The present invention provides novel compounds as well as compositions and methods using the same for preventing and/or treating degenerative disorders of the central nervous system. In particular, the present invention provides methods for preventing and/or treating Parkinson's disease.
CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/252,803, filed October 19, 2009, the contents of which is incorporated by reference herein.

FIELD OF THE INVENTION

[0002] The present invention provides novel compounds, known as pharmacological chaperones, as well as compositions and methods using the same for preventing and/or treating degenerative disorders of the central nervous system. In particular, the present invention provides methods for preventing and/or treating Parkinson’s disease.

BACKGROUND OF THE INVENTION

[0003] Many degenerative disorders of the central nervous system are associated with pathologic aggregation of proteins or lipids. For example, synucleinopathies are a group of diseases that arise from disruption of synuclein protein homeostasis. In particular, alpha-synuclein aggregation is associated with pathological conditions characterized by Lewy bodies, such as Parkinson’s disease, dementia with Lewy bodies, and multiple system atrophy. Likewise, alpha-synuclein fragment, non-Abeta component, is found in amyloid plaques of Alzheimer’s disease. Recently, enhancement of glucocerebrosidase (beta-glucosidase; GCase) activity in the brain has been shown to prevent accumulation of synuclein in the brain (Sean Clark, Ying Sun, You-Hai Xu, Gregory Grabowski, and Brandon Wustman, “A biochemical link between Gaucher and Parkinson’s disease and a potential new approach to treating synucleinopathies: a pharmacological chaperone for beta-glucocerebrosidase prevents accumulation of alpha-synuclein in a Parkinson’s mouse model,” Presented at the Society for Neuroscience Annual Meeting, San Diego, CA, 2007). Thus, agents that enhance GCase activity may provide relief for patients at risk for developing or diagnosed with degenerative disorders of the central nervous system.

[0004] There is a need for new therapeutic compounds that can be used to prevent and/or treat degenerative disorders of the central nervous system that provide patients with a higher quality of life and achieve a better clinical outcome. In particular, there is a need for new therapeutic compounds to prevent and/or treat synucleinopathies such as Parkinson’s disease and Alzheimer’s disease that provide patients with a higher quality of life and achieve a better clinical outcome.

SUMMARY OF THE INVENTION

[0005] The present invention provides novel compounds as well as compositions and methods using the same to prevent and/or treat a degenerative disorder of the central nervous system in a patient at risk for developing or diagnosed with the same which includes administering to the patient an effective amount of a compound described herein.

[0006] In one aspect, there is provided a compound as well as compositions and methods using the same to prevent and/or treat a degenerative disorder of the central nervous system in a patient at risk for developing or diagnosed with the same which includes administering to the patient an effective amount of a compound defined by Formula I:

```
wherein:
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R¹ is C(R²)(R³)(R⁴);
R² is hydrogen, -OH or halogen;
R³ is hydrogen, -OH, halogen or C₁₋₈ alkyl;
R⁴ is halogen, C₁₋₈ alkyl, substituted C₁₋₈ alkyl, aryl, substituted aryl, alkylcycloalkyl or substituted alkylcycloalkyl;
R³ and R⁴ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted, preferably with halogen and more preferably with one or more fluorine atoms;
R⁶ is hydrogen, C₁₋₈ alkyl, substituted C₁₋₈ alkyl, aryalkyl, substituted aryalkyl, alkyaryl, or substituted alkyaryl;
Z is optional, when present Z is -(CH₂)₁₋₈-, -C(=O)-, -S(=O)₂NH-, -S(=O)₂-, -C(S)NH-, -S(=O)₂CH₃, C(=O)-NH-, -S(=O)₂NR⁹R¹₀, -C(=O)CH(NH₂)CH₃;
R⁸ is hydrogen, C₁₋₈ alkyl or substituted C₁₋₈ alkyl;
R¹₀ is hydrogen, C₁₋₈ alkyl or substituted C₁₋₈ alkyl;
R⁵ is hydrogen, C₁₋₈ alkyl, substituted C₁₋₈ alkyl, aryl, substituted aryl, C₁₋₈ alkenyl, substituted C₁₋₈ alkenyl, arylalkyl, substituted aryalkyl, alkyaryl, substituted alkyaryl, aminoaryalkyl or substituted aminoaryalkyl;
R⁷ is -OH or halogen; and
R⁸ is hydrogen, halogen or C₁₋₈ alkyl,

provided that R² and R³ cannot both be hydrogen when R⁴ is a halogen, Z is not present, R⁷ is -OH, R⁵, R⁶ and R⁸ are hydrogen.

[0007] In another aspect, there is provided a compound as well as compositions and methods using the same to prevent and/or treat a degenerative disorder of the central nervous system in a patient at risk for developing or diagnosed with the same which includes administering to the patient in need thereof an effective amount of a compound defined by Formula II:

wherein:

R¹ is C(R²)(R³)(R⁴);
R² is hydrogen, -OH or halogen;
R³ is hydrogen, -OH, halogen or -CH₃;
R⁴ is halogen, -CH₃, phenyl, fluoro phenyl, methylphenyl, cyclohexymethyl, wherein when R⁴ is a halogen, both R² and R³ cannot be hydrogen;
R³ and R⁴ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted with one or more halogen atoms;
R⁶ is hydrogen, phenylalkyl or substituted phenylalkyl;
Z is optional, when present Z is -(CH₂)₁₋₈-, -C(=O)-, -S(=O)₂NH-, -S(=O)₂-, -S(=O)₂CH₃, C(=O)-NH-, -S(=O)₂NR⁹R¹₀, -C(=S)-NH- or -C(=O)₂CH₃;
R⁸ is hydrogen or CH₃;
R¹₀ is hydrogen or CH₃;
R⁵ is hydrogen or aminophenylalkyl;
R⁷ is -OH or halogen; and
R⁸ is hydrogen, halogen or -CH₃,

provided that R² and R³ cannot both be hydrogen when R⁴ is halogen, Z is not present, R⁷ is -OH, R⁵, R⁶ and R⁸ are hydrogen.
In yet another aspect, there is provided a compound as well as compositions and methods using the same to prevent and/or treat a degenerative disorder of the central nervous system in a patient at risk for developing or diagnosed with the same which includes administering to the patient in need thereof an effective amount of a compound defined by Formula III:

\[
\begin{align*}
R^1 & \text{ is } C(R^2)(R^3)(R^4); \\
R^2 & \text{ is hydrogen, } -\text{OH} \text{ or halogen; } \\
R^3 & \text{ is hydrogen, } -\text{OH}, \text{ halogen or } -\text{CH}_3; \\
R^4 & \text{ is halogen, } -\text{CH}_3, \text{ phenyl, fluorophenyl, methylphenyl, cyclohexylmethyl, wherein when } R^4 \text{ is a halogen, both } R^2 \text{ and } R^3 \text{ cannot be hydrogen; } \\
R^3 \text{ and } R^4 & \text{ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted with one or more halogen atoms; } \\
R^7 & \text{ is } -\text{OH} \text{ or halogen; and } \\
R^8 & \text{ is hydrogen, halogen or } -\text{CH}_3,
\end{align*}
\]

provided that \( R^2 \) and \( R^3 \) cannot both be hydrogen when \( R^4 \) is a halogen, \( R^7 \) is -OH and \( R^6 \) and \( R^8 \) are hydrogen.

It is understood by a person of ordinary skill in the art that \( R^2, R^3 \) and \( R^4 \) in aforementioned Formulas I, II, and III will not be selected such that an unstable molecule will result.

In still another aspect, there is provided a compound as well as compositions and methods using the same to prevent and/or treat a degenerative disorder of the central nervous system in a patient at risk for developing or diagnosed with the same which includes administering to the patient in need thereof an effective amount of a compound selected from the following:
or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

[0011] In one embodiment, the compound is (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5S)-5-benzylpiperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof. In one embodiment, the compound is (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof. In one embodiment, the compound is (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof. In one embodiment, the compound is (3R,4R,5S)-5-benzylpiperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

[0012] In one embodiment, the degenerative disorder is a synucleinopathy. In one embodiment, the degenerative disorder is characterized by Lewy bodies. In one embodiment, the degenerative disorder is Parkinson’s disease, dementia with Lewy bodies, multiple system atrophy or Alzheimer’s disease. In one embodiment, the degenerative disorder is associated with aggregation of at least one protein. In one embodiment, the degenerative disorder is associated with aggregation of alpha-synuclein. In one embodiment, the degenerative disorder is associated with aggregation of non-Abeta component. In one embodiment, the degenerative disorder is associated with accumulation of at least one glycolipid. In one embodiment, the degenerative disorder is associated with accumulation of at least one glycosphingolipid. In one embodiment, the degenerative disorder is associated with accumulation of glucocerebroside. In one embodiment, the degenerative disorder is associated with a mutation in glucocerebrosidase. In one embodiment, the method further comprises administering an effective amount of at least one other therapeutic agent. In one embodiment, at least one other therapeutic agent is levodopa, an anticholinergic, a catechol-O-methyl transferase inhibitor, a dopamine receptor agonist, a monoamine oxidase inhibitor, a peripheral decarboxylase inhibitor, or an anti-inflammatory agent.

[0013] The present invention also provides methods for preventing and/or treating Parkinson’s disease in a patient at risk for developing or diagnosed with the same, which comprises administering to the patient in need thereof an effective amount of any of the aforementioned compounds, or a pharmaceutically acceptable salt, solvate, or prodrug thereof, or any combination of two or more thereof.

[0014] In one embodiment, the method comprises administering the compound (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5S)-5-benzylpiperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof. In one embodiment, the method comprises administering the compound (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof. In one embodiment, the method comprises administering the compound (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof. In one embodiment, the method comprises administering the compound (3R,4R,5S)-5-benzylpiperidine-3,4-diol, or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

[0015] In one embodiment, the method comprises administering an effective amount of at least one other therapeutic agent. In one embodiment, at least one other therapeutic agent is levodopa, an anticholinergic, a catechol-O-methyl transferase inhibitor, a dopamine receptor agonist, a monoamine oxidase inhibitor, a peripheral decarboxylase inhibitor, or an anti-inflammatory agent.

[0016] The present invention also provides kits comprising:

- a container having an effective amount of any of the compounds of the present invention, alone or in combination; and
- instructions for using the same to prevent and/or treat a degenerative disorder of the central nervous system.

In one embodiment, the degenerative disorder of the central nervous system is Parkinson’s disease. In one embodiment, the degenerative disorder of the central nervous system is Alzheimer’s disease.

DETAILED DESCRIPTION OF THE INVENTION

[0017] As used herein the following terms shall have the definitions set forth below.

[0018] As used herein, the phrase "degenerative disorder of the central nervous system" means any disorder associated with the premature degeneration of any component of the central nervous system, such as neurons, myelin sheaths or axons. Such disorders include but are not limited to multi-infarct dementia, Huntington’s disease, Pick’s disease, amyotrophic lateral sclerosis, Creutzfeldt-Jakob’s disease, frontal-lobe degeneration, corticobasal degeneration, progressive...
As used herein the term "treating" means to ameliorate one or more symptoms associated with the referenced disorder.

As used herein, the term "preventing" means to mitigate a symptom of the referenced disorder.

As used herein the phrase "an effective amount" means an amount effective to prevent and/or treat a patient at risk for developing or diagnosed with the referenced disorder, and thus producing the desired therapeutic effect.

As used herein the term "patient" means a mammal (e.g., a human).

Listed below are chemical definitions of various terms used to describe this invention. These definitions apply to the terms as they are used throughout this specification, unless otherwise limited in specific instances, either individually or as part of a larger group.

The term "alkyl" refers to straight or branched chain unsubstituted hydrocarbon groups of 1 to 20 carbon atoms, preferably 1 to 8 carbon atoms, more preferably 1 to 6 carbon atoms. The expression "lower alkyl" refers to unsubstituted alkyl groups of 1 to 4 carbon atoms.

The term "substituted alkyl" refers to an alkyl group substituted by, for example, one to four substituents, such as, halo, hydroxy, alkoxy, oxo, alkanoyl, aryl, amino, alkylaminooxy, amino, alkylamino, aralkylamino, disubstituted amines in which the 2 amino substituents are selected from alkyl, aryl or aralkyl; alkanoylamino, arylamino, aralkylamino, substituted alkanoylamino, substituted arylamino, substituted aralkanoylamino, thiol, alkythio, arylthio, aralkylthio, arylthiono, aralkylthiono, aralkylsulfonyl, sulfonamido, e.g. SO2NH2, kanoylamino, substituted alkanoylamino, substituted arylamino, substituted aralkanoylamino, thiol, alkythio, arylthio, aralkylthio, arylthiono, aralkylthiono, aralkylsulfonyl, sulfonamido, e.g. SO2NH2, substituted sulfonamido, nitro, cyano, carboxy, carbamyl, e.g. CONH2, substituted carbamyl e.g. CONHalkyl, CONHaralkyl or cases where there are two substituents on the nitrogen selected from alkyl, aryl or aralkyl; alkoxyaryl, aryl, substituted aryl, guanidino and heterocyclos, such as, indolyl, imidazolyl, furyl, thienyl, thiazolyl, pyrroldiy, pyridyl, pyrimidyl and the like. Where noted above where the substituent is further substituted it will be with alkyl, alkoxy, aryl or aralkyl.

The term "halogen" or "halo" refers to fluorine, chlorine, bromine and iodine.

The term "aryl" refers to monocyclic or bicyclic aromatic hydrocarbon groups having 6 to 12 carbon atoms in the ring portion, such as phenyl, naphthyl, biphenyl and diphenyl groups, each of which may be substituted.

The term "aralkyl" refers to an aryl group bonded directly through an alkyl group, such as benzyl. Similarly, the term "alkylaryl" refers to an alkyl group bonded directly through an aryl group, such as methylenbenzyl.

