth or defined in this document, then those terms definitions or meanings explicitly put forth in this document shall control in all respects.  

[0024] As used herein, the terms below have the meanings indicated.  

[0025] The singular forms “a,” “an,” and “the” may refer to plural articles unless specifically stated otherwise.  

[0026] The term “about,” as used herein, is intended to qualify the numerical values which it modifies, denoting such a value as variable within a margin of error. When no particular margin of error, such as a standard deviation to a mean value given in a chart or table of data, is recited, the term “about” should be understood to mean that range which would encompass the recited value and the range which would be included by rounding up or down to that figure as well, taking into account significant figures.  

[0027] When ranges of values are disclosed, and the notation “from n₁ to n₂,” or “n₁ - n₂,” is used, where n₁ and n₂ are the numbers, then unless otherwise specified, this notation is intended to include the numbers themselves and the range between them. This range may be integral or continuous between and including the end values.  

[0028] The term “deuterium enrichment” refers to the percentage of incorporation of deuterium at a given position in a molecule in the place of hydrogen. For example, deuterium enrichment of 1% at a given position means that 1% of molecules in a given sample contain deuterium at the specified position. Because the naturally occurring distribution of deuterium in water is about 0.015%, deuterium enrichment at any position in a compound synthesized using non-enriched starting materials is about 0.015%. The deuterium enrichment can be determined using conventional analytical methods known to one of ordinary skill in the art, including mass spectrometry and nuclear magnetic resonance spectroscopy.  

[0029] The term “is/are deuterium,” when used to describe a given position in a molecule such as R₁-R₂ or the symbol “D”, when used to represent a given position in a drawing of a molecular structure, means that the specified position is enriched with deuterium above the naturally occurring distribution of deuterium. In one embodiment deuterium enrichment is no less than about 1%, in another no less than about 5%, in another no less than about 10%, in another no less than about 20%, in another no less than about 50%, in another no less than about 70%, in another no less than about 80%, in another no less than about 90%, or in another no less than about 98% of deuterium at the specified position.  

[0030] The term “isotopic enrichment” refers to the percentage of incorporation of a less prevalent isotope of an element at a given position in a molecule in the place of the more prevalent isotope of the element.  

[0031] The term “non-isotopically enriched” refers to a molecule in which the percentages of the various isotopes are substantially the same as the naturally occurring percentages.  

[0032] Asymmetric centers exist in the compounds disclosed herein. These centers are designated by the symbols “R” or “S,” depending on the configuration of substituents around the chiral carbon atom. It should be understood that the invention encompasses all stereochirally isomeric forms, including diastereomeric, enantiomeric, and epimeric forms, as well as D-isomers and L-isomers, and mixtures thereof. Individual stereoisomers of compounds can be prepared synthetically, from commercially available starting materials which contain chiral centers or by preparation of mixtures of enantiomeric products followed by separation such as conversion to a mixture of diastereomers followed by separation or recrystallization, chromatographic techniques, direct separation of enantiomers on chiral chromatographic columns, or any other appropriate method known in the art. Starting compounds of particular stereochemistry are either commercially available or can be made and resolved by techniques known in the art. Additionally, the compounds disclosed herein may exist as geometric isomers. The present invention includes all cis, trans, syn, anti, entgegen (E), and zusammen (Z) isomers as well as the appropriate mixtures thereof. Additionally, compounds may exist as tautomers; all tautomeric isomers are provided by this invention. Additionally, the compounds disclosed herein can exist as solvated forms as well as solvated forms with pharmaceutically acceptable solvents such as water, ethanol, and the like. In general, the solvated forms are considered equivalent to the unsolvated forms.  

[0033] The term “bond” refers to a covalent linkage between two atoms, or two moieties when the atoms joined by the bond are considered to be part of larger substructure. A bond may be single, double, or triple unless otherwise specified. A dashed line between two atoms in a drawing of a molecule indicates that an additional bond may be present or absent at that position.  

[0034] The term “disorder” as used herein is intended to be generally synonymous, and is used interchangeably with the terms “disease,” “syndrome,” and “condition” (as in medical condition), in that they reflect an abnormal condition of the human or animal body or of one of its parts that impairs normal functioning, is typically manifested by distinguishing signs and symptoms.  

[0035] The terms “treat,” “treating,” and “treatment” are meant to include alleviating or abrogating a disorder or one or more of the symptoms associated with a disorder; or alleviating or eradicating the cause(s) of the disorder itself. As used herein, reference to “treatment” of a disorder is intended to include prevention. The terms “prevent,” “preventing,” and “prevention” refer to a method of delaying or precluding the onset of a disorder; and/or its attendant symptoms, barring a subject from acquiring a disorder or reducing a subject’s risk of acquiring a disorder.  

[0036] The term “therapeutically effective amount” refers to the amount of a compound that, when administered, is sufficient to prevent development of, or alleviate to some extent, one or more of the symptoms of the disorder being treated. The term “therapeutically effective amount” also refers to the amount of a compound that is sufficient to elicit the biological or medical response of a cell, tissue, system,
animal, or human that is being sought by a researcher, veterinarian, medical doctor, or clinician.

[0037] The term “subject” refers to an animal, including, but not limited to, a primate (e.g., human, monkey, chimpanzee, gorilla, and the like), rodents (e.g., rats, mice, gerbils, hamsters, ferrets, and the like), lagomorphs, swine (e.g., pig, miniature pig), equine, canine, feline, and the like. The terms “subject” and “patient” are used interchangeably herein in reference, for example, to a mammalian subject, such as a human patient.

[0038] The term “combination therapy” means the administration of two or more therapeutic agents to treat a therapeutic disorder described in the present disclosure. Such administration encompasses co-administration of these therapeutic agents in a substantially simultaneous manner, such as in a single capsule having a fixed ratio of active ingredients or in multiple, separate capsules for each active ingredient. In addition, such administration also encompasses use of each type of therapeutic agent in a sequential manner. In either case, the treatment regimen will provide beneficial effects of the drug combination in treating the disorders described herein.

