

AZA-ERGOLINE DERIVATIVE AND PREPARATION METHOD THEREFOR AND APPLICATION THEREOF

[0001] The present application claims the priority of the Chinese patent application 2021101382499 with the filing date of February 1, 2021, and the Chinese patent application 2021111530798 with the filing date of September 29, 2021. This Chinese patent application is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The disclosure relates to an aza-ergoline derivative, and a preparation method therefor and an application thereof.

BACKGROUND

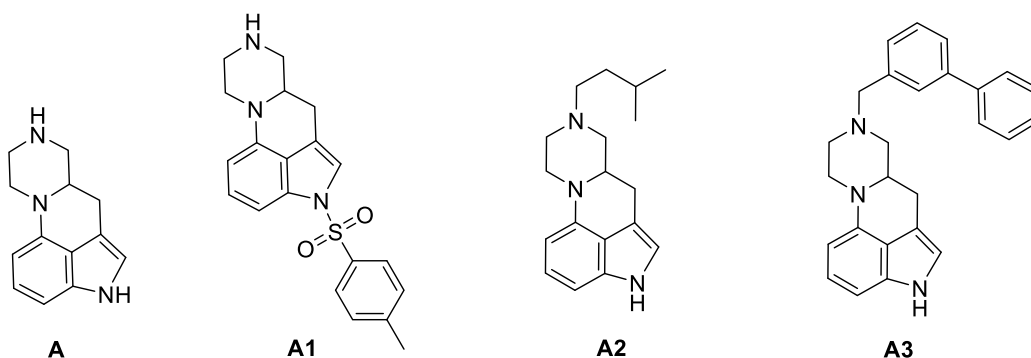
[0003] The dopaminergic signaling pathway is related to various physiological functions such as human movement, behavior, emotion, and memory, and has been one of the focuses of neurobiological research in recent decades. Dysfunction of the dopaminergic signaling pathway is believed to be the cause of many diseases such as Parkinson's disease and schizophrenia. The dopaminergic signaling pathway consists of the neurotransmitter dopamine, dopamine receptors, and downstream signaling molecules associated with dopamine receptors. Dopamine receptors belong to the G protein-coupled receptor (GPCR) superfamily and are one of the most important central nervous system (CNS) drug targets. There are five subtypes of dopamine receptors (D_{1-5}), among which D_1 and D_5 are type D_1 receptors, which are mainly coupled with G_s protein, and increase the level of intracellular cAMP after activation; D_2 , D_3 , and D_4 are type D_2 receptors, which are mainly coupled with G_i protein, and reduce the level of intracellular cAMP after activation. Different dopamine receptors have different expression levels and distributions in the central nervous system, and play different physiological functions (Martel and McArthur, Front Pharmacol 2020, 11: 1003).

[0004] Among the five subtypes of dopamine receptors, D_2 receptors are most widely and deeply studied. Drugs in clinical use, such as Pramipexole, Ropinirole, and Rotigotine, are mainly used for the treatment of Parkinson's disease and restless legs syndrome. These drugs

play a therapeutic role mainly by activating dopamine D₂ receptors, but they also have activity on other dopamine receptors such as D₃. Antischizophrenia drugs such as haloperidol and olanzapine mainly exert their therapeutic effects by antagonizing D₂ receptors, while the latest generation of drugs such as aripiprazole and cariprazine are partial agonists of dopamine D₂ receptors (Frankel and Schwartz, *The Adv Psychopharmacol* 2017, 7(1): 29-41).

[0005] Dopamine D₂ receptors share a certain degree of structural homology with other dopamine receptors and other monoamine GPCRs such as 5-hydroxytryptamine (5-HT) receptors. This homology leads to the fact that most drugs do not have target selectivity. Most of the above-mentioned antischizophrenia drugs targeting dopamine D₂ receptors have a certain degree of affinity for 5-HT receptors such as 5-HT_{2A} receptors, and the affinity of some drugs for 5-HT_{2A} receptor is even stronger than that for D₂ receptors. The dual action for D₂ receptors and 5-HT_{2A} receptors is a common feature of these drugs. Pimavanserin, which was approved by the US FDA in 2018, is a selective inverse agonist of 5-HT_{2A} receptors (Sahli and Tarazi, *Expert Opin Drug Discov* 2018, 13(1): 103-110); Lumateperone, which was approved by the US FDA in 2019, has an affinity for 5-HT_{2A} receptors that is about 60 times higher than that for D₂ receptors (Blair, *Drugs*, 2020, 80(4), 417-423). However, drugs with high selectivity for D₂ receptors have rarely been reported in the literature (Fan and Tan *et al.*, *Nat Comm*, 2020, 11, 1074).

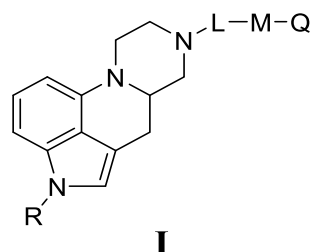
[0006] Krogsgaard-Larsen *et al.* reported a compound A with aza-ergoline skeleton, and its derivative A1 has the binding activity for 5-HT₆ receptors, and its derivative A2 has the agonistic activity for dopamine D₂ receptors, A3 has partial agonistic activity for dopamine D₂ receptors (Krogsgaard-Larsen *et al.*, *J. Med. Chem.* 2014, 57, 5823–5828; WO 2011088836; WO 2011088838). The target selectivity, *in vivo* activity in animals and other druggability of these compounds have not been reported.



CONTENT OF THE PRESENT INVENTION

[0007] The technical problem to be solved by the present invention is that the existing compounds with affinity, agonistic activity or selectivity for dopamine D₂ receptors are few, so the present disclosure provides an aza-ergoline derivative and a preparation method therefor and an application thereof. The compounds of the present invention have good affinity, agonistic activity or selectivity for dopamine D₂ receptors.

[0008] The present invention provides a compound as shown in formula I, a pharmaceutically acceptable salt thereof, a solvate thereof or a solvate of a pharmaceutically acceptable salt thereof:



wherein, L is C₁₋₁₀ alkylene, C₂₋₁₀ alkenylene, C₂₋₁₀ alkynylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH-, -CH₂-, -(CH-OH)- or -C(=O)-;

Q is C₆₋₁₈ aryl, C₆₋₁₈ aryl substituted with one or more Q¹⁻¹, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²; the heteroatoms in the 5 to 10 membered heteroaryl are one or more of N, S or O, and the number is 1, 2 or 3; the heteroatoms in the 5 to 10 membered heteroaryl substituted with one or more Q¹⁻² are one or more of N, S or O, and the number is 1, 2 or 3;

Q¹⁻¹ is independently halogen or C₁₋₄ alkyl;

Q^{1-2} is independently C_{1-4} alkyl, oxo or hydroxyl;

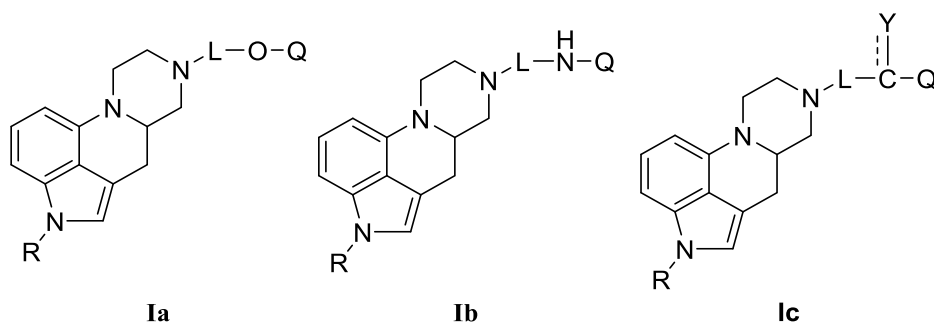
R^1 and R^2 are independently $-NR^{1-1}R^{1-2}$, 3 to 6 membered heterocycloalkyl, C_{6-18} aryl, C_{6-18} aryl substituted with one or more R^{1-3} , 5 to 10 membered heteroaryl or 5 to 10 membered heteroaryl substituted with one or more R^{1-4} ; the heteroatoms in the 3 to 6 membered heterocycloalkyl are one or more of N, S or O, and the number is 1, 2 or 3; the heteroatoms in the 5 to 10 membered heteroaryl are one or more of N, S or O, and the number is 1, 2 or 3; the heteroatoms in the 5 to 10 membered heteroaryl substituted with one or more R^{1-4} are one or more of N, S or O, and the number is 1, 2 or 3;

R^{1-1} , R^{1-2} , R^{1-3} and R^{1-4} are independently C_{1-4} alkyl;

R is hydrogen or C_{1-4} alkyl.

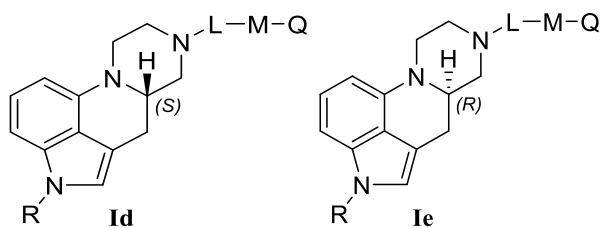
[0009] In a preferred embodiment, in the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof, some groups can be defined as follows, and the remaining groups are defined as described in any embodiment of the present invention, hereinafter referred to as "in a preferred embodiment".

[0010] In a preferred embodiment, the compound as shown in formula I is a compound as shown in formula Ia, Ib or Ic:

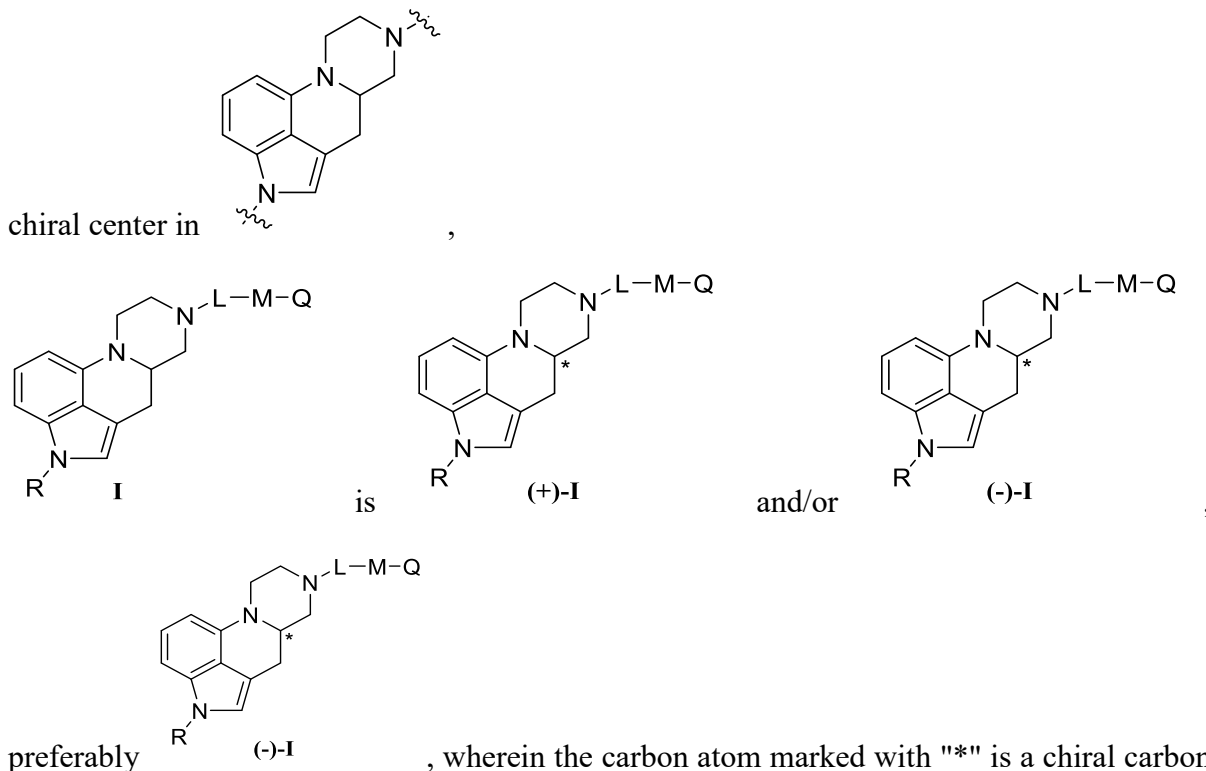


in formula Ic, "" represents a double bond or a single bond; Y is hydrogen, hydroxyl or oxygen.

[0011] In a preferred embodiment, the compound as shown in formula I is a compound as shown in formula Id and/or Ie, preferably a compound as shown in formula Id;



[0012] In a preferred embodiment, when the compound as shown in formula I has only one



atom; (+) represents a dextrorotatory compound, and (-) represents a levorotatory compound.

[0013] In a preferred embodiment,

L is C₁₋₁₀ alkylene, C₂₋₁₀ alkenylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

when M is -(CH-OH)- or -C(=O)-, R is hydrogen.

In a preferred embodiment,

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH- or -CH₂-;

Q is C₆₋₁₈ aryl, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R².

In a preferred embodiment,

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH- or -CH₂-;

Q is C₆₋₁₈ aryl, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²;

when M is -O-, Q¹⁻² is C₁₋₄alkyl or hydroxyl;

when the heteroatom in the 5 to 10 membered heteroaryl is O, the number of heteroatoms in the 5 to 10 membered heteroaryl is 1.

[0014] In a preferred embodiment,

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH- or -CH₂-;

Q is C₆₋₁₈ aryl, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²;

when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₁₋₆ alkylene in the -C₁₋₆ alkylene-C₃₋₆ cycloalkylene- is ethylene.

[0015] In a preferred embodiment,

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O- or -NH-;

Q is -C(=O)R¹ or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

R¹ is -NR¹⁻¹R¹⁻².

[0016] In a preferred embodiment, L is C₁₋₁₀ alkylene;

M is -O-;

Q is a 5 to 10 membered heteroaryl substituted with one or more Q¹⁻².

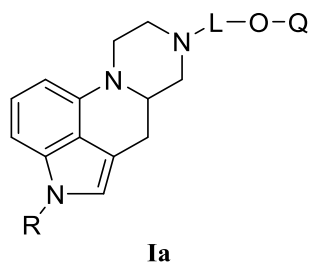
In a preferred embodiment, L is -C₁₋₆ alkylene -C₃₋₆ cycloalkylene-;

M is -NH-;

Q is -C(=O)R¹;

R¹ is -NR¹⁻¹R¹⁻².

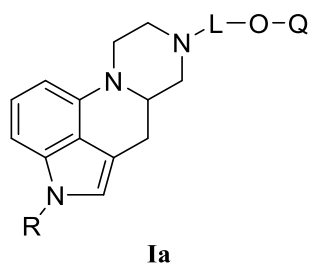
[0017] In a preferred embodiment, the molecular structure as shown in formula I is as shown in formula Ia:



L is C₁₋₁₀ alkylene or C₂₋₁₀ alkenylene;

Q is 5 to 10 membered heteroaryl, or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻².