The term "substituted aryl" refers to an aryl group substituted by, for example, one to four substituents such as alkyl, substituted alkyl, halo, trifluoromethoxy, trifluoromethyl, hydroxy, alkoxy, alkanoyl, aryl, amino, alkylamino, aralkylamino, dialkylamino, alkanoylamino, thiol, alkythio, ureido, nitro, cyano, carboxy, carboxyaryl, carbamyl, alkoxyaryl or aralkylamino, arylthiono, aralkylthiono, arylsulfonyl, sulfonamido, sulfonic acid, alkenyl, alkenynoxy, amido, and the like. The substituent may be further substituted by hydroxy, alkoxy, aryl, substituted aryl, substituted alkyl or aralkyl.

The term "heteroaryl" refers to an optionally substituted, aromatic group for example, which is a 4 to 7 membered monocyclic, 7 to 11 membered bicyclic, or 10 to 15 membered tricycllic ring system, which has at least one heteroatom and at least one carbon atom-containing ring, for example, pyridine, tetrazole, indazole.

The term "alkenyl" refers to straight or branched chain hydrocarbon groups of 2 to 20 carbon atoms, preferably 2 to 15 carbon atoms, and most preferably 2 to 8 carbon atoms, having one to four double bonds.

The term "substituted alkenyl" refers to an alkenyl group substituted by, for example, one to two substituents, such as, halo, hydroxy, alkoxy, alkanoyl, alkanoyloxy, amino, alkylamino, dialkylamino, alkanoylamino, thiol, alkythio, alkylthio, alkylsulfonyl, sulfonamido, nitro, cyano, carboxy, carbamyl, substituted carbamyl, guanidino, indolyl, imidazolyl, furyl, thienyl, thiazolyl, pyrroldiy, pyridyl, pyrimidyl and the like.

The term "alkynyl" refers to straight or branched chain hydrocarbons of 2 to 20 carbon atoms, preferably 2 to 15 carbon atoms, and most preferably 2 to 8 carbon atoms, having one to four triple bonds.

The term "substituted alkynyl" refers to an alkynyl group substituted by, for example, a substituent, such as, halo, hydroxy, alkoxy, alkanoyl, alkanoyloxy, amino, alkylamino, dialkylamino, alkanoylamino, thiol, alkythio, alkylthio, alkylsulfonyl, sulfonamido, nitro, cyano, carboxy, carbamyl, substituted carbamyl, guanidino and heterocyclos, e.g. imidazolyl, furyl, thienyl, thiazolyl, pyrroldiy, pyridyl, pyrimidyl and the like.

The term "heterocycle", "heterocyclic" and "heterocyclo" refer to an optionally substituted, fully saturated or unsaturated, aromatic or nonaromatic cyclic group, for example, which is a 4 to 7 membered monocyclic, 7 to 11 membered bicyclic, or 10 to 15 membered tricyclic ring system, which has at least one heteroatom in at least one carbon atom-containing ring. Each ring of the heterocycle containing a heteroatom may have 1, 2 or 3 heteroatoms selected from nitrogen atoms, oxygen atoms and sulfur atoms, where the nitrogen and sulfur heteroatoms may also...
Dementia with Lewy bodies (DLB) is one of the most common types of progressive dementia. The central feature of DLB is progressive cognitive decline, combined with three additional defining features: (i) parkinsonism (slow, stiff movement, writing becomes small and spidery); (ii) cerebellar dysfunction (difficulty coordinating movement and balance); and (iii) autonomic dysfunction (impaired automatic body functions) including: postural or orthostatic hypotension, resulting in dizziness or fainting upon standing up, urinary incontinence, impotence; constipation; dry mouth and skin; trouble regulating body temperature due to abnormal sweating; abnormal breathing during sleep. Notably, not all of these symptoms are experienced by all patients.

Dementia with Lewy bodies (DLB) is one of the most common types of progressive dementia. The central feature of DLB is progressive cognitive decline, combined with three additional defining features: (i) pronounced "fluctuations" in alertness and attention, such as frequent drowsiness, lethargy, lengthy periods of time spent staring into space, or disorganized speech; (ii) recurrent visual hallucinations; and (iii) parkinsonian motor symptoms, such as rigidity and the loss of spontaneous movement. People may also suffer from depression. The symptoms of DLB are caused by the build-up of Lewy bodies - accumulated bits of alpha-synuclein protein -- inside the nuclei of neurons in areas of the brain that control particular aspects of memory and motor control. Researchers don’t know exactly why alpha-synuclein accumulation, resulting in dizziness or fainting upon standing up, urinary incontinence, impotence; constipation; dry mouth and skin; trouble regulating body temperature due to abnormal sweating; abnormal breathing during sleep. Notably, not all of these symptoms are experienced by all patients.

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bodies are often also found in the brains of people with Parkinson’s and Alzheimer’s diseases. These findings suggest that either DLB is related to these other causes of dementia or that an individual can have both diseases at the same time. DLB usually occurs sporadically, in people with no known family history of the disease. However, rare familial cases have occasionally been reported.

Compounds

[0046] Novel compounds of the present invention are provided below:

(3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol

(3R,4R,5S)-5-benzylpiperidine-3,4-diol

(3R,4R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol

(3R,4R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol (stereoisomer A)

(3R,4R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol (stereoisomer B)

(3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol

(3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol (stereoisomer A)

(3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol (stereoisomer B)
(3R,4R,5S)-5-ethylpiperidine-3,4-diol

(3R,4R,5S)-5-isopropylpiperidine-3,4-diol

(3R,4R,5S)-5-(2-hydroxypropan-2-yl)piperidine-3,4-diol

(4R,5R)-3,3-difluoro-5-(hydroxymethyl)piperidin-4-ol

(4R,5R)-5-(hydroxymethyl)-3-methylpiperidine-3,4-diol

(3R,4R,5S)-5-(1,1-difluoroethyl)piperidine-3,4-diol

(3R,4R,5S)-5-(trifluoromethyl)piperidine-3,4-diol

(3R,4R,5S)-5-(2,2-difluoroethyl)piperidine-3,4-diol

(3R,4R,5S)-5-(2-fluoroethyl)piperidine-3,4-diol
(3R,4R,5S)-5-cyclopropylpiperidine-3,4-diol

(3R,4R,5S)-5-(2,2-difluorocyclopropyl)piperidine-3,4-diol

(3R,4R,5S,6S)-6-ethyl-5-(fluoromethyl)piperidine-3,4-diol

(3R,4R,5S,6R)-6-ethyl-5-(fluoromethyl)piperidine-3,4-diol

(3R,4R,5S,6S)-5-(difluoromethyl)-6-ethylpiperidine-3,4-diol

(3R,4R,5S,6R)-5-(difluoromethyl)-6-ethylpiperidine-3,4-diol

(3R,4R,5S)-1-benzyl-5-(difluoromethyl)piperidine-3,4-diol

(3R,4R,5R)-5-((S)-hydroxy(phenyl)methyl)piperidine-3,4-diol

(3R,4R,5R)-5-((S)-hydroxy(phenyl)methyl)piperidine-3,4-diol
(3R,4R,5S)-1-butyl-5-(difluoromethyl)piperidine-3,4-diol

(3R,4R,5S)-1-allyl-5-(difluoromethyl)piperidine-3,4-diol

1-((3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxypiperidin-1-yl)pentan-1-one

(3R,4R,5S)-5-(difluoromethyl)-1-(3-methoxybenzyl)piperidine-3,4-diol

(3R,4R,5S)-5-(difluoromethyl)-1-(4-methylbenzyl)piperidine-3,4-diol

(3R,4R,5S)-5-(difluoromethyl)-1-(methylsulfonyl)piperidine-3,4-diol
(3R,4R,5S)-5-(difluoromethyl)-1-(4-fluorobenzyl)piperidine-3,4-diol

(3R,4R,5R)-5-((4-fluorophenyl)(hydroxy)methyl)piperidine-3,4-diol

(3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxy-N-propylpiperidine-1-carboxamide

(3R,4R,5S)-5-(difluoromethyl)-1-tosylpiperidine-3,4-diol

(3R,4R,5S)-5-(4-methylbenzyl)piperidine-3,4-diol

(3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxy-N-phenylpiperidine-1-carboxamide
(continued)

(3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxy-N-phenylpiperidine-1-carbothioamide

(3S,4R,5R)-N-butyl-3-(difluoromethyl)-4,5-dihydroxypiperidine-1-carboxamide

(3S,4R,5R)-N-butyl-3-(difluoromethyl)-4,5-dihydroxypiperidine-1-carbothioamide

(3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxy-N,N-dimethylpiperidine-1-sulfonamide

(3R,4R,5R)-5-(2-cyclohexyl-1-hydroxyethyl)piperidine-3,4-diol

(3R,4R,5S)-5-(2-cyclohexyl-1-fluoroethyl)piperidine-3,4-diol

(3R,4R,5S)-5-(4-fluorobenzyl)piperidine-3,4-diol
(3R,4R,5R)-5-((3,5-difluorophenyl)(hydroxy)methyl)piperidine-3,4-diol

(3R,4R,5S)-5-((3,5-difluorophenyl)fluoromethyl)piperidine-3,4-diol

1-((3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxypiperidin-1-yl)ethanone

((3S,4R,5R)-3-(difluoromethyl)-4,5-dihydroxypiperidin-1-yl)(phenyl)methanone

(3R,4R,5R)-3-fluoro-5-(hydroxymethyl)piperidin-4-ol hydrochloride

(3R,4R,5R,6S)-6-((2,4-difluorobenzyl)-5-(hydroxymethyl)piperidine-3,4-diol hydrochloride

(3S,4R,5R)-3-fluoro-5-(hydroxymethyl)piperidin-4-ol hydrochloride

(3R,4R,5R)-5-(hydroxymethyl)-1-(2-nitrobenzyl)piperidine-3,4-diol
(3R,4R,5R)-1-(3-aminobenzyl)-5-(hydroxymethyl)piperidine-3,4-diol

(3R,4R,5R)-5-(hydroxymethyl)-1-(3-nitrobenzyl)piperidine-3,4-diol

(S)-2-amino-1-((3R,4R,5R)-3,4-dihydroxy-5-(hydroxymethyl)piperidin-1-yl)-4-methylpentan-1-one

(R)-2-amino-1-((3R,4R,5R)-3,4-dihydroxy-5-(hydroxymethyl)piperidin-1-yl)-4-methylpentan-1-one

(3R,4R,5S)-5-(fluoromethyl)piperidine-3,4-diol hydrochloride

(3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol

(3R,4R,5S)-5-((S)-1-fluoropropyl)piperidine-3,4-diol
Compositions of the present invention can be made in accordance of one or more of the following schemes.

Process Scheme 1:

1. A solution of 1 (20.0 g, 55.0 mmol) in MeOH (500 mL) was combined with Pd(OH)\(_2\) (4-6 g) and ammonium formate (14 g, 220 mmol) and the mixture was heated at 50-55 °C. Additional amounts (3x100.0 mmol) of ammonium formate were added over the next 8 hrs. After the final addition, the reaction mixture was further stirred and heated an additional 16 hrs at 50-55 °C. The catalyst was removed by filtration and the filtrate was evaporated in vacuo. The crude product was dissolved in acetone (150 mL), filtered, and HCl in 2-PrOH was added. After seeding and then cooling in an ice bath, the product was collected as a white crystalline solid (11.0 g, 71%). 1H NMR (DMSO-d6) 9.45 (s, 2H), 4.80 (t, 1H, ex), 3.85 (m, 1H), 3.0-3.75 (m, 11H), 2.8 (q, 2H), 1.95 (m, 1H), 1.2 (2, 6H).

2. To a solution of 2 (14.85 g, 50.0 mmol) in DMF (200 mL) was added K\(_2\)CO\(_3\) (17.25 g, 125 mmol) and the mixture was stirred at 40 °C for about 4 hrs. At this point, BnCl (5.7 mL, 50.0 mmol) was added in one portion and the reaction was stirred at 40 °C overnight. The solvent was evaporated in vacuo and the residue was suspended in water (600 mL) and HCl was added to dissolve the residue. The solution was washed with Et\(_2\)O and then basified with Na\(_2\)CO\(_3\). The solution was extracted with EtOAc (2x) and the combined extracts were washed with water and then brine and then dried over MgSO\(_4\). The solution was filtered and the filtrate evaporated in vacuo to give the title compound (17.2 g, >95%) as a colorless to very pale yellow viscous oil which was used without further purification. 1H NMR (CDCl\(_3\)) 7.3 (m, 5H), 3.6-3.8 (m, 2H), 3.5 (s, 3H), 3.4 (t, 1H), 3.26 (s, 3H), 3.268 (s, 3H), 2.9 (m, 2H), 2.2 (br s, 1H), 2.05 (m, 1H), 1.85 (t, 1H), 1.28 (s, 3H), 1.26 (s, 3H).

3. To a solution of DMSO (7.3 g, 96.9 mmol) in CH\(_2\)Cl\(_2\) (150 mL) cooled
to -78 °C was added a solution of oxalyl chloride (6.1 mL, 72.8 mmol) in CH2Cl2 dropwise. After the addition was complete the reaction mixture was stirred for an additional 30 min at which point a solution of 3 (17.0 g, 48.4 mmol) in CH2Cl2 was added dropwise. After addition was complete, the reaction was stirred for 1 hr at -78 °C and then disopropylethylamine (34.4 mL, 193 mmol) was added dropwise. After this addition was complete, the cooling bath was removed and the reaction mixture was allowed to warm to 0 °C when saturated NaHCO3 was added. The mixture was diluted with some additional CH2Cl2 and then the organic layer was separated and dried over MgSO4. After filtering, the solvent was evaporated in vacuo and the crude product was purified by silica gel chromatography (Hex/EtOAc) to give the title compound (12.7 g, 75%) as a viscous oil. 1H NMR (CDCl3) 9.73 (s, 1H), 7.2 (m, 5H), 3.75 (m, 2H), 3.5 (q, 2H), 3.2 (2s, 6H), 2.7-3.0 (m, 3H), 2.05 (m, 2H), 1.25 (2s, 6H).