[0039] The term “chronic hyperkinetic movement disorders” refers to disorders characterized by non-purposeful, repetitive, disordered motor acts, variously termed “compulsive”, “rhythmic”, or “stereotyped.” In humans, chronic hyperkinetic movement disorders can be psychogenic (e.g., tics, idiopathic (as in, e.g., Tourette’s syndrome and Parkinson’s Disease, genetic (as in, e.g., the chorea characteristic of Huntington’s Disease), infectious (as in, e.g., Sydenham’s Chorea), or, in tardive dyskinesia, drug-induced. Unless otherwise stated, “chronic hyperkinetic movement disorders” refers to and includes all psychogenic, idiopathic, genetic, and drug-induced movement disorders.

[0040] The term “stereotyped” refers to a repeated behavior that appears repetitively with slight variation or, less commonly, as a complex series of movements.

[0041] The term “VMAT2” refers to vesicular monoamine transporter 2, an integral membrane protein that acts to transport monoamines—particularly neurotransmitters such as dopamine, norepinephrine, serotonin, and histamine—from cellular cytosol into synaptic vesicles.

[0042] The term “VMAT2-mediated disorder” refers to a disorder that is characterized by abnormal VMAT2 activity. A VMAT2-mediated disorder may be completely or partially mediated by modulating VMAT2. In particular, a VMAT2-mediated disorder is one in which inhibition of VMAT2 results in some effect on the underlying disorder, e.g., administration of a VMAT2 inhibitor results in some improvement in at least some of the patients being treated.

[0043] The term “VMAT2 inhibitor,” “inhibit VMAT2,” or “inhibition of VMAT2” refers to the ability of a compound disclosed herein to alter the function of VMAT2. A VMAT2 inhibitor may block or reduce the activity of VMAT2 by forming a reversible or irreversible covalent bond between the inhibitor and VMAT2 or through formation of a noncovalently bound complex. Such inhibition may be manifest only in particular cell types or may be contingent on a particular biological event. The term “VMAT2 inhibitor,” “inhibit VMAT2,” or “inhibition of VMAT2” also refers to altering the function of VMAT2 by decreasing the probability that a complex forms between a VMAT2 and a natural substrate.

Suitable acids for use in the preparation of pharmaceutically acceptable salts include, but are not limited to, acetic acid, 2,2-dichloroacetic acid, acetylated amino acids, dicarboxylic acid, and carboxylic acids, such as phytic acid, sucrose, fructose, glucose, galactose, maltose, and lactose. Suitable bases for use in the preparation of pharmaceutically acceptable salts include, but are not limited to, alkali metal hydroxides, alkali metal carbonates, alkali metal bicarbonates, and alkali metal phosphates.

[0053] Suitable bases for use in the preparation of pharmaceutically acceptable salts, including but not limited to, inorganic bases such as magnesium hydroxide, calcium hydroxide, potassium hydroxide, zinc hydroxide, or sodium hydroxide, and organic bases, such as primary, secondary, tertiary, and quaternary, aliphatic and aromatic amines, including L-arginine, penicillin, benzylamine, choline, choline, diethanolamine, diethylamine, dimethylaniline, dippropylamine, dipropylamine, 2-(diethylamino)ethanol, ethylamine, ethylamine, ethylenediamine, isopropylamine, N-methyl-glucamine, hydrobromide, H1-imidazole, L-lysine, morpholine, 4-(2-hydroxyethyl)-morpholine, methyllamine, piperidine, piperezine, propylamine, pyrrolidine, 1-(2-hydroxyethyl)-pyrrolidine, pyridine, quinolinic acid, quinoline, isquinolinic acid, secondary amine, triethanolamine, trimethyllamine, triethylamine, N-methyl-D-glucamine, 2-amino-2-(hydroxymethyl)-1,3-propanediol, and tromethamine.

[0054] While it may be possible for the compounds of the subject invention to be administered as the raw chemical, it is also possible to present them as a pharmaceutical composition. Accordingly, provided herein are pharmaceutical compositions which comprise one or more of certain compounds disclosed herein, or one or more pharmaceutically acceptable salts, prodrugs, or solvates thereof, together with one or more pharmaceutically acceptable carriers thereof and optionally one or more other therapeutic ingredients. Proper formulation is dependent upon the route of administration chosen. Any of the well-known techniques, carriers, and excipients may be used as suitable and as understood in the art, e.g., in Remington’s Pharmaceutical Sciences. The pharmaceutical compositions disclosed herein may be manufactured in any manner known in the art, e.g., by means of conventional mixing, dissolving, granulating, dragee-making, levigating, emulsifying, encapsulating, entrapping, or compression processes. The pharmaceutical compositions may also be formulated as a modified release dosage form, including delayed-, extended-, prolonged-, sustained-, pulvulite-, controlled-, accelerated-, and fast-, targetted-, programmed-release, and gastrointestinal retention dosage forms. These dosage forms can be prepared according to conventional methods and techniques known to those skilled in the art (see, *Remington: The Science and Practice of Pharmacy*, supra; *Modified-Release Drug Deliver Technology*, Rathbone et al., Eds., Drugs and the Pharmaceutical Science, Marcel Dekker Inc., New York, N.Y., 2002; Vol. 126).

[0055] The compositions include those suitable for oral, parenteral (including subcutaneous, intradermal, intramuscular, intravenous, intrarticular, and intramundillary), intraperitoneal, transmucosal, transdermal, rectal and topical (including dermal, buccal, sublingual and intraoral) administration although the most suitable route may depend upon the condition and disorder of the recipient. The compositions may conveniently be presented in unit dosage form and may be prepared by any of the methods well known in the art of pharmacy. Typically, these methods include the step of bringing into association a compound of the subject invention or a pharmaceutically salt, prodrug, or solvate thereof (“active ingredient”) with the carrier which constitutes one or more accessory ingredients. In general, the compositions are prepared by uniformly and intimately

cinic acid, sulfuric acid, tannic acid, (+)-L-tartaric acid, thio-
cyanic acid, p-toluenesulfonic acid, undecylenic acid, and valeric acid.
bringing into association the active ingredient with liquid carriers or finely divided solid carriers or both and then, if necessary, shaping the product into the desired formulation.

Formulations of the compounds disclosed herein suitable for oral administration may be presented as discrete units such as capsules, cachets or tablets each containing a predetermined amount of the active ingredient; as a powder or granules; as a solution or a suspension in an aqueous liquid or a non-aqueous liquid; or as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion. The active ingredient may also be presented as a bolus, elixir or paste.