[0018] In a preferred embodiment, the molecular structure as shown in formula I is as shown in formula Ia:

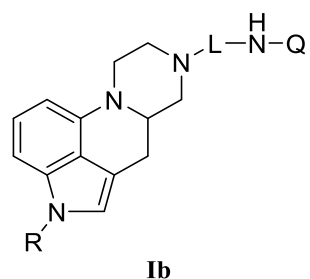


L is C₁₋₁₀ alkylene or C₂₋₁₀ alkenylene;

Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹, 5 to 10 membered heteroaryl or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

Q¹⁻¹ is halogen.

[0019] In a preferred embodiment, the molecular structure as shown in formula I is as shown in formula Ib:



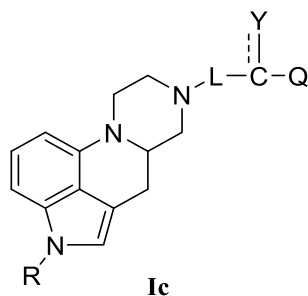
L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

Q is -C(=O)R¹ or -S(=O)₂R²;

R¹ and R² are independently -NR¹⁻¹R¹⁻², 3 to 6 membered heterocycloalkyl, C₆₋₁₈ aryl or 5 to 10 membered heteroaryl.

[0020] In a preferred embodiment, the molecular structure as shown in formula I is as shown

in formula Ic:



" --- " represents a double bond or a single bond;

Y is hydrogen, hydroxyl or oxygen;

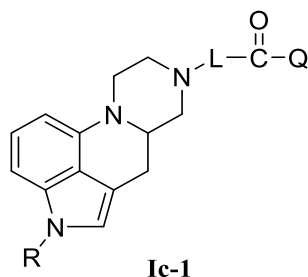
L is C₁₋₁₀ alkylene;

Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹ or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

Q¹⁻¹ is halogen;

Q¹⁻² is independently C₁₋₄ alkyl or oxo.

[0021] In a preferred embodiment, the molecular structure as shown in formula I is as shown in formula Ic-1:



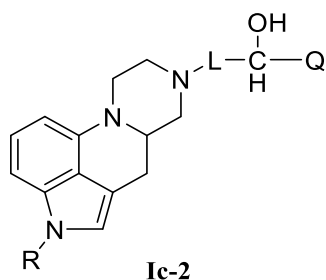
L is C₁₋₁₀ alkylene;

Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹;

Q¹⁻¹ is halogen;

R is hydrogen.

[0022] In a preferred embodiment, the molecular structure as shown in formula I is as shown in formula Ic-2:



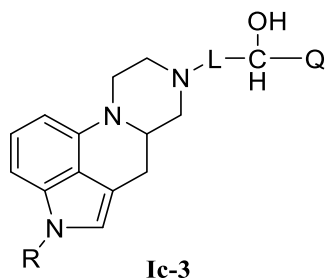
L is C₁₋₁₀ alkylene;

Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹;

Q¹⁻¹ is halogen;

R is hydrogen.

[0023] In a preferred embodiment, the molecular structure as shown in formula I is as shown in formula Ic-3:



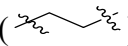
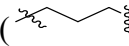
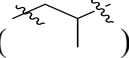
L is C₁₋₁₀ alkylene;

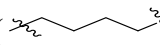
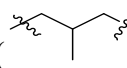
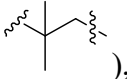
Q is a 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

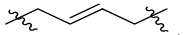
Q¹⁻¹ is C₁₋₄ alkyl or oxo;

R is hydrogen.

[0024] In a preferred embodiment, when L is C₁₋₁₀ alkylene, the C₁₋₁₀ alkylene is C₁₋₄ alkylene

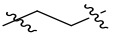
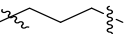
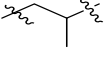
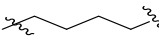
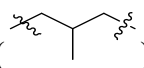
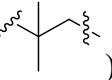
(e.g. methylene, ethylene () , n-propylene () , isopropylene () , n-

butylene () , isobutylene () or tert-butylene () , preferably n-propylene or n-butylene, more preferably n-butylene.

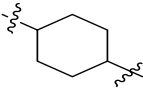
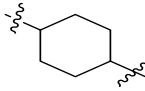
[0025] In a preferred embodiment, when L is C₂₋₁₀ alkenylene and the C₂₋₁₀ alkenylene is C₂₋₄ alkenylene, it is preferably .

[0026] In a preferred embodiment, when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₁₋₆ alkylene is connected to N, and the C₃₋₆ cycloalkylene is connected to Q.

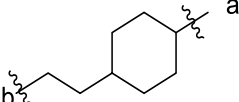
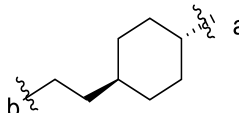
[0027] In a preferred embodiment, when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₁₋₆

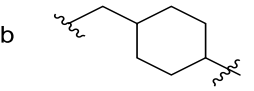
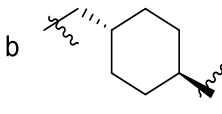
alkylene in the $-C_{1-6}$ alkylene- C_{3-6} cycloalkylene is methylene, ethylene () , n-propylene () , isopropylene () , n-butylene () , isobutylene () or tert-butylene () , preferably methylene or ethylene, more preferably ethylene.

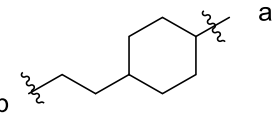
[0028] In a preferred embodiment, when L is $-C_{1-6}$ alkylene- C_{3-6} cycloalkylene-, the C_{3-6} cycloalkylene in the $-C_{1-6}$ alkylene- C_{3-6} cycloalkylene is cyclopropylene, cyclobutylene,

cyclopentylene or cyclohexylene (e.g., ) , preferably .

[0029] In a preferred embodiment, when L is $-C_{1-6}$ alkylene- C_{3-6} cycloalkylene-, the $-C_{1-6}$

alkylene- C_{3-6} cycloalkylene- is  (e.g., ) or

 (e.g., ) , wherein the a-terminal is connected to Q,

and the b-terminal is connected to N, preferably .

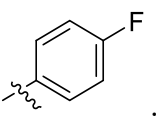
[0030] In a preferred embodiment, when Q is C_{6-18} aryl, the C_{6-18} aryl is C_{6-14} aryl (e.g., phenyl, naphthyl, anthracenyl or phenanthryl), further can be phenyl.

[0031] In a preferred embodiment, when Q is C_{6-18} aryl substituted with Q^{1-1} , the C_{6-18} aryl is C_{6-14} aryl (e.g., phenyl, naphthyl, anthracenyl or phenanthryl), further can be phenyl.

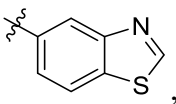
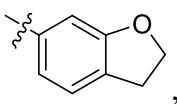
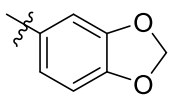
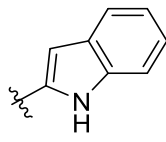
[0032] In a preferred embodiment, when Q is C_{6-18} aryl substituted with Q^{1-1} , the number of Q^{1-1} is 1 or 2. When there are more than one Q^{1-1} , Q^{1-1} can be the same or different, for example, can be different.

[0033] In a preferred embodiment, when Q^{1-1} is halogen, the halogen is F, Cl, Br or I, preferably F.

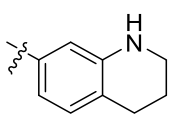
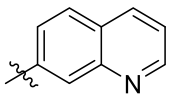
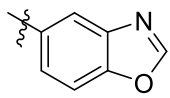
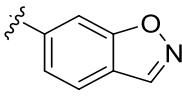
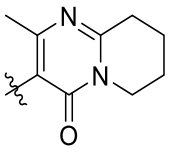
[0034] In a preferred embodiment, when Q is C_{6-18} aryl substituted with Q^{1-1} , the C_{6-18} aryl

substituted with Q^{1-1} is .

[0035] In a preferred embodiment, when Q is 5 to 10 membered heteroaryl, the 5 to 10 membered heteroaryl is 9 or 10 membered heteroaryl, and the number of heteroatoms is 1 or 2,

more preferably , ,  or .

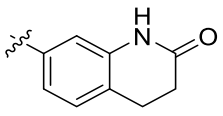
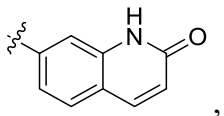
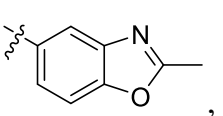
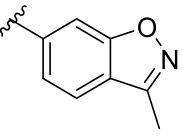
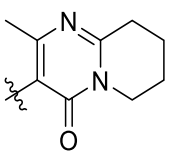
[0036] In a preferred embodiment, when Q is 5 to 10 membered heteroaryl substituted with one or more Q^{1-2} , the 5 to 10 membered heteroaryl is 9 or 10 membered heteroaryl, the heteroatom is N and/or O, the number of heteroatoms is 1 or 2, preferably tetrahydroquinolyl

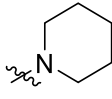
() , quinolyl (e.g., ) , benzoxazolyl (e.g., ) ,
benzioxazolyl (e.g., ) , or tetrahydropyridopyrimidinyl (e.g., )).

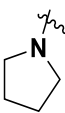
[0037] In a preferred embodiment, when Q is C_{6-18} aryl substituted with Q^{1-2} , the number of Q^{1-2} is 1 or 2. When there are more than one Q^{1-2} , the Q^{1-2} is the same or different, for example, is different.

[0038] In a preferred embodiment, when Q^{1-2} is C_{1-4} alkyl, the C_{1-4} alkyl is methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl or tert-butyl, preferably methyl.

[0039] In a preferred embodiment, when Q is 5 to 10 membered heteroaryl substituted with one or more Q^{1-2} , the 5 to 10 membered heteroaryl substituted with one or more Q^{1-2} is

, , ,  or .

[0040] In a preferred embodiment, when R^1 and R^2 are independently 3 to 6 membered heterocycloalkyl, the 3 to 6 membered heterocycloalkyl is piperidinyl (e.g., ) or

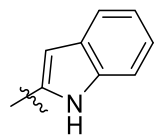
pyrrolidinyl (e.g., ) , preferably pyrrolidinyl.

[0041] In a preferred embodiment, when R^1 is 3 to 6 membered heterocycloalkyl, the 3 to 6 membered heterocycloalkyl is connected to carbonyl through a heteroatom.

[0042] In a preferred embodiment, when R^1 and R^2 are independently C_{6-18} aryl, the C_{6-18} aryl is C_{6-14} aryl (e.g., phenyl, naphthyl, anthracenyl or phenanthryl), and may be further phenyl.

[0043] In a preferred embodiment, when R^1 and R^2 are independently C_{6-18} aryl substituted with one or more R^{1-3} , the C_{6-18} aryl is C_{6-14} aryl (e.g., phenyl, naphthyl, anthracenyl or phenanthryl), further can be phenyl.

[0044] In a preferred embodiment, when R^1 and R^2 are independently 5 to 10 membered heteroaryl, the 5 to 10 membered heteroaryl is 9 or 10 membered heteroaryl, the heteroatom is

N, and the number of heteroatoms is 1 or 2, preferably indolyl (e.g., ).

[0045] In a preferred embodiment, when R^{1-1} , R^{1-2} , R^{1-3} and R^{1-4} is independently C_{1-4} alkyl, the C_{1-4} alkyl is methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl or tert-butyl, preferably methyl.

[0046] In a preferred embodiment, when R is C_{1-4} alkyl, the C_{1-4} alkyl is methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl or tert-butyl, preferably methyl.

[0047] In a preferred embodiment, L is C_{1-10} alkylene, C_{2-10} alkenylene or $-C_{1-6}$ alkylene- C_{3-6} cycloalkylene.

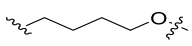
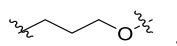
[0048] In a preferred embodiment, L is C_{1-10} alkylene or $-C_{1-6}$ alkylene- C_{3-6} cycloalkylene.

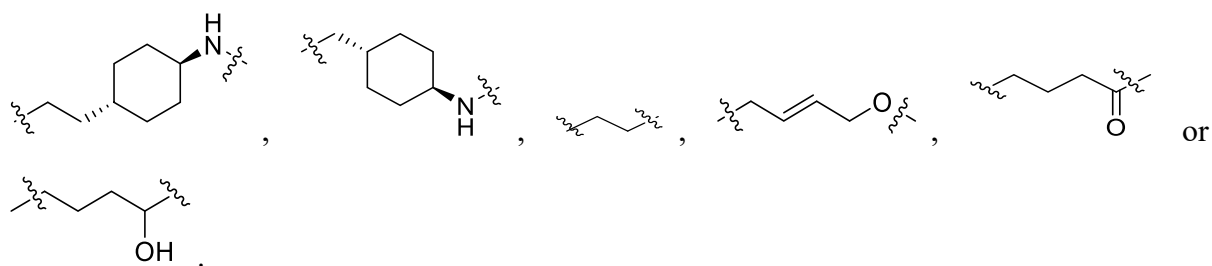
[0049] In a preferred embodiment, M is -O-, -NH- or -CH₂-.

[0050] In a preferred embodiment, Q^{1-1} is halogen.

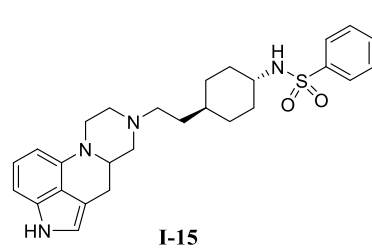
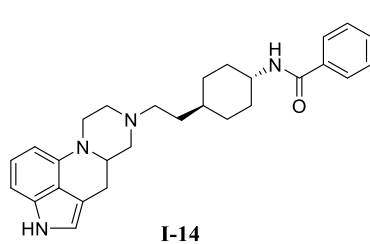
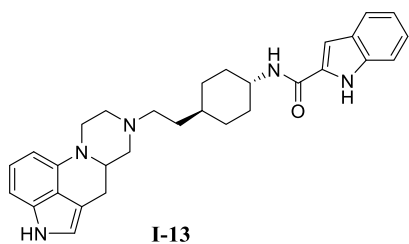
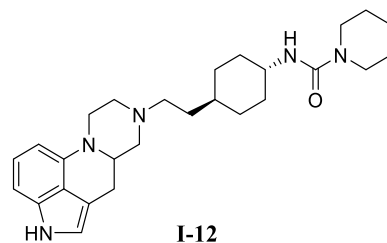
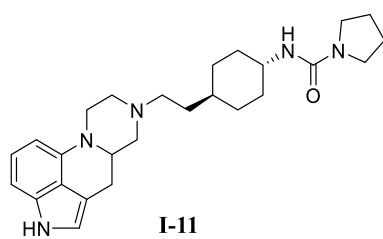
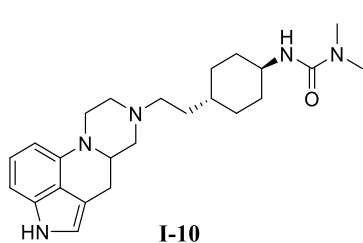
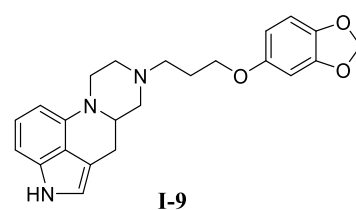
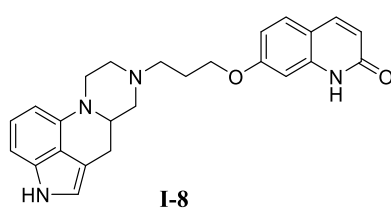
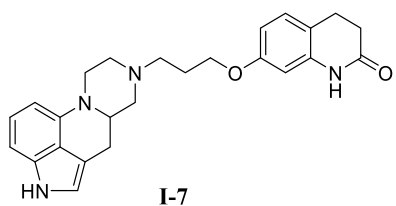
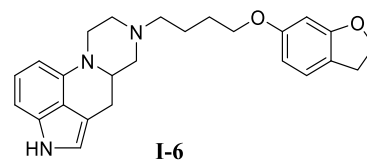
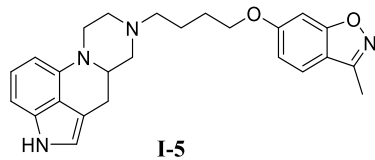
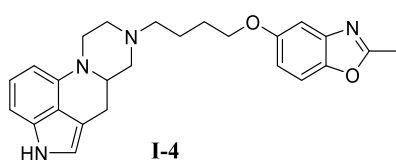
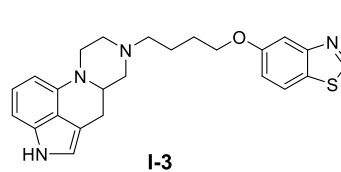
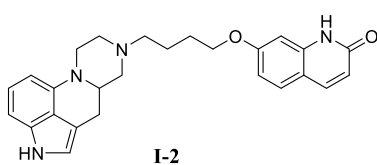
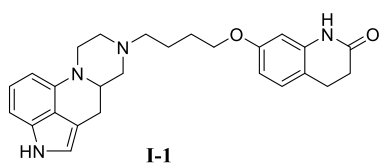
[0051] In a preferred embodiment, R^1 is $-NR^{1-1}R^{1-2}$, 3 to 6 membered heterocycloalkyl, C_{6-18} aryl or 5 to 10 membered heteroaryl, preferably $-NR^{1-1}R^{1-2}$, 3 to 6 membered heterocycloalkyl or C_{6-18} aryl.