(2S,3S,4aR,8S,8aR)-6-Benzyl-8,8-difluoromethyl-2,3-dimethoxy-2,3-dimethyloctahydro-[1,4]dioxino[2,3-c]pyridine Hydrochloride (General Procedure B) (5). To a solution of DAST (1.4 mL, 10.3 mmol) in CH2Cl2 (50 mL) cooled to -15 °C was added a solution of 4 (2.4 g, 6.9 mmol) dropwise. After 10 minutes, the ice bath was removed and the reaction was stirred at room temperature overnight. At this point the reaction mixture was again cooled in an ice bath and the reaction was quenched by addition of saturated NaHCO3 (dropwise at first since this does produce a slight exotherm). The organic layer was separated and dried over Na2SO4, filtered and the solvent was evaporated in vacuo to give a yellow oil. The residue was purified by chromatography on silica gel (Hex/EtOAc) to give the title compound (1.6 g, 62%) as a colorless oil. 1H NMR (CDCl3) 7.2 (m, 5H), 6.0 (dt, 1H), 3.75 (m, 1H), 3.55 (m, 3H), 3.2 (2s, 6H), 2.95 (m, 1H), 2.85 (m, 1H), 2.3 (m, 2H), 1.5 (br s, 1H), 1.2 (2s, 6H).

(3R,4R, 5S)-5-(Difluoromethyl)piperdine 3,4-diol Hydrochloride (General Procedure C) (6). Compound 5 (1.6 g, 4.3 mmol) was heated at reflux in a mixture of EtOH/H2O/HCl (40 mL/40 mL/5 mL) and the reaction monitored by HPLC until the starting material could no longer be detected. The solvent was evaporated in vacuo and then co-evaporated 2x with EtOH. The residue was dissolved in MeOH and hydrogenated over Pd(OH)2. When complete, the catalyst was removed by filtration and the filtrate evaporated in vacuo. The residue was recrystallized from EtOH (50 mL) to the title compound (0.55 g, 66%) as a white solid (mp 168-170 °C). 1H NMR (D2O) 6.15 (dt, 1H), 4.3-4.8 (m, 2H), 3.0 (t, 1H), 2.85 (t, 1H), 2.3 (m, 1H).
(R) and (S)-1-((2S,3S,4aR,8R,8aR)-6-Benzyl-2,3-dimethoxy-2,3-dimethyloctahydro-[1,4]dioxino[2,3-c]pyridin-8-yl)ethanol General Procedure D (15/16). To a solution of 4 (7.0 g, 20.0 mmol) in dry THF (100 mL) was added MeMgBr (20.0 mL, 1.4 M in 3:1 THF/toluene) and the reaction was stirred overnight at room temperature. The reaction was quenched with saturated NH4Cl and the mixture was extracted with EtOAc (2x). The combined extracts were washed with brine, dried over Na2SO4 and the filtrate was evaporated in vacuo. The residue was purified by silica gel chromatography (hexane/2-PrOH) to give the major isomer (15) (1.6 g, 24.6%). 1H NMR (CDCl3). 7.3 (m, 5H), 4.15 (m, 1H), 3.5-3.9 (m, 3H), 3.3 (2s, 6H), 2.85 (m, 2H), 2.0 (2m, 4H), 1.3 (2s, 6H), 1.2 (d, 3H). The minor isomer (16) was also isolated (0.55 g, 7.5%) 7.3 (m, 5H), 3.75 (m, 2H), 3.5 (m, 2H), 3.2 (2s, 6H), 2.8 (m, 2H), 2.0 (t, 1H), 1.75 (m, 2H), 1.2 (2s, 6H), 1.0 (d, 3H).

(3R,4R,5R)-5((R)-1-Hydroxyethyl)piperdine 3,4-diol (17). Compound 15 (0.55 g, 1.5 mmol) was stirred in a mixture of 9/1 TFA:H2O (20 mL) until the starting material could no longer be detected by HPLC. The volatiles were removed and the residue was co-evaporated 2-3x with EtOH and then dissolved in EtOH and treated with solid K2CO3. After filtering the solid, the filtrate was evaporated in vacuo, and the residue was converted to an HCl salt and hydrogenated over Pd(OH)2. The catalyst was filtered and the filtrate evaporated in vacuo. The crude product was purified using an ion exchange resin (Dowex 50WX8-200) eluting with 0.1 N NH4OH. The appropriate fractions were combined and lyophilized to give the title compound (0.12 g, 50%). 1H NMR (D2O) 4.2 (q, 1H), 3.65 (m, 1H), 3.45 (m, 3H), 2.8 (m, 2H), 1.65 (m, 1H), 1.15 (d, 3H).

(3R,4R,5R)-5((S)-1-Hydroxyethyl)piperdine 3,4-diol (10). Compound 16 (0.34 g, 0.93 mmol) was deprotected as described above to give the title compound (0.11 g, 75%). 1H NMR (D2O) 4.15 (m, 2H), 3.5 (m, 1H), 3.35 (t, 1H), 3.15 (m, 2H), 1.8 (m, 1H), 1.1 (d, 3H).

((2S,3S,4aR,8R,8aR)-6-Benzyl-8(S)-(1fluoroethyl)-2,3-dimethoxy-2,3-dimethyloctahydro-[1,4]dioxino[2,3-c]pyridine (11). Compound 15 (1.8 g, 5.0 mmol) was fluorinated using General Procedure B. Silica gel chroma-
tography (Hex/EtOAc) gave the title compound (0.42 g, 23%). 1H NMR (CDCl3) 7.25 (m, 5H), 4.7-4.9 (dq, 1H), 3.75 (m, 2H), 3.4 (m, 2H), 3.2 (2s, 6H), 2.8 (m, 2H), 2.0 (m, 3H), 1.35 (dd, 3H), 1.2 (2s, 6H).

[0058] (3R,4R, 5R)-5((S)-1-Fluoroethyl)piperdine 3,4-diol Hydrochloride (13). Compound 11 (0.42 g, 1.14 mmol) was deprotected as described in General Procedure C. After catalyst was removed, the filtrate was evaporated in vacuo and then co-evaporated with EtOH (2x). The resulting residue was triturated with acetone to give the title compound (0.20 g, 88%) as a white solid. 1H NMR (DMSO-d6) 9.0 (br s, 2H), 5.6 (d, 1H, ex), 5.4 (d, 1H, ex), 5.0-5.2 (dq, 1H), 3.55 (m, 1H), 3.2 (m, 2H), 2.9 (t, 1H), 2.7 (t, 1H), 2.2 (m, 1H), 1.3 (dd, 3H).

[0059] ((2S,3S,4aR,8R,8aR)-6-Benzyl-8(R)-(1fluoroethyl)-2,3-dimethoxy-2,3-dimethyloctahydro-[1,4]dioxino[2,3-c]pyridine (12). Compound 16 (0.55 g, 1.5 mmol) was fluorinated using General Procedure B to give the title compound (0.22 g, 40%). 1H NMR (CDCl3) 7.3 (m, 5H), 5.0 (dq, 1H), 3.8 (m, 1H), 3.5-3.75 (m, 3H), 3.3 (2s, 6H), 3.0 (d, 1H), 2.9 (m, 1H), 2.1 (m, 2H), 1.85 (m, 1H), 1.3 (2s, 6H).

[0060] (3R,4R, 5R)-5((R)-(1-Fluoroethyl)piperdine 3,4-diol Hydrochloride (14). Compound 12 (0.22 g, 0.6 mmol) was deprotected as described in General Procedure C. After catalyst was removed, the filtrate was evaporated in vacuo and then co-evaporated with EtOH (2x). The resulting residue was triturated with acetone to give the title compound (0.08 g, 67%) as a white solid. 1H NMR (D2O) 5.1 (dq, 1H), 3.5 (m, 4H), 2.8 (m, 2H), 1.8 (m, 1H), 1.3 (dd, 3H).

[0061] ((2S,3S,4aR,8R,8aR)-2,3-Dimethoxy-2,3-dimethyloctahydro-[1,4]dioxino[2,3-c]pyridin-8-yl)methanol Hydrochloride (2). A solution of 1 (20.0 g, 55.0 mmol) in MeOH (500 mL) was combined with Pd(OH)2 (4-6 g) and ammonium formate (14 g, 220 mmol) and the mixture was heated at 50-55 °C. Additional amounts (3x10.0 mmol) of ammonium formate were added over the next 8 hrs. After the final addition, the reaction mixture was further stirred and heated an additional 16 hrs at 50-55 °C. The catalyst was removed by filtration and the filtrate was evaporated in vacuo. The crude product was dissolved in acetone (150 mL), filtered, and HCl in 2-PrOH was added. After seeding and then cooling in an ice bath, the product was collected as a white crystalline solid (11.0 g, 71%). 1H NMR (DMSO-d6) 9.45 (s, 2H), 4.80 (t, 1H, ex), 3.85 (m, 1H), 3.0-3.75 (m, 11H), 2.8 (q, 2H), 1.95 (m, 1H), 1.2 (2s, 6H).

[0062] ((2S,3S,4aR,8R,8aR)-6-Benzyl-2,3-dimethoxy-2,3-dimethyloctahydro-[1,4]dioxino[2,3-c]pyridin-8-yl)methanol (3). To a solution of 2 (14.85 g, 50.0 mmol) in DMF (200 mL) was added K2CO3 (17.25 g, 125 mmol) and
To a solution of DAST (1.4 mL, 10.3 mmol) in CH$_2$Cl$_2$ (50 mL) cooled to -78°C was added a solution of oxalyl chloride (6.1 mL, 72.8 mmol) in CH$_2$Cl$_2$ dropwise. After the addition was complete, the mixture was stirred for an additional 30 min at which point a solution of 3 (17.0 g, 48.4 mmol) in CH$_2$Cl$_2$ was added dropwise. After addition was complete, the reaction was stirred for 1 hr at -78°C and then diisopropylethylamine (34.4 mL, 193 mmol) was added dropwise. After this addition was complete, the reaction mixture was allowed to warm to 0°C when saturated NaHCO$_3$ was added. The mixture was diluted with some additional CH$_2$Cl$_2$ and then the organic layer was separated and dried over MgSO$_4$. After filtering, the solvent was evaporated in vacuo and the crude product was purified by silica gel chromatography (Hex/EtOAc) to give the title compound (12.7 g, 75%) as a viscous oil. 

1H NMR (CDCl$_3$) 9.73 (s, 1H), 7.2 (m, 5H), 3.75 (m, 2H), 3.5 (q, 2H), 3.2 (2s, 6H), 2.95 (m, 2H), 2.25 (m, 1H). 

Following General Procedure D except that reaction was run at room temperature and using 4-fluorobenzyl bromide (0.26 g, R$_5$ = 4-fluorobenzyl). The residue was recrystallized from EtOH (50 mL) to the title compound (0.55 g, 66%) as a white solid (mp 168-170°C). 1H NMR (D$_2$O) 6.15 (dt, 1H), 4.3-4.8 (m, 2H), 3.7 (t, 1H), 3.2 (2s, 6H), 2.9 (m, 2H), 2.2 (br s, 1H), 1.95 (t, 1H). 

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[0064] ((2S,3S,4aR,5RS,8aR)-6-Benzyl-2,3-dimethoxy-2,3-dimethyloctahydropyridino[2,3-c]pyridin-8-yl)carboxaldehyde (General Procedure A) (4). To a solution of DMSO (7.3 g, 96.9 mmol) in CH$_2$Cl$_2$ (150 mL) cooled to -78°C was added a solution of oxalyl chloride (6.1 mL, 72.8 mmol) in CH$_2$Cl$_2$ dropwise. After the addition was complete, the reaction mixture was stirred for an additional 30 min at which point a solution of 3 (17.0 g, 48.4 mmol) in CH$_2$Cl$_2$ was added dropwise. After addition was complete, the reaction was stirred for 1 hr at -78°C and then diisopropylethylamine (34.4 mL, 193 mmol) was added dropwise. After this addition was complete, the reaction mixture was allowed to warm to 0°C when saturated NaHCO$_3$ was added. The mixture was diluted with some additional CH$_2$Cl$_2$ and then the organic layer was separated and dried over MgSO$_4$. After filtering, the solvent was evaporated in vacuo and the crude product was purified by silica gel chromatography (Hex/EtOAc) to give the title compound (12.7 g, 75%) as a viscous oil. 

1H NMR (CDCl$_3$) 9.73 (s, 1H), 7.2 (m, 5H), 3.75 (m, 2H), 3.5 (q, 2H), 3.2 (2s, 6H), 2.95 (m, 2H), 2.25 (m, 1H). 

Following General Procedure D except that reaction was run at room temperature and using 4-fluorobenzyl bromide (0.26 g, R$_5$ = 4-fluorobenzyl). The residue was recrystallized from EtOH (50 mL) to the title compound (0.55 g, 66%) as a white solid (mp 168-170°C). 1H NMR (D$_2$O) 6.15 (dt, 1H), 4.3-4.8 (m, 2H), 3.7 (t, 1H), 3.2 (2s, 6H), 2.9 (m, 2H), 2.2 (br s, 1H), 1.95 (t, 1H).
[0069] (3R,4R,5S)-5-(Difluoromethyl)-1-(4-methylbenzyl)piperdine 3,4-diol (7d; R5 = 4-methylbenzyl). Following General Procedure D except that reaction was run at room temperature and using 4-methylbenzyl bromide (0.26 g, 1.4 mmol) the title compound was obtained as a white solid (0.30 g, 81%). MH+ = 272. 1H NMR (DMSO-d6) 7.2 (m, 4H), 6.2 (t, 1H, J = 57 Hz), 5.2 (d, 1H, ex), 4.9 (d, 1H, ex), 3.5 (q, 2H), 3.3 (m, 1H), 3.05 (m, 1H), 2.8 (m, 2H), 2.5 (s, 3H), 1.95 (m, 2H), 1.8 (t, 1H).