Pharmaceutical preparations which can be used orally include tablets, push-fit capsules made of gelatin, as well as soft, sealed capsules made of gelatin and a plasticizer, such as glycerol or sorbitol. Tablets may be made by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a suitable machine the active ingredient in a free-flowing form such as a powder or granules, optionally mixed with binders, inert diluents, or lubricants, surface active or dispersing agents. Molded tablets may be made by molding in a suitable machine a mixture of the powdered compound moistened with an inert liquid diluent. The tablets may optionally be coated or scored and may be formulated so as to provide slow or controlled release of the active ingredient therein. All formulations for oral administration should be in dosages suitable for such administration. The push-fit capsules can contain the active ingredients in admixture with filler such as lactose, binders such as starches, and/or lubricants such as talc or magnesium stearate and, optionally, stabilizers. In soft capsules, the active compounds may be dissolved or suspended in suitable liquids, such as fatty oils, liquid paraffin, or liquid polyethylene glycol. In addition, stabilizers may be added. Dragee cores are provided with suitable coatings. For this purpose, concentrated sugar solutions may be used, which may optionally contain gum arabic, t alc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of active compound doses.

The compounds may be formulated for parenteral administration by injection, e.g., by bolus injection or continuous infusion. Formulations for injection may be presented in unit dosage form, e.g., in ampoules or in multi-dose containers, with an added preservative. The compositions may take such forms as suspensions, solutions or emulsions in oily or aqueous vehicles, and may contain formulation agents such as suspending, stabilizing and/or dispersing agents. The formulations may be presented in unit-dose or multi-dose containers, for example sealed ampoules and vials, and may be stored in powder form or in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid carrier, for example, saline or sterile pyrogen-free water, immediately prior to use. Extemporaneous injection solutions and suspensions may be prepared from sterile powders, granules and tablets of the kind previously described.

Formulations for parenteral administration include aqueous and non-aqueous (oily) sterile injection solutions of the active compounds which may contain antioxidants, buffers, bacteriostats and solutes which render the formulation isotonic with the blood of the intended recipient; and aqueous and non-aqueous sterile suspensions which may include suspending agents and thickening agents. Suitable lipophilic solvents or vehicles include fatty oils such as sesame oil, or synthetic fatty acid esters, such as ethyl oleate or triglycerides, or liposomes. Aqueous injection suspensions may contain substances which increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol, or dextran. Optionally, the suspension may also contain suitable stabilizers or agents which increase the solubility of the compounds to allow for the preparation of highly concentrated solutions.

In addition to the formulations described previously, the compounds may also be formulated as a depot preparation. Such long acting formulations may be administered by implantation (for example subcutaneously or intramuscularly) or by intramuscular injection. Thus, for example, the compounds may be formulated with suitable polymeric or hydrophilic materials (for example as an emulsion in an acceptable oil) or ion exchange resins, or as sparingly soluble derivatives, for example, as a sparingly soluble salt.

For buccal or sublingual administration, the compositions may take the form of tablets, lozenges, pastilles, or gels formulated in conventional manner. Such compositions may comprise the active ingredient in a flavored basis such as sucrose and acacia or tragacanth.

The compounds may also be formulated in rectal compositions such as suppositories or retention enemas, e.g., containing conventional suppository bases such as cocoa butter, polyethylene glycol, or other glycerides.

Certain compounds disclosed herein may be administered topically, that is by non-systemic administration. This includes the application of a compound disclosed herein externally to the epidermis or the buccal cavity and the instillation of such a compound into the ear, eye and nose, such that the compound does not significantly enter the blood stream. In contrast, systemic administration refers to oral, intravenous, intraperitoneal and intramuscular administration.

Formulations suitable for topical administration include liquid or semi-liquid preparations suitable for penetration through the skin to the site of inflammation such as gels, liniments, lotions, creams, ointments or pastes, and drops suitable for administration to the eye, ear or nose.

For administration by inhalation, compounds may be delivered from an insufflator, nebulizer pressurized packs or other convenient means of delivering an aerosol spray. Pressurized packs may comprise a suitable propellant such as dichlorodifluoromethane, trichlorofluoromethane, dichlorotetrafluoroethane, carbon dioxide or other suitable gas. In the case of a pressurized aerosol, the dosage unit may be determined by providing a valve to deliver a metered amount. Alternatively, for administration by inhalation or insufflation, the compounds according to the invention may take the form of a dry powder composition, for example a powder mix of the compound and a suitable powder base such as lactose or starch. The powder composition may be presented in unit dosage form, in for example, capsules, cartridges, gelatin or blister packs from which the powder may be administered with the aid of an inhalator or insufflator.

Preferred unit dosage formulations are those containing an effective dose, as herein below recited, or an appropriate fraction thereof, of the active ingredient.

Compounds may be administered orally or via injection at a dose of from 0.1 to 500 mg/kg per day. The dose range for adult humans is generally from 5 mg to 2 g/day. Tablets or other forms of presentation provided in discrete
units may conveniently contain an amount of one or more compounds which is effective at such dosage or as a multiple of the same, for instance, units containing 5 mg to 500 mg, usually around 10 mg to 200 mg.

[0068] The amount of active ingredient that may be combined with the carrier materials to produce a single dosage form will vary depending upon the host treated and the particular mode of administration.

[0069] The compounds can be administered in various modes, e.g. orally, topically, or by injection. The precise amount of compound administered to a patient will be the responsibility of the attendant physician. The specific dose level for any particular patient will depend upon a variety of factors including the activity of the specific compound employed, the age, body weight, general health, sex, diet, time of administration, route of administration, rate of excretion, drug combination, the precise disorder being treated, and the severity of the disorder being treated. Also, the route of administration may vary depending on the disorder and its severity.

[0070] In the case wherein the patient’s condition does not improve, upon the doctor’s discretion the administration of the compounds may be administered chronically, that is, for an extended period of time, including throughout the duration of the patient’s life in order to ameliorate or otherwise control or limit the symptoms of the patient’s disorder.