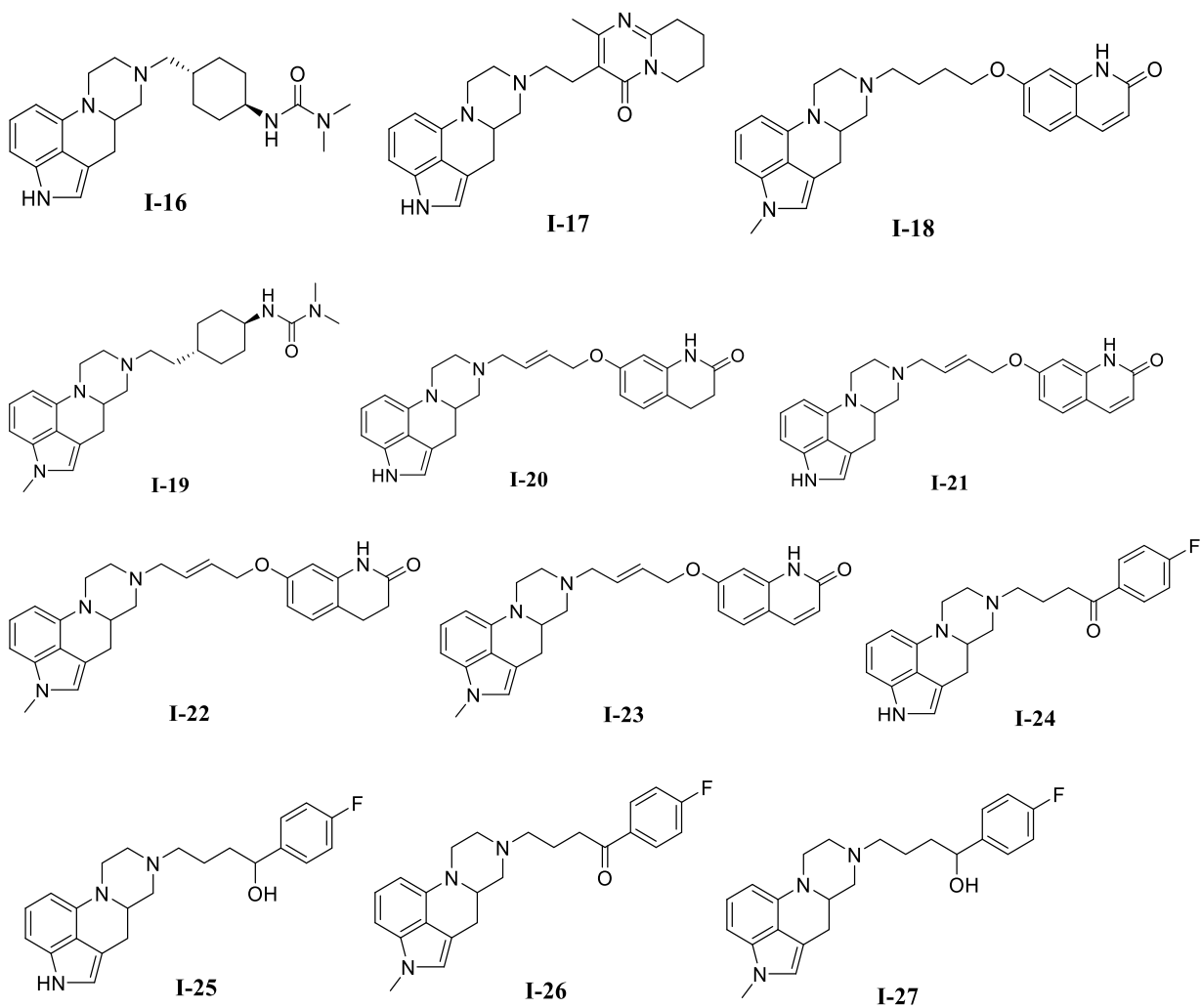
[0052] In a preferred embodiment, R is hydrogen.

[0053] In a preferred embodiment, $\text{---}L\text{---}M\text{---}$ is , ,

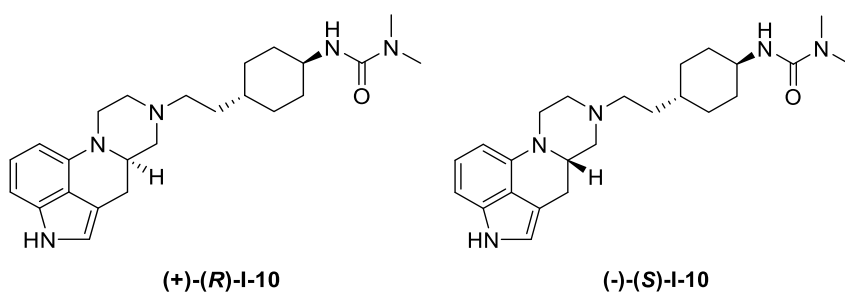


[0054] In a preferred embodiment, the compound as shown in formula I is optionally any of the following compounds:

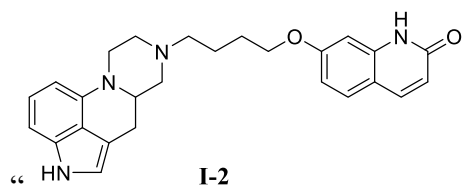




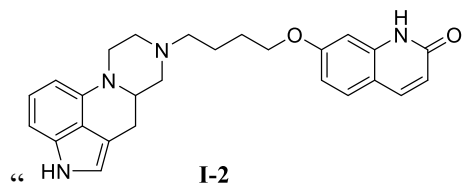
[0055] In a preferred embodiment, the compound as shown in formula I is optionally any of the following compounds:



[0056] In a preferred embodiment, the compound as shown in formula I is optionally any of the following compounds:



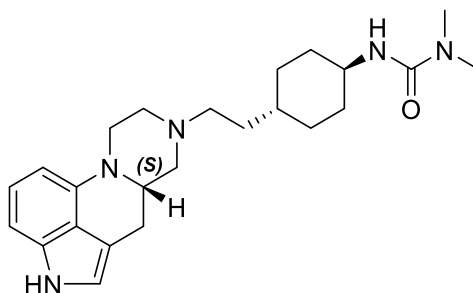
with optical rotation of +50.33° and/or retention time of 5.805 min under the following chiral preparation conditions” or



with optical rotation of -45.00 ° and/or retention time of 7.60 min under the following chiral preparation conditions”;

Chiral preparation conditions: chromatographic column: chiral column CHIRALCEL OD, column volume: 5.0 cm x 25 cm, 10 μm filler; mobile phase: MeOH/diethylamine = 100/0.1; flow rate: 30 mL/min; wavelength: UV 214 nm; temperature: 38 °C.

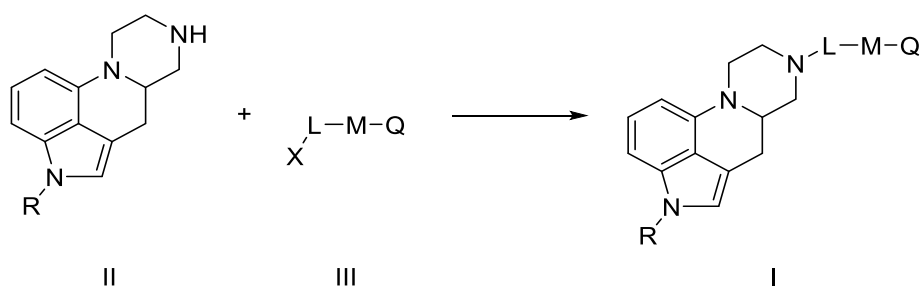
[0057] In a preferred embodiment, the compound as shown in formula I is the following compound:



(-)-(S)-I-10

[0058] The present invention also provides a method for preparing the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, the method comprises the following steps:

[0059] in the presence of a basic reagent, the compound as shown in formula II and the compound as shown in formula III are subjected to the following alkylation reaction in a solvent to obtain the compound as shown in formula I;



wherein, X is a halogen; L, M, Q and R are as defined above.

[0060] The conditions and operations of the alkylation reaction can be conventional conditions and operations of such reactions in the art, and the following conditions are particularly preferred in the present disclosure:

the basic reagent is, for example, K_2CO_3 (for example, the molar ratio of the basic reagent to the compound of formula II is 6 : 1).

[0061] The solvent is, for example, tetrahydrofuran and dimethyl sulfoxide (for example, the volume ratio of the two is 3 : 1).

[0062] The temperature of the alkylation reaction is, for example, 60 °C.

[0063] The present invention also provides a method for preparing the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, the method comprises the following steps:

in the presence of a basic reagent, the compound as shown in formula II and the compound as shown in formula III in

[0064] The present invention further provides a pharmaceutical composition, which comprises the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, and a pharmaceutical adjuvant.

[0065] The present invention further provides the use of a substance **A** in the preparation of a dopamine D_2 receptor agonist, the substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, or the pharmaceutical composition described above.

[0066] The present invention further provides the use of a substance **A** in the preparation of a

drug for treating and/or preventing a disease related to dopamine D₂ receptors; the substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, or the pharmaceutical composition described above.

[0067] The disease related to dopamine D₂ receptors refers to one or more of a neurodegenerative disease, a mental disorder, and a metabolic disease related to a mental disorder, such as Parkinson's disease, Alzheimer's disease, dementia, schizophrenia, bipolar disorder, depression, hyperactivity, restless legs syndrome, Huntington's disease, male erectile dysfunction, prolactinoma, or drug addiction.

[0068] The present disclosure further provides the use of a substance **A** in the preparation of a drug for treating and/or preventing a diseases **M**; the substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, or the pharmaceutical composition described above; the disease **M** is one or more of a neurodegenerative disease, a mental disorder, and a metabolic disease related to a mental disorder.

[0069] In the use, the disease **M** is preferably Parkinson's disease, Alzheimer's disease or dementia, schizophrenia, bipolar disorder, depression, hyperactivity, restless leg syndrome, Huntington's disease, male erectile dysfunction, prolactinoma, or drug addiction.

[0070] The present invention further provides a method for preventing or treating a disease related to dopamine D₂ receptors, and the method comprises administering a therapeutically effective amount of substance **A** to a subject. The substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, or the pharmaceutical composition described above.

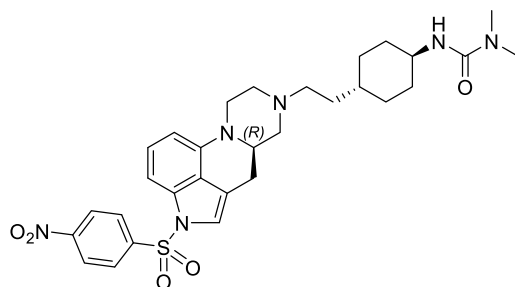
[0071] The disease related to dopamine D₂ receptors refers to one or more of a neurodegenerative disease, a mental disorder, and a metabolic disease related to a mental disorder, such as Parkinson's disease, Alzheimer's disease, dementia, schizophrenia, bipolar disorder, depression, hyperactivity, restless legs syndrome, Huntington's disease, male erectile dysfunction, prolactinoma, or drug addiction.

[0072] The present invention further provides a method for preventing or treating disease **M**,

and the method comprises administering a therapeutically effective amount of substance **A** to a subject. The substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of a pharmaceutically acceptable salt thereof described above, or the pharmaceutical composition described above; the disease **M** is one or more of a neurodegenerative disease, a mental disorder, and a metabolic disease related to a mental disorder.

[0073] In the method, the disease **M** is preferably Parkinson's disease, Alzheimer's disease or dementia, schizophrenia, bipolar disorder, depression, hyperactivity, restless legs syndrome, Huntington's disease, male erectile dysfunction, prolactinoma, or drug addiction.

[0074] The present invention further provides a crystal as shown in the formula pNs-(+)-I-10, the crystal system of which belongs to the triclinic crystal system, the P1 space group, and the unit cell parameters are $a = 9.315 \text{ \AA}$, $b = 6.564 \text{ \AA}$, $c = 23.792 \text{ \AA}$, $\alpha = 90.15^\circ$, $\beta = 99.368^\circ$, $\gamma = 90.25^\circ$;



[0075] Unless otherwise specified, terms used in the present invention have the following meanings:

[0076] As used herein, a substituent employed may be preceded by a single dash "-" to indicate that the named substituent is connected to the parent moiety by a single bond. In addition, a substituent is described by conventional chemical formulas written "left to right" or "top to bottom", for example, "-C₁₋₆ alkylene-C₃₋₆ cycloalkylene" means that C₁₋₆ alkylene is connected to N in the parent moiety through a single bond.

[0077] The terms "compound" and "pharmaceutically acceptable salt", if tautomers exist, may exist as a single tautomer or as a mixture of tautomers, preferably in the form in which a relatively stable tautomer is dominant.

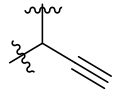
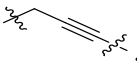
[0078] The term "halogen" refers to fluorine, chlorine, bromine or iodine.

[0079] The term "alkyl" refers to straight or branched alkyl having specified number of carbon atoms (e.g., C₁ to C₁₀). Alkyl includes but are not limited to methyl, ethyl, n-propyl, isopropyl, n-butyl, tert-butyl, isobutyl, sec-butyl, n-pentyl, n-hexyl, n-heptyl, n-octyl, *etc.*

[0080] The term "alkylene" refers to a divalent group of a straight or branched saturated aliphatic hydrocarbon group having specified number of carbon atoms. Two valences can be on the same atom, such as methylene (-CH₂-), ethylene ($\begin{array}{c} \text{---CHCH}_3 \\ | \end{array}$), and two valences can also be connected to two atoms respectively, such as 1,2-ethylene (-CH₂CH₂-).