[0070] (3R,4R,5S)-5-(Difluoromethyl)-1-(4-methoxylbenzyl)piperdine 3,4-diol (7e; R5 = 4-methoxylbenzyl). Following General Procedure D except that reaction was run at room temperature and using 4-methoxylbenzyl chloride (0.26 g, 1.4 mmol) the title compound was obtained as a colorless sirup (0.19 g, 49%). MH+ = 288. 1H NMR (DMSO-d6) 7.3 (m, 1H), 6.85 (m, 3H) 6.2 (t, 1H, J = 57 Hz), 5.2 (d, 1H, ex), 4.9 (d, 1H, ex), 3.75 (s, 3H), 3.5 (q, 2H), 3.4 (m, 1H), 3.1 (m, 1H), 2.85 (m, 2H), 1.95 (m, 2H), 1.8 (t, 1H).

[0071] 1-((3S,4R,5R)-3-(Difluoromethyl)-4,5-dihydroxypiperdine-1-yl)pentane-1-one (8a; Z = CO; R5 = butyl). Following General Procedure D, except that the reaction was run at room temperature and using pentanoyl chloride (0.17 g, 1.4 mmol), the title compound was obtained as a white solid (0.26 g, 71%). MH+ = 252. 1H NMR (DMSO-d6) 5.9-6.5 (dt, 1H), 5.35 (m, 1H, ex), 5.25 (m, 1H, ex), 4.2 (dd, 1H), 3.75 (dd, 1H), 3.35 (m, 2H), 3.1 (m, 1H), 2.85 (m, 1H), 2.3 (t, 2H), 1.9 br m, 1H), 1.4 (m, 2H), 1.25 (m, 2H), 0.85 (t, 3H).

[0072] (3R,4R,5S)-5-(Difluoromethyl)-1-(methanesulfonyl)piperdine 3,4-diol (8b; Z = SO2; R5 = Me) Following General Procedure D except that the reaction was run at room temperature and using methanesulfonyl chloride (0.16 g, 1.4 mmol), the title compound was obtained as a white solid (0.17 g, 51%). 1H NMR (DMSO-d6) 6.2 (t, 1H, J = 53 Hz), 5.43 (d, 1H, ex), 5.38 (d, 1H, ex), 3.2-3.7 (m, 4H), 2.95 (s, 3H), 2.85 (m, 1H), 2.7 (t, 1H), 2.1 (br s, 1H).

[0073] (3S,4R,5R)-3-(Difluoromethyl)-4,5-dihydroxy-N-propylpiperdine-1-carboxamide (General Procedure E) (9a; X = O; R5 = propyl). To a solution of 6 (free base) (0.29 g, 1.2 mmol) in dry DMF (5 mL), was added propyl isocyanate (0.10 g, 1.2 mmol) and the reaction was stirred at room temperature overnight. The solvent was evaporated in vacuo and the residue was purified by chromatography (CH2Cl2/MeOH) to give the title compound as a white solid (0.14 g, 48%). MH+ = 253. 1H NMR (DMSO-d6) 6.7 (t, 1H), 6.22 (t, 1H, J = 53 Hz), 5.25 (d, 1H, ex), 5.15 (d, 1H, ex), 4.05 (d, 1H), 3.9 (d, 1H), 3.5 (m, 2H), 3.0 (q, 2H), 2.5 (m, 1H), 1.8 (br d, 1H), 1.4 (m, 2H), 0.85 (t, 3H).

[0074] (3S,4R,5R)-3-(Difluoromethyl)-4,5-dihydroxy-N-phenylpiperdine-1-carboxamide (9b; X = O; R5 = phenyl). Following General Procedure E and using phenyl isocyanate (0.14 g, 1.2 mmol) the title compound was obtained as a white solid (0.21 g, 62%). MH+ = 287. 1H NMR (DMSO-d6) 8.7 (s, 1H), 7.45 (d, 2H), 7.3 (t, 2H), 6.95 (t, 1H), 6.3 (t, 1H, J = 53 Hz), 5.35 (d, 1H), 5.25 (d, 1H), 4.1 (t, 2H), 3.3 (m, 2H), 2.85 (t, 1H), 2.75 (t, 1H), 1.95 (br d, 1H).
Following General Procedure E and using butyl isocyanate (0.12 g, 1.2 mmol) the title compound was obtained as a white solid (0.24 g, 76%). MH⁺ = 267. ¹H NMR (DMSO-d₆) 6.6 (t, 1H), 6.2 (t, 1H, J = 53 Hz), 5.25 (d, 1H), 5.1 (d, 1H), 4.05 (d, 1H), 3.9 (d, 1H), 3.35 (m, 2H), 3.05 (q, 2H), 2.65 (t, 1H), 2.45 (m, 1H), 1.8 (br d, 1H), 1.2-1.4 (2m, 4H), 0.85 (t, 3H).

Following General Procedure E and using butyl isothiocyanate (0.14 g, 1.2 mmol) the title compound was obtained as a colorless sirup (0.21 g, 63%). MH⁺ = 283. ¹H NMR (DMSO-d₆) 7.85 (t, 1H), 6.25 (t, 1H), 5.35 (2d, 2H), 4.8 (d, 1H), 4.45 (d, 1H), 3.45 (m, 2H), 3.25 (m, 1H), 3.05 (t, 1H), 2.8 (t, 1H), 1.85 (br d, 1H), 1.4 (m, 2H), 1.35 (m, 2H), 1.1 (m, 1H), 0.95 (t, 3H).

Following General Procedure E and using phenyl isothiocyanate (0.16 g, 1.2 mmol) the title compound was obtained as a white solid (0.31 g, 86%). MH⁺ = 303. ¹H NMR (DMSO-d₆) 9.5 (s, 1H), 7.3 (m, 4H), 7.1 (t, 1H), 6.35 (t, 1H), 5.35 (2d, 2H), 4.85 (d, 1H), 4.55 (d, 1H), 3.45 (m, 2H), 3.2 (t, 1H), 3.0 (t, 1H), 2.05 (br d, 1H).

Compounds of the present invention can also be made by one skilled in the art using the following general schemes:

Scheme 3
Scheme 4
Scheme 5

Scheme 6
Scheme 7
Components of the present invention include pharmaceutically acceptable salts, solvates and pro-drugs of the compounds disclosed herein. Pharmaceutically acceptable salts include salts derived from inorganic bases such as Li, Na, K, Ca, Mg, Fe, Cu, Zn, Mn; salts of organic bases such as N,N'-diacetylthelylenediamine, glucamine, triethylamine,

choline, hydroxide, dicyclohexylamine, metformin, benzylamine, trialkylamine, thiamine; chiral bases like alkylphennylamine, glycyl with alkyl, benzylic, salts of natural amino acids such as glycine, alanine, valine, leucine, isoleucine, norleucine, tyrosine, cystine, cysteine, methionine, proline, hydroxy proline, histidine, ornithine, lysine, arginine, serine; non-native amino acids such as D-isomers or substituted amino acids; guanidine, substituted guanidine wherein the substituents are selected from nitro, amino, alkyl, alkenyl, alkynly, ammonium or substituted ammonium salts and aluminum salts. Salts may include acid addition salts where appropriate which are, hydrochlorides, sulphates, nitrates,

phosphates, perchlorates, acetates, tartrates, maleates, citrates, succinates, palmoates, methanesulphonates, benzoates, salicylates, benzenesulfonates, ascorbates, glycerophosphates, ketoglutarates. In one embodiment, the pharmaceutically acceptable salt of the compounds disclosed herein is the hydrochloride salt.

Solvates, solvates and prodrugs

"Solvate" denotes a physical association of a compound with one or more solvent molecules. This physical association involves varying degrees of ionic and covalent bonding, including hydrogen bonding. In certain instances the solvate will be capable of isolation, for example when one or more solvent molecules are incorporated in the crystal lattice of the crystalline solid. "Solvate" encompasses both solution-phase and isolatable solvates. "Hydrate" is a solvate wherein the solvent molecule is H2O. Other non-limiting examples of suitable solvates include alcohols (e.g., ethanolates, acetates, tartrates, maleates, citrates, succinates, palmoates, methanesulphonates, benzoates, salicylates, benzenesulfonates, ascorbates, glycerophosphates, ketoglutarates. In one embodiment, the pharmaceutically acceptable salt of the compounds disclosed herein is the hydrochloride salt.

Prodrugs are compounds which are converted in vivo to active forms (see, e.g., R. B. Silverman, 1992, "The Organic Chemistry of Drug Design and Drug Action", Academic Press, Chapter 8, incorporated herein by reference). Additional, a discussion of prodrugs is provided in T. Higuchi and V. Stella, Pro-drugs as Novel Delivery Systems, Volume 14 of the A.C.S. Symposium Series, and in Biohrevsible Carriers in Drug Design, Edward B. Roche, ed., American Pharmaceutical Association and Pergamon Press, 1987, both of which are incorporated herein by reference thereto. Prodrugs can be used to alter the biodistribution (e.g., to allow compounds which would not typically enter the reactive site of the protease) or the pharmacokinetics for a particular compound. For example, a carboxylic acid group, can be esterified, e.g., with a methyl group or an ethyl group to yield an ester. When the ester is administered to a subject, the ester is cleaved, enzymatically or non-enzymatically, reductively, oxidatively, or hydrolytically, to reveal the anionic group. An anionic group can be esterified with moieties (e.g., acyloxyaryl esters which are cleaved to reveal an intermediate compound which subsequently decomposes to yield the active compound.

Prodrugs and their uses are well known in the art (See, e.g., Berg et al. (1977) "Pharmaceutical Salts", J. Pharm. Sci. 66:1-19). The prodrugs can be prepared in situ during the final isolation and purification of the compounds, or by separately reacting the purified compound with a suitable derivatizing agent. For example hydroxy groups can be converted into esters via treatment with a carboxylic acid in the presence of a catalyst. Examples of cleavable alcohol prodrug moieties include substituted and unsubstituted, branched or unbranched lower alkyl ester moieties, (e.g., ethyl esters), lower alkenyl esters, di-lower alkyl-ester amides, (e.g., dimethylaminoethyl ester), acylamino lower alkyl esters, acyloxy lower alkyl esters (e.g., pivaloyloxymethyl ester), ary1 esters (phenyl ester), aryl-

lower alkyl esters (e.g., benzyl ester), substituted (e.g., with methyl, halo, or methoxy substituents) aryl and aryl-lower alkyl esters, amides, lower-alkyl amides, di-lower alkyl amides, and hydroxy amides.

All stereoisomers (for example, geometric isomers, optical isomers and the like) of the compounds disclosed herein (including those of the salts, solvates and prodrugs of these compounds as well as the salts and solvates of the prodrugs), such as those which may exist due to asymmetric carbons on various substituents, including enantiomeric forms (which may exist even in the absence of asymmetric carbons), rotamer forms, atropisomers, and diastereomeric forms, are contemplated within the scope of this invention. Individual stereoisomers of these compounds may, for example, be substantially free of other isomers, or may be admixed, for example, as racemates or with other, or other selected, stereoisomers. The chiral centers of the aforementioned compounds can have the S or R configuration as defined by the IUPAC 1974 Recommendations. The use of the terms "salt", "solvate" "prodrug" and the like, is intended to equally apply to the salt, solvate and prodrug of enantiomers, stereoisomers, rotamers, tautomers, racemates or prodrugs of the compounds of the present invention disclosed herein.

Formulations

The therapeutic agent(s) can be formulated to be suitable for any route of administration, including e.g., orally in the form of tablets or capsules or liquid, or in sterile aqueous solution for injection. When the therapeutic agent(s) is formulated for oral administration, tablets or capsules can be prepared by conventional means with pharmaceutically acceptable excipients such as binding agents (e.g., pregelatinized maize starch, polyvinylpyrrolidone or hydroxypropyl methylcellulose); fillers (e.g., lactose, microcrystalline cellulose or calcium hydrogen phosphate); lubricants (e.g., mag-
nesium stearate, talc or silica); disintegrants (e.g., potato starch or sodium starch glycolate); or wetting agents (e.g., sodium lauryl sulphate). The tablets may be coated by methods well known in the art. Liquid preparations for oral administration may take the form of, for example, solutions, syrups or suspensions, or they may be presented as a dry product for constitution with water or another suitable vehicle before use. Such liquid preparations may be prepared by conventional means with pharmaceutically acceptable additives such as suspending agents (e.g., sorbitol syrup, cellulose derivatives or hydrogenated edible fats); emulsifying agents (e.g., lecithin or acacia); non-aqueous vehicles (e.g., almond oil, oily esters, ethyl alcohol or fractionated vegetable oils); or preservatives (e.g., methyl or propyl-p-hydroxybenzoates or sorbic acid). The liquid preparations may also contain buffer salts, flavoring, coloring or sweetening agents as appropriate. Preparations for oral administration may be suitably formulated to give controlled or sustained release of the therapeutic agent(s).

[0085] In certain embodiments of the present invention, the therapeutic agent(s) is administered in a dosage form that permits systemic uptake, such that the therapeutic agent(s) may cross the blood-brain barrier so as to exert effects on neuronal cells. For example, pharmaceutical formulations of the therapeutic agent(s) suitable for parenteral/injectable use generally include sterile aqueous solutions (where water soluble), or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. In all cases, the form must be sterile and must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, polyethylene glycol, and the like), suitable mixtures thereof, or vegetable oils. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Prevention of the action of microorganisms can be brought about by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, benzyl alcohol, sorbic acid, and the like. In many cases, it will be reasonable to include isotonic agents, for example, sugars or sodium chloride. Prolonged absorption of the injectable compositions can be brought about by the use in the compositions of agents delaying absorption, for example, aluminum monostearate or gelatin.