[0071] In the case wherein the patient’s status does improve, upon the doctor’s discretion the administration of the compounds may be given continuously or temporarily suspended for a certain length of time (i.e., a “drug holiday”).

[0072] Once improvement of the patient’s condition has occurred, a maintenance dose is administered if necessary. Subsequently, the dosage or the frequency of administration, or both, can be reduced, as a function of the symptoms, to a level at which the improved disorder is retained. Patients can, however, require intermittent treatment on a long-term basis upon any recurrence of symptoms.

[0073] Disclosed herein are methods of treating a VMAT2-mediated disorder comprising administering to a subject having or suspected of having such a disorder, a therapeutically effective amount of a compound as disclosed herein or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

[0074] VMAT2-mediated disorders, include, but are not limited to, chronic hyperkinetic movement disorders, and/or any disorder which can lessened, alleviated, or prevented by administering a VMAT2 inhibitor. In certain embodiments, the chronic hyperkinetic movement disorder is Huntington’s disease.

[0075] In certain embodiments, a method of treating a VMAT2-mediated disorder comprises administering to the subject a therapeutically effective amount of a compound as disclosed herein, or a pharmaceutically acceptable salt, solvate, or prodrug thereof, so as to affect: (1) decreased inter-individual variation in plasma levels of the compound or a metabolite thereof; (2) increased average plasma levels of the compound or decreased average plasma levels of at least one metabolite of the compound per dosage unit; (3) decreased inhibition of, and/or metabolism by at least one cytochrome P450 or monoamine oxidase isofrom in the subject; (4) decreased metabolism via at least one polymorphically-expressed cytochrome P450 isofrom in the subject; (5) at least one statistically-significantly improved disorder-control and/or disorder-eradication endpoint; (6) an improved clinical effect during the treatment of the disorder, (7) prevention of recurrence, or delay of decline or appearance, of abnormal alimentary or hepatic parameters as the primary clinical benefit, or (8) reduction or elimination of deleterious changes in any diagnostic hepatobiliary function endpoints, as compared to the corresponding non-isotopically enriched compound.

[0076] In certain embodiments, inter-individual variation in plasma levels of the compounds as disclosed herein, or metabolites thereof, is decreased; average plasma levels of the compound as disclosed herein are increased; average plasma levels of a metabolite of the compound as disclosed herein are decreased; inhibition of a cytochrome P450 or monoamine oxidase isofrom by a compound as disclosed herein is increased; or metabolism of the compound as disclosed herein by at least one polymorphically-expressed cytochrome P450 isofrom is decreased, by greater than about 5%, greater than about 10%, greater than about 20%, greater than about 30%, greater than about 40%, or by greater than about 50% as compared to the corresponding non-isotopically enriched compound.


[0078] Examples of cytochrome P450 isofroms in a mammalian subject include, but are not limited to, CYP1A1, CYP1A2, CYP1B1, CYP2A6, CYP2A13, CYP2B6, CYP2C8, CYP2C9, CYP2C18, CYP2C19, CYP2D6, CYP2E1, CYP2G1, CYP2J2, CYP2R1, CYP3A11, CYP3A4, CYP3A5, CYP3A51, CYP3A52, CYP3A7, CYP4A11, CYP4B1, CYP4F2, CYP4F3, CYP4F8, CYP4F11, CYP4F12, CYP4X1, CYP4Z1, CYP5A1, CYP7A1, CYP7B1, CYP8A1, CYP8B1, CYP11A1, CYP11B1, CYP11B2, CYP17, CYP19, CYP21, CYP24, CYP26A1, CYP26B1, CYP27A1, CYP27B1, CYP39, CYP46, and CYP51.

[0079] Examples of monoamine oxidase isofroms in a mammalian subject include, but are not limited to, MAO-A and MAO-B.


[0081] Examples of polymorphically-expressed cytochrome P450 isofroms in a mammalian subject include, but are not limited to, CYP2C8, CYP2C9, CYP2C19, and CYP2D6.

[0082] The metabolic activities of liver microsomes, cytochrome P450 isofroms, and monoamine oxidase isofroms are measured by the methods described herein.

[0083] Examples of improved disorder-control and/or disorder-eradication endpoints, or improved clinical effects include, but are not limited to, change from baseline in the chorea score of the Unified Huntington’s Disease Rating Scale (UHDRS).

[0084] Examples of diagnostic hepatobiliary function endpoints include, but are not limited to, alanine aminotransferase (“ALT”), serum glutamic-pyruvic transaminase (“SGPT”), aspartate aminotransferase (“AST” or “SGOT”), ALT/AST ratios, serum aldolase, alkaline phosphatase (“ALP”), ammonia levels, bilirubin, gamma-glutamyl transpeptidase (“GGTP”, “γ-GTP,” or “GGT”), leucine ami-
nopeptidase ("LAP"), liver biopsy, liver ultrasonography, liver nuclear scan, 5'-nucleotidase, and blood protein. Hepatobiliary endpoints are compared to the stated normal levels as given in "Diagnostic and Laboratory Test Reference"; 4th edition, Mosby, 1999. These assays are run by accredited laboratories according to standard protocol.

Besides being useful for human treatment, certain compounds and formulations disclosed herein may also be useful for veterinary treatment of companion animals, exotic animals and farm animals, including mammals, rodents, and the like. More preferred animals include horses, dogs, and cats.

Combination Therapy

The compounds disclosed herein may also be combined or used in combination with other agents useful in the treatment of VMAT2-mediated disorders. Or, by way of example only, the therapeutic effectiveness of one of the compounds described herein may be enhanced by administration of an adjunct (i.e., by itself the adjunct may only have minimal therapeutic benefit, but in combination with another therapeutic agent, the overall therapeutic benefit to the patient is enhanced).

Such other agents, adjuvants, or drugs, may be administered, by a route and in an amount commonly used therefor, simultaneously or sequentially with a compound as disclosed herein. When a compound as disclosed herein is used contemporaneously with one or more other drugs, a pharmaceutical composition containing such other drugs in addition to the compound disclosed herein may be utilized, but is not required.