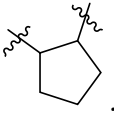
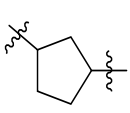
[0081] The term "alkenylene" refers to a divalent group of a straight or branched aliphatic hydrocarbon group containing one or more double bonds and specified number of carbon atoms (e.g., C₂ to C₁₀). Two valences can be on the same atom, such as $\begin{array}{c} \text{---CHCH=CHCH}_3 \\ | \end{array}$, and two valences can also be connected to two atoms respectively, such as -CH₂CH=CHCH₂-.

[0082] The term "alkynylene" refers to a divalent group of a straight or branched aliphatic hydrocarbon group containing one or more triple bonds and specified number of carbon atoms

(e.g., C₂ to C₁₀). Two valences can be on the same atom, such as , and two valences can also be connected to two atoms respectively, such as .

[0083] The term "cycloalkyl" refers to a saturated monocyclic cyclic group consisting only of carbon atoms and having specified number of carbon atoms (e.g., C₃ to C₆). Cycloalkyl includes, but is not limited to, cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, *etc.*

[0084] The term "cycloalkylene" refers to a divalent group of saturated cyclic alkylene, for

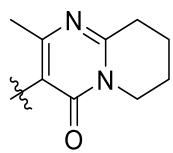
example: cyclopropylene (e.g., ,  or cyclohexylene, *etc.*).

[0085] The term "heterocycloalkyl" refers to a cyclic group with specified number of ring atoms (for example, 5 to 10 membered), specified number of heteroatoms (for example, 1, 2 or 3) and specified type of heteroatoms (one or more of N, O and S), which is a single ring, a bridged ring or a spiro ring, and each ring is saturated. Heterocycloalkyl includes, but is not limited to, azetidiny, tetrahydropyrrolyl, tetrahydrofuranyl, morpholinyl, piperidinyl, *etc.*

[0086] The term "aryl" refers to a cyclic group consisting only of carbon atoms and having specified number of carbon atoms (for example, C₆ to C₁₀), which is a monocyclic ring or a

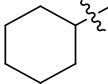
polycyclic ring, and at least one ring is aromatic (according to Huckel's rule). The aryl is connected to other segments in the molecule through an aromatic ring or a non-aromatic ring. Aryl includes, but are not limited to, phenyl, naphthyl, *etc.*

[0087] The term "heteroaryl" refers to a cyclic group with specified number of ring atoms (for example, 5 to 10 membered), specified number of heteroatoms (for example, 1, 2 or 3) and specified type of heteroatoms (one or more of N, O and S), which is a monocyclic ring or a polycyclic ring, and at least one ring is aromatic (according to Huckel's rule). The heteroaryl is connected to other segments in the molecule through an aromatic ring or a non-aromatic ring. Heteroaryl includes, but are not limited to, furyl, pyrrolyl, thienyl, pyrazolyl, imidazolyl, oxazolyl, thiazolyl, pyridyl, pyrimidinyl, indolyl, *etc.* Heteroaryl is also for example



[0088] "-" at the end of a group means that the group is connected to other segments in the molecule through this site. For example, $\text{CH}_3\text{-C(=O)-}$ refers to acetyl.

[0089] "—" in a structural segment means that the structural segment is connected to other

segments in the molecule through this site. For example,  refers to cyclohexyl.

[0090] The term "more" refers to 2, 3, 4 or 5.

[0091] When any variable (such as the group R^{1-1}) appears multiple times in the definition of a compound, their definitions are independent from each other and do not interfere with each other. For example, $\text{C}_6\text{-C}_{10}$ aryl substituted with 3 R^{1-1} means that $\text{C}_6\text{-C}_{10}$ aryl would be substituted with 3 R^{1-1} , and the definitions of the 3 R^{1-1} are independent from each other and do not interfere with each other.

[0092] The term "pharmaceutically acceptable salt" refers to a salt obtained by reacting a compound with a pharmaceutically acceptable (relatively non-toxic, safe, and suitable for use by patients) acid or base. When a compound contains relatively acidic functional groups, base addition salts can be obtained by contacting the free form of the compound with a sufficient amount of a pharmaceutically acceptable base in a suitable inert solvent. Pharmaceutically acceptable base addition salts include, but are not limited to, sodium salts, potassium salts,

calcium salts, aluminum salts, magnesium salts, bismuth salts, ammonium salts, *etc.* When the compound contains relatively basic functional groups, acid addition salts can be obtained by contacting the free form of the compound with a sufficient amount of a pharmaceutically acceptable acid in a suitable inert solvent. Pharmaceutically acceptable acid addition salts include, but are not limited to, hydrochlorides, sulfates, methanesulfonates, *etc.* For details, see Handbook of Pharmaceutical Salts: Properties, Selection, and Use (P. Heinrich Stahl, 2002).

[0093] The term "solvate" refers to a substance formed after crystallization of a compound with a solvent (including but not limited to: water, methanol, ethanol, *etc.*). Solvates are divided into stoichiometric solvates and non-stoichiometric solvates.

[0094] The term "solvate of a pharmaceutically acceptable salt" refers to a substance formed by conjugating a compound with a pharmaceutically acceptable (relatively non-toxic, safe and suitable for use by patients) acid or base and a solvent (including but not limited to: water, methanol, ethanol, *etc.*). In the term, the pharmaceutically acceptable salt has the same meaning as the term "pharmaceutically acceptable salt" described above, and the solvent is stoichiometric or non-stoichiometric. The solvate of a pharmaceutically acceptable salt includes, but not limited to, hydrochloride monohydrate.

[0095] The term "pharmaceutical adjuvant" refers to excipients and additives used in the production of drugs and formulation of prescriptions, and is all substances contained in a pharmaceutical preparation except for active ingredients. For details, see Pharmacopoeia of the People's Republic of China (2020 Edition) or Handbook of Pharmaceutical Excipients (Raymond C Rowe, 2009).

[0096] The term "treat/treating/treatment" refers to any of the following: (1) alleviating one or more biological manifestations of a disease; (2) interfering with one or more points in the biological cascade leading to a disease; and (3) slowing down the progression of one or more biological manifestations of a disease.

[0097] The term "prevent/preventing/prevention" refers to reducing the risk of developing a disease.

[0098] The term "patient" refers to any animal, preferably a mammal, most preferably a human, who has been or is about to be treated. Mammals include but not limited to cattle, horse, sheep, pig, cat, dog, mouse, rat, rabbit, guinea pig, monkey, human, *etc.*

[0099] On the basis of not departing from common knowledge in the art, the above-mentioned various preferred conditions can be combined in any manner, such that various preferred examples of the present disclosure are obtained.

[0100] Reagents and raw materials used in the present disclosure are all commercially available.

[0101] The positive effects of the present disclosure lie in: The compounds of the present invention have good affinity, agonistic activity or selectivity for dopamine D2 receptors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0102] Fig. 1 shows an X-single crystal diffraction pattern of the crystal of the compound as shown in pNs-(+)-I-10.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0103] The present disclosure is further described below by way of examples; however, the present disclosure is not limited to the scope of the described examples. For the experimental methods in which no specific conditions are specified in the following examples, selections are made according to conventional methods and conditions or according to the product instructions.

Materials and methods

1. Cell culture

[0104] Human renal epithelial cell HEK-293T were cultured in DMEM medium containing 10% fetal bovine serum (FBS), and the culture dish was cultured at 37 °C and 5% CO₂. After the culture dish was covered with adherent cells, the culture medium was removed with a pipette. By adding 1 mL of phosphate buffered saline (pH 7.4), the cells were washed slowly to remove excess serum, and then 800 µL of 0.25% trypsin was added. The cells were placed in an incubator and digested for 2 min, and then taken out and observed under the microscope. The cells became round and swam freely at the bottom of the dish. 2 mL of culture medium containing 10% serum was added to stop the digestion, and the cells were gently pipetted with a 1 mL pipette to disperse them into single cells. Finally, further subculture or further experiment was performed according to the experimental needs.

2. Cell transfection

[0105] The day before transfection, HEK-293T cells grown in a 10 cm diameter dish were split at 1:4 ratio into a 6 cm culture dish for subculture. After 20 hours, when the cell density reached 50%-70%, the cells were ready for transfection. 500 μ L of 150 mM sodium chloride was taken and placed in a clean EP tube, an appropriate amount of plasmids was added, and at the same time, the transfection reagent PEI was added in the amount of 4 times that of the plasmids, mixed well and incubated at room temperature for 20 minutes. 500 μ L of transfection solution was added dropwise above the dish to the dish and shaken gently to mix same evenly.

3. Preparation of a cell membrane component containing specific dopamine D₂ receptors

[0106] A 10 cm diameter dish was used for transfection with 10 ng of the dopamine D₂ receptors and 40 μ L of PEI. After 48 hours, the 10 cm dish was taken out from the cell culture room and the cultured cells had expressed the dopamine D₂ receptors. A vacuum pump was used to suck off the culture medium, 3 mL of lysis buffer (50 mM Tris hydrochloric acid buffer, pH 7.4) was added to each well, and the cells were placed in a 4 °C freezer for 10 minutes. After the cells were detached, the cells were transferred to a 15 mL centrifuge tube and centrifuged at 1500 rpm for 5 minutes at 4 °C, and the supernatant was discarded. The cell pellet was transferred to a tissue homogenizer, and 3 mL of lysis buffer was added and fully ground until the cells were broken. Then, cell suspension was equally divided into several EP tubes, centrifuged at 4 °C and 12000 rpm for 5 min, and the supernatant was discarded. The precipitate was the cell membrane component containing the dopamine D₂ receptors and stored at -80 °C.

4. Radioligand-receptor binding experiment

[0107] A ligand-receptor binding experiment was performed on HEK-293T membrane component transiently expressing the dopamine D₂ receptors. First, a standard binding buffer (50 mM HEPES, 50 mM NaCl, 5 mM MgCl₂, 0.5 mM EDTA, pH 7.4) was added to the cell membrane component containing the dopamine D₂ receptors, and the cell membrane was disrupted and resuspended with an electric tissue homogenizer. 30 μ L of membrane protein suspension was added to each well of a 96-well plate. Then, 30 μ L of different drugs were added to the 96-well plate from left to right to ensure that the final drug concentrations were

10^{-5} M, 10^{-6} M, 10^{-7} M, 10^{-8} M, 10^{-9} M and 0 M, with two replicates per treatment. Next, 30 μ L [3 H]-N-Methylspiperone was added to each well of the 96-well plate, and the plate was incubated for 2 hours at room temperature in the dark. The unbound isotopes were removed by Whatman GF/C filter membrane and vacuum pump, and the isotopes bound to the receptors were detected by MicroBeta isotope liquid scintillation counter.

5. G protein $G\alpha_{i1-\gamma 9}$ dissociation experiment based on bioluminescence resonance energy transfer (BRET)

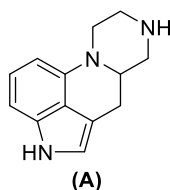
[0108] To examine downstream G protein signaling mediated by dopamine D_2 receptors, 6 cm dish was used for transfection with 1 μ g of dopamine D_2 receptors, 1 μ g of $G\alpha_{i1}$ fused to seaweed luciferase ($G\alpha_{i1}$ -Rluc), 1 μ g of $G\beta_3$, 1 μ g of $G\gamma_9$ fused to green fluorescent protein ($G\gamma_9$ -GFP) and 16 μ L of transfection reagent PEI. The next day, the overgrown cells were digested by using 0.25% trypsin and plated a 96-well plate at the amount of cells contained in a 6 cm culture dish with overgrown cells, and 100 μ L of culture medium was added to each well. On the third day, the drugs were added for test. The 96-well plate was taken out from the cell culture room to remove the culture medium, 40 μ L of buffer (1X HBSS, 20 mM HEPES, pH 7.4) containing the substrate coelenterazine 400a (7.5 μ M) was added to each well, and then 20 μ L of different drugs were added in turn from left to right to ensure that the final concentration of the drugs decreased gradually from bottom to top, and each treatment was repeated twice. The readings at 395 nm and 510 nm were determined using an LB940 Mithras plate reader (Berthold Technologies), and the ratio of the value at 510 nm to the value at 395 nm was taken as the final value.

6. β -arrestin2 recruitment experiment based on bioluminescence resonance energy transfer (BRET)

[0109] To examine the downstream β -arrestin2 signaling pathway mediated by dopamine D_2 receptors, 6 cm dish was used for transfection with 500 μ g of dopamine D_2 receptors fused to seaweed luciferase (D_2 -Rluc), 500 μ g of G protein-coupled receptor kinase 2 (GRK2), 2500 μ g of β -arrestin2 fused to green fluorescent protein (GFP2-ARRB2) and 14 μ L of transfection reagent PEI. The next day, the overgrown cells were digested and plated a 96-well plate at the amount of cells contained in a 6 cm culture dish with overgrown cells, and 100 μ L of culture medium was added to each well. On the third day, the drugs were added for test. The 96-

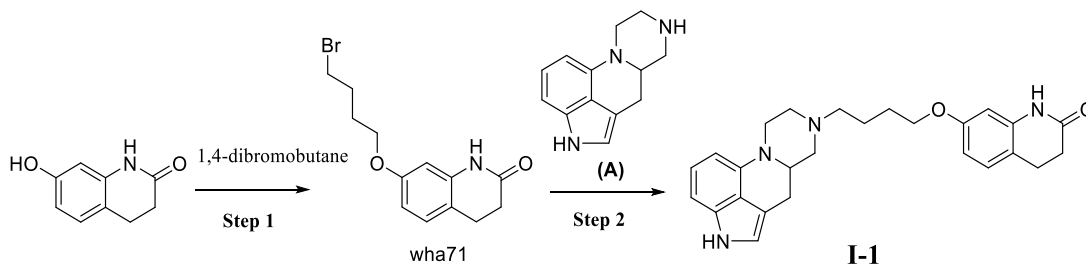
well plate was taken out from the cell culture room to remove the culture medium, 40 μL of buffer (1X HBSS, 20 mM HEPES, pH 7.4) containing the substrate coelenterazine 400a (7.5 μM) was added to each well, and then 20 μL of different drugs were added in turn from left to right to ensure that the final concentration of the drugs decreased gradually from bottom to top, and each treatment was repeated twice. The readings at 395 nm and 510 nm were determined using an LB940 Mithras plate reader (Berthold Technologies), and the ratio of the value at 510 nm to the value at 395 nm was taken as the final value.

Preparation of starting material (A) (6,6a,7,8,9,10-hexahydro-4H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinoline)



[0110] It was prepared according to the method in the literature (Krogsgaard-Larsen *et al.*, J. Med. Chem. 2014, 57, 5823–5828). It is a brown solid. ^1H NMR (800 MHz, CDCl_3) δ 7.82 (s, 1H), 7.08 (t, $J = 7.8$ Hz, 1H), 6.81 (d, $J = 8.1$ Hz, 1H), 6.73 (t, $J = 1.9$ Hz, 1H), 6.34 (d, $J = 7.6$ Hz, 1H), 3.81 (d, $J = 11.5$ Hz, 1H), 3.21 (dd, $J = 12.4, 3.2$ Hz, 2H), 3.10 - 3.03 (m, 2H), 2.97 (dd, $J = 15.2, 3.7$ Hz, 1H), 2.83 - 2.79 (m, 3H).