[0086] Sterile injectable solutions are prepared by incorporating the therapeutic agent(s) in the required amount in the appropriate solvent with various of the other ingredients enumerated above, as required, followed by filter or terminal sterilization. Generally, dispersions are prepared by incorporating the various sterilized active ingredients into a sterile vehicle which contains the basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and the freeze-drying technique which yield a powder of the active ingredient plus any additional desired ingredient from previously sterile-filtered solution thereof.

[0087] The formulation can contain an excipient. Pharmaceutically acceptable excipients which may be included in the formulation are buffers such as citrate buffer, phosphate buffer, acetate buffer, and bicarbonate buffer, amino acids, urea, alcohols, ascorbic acid, phospholipids; proteins, such as serum albumin, collagen, and gelatin; salts such as EDTA or EGTA, and sodium chloride; liposomes; polyvinylpyrrolidone; sugars, such as dextran, mannitol, sorbitol, and glycogen; propylene glycol and polyethylene glycol (e.g., PEG-4000, PEG-6000); glycerol; glycine or other amino acids; and lipids. Buffer systems for use with the formulations include citrate; acetate; bicarbonate; and phosphate buffers. Phosphate buffer is a preferred embodiment.

[0088] The formulation can also contain a non-ionic detergent. Preferred non-ionic detergents include Polysorbate 20, Polysorbate 80, Triton X-100, Triton X-114, Nonidet P-40, Octyl α-glucoside, Octyl β-glucoside, Brij 35, Pluronic, and Tween 20.

Routes of Administration

[0089] The therapeutic agent(s) may be administered orally or parenterally, including intravenously, subcutaneously, intra-arterially, intraperitoneally, ophthalmically, intramuscularly, buccally, rectally, vaginally, intraorbitally, intracutaneously, intracisternally, intracapsulally, intrapulmonarylly, intranasally, transmucosally, transdermally, or via inhalation. In one preferred embodiment, the therapeutic agent(s) is administered orally.

[0090] Administration of therapeutic agent(s) may be by periodic injections of a bolus of the formulation, or may be administered by intravenous or intraperitoneal administration from a reservoir which is external (e.g., an i.v. bag) or internal (e.g., a bioerodable implant). See, e.g., U.S. Pat. Nos. 4,407,957 and 5,798,113, each incorporated herein by reference. Intrapulmonary delivery methods and apparatus are described, for example, in U.S. Pat. Nos. 5,654,007, 5,780,014, and 5,814,607, each incorporated herein by reference. Other useful parenteral delivery systems include ethylene-vinyl acetate copolymer particles, osmotic pumps, implantable infusion systems, pump delivery, encapsulated cell delivery, liposomal delivery, needle-delivered injection, needle-less injection, nebulizer, aerosolizer, electroporation, and transdermal patch. Needle-less injector devices are described in U.S. Pat. Nos. 5,879,327; 5,520,639; 5,846,233.
and 5,704,911, the specifications of which are herein incorporated by reference. Any of the formulations described above can be administered using these methods.

Subcutaneous injections have the advantages allowing self-administration, while also resulting in a prolonged plasma half-life as compared to intravenous administration. Furthermore, a variety of devices designed for patient convenience, such as refillable injection pens and needle-less injection devices, may be used with the formulations of the present invention as discussed herein.

**Dosage**

A suitable pharmaceutical preparation is in a unit dosage form. In such form, the preparation is subdivided into suitably sized unit doses containing appropriate quantities of the active component, e.g., an effective amount to achieve the desired purpose. In certain embodiments, the therapeutic agent(s) is administered in one or more daily doses (e.g., once-a-day, twice-a-day, thrice-a-day). In certain embodiments, the therapeutic agent(s) is administered in intermittently.

Exemplary dosing regimens are described in International patent application PCT/US08/61764 published as WO 2008/134628 on June 11, 2008 and U.S. provisional patent application 61/108,192, filed on October 24, 2008, both of which are incorporated by reference herein in their entirety. In one embodiment, the therapeutic agent(s) is administered in an intermittent dosing regimen that includes an initial "loading dose" given daily, followed by a period of non-daily interval dosing.

The amount of effective therapeutic agent(s) for preventing or treating the referenced disorder can be determined on a case-by-case basis by those skilled in the art. The amount and frequency of administration of the therapeutic agent(s) will be regulated according to the judgment of the attending clinician (physician) considering such factors as age, condition and size of the patient as well as risk for developing disorder or severity of the symptoms of the referenced disorder being treated.

**Combination Drug Therapy**

The therapeutic agent(s) of the present invention can be administered in combination with at least one other therapeutic agent. Administration of the therapeutic agent(s) of the present invention with at least one other therapeutic agent is understood to encompass administration that is sequential or concurrent. In one embodiment, the therapeutic agents are administered in separate dosage forms. In another embodiment, two or more therapeutic agents are administered concurrently in the same dosage form.

In certain embodiments, the therapeutic agent(s) of the present invention are administered in combination with at least one other therapeutic agent which is an anti-dyskinesia Agent (e.g., Carbidopa, Levodopa), an anti-infective agent (e.g., Miglustat), an antineoplastic agent (e.g., Busulfan, Cyclophosphamide), a gastrointestinal agent (e.g., Methylprednisolone), a micronutrient (e.g., Calcitriol, Cholecalciferol, Ergocalciferols, Vitamin D), a vasoconstrictor agent (e.g., Calcitriol).

In certain embodiments, the therapeutic agent(s) of the present invention are administered in combination with allopregnanolone, a low-cholesterol diet, or cholesterol-lowering agents such as statins (e.g., Lipitor®); fibrates such as fenofibrate (Lipidil®); niacin; and/or binding resins such as cholestyramine (Questran®).

In one embodiment, the therapeutic agent(s) of the present invention is administered in combination with allopregnanolone, a low-cholesterol diet, or cholesterol-lowering agents such as statins (e.g., Lipitor®); fibrates such as fenofibrate (Lipidil®); niacin; and/or binding resins such as cholestyramine (Questran®).

In one embodiment, the therapeutic agent(s) of the present invention is administered in combination with gene therapy. Gene therapy is contemplated both with replacement genes such as glucocerebrosidase or with inhibitory RNA (siRNA) for the SNCA gene. Gene therapy is described in more detail in U.S. Patent No. 7,446,098, filed on February 17, 2004.

In one embodiment, the therapeutic agent(s) of the present invention is administered in combination with at least one other therapeutic agent which is an anti-inflammatory agent (e.g., ibuprofen or other NSAID).

In one embodiment, the therapeutic agent(s) of the present invention is administered in combination with a substrate inhibitor for glucocerebrosidase, such as N-butyl-deoxyajirimycin (Zavesca®; miglustat available from Actelion Pharmaceuticals, US, Inc., South San Francisco, CA, US).

Combinations of the therapeutic agent(s) of the present invention with at least one other therapeutic agent which is a therapeutic agent for one or more other lysosomal enzymes are also contemplated. Following is a non-limiting list of therapeutic agents for lysosomal enzymes.

<table>
<thead>
<tr>
<th>LYSOSOMAL ENZYME</th>
<th>THERAPEUTIC AGENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-Glucosidase</td>
<td>1-deoxyajirimycin (DNJ)</td>
</tr>
<tr>
<td>GenBank Accession No. Y00839</td>
<td>α-homonojirimycin</td>
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Table 1
<table>
<thead>
<tr>
<th>LYSOSOMAL ENZYME</th>
<th>THERAPEUTIC AGENT</th>
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</thead>
<tbody>
<tr>
<td>Acid β-Glucosidase (β-glucocerebrosidase)</td>
<td>castanospermine</td>
</tr>
<tr>
<td>GenBank Accession No. J03059</td>
<td>isofagomine</td>
</tr>
<tr>
<td></td>
<td>C-benzyl isofagomine and derivatives</td>
</tr>
<tr>
<td></td>
<td>N-alkyl (C9-12)-DNJ</td>
</tr>
<tr>
<td></td>
<td>Glucoimidazole (and derivatives)</td>
</tr>
<tr>
<td></td>
<td>C-alkyl-IFG (and derivatives)</td>
</tr>
<tr>
<td></td>
<td>N-alkyl-β-valeinamines</td>
</tr>
<tr>
<td></td>
<td>Fluphenozine</td>
</tr>
<tr>
<td></td>
<td>calystegines A₃, B₁, B₂ and C₁</td>
</tr>
<tr>
<td>α-Galactosidase A</td>
<td>1-deoxygalactonojirimycin (DGJ)</td>
</tr>
<tr>
<td>GenBank Accession No. NM000169</td>
<td>α-allo-homonojirimycin</td>
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<tr>
<td></td>
<td>α-galacto-homonojirimycin</td>
</tr>
<tr>
<td></td>
<td>β-1-C-butyl-deoxynojirimycin</td>
</tr>
<tr>
<td></td>
<td>calystegines A₂ and B₂</td>
</tr>
<tr>
<td></td>
<td>N-methyl calystegines A₂ and B₂</td>
</tr>
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<td>Acid β-Galactosidase</td>
<td>4-epi-isofagomine</td>
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<td>Galactocerebrosidase (Acid β-Galactosidase)</td>
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<td>Swainsonine</td>
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<td></td>
<td>Mannostatin A</td>
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<td>2-hydroxy-isofagomine</td>
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<td>2,5-imino-1,2,5-trideoxy-L-glucitol</td>
</tr>
<tr>
<td></td>
<td>2,5-deoxy-2,5-imino-D-fucitol</td>
</tr>
<tr>
<td></td>
<td>2,5-imino-1,2,5-trideoxy-D-altrotol</td>
</tr>
<tr>
<td>α-N-Acetylglucosaminidase</td>
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<tr>
<td>GenBank Accession No. U40846</td>
<td></td>
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<tr>
<td>α-N-Acetylgalactosaminidase</td>
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<td>β-Hexosaminidase A</td>
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<tr>
<td>β-Hexosaminidase B</td>
<td>2-N-acetamido-isofagomine</td>
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<td>1,2-dideoxy-2-acetamido-nojirimycin Nagstatin</td>
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<td>α-L-Iduronidase</td>
<td>1-deoxyiduronojirimycin</td>
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<td>GenBank Accession No. NM_000203</td>
<td>2-carboxy-3,4,5-trideoxypiperidine</td>
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<tr>
<td>β-Glucuronidase</td>
<td>6-carboxy-isofagomine</td>
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<tr>
<td>GenBank Accession No. NM_000181</td>
<td>2-carboxy-3,4,5-trideoxypiperidine</td>
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<td>Sialidase</td>
<td>2,6-dideoxy-2,6, imino-sialic acid</td>
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<td>GenBank Accession No. U84246</td>
<td>Siastatin B</td>
</tr>
<tr>
<td>Iduronate sulfatase</td>
<td>2,5-anhydromannitol-6-sulphate</td>
</tr>
</tbody>
</table>
In certain embodiments, the therapeutic agent(s) of the present invention are administered in combination with at least one other therapeutic agent which is an anti-dyskinesia agent (e.g., Carbidopa, Levodopa), an antineoplastic agent (e.g., Alemtuzumab, Busulfan, Cyclophosphamide, Melphalan, Methotrexate, Rituximab), an antirheumatic agent (e.g., Rituximab) a gastrointestinal agent (e.g., Methylprednisolone), a micronutrient (e.g., Calcitriol, Cholecalciferol, Ergocalciferols, Folic Acid, Vitamin D), a reproductive control agent (e.g., Methotrexate), a respiratory system agent (e.g., Tetrahydrozoline), a vasocostrictor agent (e.g., Calcitriol, Tetrahydrozoline).

In one embodiment, the therapeutic agent(s) of the present invention can be administered in combination with at least one therapeutic agent which includes but is not limited to, RNAi, dopamine replacement (e.g., levadopa (L-DOPA)), dopamine replacement stabilizer (e.g., carbidopa, and entacapone), anticholinergic (e.g., trihexyphenidyl, benzotropine mesylate (Cogentin®), trihexyphenidyl HCL (Artane®), and procyclidine), catechol–methyltransferase (COMT) inhibitor (e.g., entacapone (Comtan®) and tolcapone (Tasmar®)), dopamine receptor agonist (e.g., bromocriptine (Parlodel®), pramipexole (Mirapex®), ropinirole (Requip®), pergolide (Permax), and APOKYN™ injection (apomorphine hydrochloride), monoamine oxidase (MAO) inhibitor (i.e., MAO-A and/or MAO-B inhibitors, e.g., selegiline (Deprenyl, Eldepryl®, Carbex®), selegiline HCl orally disintegrating tablet (Zelapar®), and rasagiline (Azilect®)), peripheral decarboxylase inhibitor, amantadine (Symmetrel®), and rivastigmine tartrate (Exelon®).
an antiemetic (e.g., Trimethobenzamide), an antihypertensive agent (e.g., Trandolapril), an antineoplastic agent (e.g., Cabergoline, PS-K), central nervous system depressant (e.g., Aripiprazole, Benzocaine, Clozapine, Cocaine, Dextemeto-dimidine, Diphenhydramine, Isoflurane, Lithium, Lithium Carbonate, Metyleron, Morphine, Propofol, Quetiapine, Raclopide, Remifentanil, Sodium Oxybate), a central nervous system stimulant (e.g., Caffeine citrate, Modafinil, Nicotine polacrilex), a coagulant (e.g., Arginine Vasopressin, Deamino Arginine Vasopressin, Vasopressins), a dermatologic agent (e.g., Loratadine, Promethazine), a gastrointestinal agent (e.g., Diphenhydramine, Domperidone, Omeprazole, Trimethobenzamide), a hypnotic and/or sedative (e.g., Remifentanil), a micronutrient (e.g., Alpha-Tocopherol, Coenzyme Q10, Ergocalciferols, Hydroxocobalamin, Iron, Tocopherol acetate, Tocopherols, Vitamin B 12, Vitamin D, Vitamin E), a neuroprotective agent (e.g., Etizolam, Modafinil, Rasagiline, Rivastigmine, Topiramate), a nootropic agent (e.g., Donepezil, Etracetam), a psychotropic drug (e.g., Aripiprazole, Citalopram, Clozapine, Duloxetine, Lithium, Lithium Carbonate, Metyleron, Nortriptiline, Paroxetine, Quetiapine, Raclopide, Venlafaxine), a respiratory system agent (e.g., Acetylcysteine, Dextromethorphan, Guaifenesin, Ipratropium, Naphazoline, Oxymetazoline, Phenylephrine, Phenylephrine, Phenylpropanolamine), a vasoconstrictor agent (e.g., Naphazoline, Oxymetazoline, Phenylephrine, Phenylpropanolamine).