In certain embodiments, the compounds disclosed herein can be combined with one or more anti-psychotics, including, but not limited to, chlorpromazine, levomepromazine, promazine, acepromazine, triflupromazine, cyamazine, chlorprothixene, dixyrazine, fluphenazine, perphenazine, prochlorperazine, thiothixene, trifluoperazine, acetylperazine, thiothyperazine, butaparazine, perazine, percinazine, thiopromazine, mesoridazine, pipotizine, haloperidol, trifluoperidol, melperone, meporene, pipamperone, bromperidol, benperidol, droperidol, fluanisone, oxyperazine, molindone, sertindole, ziprasidone, fluphenixol, clophenthixol, chlorprothixene, thiophene, zuclopenthixol, flupirenizine, pimozide, perindoline, fluroxpine, clonazepam, olanzapine, quetiapine, tetrabenazine, sulpiride, sulphoxide, tiapride, remoxipride, amisulpride, voralpiride, levoluluride, lithium, prothipendyl, risperidone, clozapine, memantine, zotepine, aripiprazole, and paliperidone.

In certain embodiments, the compounds disclosed herein can be combined with one or more benzodiazepines ("minor tranquilizers"), including, but not limited to alprazolam, adinazolam, bromazepam, camaepam, clonazepam, clonazepam, clorazepate, estazolam, fludiazepam, flurazepam, halazepam, ketazolam, lorazepam, medazepam, dolazolam, nitrazepam, nordazepam, oxazepam, potassium clorazepate, pinazepam, prazepam, tofisopam, triazolam, temazepam, and chlordiazepoxide.

In certain embodiments, the compounds disclosed herein can be combined with olanzapine or pimozide.

The compounds disclosed herein can also be administered in combination with other classes of compounds, including, but not limited to, anti-retroviral agents; CYP3A inhibitors; CYP3A inducers; protease inhibitors; adrenergic agonists; anti-cholinergics; mast cell stabilizers; xanthines; leukotriene antagonists; glucocorticoids treatments; local or general anesthetics; non-steroidal anti-inflammatory agents (NSAIDs), such as naproxen; antibacterial agents, such as amoxicillin; cholesteryl ester transfer protein (CETP) inhibitors, such as anacetrapib; anti-fungal agents, such as isoconazole; sepsis treatments, such as drotrecogin-a; steroids, such as hydrocortisone; local or general anesthetics, such as ketamine; norepinephrine reuptake inhibitors (NRIs) such as atomoxetine; dopamine reuptake inhibitors (DARIs), such as methylphenidate; serotonin-norepinephrine reuptake inhibitors (SNRIs), such as milnacipran; sedatives, such as diazepam; norepinephrine-dopamine reuptake inhibitor (NDRIs), such as bupropion; serotonin-norepinephrine-dopamine-reuptake-inhibitors (SNDRIs), such as venlafaxine; monoamine oxidase inhibitors, such as selegiline; hypothyric phospholipids; endothelin converting enzyme (ECE) inhibitors, such as phosphomidon; opioids, agents such as tramadol; thromboxane receptor antagonists, such as ifetroban; potassium channel openers; thiorphan inhibitors, such as hirudin; hypothyric phospholipids; growth factor inhibitors, such as modulators of PDGF activity; platelet activating factor (PAF) antagonists; anti-platelet agents, such as GPIIb/IIIa blockers (e.g., abxiximab, eptifibatide, and tirofiban), P2Y(12) antagonists, such as prasugrel (e.g., CS-747, and aspirin; anticoagulants, such as warfarin; low molecular weight heparins, such as enoxaparin; Factor Vila Inhibitors and Factor Xa Inhibitors; renin inhibitors; neutral endopeptidase (NEP) inhibitors; vasoopresidase inhibitors (dual NEP-ACE inhibitors), such as omapatrilat and enopatrilat; HMG CoA reductase inhibitors, such as pravastatin, lovastatin, atorvastatin, simvastatin (a.k.a. itavastatin, nisvastatin, or nisvastatin), and ZD-4522 (also known as rosuvastatin, or atavastatin or visastatin); squalene synthetase inhibitors; fbrates; bile acid sequestrants, such as questan; niacin; anti-atherosclerotic agents, such as ACAT inhibitors; MTP Inhibitors; calcium channel blockers, such as amiodipine besylate; potassium channel activators; alpha-mussaracine agents, including, such as amicrosarin, amikacin, aprotinin, atherosclerotic agents, such as carvedilol and metoprolol; antiarrhythmic agents, diuretics, such as chlorothalidone, hydrochlorothiazide, furosemide, hydroflumethiazide, bendroflumethiazide, methyldi-hydrochlorothiazide, trimethiazide, hydrochlorothiazide, pentoxyfylline, ethacrynic acid, thiazides, hydrochlorothiazide, furosemide, musinespine, bumetanide, triamterene, amiloride, and spironolactone; thienopyridine agents, such as tissue plasminogen activator (tPA), recombinant tPA, streptokinase, urokinase, prourokinase, and urokinase, plasminogen, streptokinase activator complex (APSAC); anti-diabetic agents, such as biguanides (e.g. metformin), glucosidase inhibitors (e.g., acarbose), insulins, meglitinides (e.g., repaglinide), sulfonylureas (e.g., glimepiride, glyburide, and glipizide), thiazolidinediones (e.g. troglitazone, rosiglitazone and pioglitazone), and PPAR-gamma agonists; mineralocorticoid receptor antagonists, such as spironolactone and eplerenone; growth hormone secretagogues; aP2 inhibitors; phosphodiesterase inhibitors, such as PDE III inhibitors (e.g., cilostazol) and PDE V inhibitors (e.g., sildenafil, tadalaflil, vardenafil); protein tyrosine kinase inhibitors; anti-inflammatories; anti-proliferative agents, such as methotrexate, 5-Fluorouracil (5-FU), Prograf, mycophenolate mofetil, cyclophosphamide, thiopeta agents; immunosuppressants; anticancer agents and cytotoxic agents (e.g., alkylating agents, such as nitrogen mustards, alkyl sulfonates, nitrosoureas, ethylénienes, and triazenes); antimetabolites, such as folate antagonists, purine analogues, and pyridine analogues; antibiotics, such as antirnucyclines, bleomycins, mitomycins, daunomycins, and plamycins; enzymes, such as L-asparaginase; farnesyl-protein transferase inhibitors; hormonal agents, such as glucocorticoids (e.g., cortisone), estrogens/antiestrogens, androgens/antiandrogens, progestins, and luteinizing hormone-releasing hormone antagonists, and oestrogen acetate; microtubule-disrupter agents, such as etoposide; microtubule-stabilizing agents, such as paclitaxel, docetaxel, and epothilones A-F; plant-derived products, such as vinca alka-
loids, epipodophyllotoxins, and taxanes; and topoisomerase inhibitors; prenyl-protein transferase inhibitors; and cyclorsporins; steroids, such as prednisone and dexamethasone; cytotoxic drugs, such as azathiprine and cyclophosphamide; TNF-alpha inhibitors, such as etanercept; anti-TNF antibodies or soluble TNF receptor, such as etanercept, rapamycin, and leflunomide; and cyclooxygenase-2 (COX-2) inhibitors, such as celecoxib and rofecoxib; and miscellaneous agents such as, hydroxyurea, procarbazine, mitotane, hexamethylmelamine, gold compounds, platinum coordination complexes, such as cisplatin, satraplatin, and carboplatin.