Example 1: 7-(4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)butoxy)-3,4-dihydroquinolin-2(1H)-one (Compound I-1)

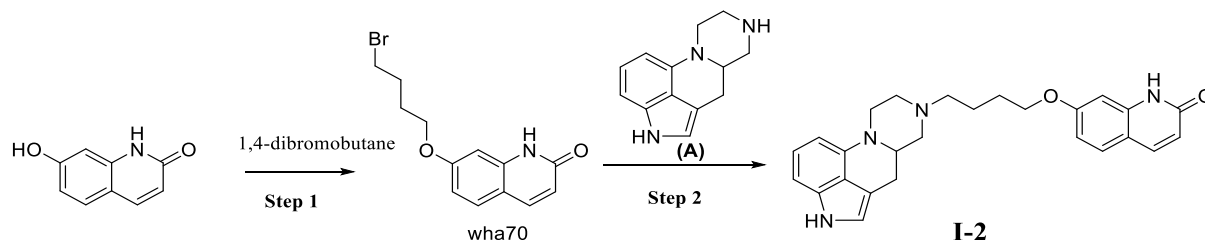


[0111] Step 1: 7-hydroxy-3,4-dihydroquinolin-2(1H)-one (1.5 g, 9.19 mmol), 1,4-dibromobutane (5.92 g, 27.6 mmol), K_2CO_3 (1.9 g, 13.7 mmol) and solvent DMF (20 mL) were successively added into a round bottom flask, and the reaction system was stirred overnight at room temperature. The solvent was evaporated under reduced pressure and the residue was purified by flash column chromatography (eluent: ethyl acetate/petroleum ether mixture containing 20-50% ethyl acetate) to give intermediate **wha71** (1.75 g, 64%) as a white solid.

^1H NMR (800 MHz, CDCl_3) δ 7.74 (s, 1H), 7.05 (d, J = 8.3 Hz, 1H), 6.52 (dd, J = 8.3, 1.9 Hz, 1H), 6.30 (d, J = 2.3 Hz, 1H), 3.97 (t, J = 6.1 Hz, 2H), 3.48 (t, J = 6.6 Hz, 2H), 2.90 (t, J = 7.5 Hz, 2H), 2.65 - 2.60 (m, 2H), 2.09 - 2.03 (m, 2H), 1.95-1.93 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{13}\text{H}_{17}\text{BrNO}_2^+ [\text{M}+\text{H}]^+$, calculated: 298.0437; found: 298.0432 and 300.0412.

[0112] Step 2: The intermediate A (50 mg, 0.23 mmol), the intermediate **wha71** (82 mg, 0.28 mmol) and K_2CO_3 (0.2 g, 1.38 mmol) were successively added into a round bottom flask, then solvents THF (3 mL) and DMSO (1 mL) were added. The reaction system was heated and stirred at 60 °C for 16 hours. After the reaction was completed, the solvent was removed and purified by flash silica gel column chromatography (eluent: 0-10% methanol/dichloromethane) to obtain compound **I-1** (90 mg, 91%) as an off-white solid. ^1H NMR (800 MHz, $\text{DMSO}-d_6$) δ 10.51 (s, 1H), 9.97 (d, J = 7.1 Hz, 1H), 7.03 (d, J = 8.2 Hz, 1H), 6.88 (t, J = 7.7 Hz, 1H), 6.78 (s, 1H), 6.70 (d, J = 8.1 Hz, 1H), 6.48 (dd, J = 8.2, 2.5 Hz, 1H), 6.43 (d, J = 2.5 Hz, 1H), 6.20 (d, J = 7.5 Hz, 1H), 3.96 - 3.86 (m, 2H), 3.74-3.69 (m, 1H), 3.09 - 3.00 (m, 2H), 2.96 - 2.87 (m, 2H), 2.76 (t, J = 6.8 Hz, 2H), 2.71 - 2.61 (m, 2H), 2.40 (t, J = 7.7 Hz, 4H), 2.20 - 2.14 (m, 1H), 2.03 - 1.88 (m, 1H), 1.76 - 1.68 (m, 2H), 1.65 - 1.60 (m, 2H); ^{13}C NMR (201 MHz, $\text{DMSO}-d_6$) δ 170.40, 157.75, 140.00, 139.26, 134.17, 128.46, 123.05, 117.70, 116.56, 115.74, 107.57, 106.08, 103.24, 101.80, 98.96, 66.72, 55.71, 55.00, 53.69, 50.62, 43.43, 30.79, 26.26, 25.87, 24.03, 20.32. HR-MS (ES, m/z): $\text{C}_{26}\text{H}_{31}\text{N}_4\text{O}_2^+ [\text{M}+\text{H}]^+$, calculated: 431.2442; found: 431.2440.

Example 2: 7-(4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)butoxy)quinolin-2(1H)-one (Compound I-2)



[0113] Step 1: Following the method of step 1 of example 1, the alkylation reaction was carried out using "7-hydroxy-quinolin-2(1H)-one" and 1,4-dibromobutane as raw materials to prepare intermediate **wha70** (1.06 g, 38%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.79 (d, J = 9.4 Hz, 1H), 7.48 (d, J = 8.4 Hz, 1H), 6.87 - 6.83 (m, 2H), 6.60 (d, J = 9.3 Hz, 1H),

4.11 (t, J = 6.0 Hz, 2H), 3.51 (t, J = 6.6 Hz, 2H), 2.12 - 2.07 (m, 2H), 2.04 - 1.97 (m, 2H). HR-MS (ESI, m/z): $C_{13}H_{15}BrNO_2^+ [M+H]^+$, calculated: 296.0281; found: 296.0220.

[0114] Step 2: Following the method of step 2 of example 1, the intermediate **wha70** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-2** (60 mg, 61%) which was purified by preparative HPLC: t_R = 18.5 min (20-80% MeOH/H₂O) to obtain a white solid. ¹H NMR (800 MHz, CD₃OD) δ 7.91 (d, J = 9.4 Hz, 1H), 7.61 (d, J = 8.7 Hz, 1H), 7.03 (t, J = 7.8 Hz, 1H), 6.92 (dd, J = 8.7, 2.4 Hz, 1H), 6.89 - 6.84 (m, 3H), 6.47 (d, J = 9.4 Hz, 1H), 6.40 (d, J = 7.5 Hz, 1H), 4.19 (t, J = 5.8 Hz, 3H), 3.79 (t, J = 10.0 Hz, 2H), 3.41 - 3.33 (m, 4H), 3.19 (dd, J = 15.2, 3.9 Hz, 1H), 3.14 - 3.06 (m, 2H), 2.90 (dd, J = 15.0, 9.5 Hz, 1H), 2.09 - 2.05 (m, 2H), 2.00 - 1.96 (m, 2H); ¹³C NMR (201 MHz, DMSO-d₆) δ 162.35, 160.31, 140.68, 140.08, 139.97, 134.18, 129.32, 123.06, 118.61, 117.70, 116.57, 113.46, 110.81, 106.06, 103.25, 98.97, 98.73, 67.01, 55.65, 54.95, 53.67, 50.59, 43.41, 26.25, 25.76, 20.25; HR-MS (ESI, m/z): $C_{26}H_{29}N_4O_2^+ [M+H]^+$, calculated: 429.2285; found: 429.2281.

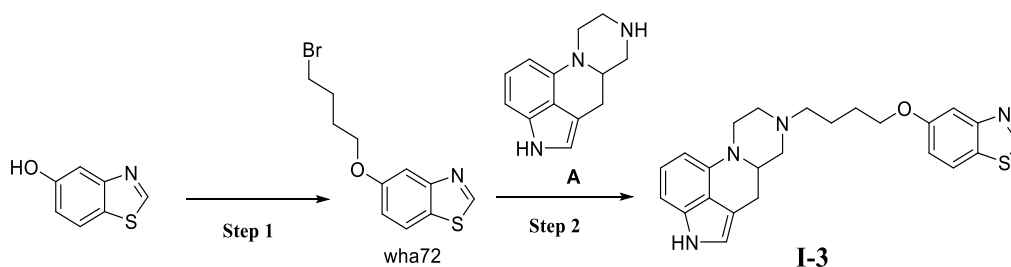
[0115] Compound **I-2** was chirally resolved.

[0116] Chiral analysis conditions: chiral column Daicel CHIRALCEL OD-H (ODH0CD-TC013) (Daicel), column volume: 0.46 cm (diameter) x 15 cm (column length) (5 μ m filler); Mobile phase: MeOH/Diethylamine = 100/0.1 (V/V/); flow rate: 1.0 mL/min; wavelength: UV 214 nm; temperature: 35 °C; HPLC instrument: Shimadzu LC-20AD. Peak 1 (prepeak) t_R = 5.805 min; peak 2 (postpeak): t_R = 7.548 min.

[0117] Chiral preparation conditions: chiral column CHIRALCEL OD (Dacel), column volume: 5.0 cm (diameter) x 25 cm (column length) (10 μ m filler); Mobile phase: MeOH/Diethylamine = 100/0.1 (V/V/); flow rate: 30 mL/min; wavelength: UV 214 nm; temperature: 38 °C.

[0118] Resolution preparation: racemate compound **I-2** (0.103 g). Peak 1 (prepeak) t_R = 5.830 min, 0.048 g obtained, > 98% ee; optical rotation $[\alpha]_D^{25} = +50.33^\circ$ (c = 0.1, MeOH), > 98% ee (the compound is a trifluoroacetate). peak 2 (postpeak) t_R = 7.60 min, 0.042 g obtained, > 98% ee; optical rotation $[\alpha]_D^{25} = -45.00^\circ$ (c = 0.1, MeOH), > 98% ee (the compound is a trifluoroacetate).

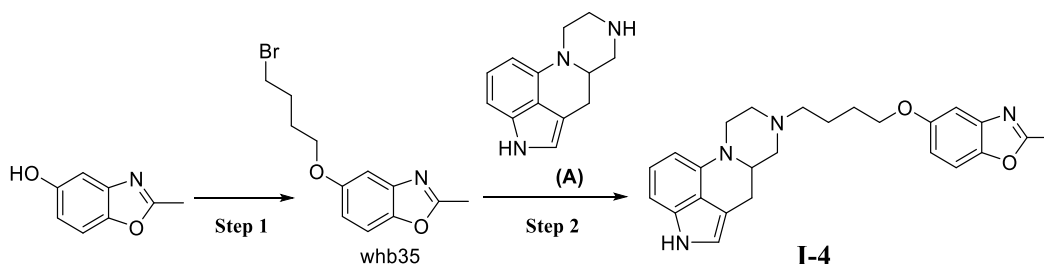
Example 3: 5-(4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrazolo[4,3,2-de]quinolin-8-yl)butoxy)benzo[d]thiazole (Compound I-3)



[0119] Step 1: Following the method in step 1 of example 1, "5-hydroxy-benzo[d]thiazole" and 1,4-dibromobutane were used as raw materials to prepare intermediate **wha72** (1.23 g, 65%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 8.98 (s, 1H), 7.80 (d, J = 8.7 Hz, 1H), 7.60 (d, J = 2.4 Hz, 1H), 7.09 (dd, J = 8.7, 2.4 Hz, 1H), 4.10 (t, J = 6.1 Hz, 2H), 3.51 (t, J = 6.6 Hz, 2H), 2.13 - 2.09 (m, 2H), 2.04 - 1.97 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{11}\text{H}_{13}\text{BrNOS}^+ [\text{M}+\text{H}]^+$, calculated: 285.9896; found: 285.9894 and 287.9875.

[0120] Step 2: Following the method of step 2 of example 1, the intermediate **wha72** and the starting material (A) were subjected to alkylation reaction to obtain compound **I-3** (30 mg, 51%) as a yellow solid. ^1H NMR (800 MHz, CD_3OD) δ 9.18 (s, 1H), 7.90 (d, J = 8.8 Hz, 1H), 7.59 (d, J = 2.4 Hz, 1H), 7.16 (dd, J = 8.8, 2.4 Hz, 1H), 6.96 (t, J = 7.8 Hz, 1H), 6.78 (d, J = 8.1 Hz, 1H), 6.73 (d, J = 1.6 Hz, 1H), 6.29 (d, J = 7.5 Hz, 1H), 4.15 - 4.08 (m, 2H), 3.80 (d, J = 12.0 Hz, 1H), 3.15 - 3.10 (m, 2H), 3.09 - 3.05 (m, 1H), 2.95 (dd, J = 15.2, 3.6 Hz, 1H), 2.86 - 2.83 (m, 1H), 2.79 - 2.76 (m, 1H), 2.53 (t, J = 4.8 Hz, 2H), 2.37 - 2.34 (m, 1H), 2.12 (t, J = 10.9 Hz, 1H), 1.92 - 1.85 (m, 2H), 1.83 - 1.77 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 158.55, 155.05, 154.79, 142.34, 134.44, 125.59, 124.18, 122.15, 118.18, 116.59, 115.04, 109.55, 106.60, 102.06, 99.12, 68.28, 60.25, 58.35, 56.28, 53.13, 46.38, 27.63, 27.36, 23.60. HR-MS (ESI, m/z): $\text{C}_{24}\text{H}_{27}\text{N}_4\text{OS}^+ [\text{M}+\text{H}]^+$, calculated: 419.1900; found: 419.1901.

Example 4: 5-(4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)butoxy)-2-methylbenzo[d]oxazole (Compound I-4)

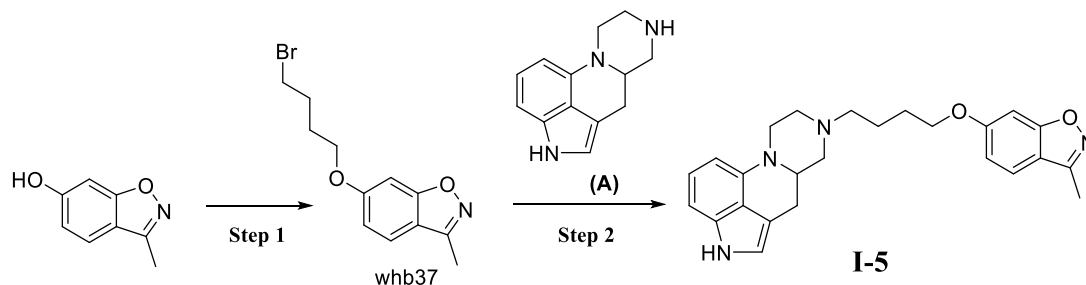


[0121] Step 1: Following the method of step 1 of example 1, "2-methyl-5-hydroxy-

benzo[d]thiazole" and 1,4-dibromobutane were used as raw materials to prepare intermediate **whb35** (0.15 g, 31%) as a pale yellow solid. ^1H NMR (800 MHz, CDCl_3) δ 7.35 (d, J = 8.8 Hz, 1H), 7.14 (d, J = 2.5 Hz, 1H), 6.89 (dd, J = 8.8, 2.5 Hz, 1H), 4.03 (t, J = 6.1 Hz, 2H), 3.50 (t, J = 6.7 Hz, 2H), 2.64 (s, 3H), 2.12 - 2.06 (m, 2H), 2.00 - 1.94 (m, 2H). ^{13}C NMR (201 MHz, deuterated chloroform) δ 164.83, 156.41, 145.75, 142.33, 113.34, 110.45, 103.63, 68.18, 67.83, 33.58, 29.64, 28.06, 14.75. HR-MS (ESI, m/z): $\text{C}_{12}\text{H}_{15}\text{BrNO}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 284.0281; found: 284.0280 and 286.0281.