[0112] In one preferred embodiment, the aforementioned other therapeutic agents are administered when the disorder is Parkinson’s disease.

[0113] In certain embodiments, the therapeutic agent(s) of the present invention is administered in combination with at least one other therapeutic agent which is a nonnarcotic alpha-7 agonist (e.g., MEM 3454 or MEM 63908 both of which are available from Memory Pharmaceuticals). In certain embodiments, the therapeutic agent(s) of the present invention is administered in combination with at least one other therapeutic agent which is R3487 and/or R4996 (both of which are available from Roche). Also contemplated are combinations of the therapeutic agent(s) of the present invention with more than one other therapeutic agents. Exemplary combinations of other therapeutic agents include, but not are not limited to, R3487/MEM 3454 and R4996/MEM 63908.

[0114] In certain embodiments, the therapeutic agent(s) of the present invention is administered in combination with at least one cholinesterase inhibitor (e.g., donepezil (brand name Anceopt), galantamine (brand name Razadyne), and rivastigmine (branded as Exelon and Exelon Patch).

[0115] In certain embodiments, the therapeutic agent(s) of the present invention is administered in combination with at least one noncompetitive NMDA receptor antagonist (e.g., memantine (brand names Akatinol, Axxra, Ebixa/Abixa, Memox and Namenda)).

[0116] In certain embodiments, the therapeutic agent(s) of the present invention is administered in combination with at least one other therapeutic agent which is a non-narcotic analgesic (e.g., Celecoxib, Resveratrol, Rofecoxib, TNFR-Fc fusion protein), an anti-dyskinesia agent (e.g., Dextemide, Gabapentin, Levodopa, Memantine), an anti-infective agent (e.g., Acetylcytstene, Acyclovir, Benzatoes, Deoxyglucose, Doxyycline, Interferon Alpha-2a, Interferon-alpha, Interferons, Moxifloxacin, PS-K, Quinacrine, Rifampin, Salicylic Acid, Valacyclovir), an anti-Inflammatory agent (e.g., Aspirin, Celecoxib, Curcumin, Ibuprofen, Indomethacin, Naproxen, Resveratrol, Rofecoxib, TNFR-Fc fusion protein), an anti-obesity agent (e.g., Phenylpropanolamine), an antiplatelet agent (e.g., Clopidogrel, Ticagrelor), an anticoagulant agent (e.g., Arginine Vasopressin), a channel blocker (e.g., Gabapentin, Lamotrigine), a coagulant (e.g., Antiplasmin, Vitamin K), a dermatologic agent (e.g., Mineral Oil, Salicylic Acid), a gastrointestinal agent (e.g., Choline, Haloperidol, Loratadine, Promethazine), a gastrointestinal agent (e.g., Diphenhydramine, Domperidone, Omeprazole, Omeprazole, TNFR-Fc fusion protein), a hypnotic and/or sedative agent (e.g., Zolpidem), a hypoglycemic agent (e.g., Acetylcysteine, Dextromethorphan, Guafenesin, Leuprolide, Medroxyprogesterone, Medroxyprogesterone 17-Acetate, Mifepristone), a psychiatric drug (e.g., Aripiprazole, Buproprion, Citalopram, Duloxetine, Gabapentin, Haloperidol, Haloperidol decanoate, Lithium, Lithium Carbonate, Lorazepam, Midazolam, Olanzapine, Perhexazine, Propofol, Quetiapine, Risperidone, Sodium Oxybate, Trazodone, Valproic Acid, Zolpidem), a psychotropic drug (e.g., Aripiprazole, Citalopram, Clozapine, Duloxetine, Lithium, Lithium Carbonate, Metyleron, Nortriptiline, Paroxetine, Quetiapine, Raclopide, Venlafaxine), a respiratory system agent (e.g., Dextromethorphan, Guafenesin, Ipratropium, Naphazoline, Oxymetazoline, Phenylephrine, Phenylephrine, Phenylpropanolamine), or a vasoconstrictor agent (e.g., Naphazoline, Oxymetazoline, Phenylephrine, Phenylpropanolamine).
In one preferred embodiment, the aforementioned other therapeutic agents are administered when the disorder is Alzheimer’s disease.

EXAMPLES

The present invention is further described by means of the examples, presented below. The use of such examples is illustrative only and in no way limits the scope and meaning of the invention or of any exemplified term. Likewise, the invention is not limited to any particular preferred embodiments described herein. Indeed, many modifications and variations of the invention will be apparent to those skilled in the art upon reading this specification. The invention is therefore to be limited only by the terms of the appended claims along with the full scope of equivalents to which the claims are entitled.

EXAMPLE 1 Determination of Inhibition Constants

The binding affinity (defined here by $K_i$, binding constant) of GCase for novel compounds of the present invention were empirically determined using enzyme inhibition assays. In brief, the enzyme inhibition assays used monitored the ability of a test compound to bind and prevent the hydrolysis of a fluorogenic substrate in a concentration-dependent manner. Specifically, the enzyme activity of recombinant human GCase (rhGCase; Cerezyme®, Genzyme Corp.) was measured using the 4-methylumbelliferyl-$\beta$-D-glucopyranoside (4-MU-$\beta$-D-Glc) fluorogenic substrate in the absence or in the presence of varying amounts of each test compound. The resultant data were analyzed by comparing all test samples to the no inhibition control sample (no compound; corresponding to 100% enzyme activity) to determine the residual enzyme activity in the presence of test compound. The normalized residual activity data were subsequently graphed (on y-axis) relative to the concentration of test compound (on x-axis) to extrapolate the test compound concentration which leads to 50% inhibition of enzyme activity (defined as IC$_{50}$). The IC$_{50}$ value for each test compound was then inserted into the Cheng-Prusoff equation (detailed below) to derive the absolute inhibition constant $K_i$ that accurately reflects the binding affinity of GCase for the test compound. The enzyme inhibition assays were performed at both pH 7.0 (endoplasmic reticulum pH) and at pH 5.2 (lysosomal pH) to gain insight into the binding affinity (i.e., potency) of compounds for GCase in the endoplasmic reticulum and lysosome.

In vitro assay

Various concentrations of test compounds were prepared in buffer "M" consisting of 50mM sodium phosphate buffer with 0.25% sodium taurocholate at pH 7.0 and pH 5.2. Enzyme (Cerezyme®, a recombinant form of the human enzyme $\beta$-glucocerebrosidase) was also diluted in the same buffer "M" at pH 7.0 and pH 5.2. The substrate solution consisted of 3 mM 4-methylumbelliferyl-$\beta$-D-glucopyranoside in buffer "M" with 0.15% Triton X-100 at both pH’s. Five microliters of diluted enzyme was added to 15 $\mu$L of the various inhibitor concentrations or buffer "M" alone and incubated at 37°C for 1 hour with 50 $\mu$L of the substrate preparation to assess $\beta$-glucosidase activity at pH 7.0 and pH 5.2. Reactions were stopped by addition of an equal volume of 0.4 M glycine, pH 10.6. Fluorescence was measured on a plate reader for 1 sec/well using 355 nm excitation and 460 nm emission. Incubations without added enzyme or without added inhibitors were used to define no enzyme activity and maximum activity, respectively, and normalize % inhibition for a given assay. The results of such in vitro inhibition assays for reference compound IFG-tartrate and several test compounds are summarized below in Table 2A.
Table 2A: *In vitro* Determination of Inhibition Constants

<table>
<thead>
<tr>
<th>Cmpd #</th>
<th>Compound Name</th>
<th>IC_50 (μM) pH 5.2</th>
<th>K_i (μM) pH 5.2</th>
<th>IC_50 (μM) pH 7.0</th>
<th>K_i (μM) pH 7.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>(3R,4R,5S)-5-(difluoromethyl)-piperidine-3,4-diol</td>
<td>0.0259 ± 0.0014</td>
<td>0.0136 ± 0.0008</td>
<td>0.0058 ± 0.00023</td>
<td>0.00306 ± 0.00012</td>
</tr>
<tr>
<td>13</td>
<td>(3R,4R,5S)-5-(1-fluoroethyl)-piperidine-3,4-diol*</td>
<td>0.0946 ± 0.0028</td>
<td>0.0498 ± 0.0015</td>
<td>0.0171 ± 0.0008</td>
<td>0.009 ± 0.0004</td>
</tr>
<tr>
<td>9</td>
<td>(3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol*</td>
<td>0.107 ± 0.0041</td>
<td>0.044 ± 0.0017</td>
<td>0.020 ± 0.0008</td>
<td>0.010 ± 0.0004</td>
</tr>
<tr>
<td>10</td>
<td>(3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol*</td>
<td>0.343 ± 0.021</td>
<td>0.142 ± 0.0088</td>
<td>0.066 ± 0.0041</td>
<td>0.035 ± 0.0021</td>
</tr>
<tr>
<td>14</td>
<td>(3R,4R,5S)-5-(1-fluoroethyl)-piperidine-3,4-diol*</td>
<td>0.038 ± 0.0016</td>
<td>0.016 ± 0.0007</td>
<td>0.007 ± 0.0003</td>
<td>0.004 ± 0.0001</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5S)-5-((R)-1-fluoropropyl)-piperidine-3,4-diol hydrochloride</td>
<td>0.291 ± 0.006</td>
<td>0.121 ± 0.0026</td>
<td>0.060 ± 0.0029</td>
<td>0.031 ± 0.0015</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5S)-5-benzyl-piperidine-3,4-diol</td>
<td>0.659 ± 0.028</td>
<td>0.273 ± 0.012</td>
<td>0.127 ± 0.01</td>
<td>0.067 ± 0.005</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5R)-5-((S)-hydroxy(phenyl)methyl)-piperidine-3,4-diol</td>
<td>3.29 ± 0.25</td>
<td>1.36 ± 0.10</td>
<td>0.017 ± 0.0035</td>
<td>0.0089 ± 0.0018</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5S)-5-(2-hydroxypropan-2-yl)piperidine-3,4-diol</td>
<td>0.234 ± 0.0037</td>
<td>0.097 ± 0.0015</td>
<td>0.029 ± 0.0013</td>
<td>0.015 ± 0.0007</td>
</tr>
<tr>
<td>none</td>
<td>IFG-tartrate</td>
<td>0.049 ± 0.0029</td>
<td>0.026 ± 0.0015</td>
<td>0.0074 ± 0.00007</td>
<td>0.0039 ± 0.00037</td>
</tr>
</tbody>
</table>

Notes:
* Stereoisomer A and/or B
**In situ assay**

The effect of the novel compounds of the present invention on lysosomal GCase activity was assayed *in situ* using fibroblasts established from a normal subject. Cells seeded in 48-well plates were incubated with the indicated concentrations of compound for 16-24 hours. For the dose-response assays, cells were incubated with the *in situ* substrate 5-(pentafluorobenzoylamino)fluorescein di-β-D-glucopyranoside (PFBFDGlu) for 1 hour and subsequently lysed to determine the extent of substrate hydrolysis in the presence of compound. The assay employed a range of 12 concentrations encompassing 5 orders of magnitude, centered on the IC50. Specifically, the following concentration ranges were employed: (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol, (3R,4R,5R)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol: 1.0 x 10^{-3} to 3.0 x 10^{-9} M; (3R,R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol: 1.0 x 10^{-4} to 3.0 x 10^{-10} M; and (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol: 1.0 x 10^{-3} to 3.0 x 10^{-11} M; wherein compound was serially diluted 1:3 from the highest concentration in the ranges specified. Inhibition was determined as the ratio of activity in the presence of compound to that in the absence of compound. For the washout assays, cells were treated with compound for 16-24 hours at a concentration equal to the IC90. Cells were washed extensively and incubated in drug-free medium to allow net compound efflux from cells. Cells were then tested for lysosomal GCase activity at 2 hour intervals over a total period of 8 hours following compound removal. The increase in activity over time was fitted with a single exponential function to determine the compound’s washout time. The results of these *in situ* inhibition assays for reference compound IFG-tartrate and several test compounds are summarized below in Table 2B.