[0092] Thus, in another aspect, certain embodiments provide methods for treating VMA12-mediated disorders in a subject in need of such treatment comprising administering to said subject an amount of a compound disclosed herein effective to reduce or prevent said disorder in the subject, in combination with at least one additional agent for the treatment of said disorder. In a related aspect, certain embodiments provide therapeutic compositions comprising at least one compound disclosed herein in combination with one or more additional agents for the treatment of VMA12-mediated disorders.

General Synthetic Methods for Preparing Compounds

[0093] Isotopic hydrogen can be introduced into a compound as disclosed herein by synthetic techniques that employ deuterated reagents, whereby incorporation rates are pre-determined; and/or by exchange techniques, wherein incorporation rates are determined by equilibrium conditions, and may be highly variable depending on the reaction conditions. Synthetic techniques, where tritium or deuterium is directly and specifically inserted by tritiated or deuterated reagents of known isotopic content, may yield high tritium or deuterium abundance, but can be limited by the chemistry required. Exchange techniques, on the other hand, may yield lower tritium or deuterium incorporation, often with the isotope being distributed over many sites on the molecule.

[0094] The compounds as disclosed herein can be prepared by methods known to one of skill in the art and routine modifications thereof, and/or following procedures similar to those described in the Example section herein and routine modifications thereof, and/or procedures found in DaSilva et al., *Appl. Radiat. Isot.*, 1993, 44(4), 673-676; Popp et al., *J. Pharm. Sci.*, 1978, 67(6), 871-875; Ivanov et al., *Heterocycles*, 2001, 55(8), 1569-1572; U.S. Pat. No. 2,830,993; U.S. Pat. No. 3,045,021; WO 2007/130365; WO 2008/058261, which are hereby incorporated in their entirety, and references cited therein and routine modifications thereof. Compounds as disclosed herein can also be prepared as shown in any of the following schemes and routine modifications thereof.

[0095] The following schemes can be used to practice the present invention. Any position shown as hydrogen may be optionally substituted with deuterium.
Compound 1 is reacted with compound 2 in an appropriate solvent, such as nitromethane, in the presence of an appropriate acid, such as ammonium acetate, at an elevated temperature to give compound 3. Compound 3 is reacted with compound 4 in the presence of an appropriate base, such as potassium carbonate, in an appropriate solvent, such as N,N-dimethylformamide, at an elevated temperature to afford compound 5. Compound 5 is reacted with an appropriate reducing reagent, such as lithium aluminum hydride, in an appropriate solvent, such as tetrahydrofuran, at an elevated temperature to give compound 6. Compound 6 is reacted with compound 7 in the presence of an appropriate acid, such as trifluoroacetic acid, in an appropriate solvent, such as acetic acid, at an elevated temperature to give compound 8. Compound 9 is reacted with compound 10 and compound 11, in an appropriate solvent, such as methanol, at an elevated temperature to afford compound 12. Compound 12 is reacted with compound 13 in an appropriate solvent, such as ethyl acetate, to give compound 14. Compound 14 is reacted with compound 8 in an appropriate solvent, such as ethanol, at an elevated temperature to give compound 15 of Formula I.

Deuterium can be incorporated to different positions synthetically, according to the synthetic procedures as shown in Scheme I, by using appropriate deuterated intermediates. For example, to introduce deuterium at one or more positions of R₄₋R₅, compound 4 with the corresponding deuterium substitutions can be used. To introduce deuterium at one or more positions of R₇₋R₈, compound 1 with the corresponding deuterium substitutions can be used. To introduce deuterium at one or more positions of R₉₋R₁₀, compound 2 with the corresponding deuterium substitution can be used. To introduce deuterium at one or more positions of R₁₁₋R₁₂, compound 10 with the corresponding deuterium substitutions can be used. To introduce deuterium at R₁₃₋R₁₄, compound 7 with the corresponding deuterium substitution can be used. To introduce deuterium at one or more positions of R₁₅₋R₂₀, compound 9 with the corresponding deuterium substitutions can be used.
Compound 8 is reacted with compound 16 in an appropriate solvent, such as water, in the presence of an appropriate base, such as sodium hydroxide, to yield a compound 15 of Formula I.

Deuterium can be incorporated to different positions synthetically, according to the synthetic procedures as shown in Scheme II, by using appropriate deuterated intermediates. For example, to introduce deuterium at one or more positions of R1-R12 and R15, compound 8 with the corresponding deuterium substitutions can be used. To introduce deuterium at one or more positions of R13, R14, and R17, and R15, compound 16 with the corresponding deuterium substitutions can be used. To introduce deuterium at R18, deuterium oxide can be used.

Deuterium can also be incorporated to various positions, selectively or non-selectively through a proton-deuterium exchange method known in the art.

The invention is further illustrated by the following examples. All IUPAC names were generated using CambridgeSoft’s ChemDraw 10.0.