[0122] Step 2: Following the method of step 2 of example 1, the intermediate **whb35** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-4** (41 mg, 43%) as an off-white solid. ^1H NMR (600 MHz, CDCl_3) δ 7.90 (s, 1H), 7.33 (d, J = 8.8 Hz, 1H), 7.13 (d, J = 1.3 Hz, 1H), 7.07 (t, J = 7.7 Hz, 1H), 6.88 (dd, J = 8.8, 1.8 Hz, 1H), 6.79 (d, J = 8.1, 1.2 Hz, 1H), 6.71 (t, J = 1.8 Hz, 1H), 6.33 (d, J = 7.6 Hz, 1H), 4.03 (t, J = 6.2 Hz, 2H), 3.80 (d, J = 12.1 Hz, 1H), 3.23 (t, J = 11.0 Hz, 1H), 3.11 (d, J = 3.8 Hz, 2H), 3.01 - 2.93 (m, 2H), 2.81 (dd, J = 13.8, 11.0 Hz, 1H), 2.60 (d, J = 1.2 Hz, 3H), 2.52 (t, J = 7.6 Hz, 2H), 2.41 - 2.34 (m, 1H), 2.14 (t, J = 10.9 Hz, 1H), 1.88 - 1.85 (m, 2H), 1.82 - 1.74 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 164.76, 156.53, 145.69, 142.42, 134.44, 124.15, 118.17, 115.10, 113.33, 110.39, 109.40, 103.68, 102.12, 99.14, 68.64, 60.00, 58.31, 56.13, 52.96, 46.24, 29.82, 27.69, 27.43, 23.45, 14.73. HR-MS (ESI, m/z): $\text{C}_{25}\text{H}_{29}\text{N}_4\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 417.2285; found: 417.2289.

Example 5: 6-(4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)butoxy)-3-methylbenzo[d]isoxazole (Compound I-5)

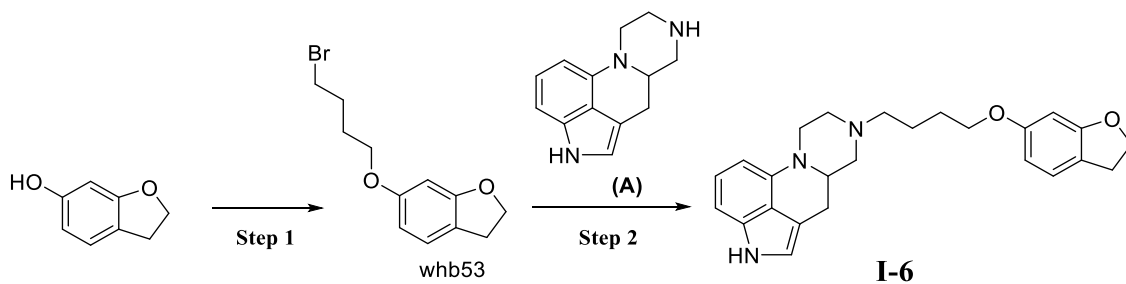


[0123] Step 1: Following the method of step 1 of example 1, "3-methyl-6-hydroxybenzo[d]isoxazole" and 1,4-dibromobutane were used as raw materials to prepare intermediate **whb37** (0.16 g, 42%) as a pale yellow solid. ^1H NMR (800 MHz, CDCl_3) δ 7.52 (d, J = 8.6 Hz, 1H), 7.00 (d, J = 2.3 Hz, 1H), 6.89 (dd, J = 8.7, 2.4 Hz, 1H), 4.03 (t, J = 6.1 Hz, 2H), 3.50

(t, J = 6.6 Hz, 2H), 2.62 (s, 3H), 2.11 - 2.07 (m, 2H), 2.01 - 1.95 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 162.98, 157.05, 151.85, 135.32, 119.44, 112.62, 96.17, 67.79, 33.52, 29.57, 28.00, 14.58. HR-MS (ESI, m/z): $\text{C}_{12}\text{H}_{15}\text{BrNO}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 284.0281; found: 284.0261 and 286.0241.

[0124] Step 2: Following the method of step 2 of example 1, the intermediate **whb37** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-5** (58 mg, 60%) as an off-white solid. ^1H NMR (600 MHz, CDCl_3) δ 8.03 (s, 1H), 7.49 (d, J = 8.7 Hz, 1H), 7.06 (t, J = 7.8 Hz, 1H), 7.00 (d, J = 2.5 Hz, 1H), 6.89 (dd, J = 8.7, 2.4 Hz, 1H), 6.77 (d, J = 8.1 Hz, 1H), 6.69 (s, 1H), 6.32 (d, J = 7.6 Hz, 1H), 4.02 (t, J = 6.3 Hz, 2H), 3.79 (d, J = 12.0 Hz, 1H), 3.21 (t, J = 10.8 Hz, 1H), 3.09 - 3.06 (m, 2H), 2.98 - 2.90 (m, 2H), 2.81 (dd, J = 15.4, 10.9 Hz, 1H), 2.58 (s, 3H), 2.52 - 2.46 (m, 2H), 2.34 (t, J = 11.7 Hz, 1H), 2.11 (t, J = 10.9 Hz, 1H), 1.91 - 1.82 (m, 2H), 1.79 - 1.73 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 162.87, 157.17, 151.85, 142.22, 135.21, 134.41, 124.09, 119.37, 118.15, 115.09, 112.65, 109.35, 102.12, 99.07, 96.13, 68.58, 60.10, 58.25, 56.19, 53.01, 46.28, 27.69, 27.34, 23.43, 14.53. HR-MS (ESI, m/z): $\text{C}_{25}\text{H}_{29}\text{N}_4\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 417.2285; found: 417.2290.

Embodiment 6: 8-(4-((2,3-dihydrobenzofuran-6-yl)oxy)butyl)-6,6a,7,8,9,10-hexahydro-4H-pyrazino[1, 2-a]pyrrolo[4,3,2-de]quinoline (Compound I-6)

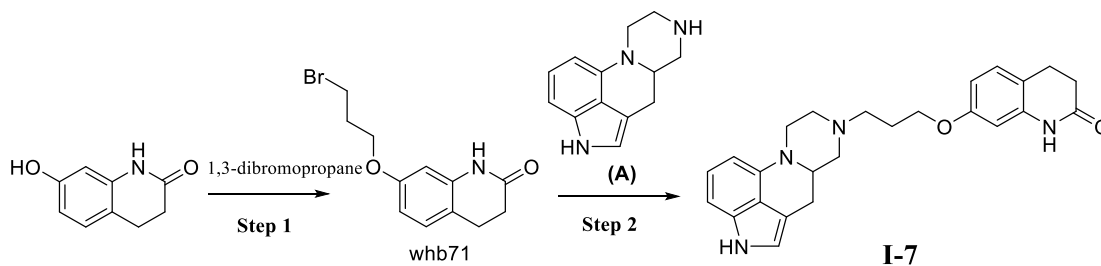


[0125] Step 1: Following the method in step 1 of example 1, "6-hydroxy-2,3-dihydrobenzofuran" and 1,4-dibromobutane were used as raw materials to prepare intermediate **whb53** (0.29 g, 81%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.05 (d, J = 7.9 Hz, 1H), 6.39 - 6.35 (m, 2H), 4.57 (t, J = 8.6 Hz, 2H), 3.95 (t, J = 6.1 Hz, 2H), 3.48 (t, J = 6.7 Hz, 2H), 3.13 (t, J = 8.6 Hz, 2H), 2.08 - 2.02 (m, 2H), 1.95 - 1.89 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 161.44, 159.64, 124.93, 119.03, 106.53, 96.87, 72.16, 67.24, 33.65, 29.64, 29.22, 28.14.

[0126] Step 2: Following the method of step 2 of example 1, the intermediate wha53 and the

starting material (**A**) were subjected to alkylation reaction to obtain compound **I-6** (30 mg, 32%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.82 (s, 1H), 7.08 (t, $J = 7.8$ Hz, 1H), 7.06 - 7.01 (m, 1H), 6.80 (d, $J = 8.1$ Hz, 1H), 6.73 (s, 1H), 6.40 - 6.37 (m, 2H), 6.33 (d, $J = 7.6$ Hz, 1H), 4.56 (t, $J = 8.6$ Hz, 2H), 3.96 (t, $J = 6.2$ Hz, 2H), 3.82 - 3.78 (m, 1H), 3.23 - 3.16 (m, 1H), 3.15 - 3.10 (m, 2H), 3.11 - 3.06 (m, 2H), 3.00 - 2.95 (m, 2H), 2.82 (dd, $J = 15.3, 10.8$ Hz, 1H), 2.51 - 2.46 (m, 2H), 2.39 - 2.31 (m, 1H), 2.14 - 2.07 (m, 1H), 1.85 - 1.80 (m, 2H), 1.79 - 1.71 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 161.41, 159.77, 134.44, 124.90, 124.18, 118.85, 118.17, 115.09, 109.46, 106.60, 102.11, 99.16, 96.90, 72.13, 68.06, 59.98, 58.30, 56.12, 52.95, 46.23, 29.21, 27.69, 27.40, 23.40. HR-MS (ESI, m/z): $\text{C}_{25}\text{H}_{30}\text{N}_3\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 404.2333; found: 404.2330.

Example 7: 7-(3-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)propoxy)-3,4-dihydroquinolin-2(1H)-one (Compound I-7)

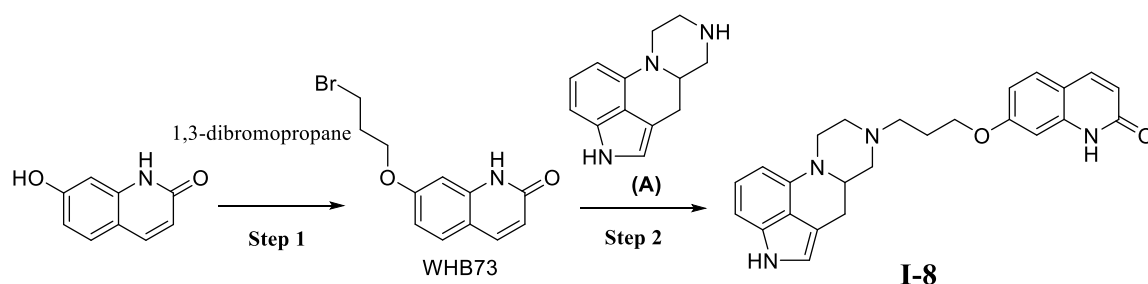


[0127] Step 1: Following the method in step 1 of example 1, "7-hydroxy-3,4-dihydroquinoline-2(1H)-one" and 1,3-dibromopropane were used as raw materials to prepare intermediate **whb71** (2.85 g, 81%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 8.94 (s, 1H), 7.05 (d, $J = 8.1$ Hz, 1H), 6.54 (dd, $J = 7.9, 2.4$ Hz, 1H), 6.41 (d, $J = 2.4$ Hz, 1H), 4.07 (t, $J = 5.8$ Hz, 2H), 3.59 (t, $J = 6.4$ Hz, 2H), 2.90 (t, $J = 8.7$ Hz, 2H), 2.63 (t, $J = 8.7$ Hz, 2H), 2.31 - 2.28 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{12}\text{H}_{15}\text{BrNO}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 284.0281, found: 284.0273 and 286.0255.

[0128] Step 2: Following the method of step 2 of example 1, the intermediate **whb71** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-7** (60 mg, 63%) as an off-white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.95 (s, 1H), 7.89 (s, 1H), 7.08 (t, $J = 7.8$ Hz, 1H), 7.04 (d, $J = 8.3$ Hz, 1H), 6.80 (d, $J = 8.1$ Hz, 1H), 6.72 (s, 1H), 6.54 (dd, $J = 8.3, 2.4$ Hz, 1H), 6.34 (d, $J = 7.6$ Hz, 1H), 6.32 (d, $J = 2.4$ Hz, 1H), 4.02 (t, $J = 6.3$ Hz, 2H), 3.81 (d, $J = 11.8$ Hz, 1H), 3.22 (t, $J = 9.7$ Hz, 1H), 3.12 - 3.07 (m, 2H), 3.02 - 2.93 (m, 2H), 2.89 (t, $J =$

7.5 Hz, 2H), 2.83 (dd, $J = 15.2, 11.0$ Hz, 1H), 2.39 (t, $J = 11.6$ Hz, 1H), 2.16 (t, $J = 10.56$ Hz, 1H), 2.05 - 2.01 (m, 2H), 1.81-1.67 (m, 4H). ^{13}C NMR (201 MHz, DMSO- d_6) δ 170.31, 157.88, 141.95, 139.21, 134.02, 128.42, 122.97, 117.86, 115.56, 107.66, 102.07, 101.69, 98.01, 65.86, 59.55, 56.06, 54.40, 52.51, 45.91, 30.76, 27.09, 26.17, 24.00. HR-MS (ESI, m/z): $\text{C}_{25}\text{H}_{29}\text{N}_4\text{O}_2^+[\text{M}+\text{H}]^+$, calculated: 417.2285; found: 417.2284.

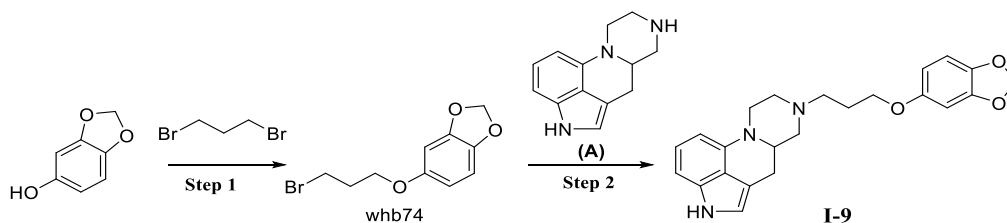
Example 8: 7-(3-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)propoxy)quinolin-2(1H)-one (Compound I-8)



[0129] Step 1: Following the method in step 1 of example 1, "7-hydroxy-quinolin-2(1H)-one" and 1,3-dibromopropane were used as raw materials to prepare intermediate **whb73** (1.36 g, 39%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 12.45 (s, 1H), 7.74 (d, $J = 9.3$ Hz, 1H), 7.46 (d, $J = 8.6$ Hz, 1H), 6.88 (d, $J = 2.3$ Hz, 1H), 6.82 (dd, $J = 8.0$ and 2.4 Hz, 1H), 6.57 (d, $J = 9.4$ Hz, 1H), 4.21 (t, $J = 5.7$ Hz, 2H), 3.62 (t, $J = 6.5$ Hz, 2H), 2.37 - 2.34 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{12}\text{H}_{13}\text{BrNO}_2^+[\text{M}+\text{H}]^+$, calculated: 282.0124; found: 282.0128 and 284.0109.