### Table 2B: In situ Determination of Inhibition Constants

<table>
<thead>
<tr>
<th>Cmpd #</th>
<th>Compound Name</th>
<th>In situ IC_{50} (µM)</th>
<th>in situ washout (hr)</th>
<th>EC_{50} (µM)</th>
<th>Emax (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>(3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol</td>
<td>0.408 ± 0.046</td>
<td>2.1 ± 0.30</td>
<td>0.018 ± 0.008</td>
<td>105.6 ± 8.7</td>
</tr>
<tr>
<td>13</td>
<td>(3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol*</td>
<td>0.650 ± 0.172</td>
<td>2.7 ± 0.12</td>
<td>0.044 ± 0.005</td>
<td>92.8 ± 6.6</td>
</tr>
<tr>
<td>9</td>
<td>(3R,4R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol*</td>
<td>0.518 ± 0.022</td>
<td>10.5 ± 1.75</td>
<td>0.49 ± 0.06</td>
<td>83.7 ± 2.9</td>
</tr>
<tr>
<td>10</td>
<td>(3R,4R,5R)-5-(1-hydroxyethyl)piperidine-3,4-diol*</td>
<td>0.798 ± 0.043</td>
<td>12 ± 1.65</td>
<td>1.06 ± 0.12</td>
<td>99.3 ± 4.9</td>
</tr>
<tr>
<td>14</td>
<td>(3R,4R,5S)-5-(1-fluoropropyl)piperidine-3,4-diol*</td>
<td>0.061 ± 0.019</td>
<td>3.7 ± 0.63</td>
<td>0.026 ± 0.003</td>
<td>89.7 ± 3.5</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride</td>
<td>0.972 ± 0.201</td>
<td>ND</td>
<td>0.086 ± 0.002</td>
<td>84.0 ± 4.1</td>
</tr>
<tr>
<td>45</td>
<td>(3R,4R,5S)-5-benzylpiperidine-3,4-diol</td>
<td>1.299 ± 0.323</td>
<td>1.2 ± 0.13</td>
<td>0.18 ± 0.01</td>
<td>98.0 ± 4.5</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5R)-5-((S)-hydroxyphenyl)methyl)piperidine-3,4-diol</td>
<td>ND</td>
<td>ND</td>
<td>4.99 ± 0.86</td>
<td>72.1 ± 3.5</td>
</tr>
<tr>
<td>none</td>
<td>(3R,4R,5S)-5-(2-hydroxypropan-2-yl)piperidine-3,4-diol</td>
<td>ND</td>
<td>ND</td>
<td>0.791 ± 0.162</td>
<td>109.3 ± 3.6</td>
</tr>
<tr>
<td>none</td>
<td>IFG-tartrate</td>
<td>0.271 ± 0.012</td>
<td>8.2 ± 0.04</td>
<td>0.31 ± 0.11</td>
<td>105.5 ± 12.8</td>
</tr>
</tbody>
</table>

Notes:
* Stereoisomer A and/or B

Cheng-Prusoff equation: \( K_i = IC_{50} / (1 + [S]/K_m) \)
Table 2B: In situ Determination of Inhibition Constants

<table>
<thead>
<tr>
<th>Cmpd #</th>
<th>Compound Name</th>
<th>In situ IC₅₀ (µM)</th>
<th>in situ washout (hr)</th>
<th>EC₅₀ (µM)</th>
<th>Emax (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where [S] = substrate concentration; 2.5 mM 4-MU-β-D-Glc was used

Kₘ = Michaelis constant that defines substrate affinity; 1.8 ± 0.6 mM for 4-MU-β-D-Glc (Liou et al., 2006) J Biol Chem. 281 (7), 4242-53

[0122] When compared to reference compound IFG-tartrate, the following is notable:

(i) test compounds (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol, (3R,4R,5S)-5-(R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol, were found to cause a concentration-dependent increase in GCase activity and enhanced enzyme activity to the same maximum level as reference compound IFG-tartrate at much lower concentration; (ii) test compounds (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol, washed out of the lysosomal compartment (in situ washout) considerably faster than reference compound IFG-tartrate; and (iii), test compounds (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol, inhibited GCase activity.

EXAMPLE 2: Blood brain barrier penetration

[0123] The blood-brain barrier (BBB) penetration of reference compound IFG-tartrate and several compounds of the present invention (i.e., (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol) were assayed after oral administration to mice. For this purpose, 8-week old wild-type male mice (C57BL/6) were administered a single 30 mg/kg (free base equivalent) p.o. dose of reference compound (i.e., IFG-tartrate) or test compound (i.e., (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol, or (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol) reflect that (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol, inhibited GCase activity.

Plasma was derived by spinning whole blood at 2,700 x g for 10 minutes at 4°C followed by storage on dry ice. Whole plasma was then combined with 25 µl of internal standard (100 ng/mL IFG-tartrate 13C₂-15N in 0.5% formic acid in (70:30) acetonitrile:methanol). Samples were then clarified by centrifugation. Between 20 and 30 µl sample was injected for analysis. For calculating drug concentrations, raw data for plasma (ng/mL) and brain (ng/g) was converted to nM using the molecular weight of respective compounds and assuming 1 g of tissue is equivalent to 1 mL volume. Concentration as a function of time was plotted in GraphPad Prism version 4.02.

[0124] The plasma levels and brain levels detected in mice administered a single 30 mg/kg (free base equivalent) p.o. dose of reference compound (i.e., IFG-tartrate) or test compound (i.e., (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol) reflect that (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol crossed the blood brain barrier more readily as compared to IFG-tartrate. Additionally, higher levels of (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol were detected in brain than that observed following administration of IFG-tartrate.
EXAMPLE 3: GCase enhancement

[0125] The ability of orally administered test compounds ((3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, or (3R,4R,5S)-5-benzylpiperidine-3,4-diol) to elevate GCase levels was assessed in mice. For this purpose, 8-week old wild-type male mice (C57BL/6) were administered a single p.o. (gavage) dose of a compound of the present invention (i.e., (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, (3R,4R,5S)-5-((R)-1-fluoropropyl)piperidine-3,4-diol hydrochloride, or (3R,4R,5S)-5-benzylpiperidine-3,4-diol). Details of the dose administered for each compound are provided in Tables 3A and 3B. The dosing solutions were prepared in water. Compounds were administered over 2 weeks as follows: week 1, Mon-Fri (On), Sat-Sun (Off); week 2, Mon-Thu (On); necropsy on Friday. Thus, a total of 9 doses (dosing solutions prepared fresh every day) were given to each mouse, with a 24-hour washout between the last dose and necropsy.

[0126] After completion of dosing, mice were euthanized with CO₂ and whole blood was drawn into lithium heparin tubes from the inferior vena cava. Plasma was collected by spinning blood at 2700g for 10 minutes at 4°C. Liver, spleen, lung, and brain tissues were removed, washed in cold PBS, blotted dry, flash frozen on dry ice, and stored at -80°C until analysis. GCase levels were measured by homogenizing approximately 50 mg tissue in 500 μL Mcllvane (MI) buffer (100 mM sodium citrate, 200 mM sodium phosphate dibasic, 0.25% sodium taurocholate, and 0.1% Triton X-100, pH 5.2) at pH 5.2 for 3-5 seconds on ice with a micro homogenizer. Homogenates were then incubated at room temperature without and with 2.5 mM conduritol-B-epoxide (CBE) for 30 min. Finally, 3.7 mM 4-methylumbeliferryl-β-glucoside (4-MUG) substrate was added and incubated at 37°C for 60 min. Reactions were stopped by addition of 0.4 M glycine, pH 10.6. Fluorescence was measured on a plate reader for 1 sec/well using 355 nm excitation and 460 nm emission. Total protein was determined in lysates using the MicroBCA kit according to the manufacturer’s instructions. A 4-methylumbelliferone (4-MU) standard curve ranging from 1.0 nM to 50 μM was run in parallel for conversion of raw fluorescence data to absolute GCase activity (in the presence and absence of CBE) and expressed as nanomoles of 4-MU released per milligram of protein per hour (nmol/mg protein/hr). GCase levels and protein levels were calculated using Microsoft Excel (Redmond, WA) and GraphPad Prism version 4.02.

[0127] Tables 3A and 3B summarize the dose administered for each compound examined in mice as described above as well as the resultant level of GCase enhancement in brain and spleen, respectively, compound concentration in tissue, compound concentration in GCase assay and inhibition constant (Ki).
<table>
<thead>
<tr>
<th>Compound Name</th>
<th>Dose (mg/kg)</th>
<th>GCase increase (fold)</th>
<th>Compound concentration in tissue (2.2 nmol/kg)</th>
<th>Compound concentration in GCase assay (μM)</th>
<th>Ki pH 5.2 (μM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3R,4R,5S)-5-(difluoromethyl)-piperidine-3,4-diol</td>
<td>10</td>
<td>2.1</td>
<td>55</td>
<td>0.0002</td>
<td>0.0136±0.0008</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(difluoromethyl)-piperidine-3,4-diol</td>
<td>100</td>
<td>2.6</td>
<td>301</td>
<td>0.0010</td>
<td></td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(1-fluoroethyl)-piperidine-3,4-diol*</td>
<td>10</td>
<td>1.5</td>
<td>50</td>
<td>0.0002</td>
<td>0.0498±0.0015</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(1-fluoroethyl)-piperidine-3,4-diol*</td>
<td>100</td>
<td>2.4</td>
<td>415</td>
<td>0.0014</td>
<td></td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(1-hydroxyethyl)-piperidine-3,4-diol*</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.044±0.0017</td>
</tr>
<tr>
<td>(3R,4R,5R)-5-(1-hydroxyethyl)-piperidine-3,4-diol*</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.142±0.0088</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(1-fluoroethyl)-piperidine-3,4-diol*</td>
<td>10</td>
<td>1.5</td>
<td>BLQ(1)</td>
<td>BLQ</td>
<td>0.016±0.0007</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(1-fluoroethyl)-piperidine-3,4-diol*</td>
<td>100</td>
<td>2.2</td>
<td>41</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>(3R,4R,5S)-5-((R)-1-fluoropropyl)-piperidine-3,4-diol hydrochloride</td>
<td>10</td>
<td>0.9</td>
<td>BLQ (2)</td>
<td>BLQ</td>
<td>0.121±0.0026</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-((R)-1-fluoropropyl)-piperidine-3,4-diol hydrochloride</td>
<td>100</td>
<td>1.1</td>
<td>38</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>(3R,4R,5S)-5-benzyl-piperidine-3,4-diol</td>
<td>10</td>
<td>1.2</td>
<td>ND</td>
<td>ND</td>
<td>0.273±0.012</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-benzyl-piperidine-3,4-diol</td>
<td>100</td>
<td>1.4</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>(3R,4R,5R)-5-((S)-hydroxy(phenyl)methyl)-piperidine-3,4-diol</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>1.36±1.00</td>
</tr>
<tr>
<td>(3R,4R,5S)-5-(2-hydroxypropan-2-yl)piperidine-3,4-diol</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.097±0.0015</td>
</tr>
</tbody>
</table>

Notes:
Table 3A: GCase enhancement in Brain

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>Dose (mg/kg)</th>
<th>GCase increase (fold)</th>
<th>Compound concentration in tissue 2.2 nmol/kg</th>
<th>Compound concentration in GCase assay (μM)</th>
<th>Ki pH 5.2 (uM)</th>
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* Stereoisomer A and/or B
(1) BLQ < 7.4 nmol/kg; (2) BLQ < 2.2 nmol/kg
ND: Not determined
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<th>Compound Name</th>
<th>Dose (mg/kg)</th>
<th>GCase increase (fold)</th>
<th>Compound concentration in tissue</th>
<th>Compound concentration in GCase assay</th>
<th>Ki pH 5.2 (uM)</th>
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<td>(3R,4R,5S)-5-((difluoromethyl)-piperidine-3,4-diol</td>
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<td>ND</td>
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Notes:
* Stereoisomer A and/or B
(1) BLQ < 6.8 nmol/kg; (2) BLQ < 7.9 nmol/kg
ND: Not determined
As reflected in Tables 3A and 3B, mice administered (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, or (3R,4R,5S)-5-benzylpiperidine-3,4-diol demonstrated significant GCase enhancement in brain and spleen.

EXAMPLE 4: Rat pharmacokinetics

Pharmacokinetic (PK) data was obtained in rats to assess the bioavailability of test compound. In particular, the following PK parameters were calculated: bioavailability as measured by area under the Concentration/Time curve (AUC), fraction of dose available (%F; further defined below), clearance (CL), volume of distribution (Vd), and half-life (t½). For this purpose, 8-week old Sprague-Dawley male rats were given either a single intravenous (IV) dose equivalent to 3 mg/kg of free base or single escalating p.o. (gavage) doses of test compound equivalent to 10, 30, and 100 mg/kg of free base. Three rats were used per dosing group. Blood was collected over a 24-hr period. The time points for blood collection after intravenous administration were: 0, 2.5, 5, 10, 15, 45 min, 1, 2, 4, 8, 12, and 24 hrs; time points for blood collection after p.o. administrations were: 0, 5, 15, 30, 45 min, 1, 2, 3, 4, 8, 12, and 24 hrs. Plasma samples were analyzed for compound levels by LC-MS/MS at PPD. Raw data was analyzed by non-compartmental analysis in WinNonLin to calculate Vd, %F, CL, and t½.

Various pharmacokinetic parameters for (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol based on the aforementioned study are detailed below in Tables 4A-D.
As reflected in Tables 4A-D, (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol have favorable pharmacokinetic profiles for drug development. In particular, (3R,4R,5S)-5-(difluoromethyl)piperidine-3,4-diol, (3R,4R,5S)-5-(1-fluoroethyl)piperidine-3,4-diol, and (3R,4R,5S)-5-benzylpiperidine-3,4-diol have favorable pharmacokinetic profiles for drug development.
and (3R,4R,5S)-5-benzylpiperidine-3,4-diol show excellent oral bioavailability (approximately 50-100%) and dose proportionality, a half-life of 1.0 to 4.0 hours, and a volume of distribution suggesting adequate penetration into peripheral tissues.

Paragraphs of advantage

[0132]

A1. A compound of Formula I:

wherein:

$R^1$ is $C(R^2)(R^3)(R^4)$;
$R^2$ is hydrogen, -OH or halogen;
$R^3$ is hydrogen, -OH, halogen or C$_{1-8}$ alkyl;
$R^4$ is halogen, C$_{1-8}$ alkyl, substituted C$_{1-8}$ alkyl, aryl, substituted aryl, alkylcycloalkyl or substituted alkylcycloalkyl;
$R^3$ and $R^4$ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted, preferably with halogen and more preferably with one or more fluorine atoms;
$R^6$ is hydrogen, C$_{1-8}$ alkyl, substituted C$_{1-8}$ alkyl, arylalkyl, substituted arylalkyl, alkylaryl, or substituted alkylaryl;
$Z$ is optional, when present $Z$ is -(CH$_2$)$_{1-8}$-, -C(=O)-, -S(=O)$_2$NH-, -S(=O)$_2$-, -C(=S)NH-, -S(=O)$_2$CH$_3$, C(=O)-NH-, -S(=O)$_2$NR$_9$R$_{10}$, -C(=O)C$_{1-8}$ alkyl or -C(=O)CH(NH$_2$)CH$_3$;
$R^7$ is hydrogen, C$_{1-8}$ alkyl or substituted C$_{1-8}$ alkyl;
$R^{10}$ is hydrogen, C$_{1-8}$ alkyl or substituted C$_{1-8}$ alkyl;

provided that $R^2$ and $R^3$ cannot both be hydrogen when $R^4$ is a halogen, $Z$ is not present, $R^7$ is -OH, $R^5$, $R^6$ and $R^8$ are hydrogen.