**EXAMPLE 1**

3-Isobutyl-9,10-bis(methylamino)-3,4,6,7-tetrahydro-1H-pyrido[2,1-a]isoquinolin-2(11bH)-one (tetra benzazine)

Acetic acid/trifluoroacetic acid (100 mL) was added to a solution of 2-(3,4-dimethoxyphenyl)ethanamine (20 g, 110.38 mmol, 1.00 equiv) and hexamethylenetetramine (31 g, 221.11 mmol, 2.00 equiv). The resulting solution was heated at reflux for about 5 hours in an oil bath. After adding water (100 mL), the solution was extracted with dichloromethane (3×200 mL), and the organic layers were combined and dried over anhydrous sodium sulfate. Solids were removed by filtration, and the resulting filtrate was concentrated in vacuo to give the title product as a yellow oil (20 g, yield=95%).

LC-MS: m/z=192 (MH)^{+}. 
Step 2

[0105]

3-((Dimethylamino)methyl)-5-methyl-hexan-2-one

[0106] Paraformaldehyde (5.5 g, 183.33 mmol, 1.60 equiv) and dimethylamine hydrochloride (10 g, 122.70 mmol, 1.00 equiv) were added to a solution of 5-methylhexan-2-one (50 g, 437.83 mmol, 3.00 equiv) and methanol (30 mL). The resulting solution was heated at reflux for about 16 hours, and then the pH was adjusted to about 8 with sodium hydroxide (10%). Standard extractive workup with ether (3x100 mL) gave the title product as a yellow oil (12 g, yield=57%).

Step 3

[0107]

3-Isobutyl-9,10-dimethoxy-3,4,6,7-tetrahydro-1H-pyrido[2,1-alisoquinolin-2(11bH)-one

[0108] Iodomethane (20 g, 140.94 mmol, 2.00 equiv) was added dropwise to a solution of 3-((dimethylamino)methyl)-5-methylhexan-2-one (12 g, 70.05 mmol, 1.00 equiv) and ethyl acetate (50 mL). The solution was stirred at ambient temperature for about 16 hours, and the resulting precipitant was collected by filtration to afford the title product (15 g, yield=68%).
Step 1

4-(2-Nitrovinyl)benzene-1,2-diol

Ammonium acetate (5.6 g, 72.73 mmol, 1.00 equiv) was added to a solution of 3,4-dihydroxybenzaldehyde (10 g, 72.41 mmol, 1.00 equiv) and nitromethane (50 mL). The resulting mixture was heated at reflux for about 16 hours, and then concentrated in vacuo. The resulting residue was then purified by silica gel column chromatography (ethyl acetate/petroleum ether (1:5)) to give the title compound as a yellow oil (8 g, yield=61%).

Step 2

d-(E)-1,2-Dimethoxy-4-(2-nitrovinyl)benzene

Iodomethane (4.3 g, 31 mmol, 1.00 equiv) was added dropwise to a solution of (E)-4-(2-nitrovinyl)benzene-1,2-diol (5 g, 28 mmol, 1.00 equiv), dimethylformamide (50 mL), and potassium carbonate (20 g, 140 mmol, 5.00 equiv). The resulting suspension was stirred at about 50°C for about 16 hours. The suspension was filtered, the filter cake was washed with ethyl acetate, and the washes were combined with the filtrate. The resulting mixture was then extracted with ethyl acetate (200 mL) and washed with brine. The mixture was dried over anhydrous sodium sulfate and concentrated in vacuo to give the title product as a yellow oil (5 g, yield=93%). LC-MS: m/z = 188 (MH)⁺.

Step 3

6,7-d-(E)-Dihydroisoquinoline

The procedure of Example 1, Step 1 was followed, but substituting 2-(3,4-dimethoxyphenyl)ethanamine for 2-(3,4-dimethoxyphenyl)ethanamine. The title product was isolated as a yellow oil (20 g, yield=95%).
3-Isobutyl-9,10-d_4-dimethoxy-3,4,6,7-tetrahydro-1H-pyrido[2,1-a]isoquinolin-2(11bH)-one

[0121] The procedure of Example 1, Step 4 was followed but substituting 6,7-d_4-dimethoxy-3,4-dihydroisoquinoline for 6,7-dimethoxy-3,4-dihydroisoquinoline. The title product was isolated as a white solid (300 mg, yield=35%). 1H NMR (300 MHz, CDCl_3), δ 6.63 (s, 1H), 6.55 (s, 1H), 5.55 (s, 1H), 3.22-3.28 (m, 1H), 2.94-3.14 (m, 4H), 2.31-2.36 (m, 4H), 1.73-1.81 (t, 1H, J=11.4), 1.33-1.39 (m, 1H), 0.99-1.06 (t, 1H, J=10.5), 0.79-0.85 (m, 6H) LC-MS: m/z=326 (M+)^+.

[0122] The following compounds can generally be made using the methods described above. It is expected that these compounds when made will have activity similar to those described in the examples above.
Changes in the metabolic properties of the compounds disclosed herein as compared to their non-isotopically enriched analogs can be shown using the following assays. Compounds listed above which have not yet been made and/or tested are predicted to have changed metabolic properties as shown by one or more of these assays as well.

**Biological Activity Assays**

**In Vitro Liver Microsomal Stability Assay**

Liver microsomal stability assays are conducted at 1 mg per mL liver microsome protein with an NADPH-generating system in 2% sodium bicarbonate (2.2 mM NADPH, 25.6 mM glucose 6-phosphate, 6 units per mL glucose 6-phosphate dehydrogenase and 3.3 mM magnesium chloride). Test compounds are prepared as solutions in 20% acetonitrile-water and added to the assay mixture (final assay concentration 5 microgram per mL) and incubated at 37°C. Final concentration of acetonitrile in the assay should be <1%. Aliquots (50 µL) are taken out at times 0, 15, 30, 45, and 60 minutes, and diluted with ice cold acetonitrile (200 µL) to stop the reactions. Samples are centrifuged at 12,000 RPM for 10 minutes to precipitate proteins. Supernatants are transferred to microcentrifuge tubes and stored for LC/MS/MS analysis of the degradation half-life of the test compounds. It has thus been found that certain deuterium-enriched compounds disclosed herein that have been tested in this assay showed an increased degradation half-life as compared to the non-isotopically enriched drug. In certain embodiments, the increase in degradation half-life is at least 5%.