[0130] Step 2: Following the method of step 2 of example 1, the intermediate **whb73** and the starting material (A) were subjected to alkylation reaction to obtain compound **I-8** (0.10 g, 51%) as a white solid. ^1H NMR (600 MHz, CD_3OD) δ 7.91 (d, $J = 9.4$ Hz, 1H), 7.62 (d, $J = 8.7$ Hz, 1H), 7.07 - 7.01 (m, 1H), 6.94 (dd, $J = 8.7, 2.4$ Hz, 1H), 6.91 - 6.85 (m, 3H), 6.48 (d, $J = 9.4$ Hz, 1H), 6.42 (d, $J = 7.6$ Hz, 1H), 4.26 (t, $J = 5.7$ Hz, 2H), 3.88 - 3.82 (m, 2H), 3.52 - 3.46 (m, 2H), 3.42 - 3.38 (dd, $J = 12.6, 3.5$ Hz, 1H), 3.24 - 3.08 (m, 3H), 2.92 (dd, $J = 15.3, 9.6$ Hz, 1H), 2.41 - 2.36 (m, 2H), 2.07 - 2.03 (m, 1H), 1.62 (t, $J = 7.4$ Hz, 1H). ^{13}C NMR (201 MHz, DMSO- d_6) δ 162.32, 160.03, 140.63, 140.05, 134.16, 129.37, 123.05, 118.78, 117.70, 116.56, 113.60, 110.58, 106.08, 103.23, 98.90, 65.09, 53.78, 53.50, 50.77, 48.62, 43.51, 26.29, 23.44. HR-MS (ESI, m/z): $\text{C}_{25}\text{H}_{27}\text{N}_4\text{O}_2^+[\text{M}+\text{H}]^+$, calculated: 415.2129; found: 415.2129.

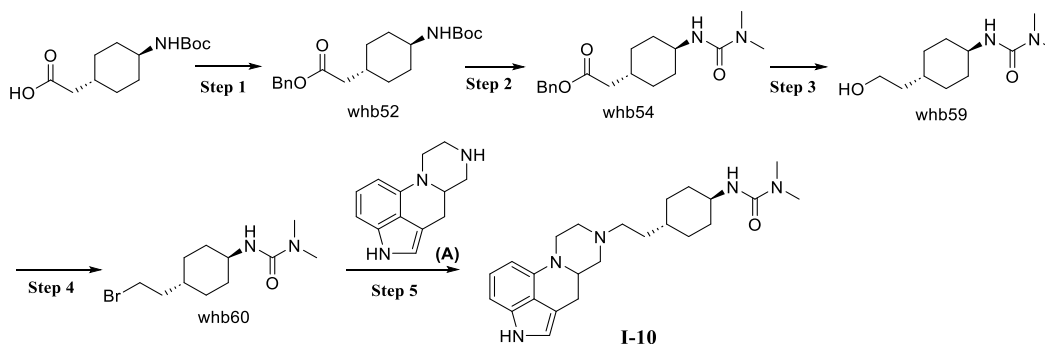
Example 9: 8-(3-(benzo[d][1,3]dioxol-5-yloxy)propyl)-6,6a,7,8,9,10-hexahydro-4H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinoline (Compound I-9)



[0131] Step 1: Following the method in step 1 of example 1, sesamol (CAS#533-31-3) and 1,3-dibromopropane were used as raw materials to prepare intermediate **whb74** (1.67 g, 45%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 6.70 (d, J = 8.5 Hz, 1H), 6.49 (d, J = 2.5 Hz, 1H), 6.33 (dd, J = 8.5, 2.5 Hz, 1H), 5.91 (s, 2H), 4.02 (t, J = 5.8 Hz, 2H), 3.59 (t, J = 6.4 Hz, 2H), 2.29 - 2.26 (m, 2H).

[0132] Step 2: Following the method of step 2 of example 1, the intermediate **whb74** and the starting material (**A**) were subjected to alkylation reaction to prepare compound **I-9** (20 mg, 22%) as an off-white solid. ^1H NMR (600 MHz, CDCl_3) δ 7.87 (s, 1H), 7.07 (t, J = 7.8 Hz, 1H), 6.79 (d, J = 8.1 Hz, 1H), 6.72 - 6.67 (m, 2H), 6.50 (d, J = 2.4 Hz, 1H), 6.37 - 6.30 (m, 2H), 5.90 (s, 2H), 3.97 (t, J = 6.3 Hz, 2H), 3.80 (d, J = 11.9 Hz, 1H), 3.21 (t, J = 10.7 Hz, 1H), 3.08 - 3.07 (m, 2H), 3.02 - 2.89 (m, 2H), 2.82 (dd, J = 15.3, 11.0 Hz, 1H), 2.59 (t, J = 7.4 Hz, 2H), 2.37 (t, J = 11.7 Hz, 1H), 2.14 (t, J = 10.8 Hz, 1H), 2.05 - 1.96 (m, 2H). ^{13}C NMR (201 MHz, $\text{DMSO}-d_6$) δ 154.09, 147.91, 141.95, 141.01, 134.01, 122.96, 117.85, 115.54, 108.02, 107.65, 105.72, 102.05, 100.92, 97.99, 97.82, 66.64, 59.54, 56.05, 54.40, 52.50, 45.91, 27.09, 26.22. HR-MS (ESI, m/z): $\text{C}_{23}\text{H}_{26}\text{N}_3\text{O}_3^+ [\text{M}+\text{H}]^+$, calculated: 392.1969; found: 392.1970.

Example 10: 3-(4-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)trans-cyclohexyl)-1,1-dimethylurea (Compound I-10)



[0133] Step 1: 2-(4-((tert-butoxycarbonyl)amino)trans-cyclohexyl)acetic acid (2.0 g, 7.77 mmol) and solvent DMF (15 mL) were added to a round-bottomed flask, and then Cs_2CO_3 (7.6 g, 23.3 mmol) and benzyl bromide BnBr (5.32 g, 11.7 mmol) were successively added, and

stirred overnight at room temperature. After the reaction was completed, the reaction was filtered, the filtrate was concentrated and the residue was purified by column chromatography (eluent: dichloromethane containing 0-20% methanol) to obtain the compound **whb52** of interest (2.36 g, yield 87%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.39 - 7.30 (m, 5H), 5.11 (s, 2H), 4.36 (s, 1H), 3.36 (s, 1H), 2.24 (d, $J = 6.7$ Hz, 2H), 2.00 - 1.96 (m, 2H), 1.79 - 1.72 (m, 3H), 1.43 (s, 9H), 1.14 - 1.04 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{20}\text{H}_{29}\text{NO}_4\text{Na}^+$ $[\text{M}+\text{Na}]^+$, calculated: 370.1989; found: 370.1989 ($\text{M}+\text{Na}^+$).

[0134] Step 2: **whb52** (0.16 g, 0.46 mmol) from the previous step was dissolved in dichloromethane (3 mL), and trifluoroacetic acid (1.5 mL) was added and stirred at room temperature for 3 hours. The resulting mixture was concentrated under reduced pressure, the residue was dissolved in THF (5 mL), and then Et_3N (1 mL) and dimethylcarbamoyl chloride (54 mg, 0.5 mmol) were successively added. The reaction system was stirred overnight at room temperature. After the reaction was completed, the solvent was removed and the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 0-20% methanol) to obtain the compound **whb54** of interest (0.78 g, 83%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.38 - 7.30 (m, 5H), 5.11 (s, 2H), 3.60 - 3.55 (m, 1H), 2.88 (s, 6H), 2.26 (d, $J = 6.7$ Hz, 2H), 2.04 - 1.99 (m, 2H), 1.80 - 1.76 (m, 3H), 1.17 - 1.09 (m, 4H). ^{13}C NMR (151 MHz, CDCl_3) δ 172.80, 157.86, 136.07, 128.59, 128.23, 128.19, 66.12, 49.49, 41.47, 36.19, 34.23, 33.69, 31.76. HR-MS (ESI, m/z): $\text{C}_{18}\text{H}_{27}\text{N}_2\text{O}_3^+$ $[\text{M}+\text{H}]^+$, calculated: 319.2016; found: 319.2201.

[0135] Step 3: **whb54** (0.78 g, 2.45 mmol) was dissolved in THF (20 mL), and cooled down to -10°C under the protection of argon (Ar). Then DABAL-H (14.7 mL, 1 M) was added. Then the reaction system was further stirred at 0°C for 5 hours. After the reaction was completed, the reaction was quenched with saturated sodium potassium tartrate solution (5 mL). After removal of the solvent, the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 0-20% methanol) to give **whb59** (0.50 g, yield 95%) as a white solid. ^1H NMR (600 MHz, CDCl_3) δ 4.27 (d, $J = 7.7$ Hz, 1H), 3.65 (t, $J = 6.7$ Hz, 2H), 3.59-3.52 (m, 1H), 2.88 (s, 6H), 2.00 (d, $J = 10.6$ Hz, 2H), 1.81 - 1.75 (m, 2H), 1.49 - 1.46 (m, 2H), 1.40-1.34 (m, 1H), 1.15 - 1.01 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{11}\text{H}_{23}\text{N}_2\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 215.1754; found: 215.1983.

[0136] Step 4: **whb59** (0.65 g, 3.04 mmol) and CBr₄ (1.5 g, 4.56 mmol) were dissolved in dichloromethane (15 mL), cooled and stirred under an ice-water bath. PPh₃ (1.2 g, 4.56 mmol) was added, then moved to room temperature and stirred for 4 hours. The solvent was evaporated under reduced pressure, and the residue was purified by silica gel column chromatography (mobile phase: dichloromethane containing 0-3% methanol) to obtain **whb60** (0.25 g, 38%) as a white solid. ¹H NMR (800 MHz, CDCl₃) δ 4.16 - 4.00 (m, 1H), 3.61 - 3.57 (m, 1H), 3.43 (t, J = 7.0 Hz, 1H), 2.88 (s, 6H), 2.03 (d, J = 10.0, Hz, 2H), 1.80 - 1.74 (m, 4H), 1.47-1.43 (m, 1H), 1.14 - 1.03 (m, 4H). HR-MS (ESI, m/z): C₁₁H₂₂BrN₂O⁺ [M+H]⁺, calculated: 277.0910; found: 277.0924 and 279.0925.

[0137] Step 5: The experimental method was the same as step 2 of example 1, and **whb60** and the starting material (**A**) were subjected to alkylation reaction to prepare compound **I-10** (0.18 g, 95%) as an off-white solid. ¹H NMR (800 MHz, CDCl₃) δ 7.93 (s, 1H), 7.07 (t, J = 7.8 Hz, 1H), 6.79 (d, J = 8.1 Hz, 1H), 6.72 (t, J = 1.7 Hz, 1H), 6.33 (d, J = 7.6 Hz, 1H), 4.12 (d, J = 7.6 Hz, 1H), 3.79 (d, J = 11.7, 2.7 Hz, 1H), 3.61 - 3.56 (m, 1H), 3.21 (s, 1H), 3.07 (d, J = 10.2 Hz, 2H), 2.97 (dd, J = 15.2, 3.7 Hz, 1H), 2.93 (t, J = 11.8 Hz, 1H), 2.88 (s, 6H), 2.84 - 2.78 (m, 1H), 2.43 (t, J = 7.9 Hz, 2H), 2.32 (t, J = 10.9 Hz, 1H), 2.09 (t, J = 10.8 Hz, 1H), 2.04 - 1.99 (m, 2H), 1.81 - 1.75 (m, 2H), 1.49 - 1.46 (m, 2H), 1.29 - 1.24 (m, 1H), 1.14 - 1.04 (m, 3H). ¹³C NMR (201 MHz, CDCl₃) δ 157.97, 142.19, 134.40, 123.92, 118.14, 115.13, 109.19, 102.14, 98.90, 65.92, 60.19, 56.70, 56.18, 53.11, 49.93, 46.26, 40.99, 36.22, 35.70, 34.05, 33.80, 32.14, 27.70, 15.34. HR-MS (ESI, m/z): C₂₄H₃₆N₅O⁺ [M+H]⁺, calculated: 410.2914, found: 410.2914.

Chiral resolution of compound I-10

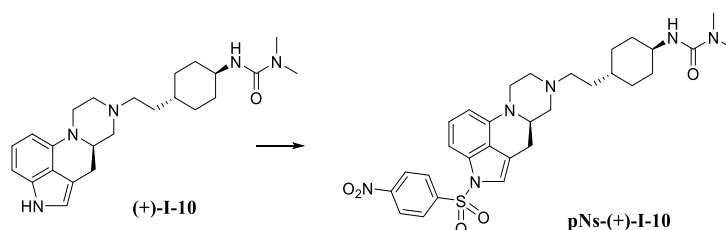
[0138] Chiral analysis conditions: chiral column CHIRALPAK IG (Dacel), column volume: 0.46 cm (diameter) x 15 cm (column length) (5 μm particle size filler); mobile phase: methanol/acetonitrile/diethylamine = 80/20/0.1 (V/V/V); flow rate: 1.0 mL/min; wavelength: UV 210 nm; temperature: 25 °C; HPLC instrument: Shimadzu LC-2010 BJ. Peak 1 (prepeak) t_R = 3.113 min; peak 2 (postpeak): t_R = 4.622 min.

[0139] Chiral preparation conditions: chiral column CHIRALPAK IG (Dacel), column volume: 2.5 cm (diameter) x 25 cm (column length) (10 μm particle size filler); mobile phase: methanol/acetonitrile/diethylamine = 80/20/0.1 (V/V/V); flow rate: 1.0 mL/min; wavelength:

UV 210 nm; temperature: 25 °C; HPLC instrument: Shimadzu LC-2010 BJ. Peak 1 (prepeak) $t_R = 3.113$ min; peak 2 (postpeak): $t_R = 4.622$ min.

[0140] Chiral resolution: racemate compound I-10 (1.20 g), **(-)-I-10** is the prepeak (peak 1), $t_R = 3.057$ min, 0.566 g obtained, > 99% ee, optical rotation $[\alpha]_D^{25} = -56.67^\circ$ ($c = 0.1$, CHCl_3); **(+)-I-10** is the postpeak (peak 2), $t_R = 4.512$ min, 0.599 g obtained, > 99% ee, optical rotation $[\alpha]_D^{25} = +50.33^\circ$ ($c = 0.1$, CHCl_3).

Synthesis of pNs-(+)-I-10 and determination of its chiral configuration:



[0141] Step: (+)-I-10 (23 mg, 0.056 mmol) was dissolved in DMF (3 mL), then potassium tert-butoxide (13 mg, 0.116 mmol) and p-nitrobenzenesulfonyl chloride (14 mg, 0.063 mmol) were successively added, and the reaction liquid was stirred at room temperature for one hour. After the reaction was completed, water was added, and then extracted three times with dichloromethane solvent, and the organic phases were combined and concentrated. The crude product obtained by concentration was purified by flash silica gel column chromatography (eluent: 0-10% methanol/dichloromethane) to obtain **pNs-(+)-I-10** (20 mg, yield 60%) as an orange-yellow solid. ^1H NMR (800 MHz, CDCl_3) δ 8.27 - 8.23 (m, 2H), 8.05 - 8.01 (m, 2H), 7.32 (d, $J = 8.2$ Hz, 1H), 7.22 (t, $J = 8.0$ Hz, 1H), 7.01 (d, $J = 1.9$ Hz, 1H), 6.50 (d, $J = 7.9$ Hz, 1H), 4.10 (d, $J = 7.6$ Hz, 1H), 3.71-3.68 (m, 1H), 3.60-3.55 (m, 1H), 3.16-3.12 (m, 1H), 3.07-3.04 (m, 2 H), 2.90-2.88 (m, 7H), 2.69-2.65 (m, 1H), 2.44-2.40 (m, 2H), 2.28-2.25 (m, 1H), 2.11 - 1.96 (m, 3H), 1.78-1.75 (m, 2H), 1.47-1.42 (m, 2H), 1.33-1.27 (m, 1H), 1.13 - 1.03 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{30}\text{H}_{39}\text{N}_6\text{O}_5\text{S}^+[\text{M}+\text{H}]^+$, calculated: 595.2697; found: 595.2663. Optical rotation $[\alpha]_D^{25} = +47.67^\circ$ ($c = 0.1$, CDCl_3).