A2. A compound of Formula II:
wherein:

R¹ is C(R²)(R³)(R⁴);
R² is hydrogen, -OH or halogen;
R³ is hydrogen, -OH, halogen or -CH₃;
R⁴ is halogen, -CH₃, phenyl, fluorophenyl, methylphenyl, cyclohexylmethyl, wherein when R⁴ is a halogen, both R² and R³ cannot be hydrogen;
R³ and R⁴ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted with one or more halogen atoms; R⁶ is hydrogen, phenylalkyl or substituted phenylalkyl;
Z is optional, when present Z is -(CH₂)_, -C(=O)_, -S(=O)₂NH_-, -S(=O)₂-, -S(=O)₂CH₃, C(=O)-NH_, -S(=O)₂NR⁹R¹⁰, -C(=S)-NH_ or -C(=O)₂CH₃,
R⁶ is hydrogen or CH₃;
R¹⁰ is hydrogen or CH₃;
R⁵ is hydrogen or aminophenylalkyl;
R⁷ is -OH or halogen; and
R⁸ is hydrogen, halogen or -CH₃.

provided that R² and R³ cannot both be hydrogen when R⁴ is halogen, Z is not present, R⁷ is -OH, R⁵, R⁶ and R⁸ are hydrogen.

A3. A compound of Formula III:

wherein:

R¹ is C(R²)(R³)(R⁴);
R² is hydrogen, -OH or halogen;
R³ is hydrogen, -OH, halogen or -CH₃;
R⁴ is halogen, -CH₃, phenyl, fluorophenyl, methylphenyl, cyclohexylmethyl, wherein when R⁴ is a halogen, both R² and R³ cannot be hydrogen;
R³ and R⁴ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted with one or more halogen atoms; R⁷ is -OH or halogen; and
R⁸ is hydrogen, halogen or -CH₃,

provided that R² and R³ cannot both be hydrogen when R⁴ is a halogen, R⁷ is -OH and R⁶ and R⁸ are hydrogen.

A4. A compound selected from the following:
or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A5. The compound of Paragraph A4 which is:

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A6. The compound of Paragraph A4 which is:

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A7. The compound of Paragraph A4 which is:
or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A8. The compound of Paragraph A4 which is:

![Chemical structure]

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A9. The compound of Paragraph A4 which is:

![Chemical structure]

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A10. A pharmaceutical composition comprising the compound of Paragraph A1 and at least one pharmaceutically acceptable carrier.

A11. A method for preventing and/or treating Parkinson's disease in a patient at risk for developing or diagnosed with the same, which comprises administering to the patient in need thereof an effective amount of a compound of Paragraph A1.

A12. A method for preventing and/or treating Parkinson's disease in a patient at risk for developing or diagnosed with the same, which comprises administering to the patient in need thereof an effective amount of a compound of Paragraph A2.

A13. A method for preventing and/or treating Parkinson's disease in a patient at risk for developing or diagnosed with the same, which comprises administering to the patient in need thereof an effective amount of a compound of Paragraph A3.

A14. A method for preventing and/or treating Parkinson's disease in a patient at risk for developing or diagnosed with the same, which comprises administering to the patient in need thereof an effective amount of a compound of Paragraph A4.

A15. The method of Paragraph A14, wherein the compound is:

![Chemical structure]

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A16. The method of Paragraph A14, wherein the compound is:
or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A17. The method of Paragraph A14, wherein the compound is:

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A18. The method of Paragraph A14, wherein the compound is:

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A19. The method of Paragraph A14, wherein the compound is:

or a pharmaceutically acceptable salt, solvate, or prodrug thereof.

A20. The method of Paragraph A11, further comprising administering an effective amount of at least one other therapeutic agent.

A21. The method of Paragraph A11, wherein at least one other therapeutic agent is levodopa, an anticholinergic, a catechol-O-methyl transferase inhibitor, a dopamine receptor agonist, a monoamine oxidase inhibitor, a peripheral decarboxylase inhibitor, or an anti-inflammatory agent.

A22. A kit comprising:

• a container having an effective amount of a compound of Paragraph A1, or a pharmaceutically acceptable salt, solvate, or prodrug thereof, or any combination of two or more thereof; and
• instructions for using the same to prevent and/or treat Parkinson’s disease.
Claims

1. A compound of Formula I:

wherein:

- $R^1$ is $C(R^2)(R^3)(R^4)$;
- $R^2$ is hydrogen, -OH or halogen;
- $R^3$ is hydrogen, -OH, halogen or C$_{1-8}$ alkyl;
- $R^4$ is halogen, C$_{1-8}$ alkyl, substituted C$_{1-8}$ alkyl, aryl, substituted aryl, alkylcycloalkyl or substituted alkylcycloalkyl;
- $R^3$ and $R^4$ may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally substituted, preferably with halogen and more preferably with one or more fluorine atoms;
- $R^5$ is hydrogen, C$_{1-8}$ alkyl, substituted C$_{1-8}$ alkyl, arylalkyl, substituted arylalkyl, alkylaryl, or substituted alkylaryl;
- $Z$ is optional, when present $Z$ is -{(CH$_2$)$_{1-8}$}, -C(=O)-, -S(=O)$_2$NH-, -S(=O)$_2$-, -C(=S)NH-, -S(=O)$_2$-CH$_2$-, C(=O)-NH-, -S(=O)$_2$NR$_9$-, -C(=O)C$_{1-8}$ alkyl or -C(=O)CH(NH$_2$)CH$_2$-;
- $R^6$ is hydrogen, C$_{1-8}$ alkyl or substituted C$_{1-8}$ alkyl;
- $R^7$ is hydrogen, C$_{1-8}$ alkyl, substituted C$_{1-8}$ alkyl, aryl, substituted aryl, C$_{1-8}$ alkenyl, substituted C$_{1-8}$ alkenyl, arylalkyl, substituted arylalkyl, alkylaryl, substituted alkylaryl, aminoarylalkyl or substituted aminoarylalkyl;
- $R^7$ is -OH or halogen; and
- $R^7$ is hydrogen, halogen or C$_{1-8}$ alkyl;

provided that $R^2$ and $R^3$ cannot both be hydrogen when $R^4$ is a halogen, $Z$ is not present, $R^7$ is -OH, $R^5$, $R^6$ and $R^8$ are hydrogen; or a pharmaceutically acceptable salt thereof.

2. A compound of Formula II:

wherein:
R\textsuperscript{1} is C(R\textsuperscript{2})(R\textsuperscript{3})(R\textsuperscript{4});
R\textsuperscript{2} is hydrogen, -OH or halogen;
R\textsuperscript{3} is hydrogen, -OH, halogen or -CH\textsubscript{3};
R\textsuperscript{4} is halogen, -CH\textsubscript{3}, phenyl, fluorophenyl, methylphenyl, cyclohexylmethyl, wherein when R\textsuperscript{4} is a halogen, both
R\textsuperscript{2} and R\textsuperscript{3} cannot be hydrogen;
R\textsuperscript{3} and R\textsuperscript{4} may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally
substituted with one or more halogen atoms;
R\textsuperscript{6} is hydrogen, phenylalkyl or substituted phenylalkyl;
Z is optional, when present Z is -(CH\textsubscript{2})\textsubscript{n}-, -C(=O)-, -S(=O)\textsubscript{2}NH-, -S(=O)\textsubscript{2}-, -S(=O)\textsubscript{2}CH\textsubscript{2}-, C(=O)-NH-, -S(=O)\textsubscript{2}NR\textsuperscript{9}-,
-C(=S)-NH- or -C(=O)\textsubscript{2}CH\textsubscript{2}-,
R\textsuperscript{8} is hydrogen or CH\textsubscript{3};
R\textsuperscript{5} is hydrogen or aminophenylalkyl;
R\textsuperscript{7} is -OH or halogen; and
R\textsuperscript{8} is hydrogen, halogen or -CH\textsubscript{3},

provided that R\textsuperscript{2} and R\textsuperscript{3} cannot both be hydrogen when R\textsuperscript{4} is halogen, Z is not present, R\textsuperscript{7} is -OH, R\textsuperscript{5}, R\textsuperscript{6} and R\textsuperscript{8}
are hydrogen; or a pharmaceutically acceptable salt thereof.

3. A compound of Formula III:

wherein:

R\textsuperscript{1} is C(R\textsuperscript{2})(R\textsuperscript{3})(R\textsuperscript{4});
R\textsuperscript{2} is hydrogen, -OH or halogen;
R\textsuperscript{3} is hydrogen, -OH, halogen or -CH\textsubscript{3};
R\textsuperscript{4} is halogen, -CH\textsubscript{3}, phenyl, fluorophenyl, methylphenyl, cyclohexylmethyl, wherein when R\textsuperscript{4} is a halogen, both
R\textsuperscript{2} and R\textsuperscript{3} cannot be hydrogen;
R\textsuperscript{3} and R\textsuperscript{4} may join with the carbon to which they are attached to form a cycloalkyl ring, which may be optionally
substituted with one or more halogen atoms;
R\textsuperscript{7} is -OH or halogen; and
R\textsuperscript{8} is hydrogen, halogen or -CH\textsubscript{3},

provided that R\textsuperscript{2} and R\textsuperscript{3} cannot both be hydrogen when R\textsuperscript{4} is halogen, R\textsuperscript{7} is -OH and R\textsuperscript{6} and R\textsuperscript{8}
are hydrogen; or a pharmaceutically acceptable salt thereof.

4. A compound selected from the following:
5. A pharmaceutical composition comprising a compound according to any one of claims 1 to 4 and at least one pharmaceutically acceptable carrier.

6. A compound according to any one of claims 1 to 4 for use in preventing and/or treating a condition selected from Parkinson’s disease, dementia with Lewy bodies, multiple system atrophy or Alzheimer’s disease in a patient at risk for developing or diagnosed with the same.

7. A compound for use according to claim 6, wherein the compound is:

![Chemical Structure]

or a pharmaceutically acceptable salt or solvate thereof.

8. A compound for use according to claim 6, wherein the compound is:

![Chemical Structure]

or a pharmaceutically acceptable salt or solvate thereof.

9. A compound for use according to claim 6, wherein the compound is:

![Chemical Structure]

or a pharmaceutically acceptable salt or solvate thereof.

10. A compound for use according to claim 6, wherein the compound is:

![Chemical Structure]

or a pharmaceutically acceptable salt or solvate thereof.

11. A compound for use according to claim 6, wherein the compound is:
or a pharmaceutically acceptable salt or solvate thereof.

12. A compound for use according to any one of claims 6 to 11, wherein the compound is administered in combination with at least one other therapeutic agent selected from levodopa, an anticholinergic, a catechol-O-methyl transferase inhibitor, a dopamine receptor agonist, a monoamine oxidase inhibitor, a peripheral decarboxylase inhibitor, or an anti-inflammatory agent.
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<th>Category</th>
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<td>SUN H ET AL: &quot;A new asymmetric route to substituted piperidines: synthesis of N-alkyl-3,4-dihydroxy-5-alkylpiperidines&quot;, TETRAHEDRON LETTERS, ELSEVIER, AMSTERDAM, NL, vol. 41, no. 16, 1 April 2000 (2000-04-01), pages 2801-2804, XP004195675, ISSN: 0040-4039, DOI:10.1016/S0040-4039(00)00267-7 * a and b for each example.; examples 4, 5, 11, 12, 15, 17 *</td>
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<td>RIVES, ARNAUD ET AL: &quot;Enantioselective access to all-trans 5-alkylpiperidine-3,4-diols: application to the asymmetric synthesis of the 1-N-iminosugar (+)-isofagomine&quot;, SYNTHESIS, (19), 3251-3258 CODEN: SYNTBF; ISSN: 0039-7881, 2009, XP002696027, * example 8 *</td>
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The present search report has been drawn up for all claims

Place of search: Munich
Date of completion of the search: 18 January 2017
Examiner: Von Daackle, Axel
### DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>X</td>
<td>IMANISHI, TAKESHI ET AL: <em>1,6-Dihydro-3(2H)-pyridinones. IX. A regioselective synthesis of ethyl 3-methoxycarbonylmethyl-4-oxopiperidine-1-carboxylate from ethyl 3-hydroxy-1,2,3,6-tetrahydropyridine-1-carboxylate</em>, CHEMICAL &amp; PHARMACEUTICAL BULLETIN, 31(11), 4135-8 CODEN: CPBTAL; ISSN: 0009-2363, 1983, XP002696028, * example 12 *</td>
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The present search report has been drawn up for all claims.

**Place of search**

**Date of completion of the search**

**Examiner**

Munich
18 January 2017
Von Daacke, Axel

**CATEGORY OF CITED DOCUMENTS**

- **T**: theory or principle underlying the invention
- **E**: earlier patent document, but published on, or after the filing date
- **D**: document cited in the application
- **L**: document cited for other reasons
- **A**: technological background
- **O**: non-written disclosure
- **P**: intermediate document

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18-01-2017

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For more details about this annex: see Official Journal of the European Patent Office, No. 12/82.
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