**In Vitro Metabolism Using Human Cytochrome P450 Enzymes**

The cytochrome P450 enzymes are expressed from the corresponding human cDNA using a baculovirus expression system (BD Biosciences, San Jose, Calif.). A 0.25 milliliter reaction mixture containing 0.8 milligrams per milliliter protein, 1.3 millimolar NADP⁺, 3.3 millimolar glucose-6-phosphate, 0.4 U/mL glucose-6-phosphate dehydrogenase, 3.3 millimolar magnesium chloride and 0.2 millimolar of a compound of Formula I, the corresponding non-isotopically...
enriched compound or standard or control in 100 millimolar potassium phosphate (pH 7.4) is incubated at 37°C for 20 minutes. After incubation, the reaction is stopped by the addition of an appropriate solvent (e.g., acetonitrile, 20% trichloroacetic acid, 94% acetonitrile/6% glacial acetic acid, 70% perchloric acid, 94% acetonitrile/6% glacial acetic acid) and centrifuged (10,000 g) for 5 minutes. The supernatant is analyzed by HPLC/MS/MS.

<table>
<thead>
<tr>
<th>Cytchrome P450</th>
<th>Standard</th>
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<tbody>
<tr>
<td>CYP1A2</td>
<td>Phenacetin</td>
</tr>
<tr>
<td>CYP2A6</td>
<td>Coumarin</td>
</tr>
<tr>
<td>CYP2B6</td>
<td>[14C]-[S]-mephenytoin</td>
</tr>
<tr>
<td>CYP2C9</td>
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<td>CYP2C19</td>
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<td>CYP2D6</td>
<td>(+/-)-Bufuralol</td>
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<tr>
<td>CYP2E1</td>
<td>Chlorzoxazone</td>
</tr>
<tr>
<td>CYP3A4</td>
<td>Testosterone</td>
</tr>
<tr>
<td>CYP4A</td>
<td>[14C]-Lauric acid</td>
</tr>
</tbody>
</table>

Monoamine Oxidase A Inhibition and Oxidative Turnover

[0126] The procedure is carried out using the methods described by Weyer et al., Journal of Biological Chemistry 1985, 260, 1319-13207, which is hereby incorporated by reference in its entirety. Monoamine oxidase A activity is measured spectrophotometrically by monitoring the increase in absorbance at 314 nm on oxidation of kynuramine with formation of 4-hydroxyquinoline. The measurements are carried out, at 30°C, in 50 mM sodium phosphate buffer, pH 7.2, containing 0.2% Triton X-100 (monoamine oxidase assay buffer), plus 1 mM kynuramine, and the desired amount of enzyme in 1 mL total volume.

Monoamine Oxidase B Inhibition and Oxidative Turnover

[0127] The procedure is carried out as described in Uebelhack et al., Psychopharmacology 1998, 31(5), 187-192, which is hereby incorporated by reference in its entirety.

Determination of Tetrabenazine and an Active Metabolite by HPLC

[0128] The procedure is carried out as described in Roberts et al., Journal of Chromatography, Biomedical Applications 1981, 226(1), 175-82, which is hereby incorporated by reference in its entirety.

Pharmacokinetic Assays of Tetrabenazine and its Major Metabolite in Man and Rat

[0129] The procedure is carried out as described in Mehvar et al., Drug Metabolism and Disposition 1987, 15(2), 250-5, which is hereby incorporated by reference in its entirety.

Detecting Tetrabenazine Metabolites in Animals and Man

[0130] The procedure is carried out as described in Schwartz et al., Biochemical Pharmacology 1966, 15(5), 645-55, which is hereby incorporated by reference in its entirety.

Mass Spectrometric Determination of Tetrabenazine

[0131] The procedure is carried out as described in Jindal et al., Journal of Chromatography, Biomedical Applications 1989, 493(2), 392-7, which is hereby incorporated by reference in its entirety.

In Vitro Radioligand Binding Assay

[0132] The procedure is carried out as described in Scherman et al., Journal of Neurochemistry 1988, 50(4), 1131-36, which is hereby incorporated by reference in its entirety.

In Vitro Radioligand Binding Assay

[0133] The procedure is carried out as described in Kilbourn et al., Synapse 2002, 43(3), 188-194, which is hereby incorporated by reference in its entirety.

In Vitro Radioligand Binding Assay

[0134] The procedure is carried out as described in Kilbourn et al., European Journal of Pharmacology 1997, 331(2-3), 161-68, which is hereby incorporated by reference in its entirety.

3H-Histamine Transport Assay

[0135] The procedure is carried out as described in Erickson et al., Journal of Molecular Neuroscience 1995, 6(4), 277-87, which is hereby incorporated by reference in its entirety.

[0136] From the foregoing description, one skilled in the art can ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various uses and conditions.

What is claimed is:

1. A pharmaceutical composition comprising a pharmaceutically acceptable carrier together with compounds of structural Formula I

or a salt thereof, wherein:

in each compound of Formula I, R1-R27 are independently selected from the group consisting of hydrogen and deuterium;

the composition has deuterium enrichment of at least 10% at each of the positions R1-R27 in the compounds of Formula I;

the positions R2-R27 in the compounds of Formula I are not isotopically enriched; and

the pharmaceutical composition is an oral dosage form.

2. The composition as recited in claim 1 wherein R1-R27 each have deuterium enrichment of no less than 50%.

3. The composition as recited in claim 1 wherein R1-R27 each have deuterium enrichment of no less than 90%.

4. The composition as recited in claim 1 wherein R1-R27 each have deuterium enrichment of no less than 98%.

5. The pharmaceutical composition as recited in claim 1, wherein said oral dosage form is a tablet or capsule.
6. A pharmaceutical composition comprising a pharmaceutically acceptable carrier together with compounds of structural Formula I

\[
\text{(I)}
\]

or a salt thereof, wherein:

- in each compound of Formula I, \( R_1-R_{27} \) are independently selected from the group consisting of hydrogen and deuterium;
- the composition has deuterium enrichment of at least 10% at each of the positions \( R_1-R_5 \) in the compounds of Formula I;
- the positions \( R_6-R_{27} \) in the compounds of Formula I are not isotopically enriched; and
- the pharmaceutical composition is a parenteral dosage form.

7. The pharmaceutical composition as recited in claim 6, wherein said parenteral dosage form is formulated for intravenous dosage.

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