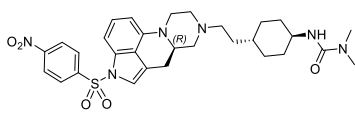
Single crystal preparation of the compound as shown in formula pNs-(+)-I-10

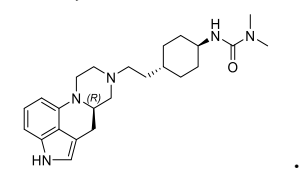
[0142] Single crystal growth by volatilization method: 10 mg of compound pNs-(+)-I-10 was weighed in 1 mL of chloroform, and then 10 mL of petroleum ether was added. The test tube was placed at room temperature for slow volatilization for crystallization.

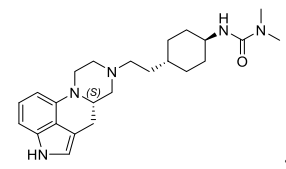
Detection method X-ray single crystal diffraction

[0143] After detection, the crystal system of the compound as shown in the formula pNs-(+)-I-10 belonged to the triclinic crystal system, the P1 space group, and the unit cell parameters were $a = 9.315 \text{ \AA}$, $b = 6.564 \text{ \AA}$, $c = 23.792 \text{ \AA}$, $\alpha = 90.15^\circ$, $\beta = 99.368^\circ$, $\gamma = 90.25^\circ$, the number of asymmetric unit Z in the unit cell was 2; the X-ray single crystal diffraction is shown in Fig. 1.

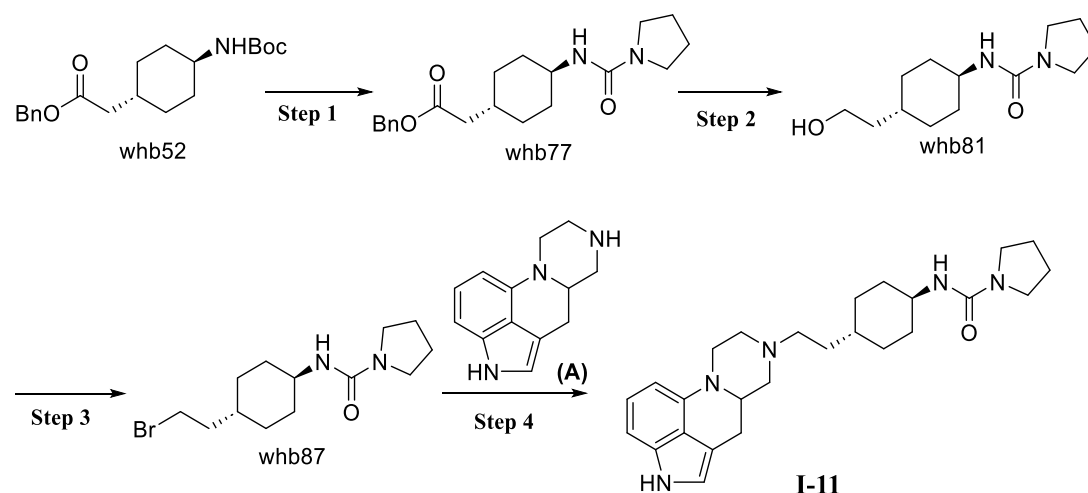
[0144] The characterization results of X-ray single crystal diffraction can determine that the

configuration of compound pNs-(+)-I-10 is , thus it can be

deduced that the configuration of (+)-I-10 compound is .

Correspondingly, the configuration of compound (-)-I-10 is .

Example 11: N-(4-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)trans-cyclohexyl)tetrahydropyrrole-1-carboxamide (Compound I-11)



[0145] Step 1: Using **whb52** as a raw material, following the method of step 2 of example 10 and replacing "dimethylcarbamoyl chloride" with "tetrahydropyrrole-1-formyl chloride", the intermediate **whb77** (0.54 g, 87%) was prepared as a white solid. $^1\text{H NMR}$ (800 MHz, CDCl_3) δ 7.39 - 7.30 (m, 5H), 5.11 (s, 2H), 3.95 (br, 1H), 3.61-3.56 (m, 1H), 3.31 - 3.29 (m, 4H), 2.25 (d, $J = 6.8 \text{ Hz}$, 2H), 2.06 - 2.00 (m, 2H), 1.91 - 1.87 (m, 4H), 1.65-1.59 (m, 2H), 1.17 - 1.07 (m,

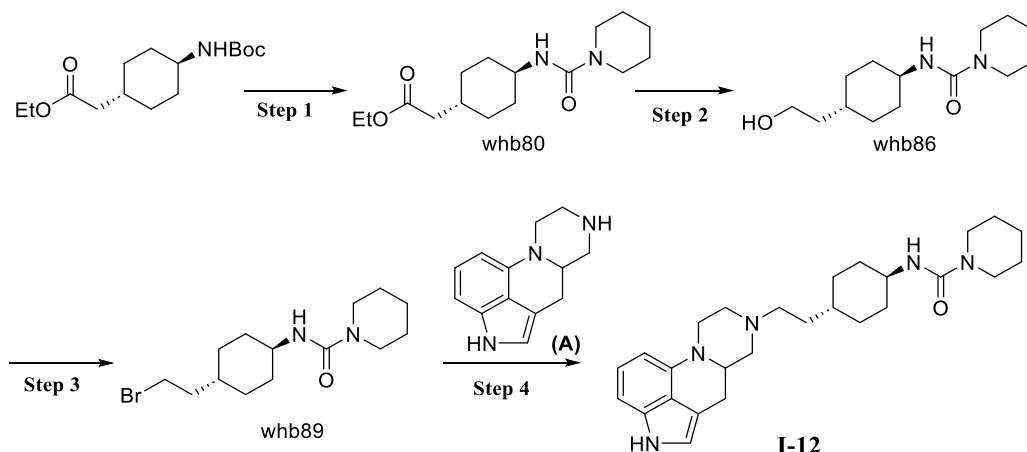
4H).

[0146] Step 2: Following the method of step 3 of example 10, **whb77** was converted to **whb81** (0.36 g, 96%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 3.69 (t, $J = 6.7$ Hz, 2H), 3.63-3.59 (m, 1H), 3.34 - 3.32 (d, $J = 6.4$ Hz, 4H), 2.06 - 2.01 (m, 2H), 1.93 - 1.88 (m, 4H), 1.82 - 1.77 (m, 2H), 1.50 - 1.47 (m, 2H), 1.40 - 1.36 (m, 1H), 1.15 - 1.05 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{13}\text{H}_{25}\text{N}_2\text{O}_2^+ [\text{M}+\text{H}]^+$, calculated: 241.1911; found: 241.1945.

[0147] Step 3: Following the method of step 4 of example 10, the intermediate **whb81** was converted into **whb87** (0.34 g, yield 76%) as a white solid. ^1H NMR (600 MHz, CDCl_3) δ 3.99 - 3.93 (m, 1H), 3.63 - 3.58 (m, 1H), 3.44 (t, $J = 7.0$ Hz, 2H), 3.32 - 3.29 (m, 4H), 2.08 - 2.01 (m, 2H), 1.93 - 1.85 (m, 3H), 1.83 - 1.73 (m, 4H), 1.50 - 1.40 (m, 1H), 1.17 - 1.02 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{13}\text{H}_{24}\text{BrN}_2\text{O}^+ [\text{M}+\text{H}]^+$, calculated: 303.1067; found: 303.1073 and 305.1080.

[0148] Step 4: Following the method of step 5 of example 10, **whb87** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-11** (50 mg, 50%) as an off-white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.97 (d, $J = 4.7$ Hz, 1H), 7.07 (t, $J = 7.8$ Hz, 1H), 6.79 (d, $J = 8.1$ Hz, 1H), 6.72 (d, $J = 1.8$ Hz, 1H), 6.33 (d, $J = 7.6$ Hz, 1H), 3.95 (d, $J = 7.8$ Hz, 1H), 3.79 (d, $J = 11.9$ Hz, 1H), 3.63 - 3.58 (m, 1H), 3.32 - 3.29 (m, 4H), 3.22 (t, $J = 10.24$ Hz, 1H), 3.10 - 3.06 (m, 2H), 2.98 (dd, $J = 15.3, 3.8$ Hz, 1H), 2.94 (d, $J = 11.9$ Hz, 1H), 2.82 (dd, $J = 15.3, 10.9$ Hz, 1H), 2.44 (t, $J = 7.9$ Hz, 2H), 2.36 - 2.30 (m, 1H), 2.10 (t, $J = 10.8$ Hz, 1H), 2.05 - 2.01 (m, 2H), 1.92 - 1.85 (m, 3H), 1.80 - 1.75 (m, 2H), 1.51 - 1.44 (m, 2H), 1.29 - 1.24 (m, 1H), 1.13 - 1.05 (m, 4H). ^{13}C NMR (201 MHz, CDCl_3) δ 156.13, 141.91, 134.14, 123.77, 117.87, 114.85, 114.83, 109.04, 101.83, 98.74, 98.72, 59.86, 56.45, 55.87, 52.82, 49.30, 45.97, 45.29, 35.45, 33.93, 33.52, 31.91, 27.42, 25.37. HR-MS (ESI, m/z): $\text{C}_{26}\text{H}_{38}\text{N}_5\text{O}^+ [\text{M}+\text{H}]^+$, calculated: 436.3071; found: 436.3072.

Example 12: N-(4-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)trans-cyclohexyl)piperidine-1-carboxamide (Compound **I-12**)



[0149] Step 1: Following the method of step 2 of example 10 and replacing "dimethylcarbamoyl chloride" with "piperidine-1-formyl chloride", the intermediate **whb80** was prepared as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 4.28 - 4.17 (m, 1H), 4.12 (q, J = 7.1 Hz, 2H), 3.62 - 3.56 (m, 1H), 3.31 - 3.27 (m, 4H), 2.19 (d, J = 7.0 Hz, 2H), 2.02 (m, 2H), 1.80 - 1.77 (m, 2H), 1.59 - 1.57 (m, 2H), 1.56 - 1.53 (m, 4H), 1.25 (t, J = 7.1 Hz, 3H), 1.15 - 1.08 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{16}\text{H}_{29}\text{N}_2\text{O}_3^+$ $[\text{M}+\text{H}]^+$, calculated: 297.2173; found: 297.2373.

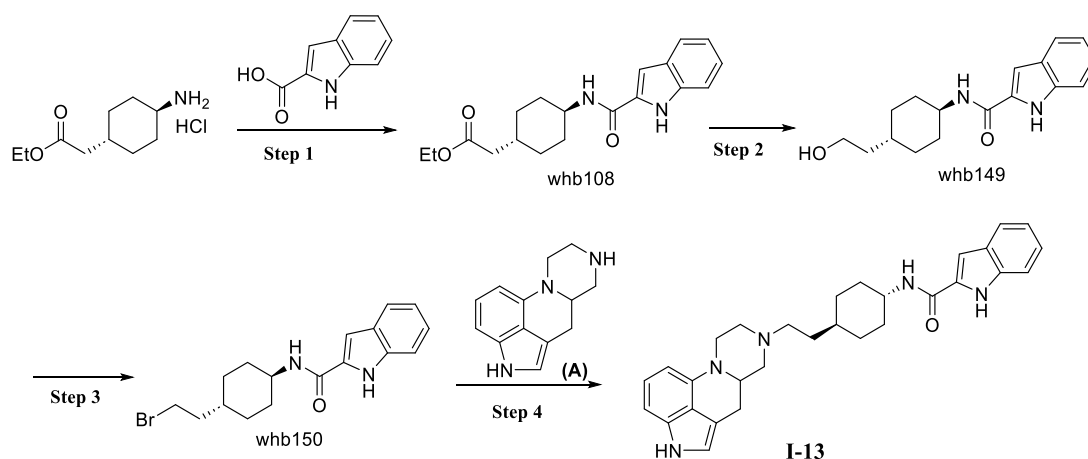
[0150] Step 2: Following the method of step 3 of example 11, **whb80** was converted to **whb86** as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 4.27 (s, 1H), 3.69 (t, J = 6.6 Hz, 2H), 3.59 (s, 1H), 3.31 - 3.27 (m, 4H), 2.02 (dd, J = 7.0, 3.7 Hz, 2H), 1.81 - 1.75 (m, 2H), 1.59-1.53 (m, 6H), 1.48 (q, J = 6.7 Hz, 2H), 1.40 - 1.36 (m, 1H), 1.12 - 1.04 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{14}\text{H}_{27}\text{N}_2\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 255.2067; found: 255.2057.

[0151] Step 3: Following the method of step 4 of example 10, the intermediate **whb86** was converted into **whb89** (yield 80%) as a white solid. ^1H NMR (600 MHz, CDCl_3) δ 4.25 (s, 1H), 3.59 (s, 1H), 3.44 (t, J = 7.0 Hz, 2H), 3.32 - 3.27 (m, 4H), 2.04 - 2.02 (m, 2H), 1.78 - 1.75 (m, 4H), 1.62 - 1.50 (m, 5H), 1.48 - 1.43 (m, 1H), 1.17 - 1.00 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{14}\text{H}_{26}\text{BrN}_2\text{O}^+$ $[\text{M}+\text{H}]^+$, calculated: 317.1223; found: 317.1260 and 319.1141.

[0152] Step 4: Following the method of step 5 of example 10, **whb89** and the starting material (A) were subjected to alkylation reaction to obtain compound **I-12** (62 mg, 98%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.91 (s, 1H), 7.07 (t, J = 7.8 Hz, 1H), 6.80 (d, J = 8.1 Hz, 1H), 6.72 (t, J = 1.8 Hz, 1H), 6.33 (d, J = 7.6 Hz, 1H), 4.20 (d, J = 7.5 Hz, 1H), 3.79 (d, J = 11.9 Hz, 1H), 3.61 - 3.57 (m, 1H), 3.29 (t, J = 5.5 Hz, 4H), 3.22 (s, 1H), 3.07 (d, J = 10.9 Hz,

2H), 2.98 (dd, $J = 15.2, 3.8$ Hz, 1H), 2.94 (d, $J = 12.0$ Hz, 1H), 2.82 (dd, $J = 15.3, 11.0$ Hz, 1H), 2.44 (t, $J = 8.0$ Hz, 2H), 2.33 (t, $J = 11.6$ Hz, 1H), 2.09 (t, $J = 10.8$ Hz, 1H), 2.04 - 1.99 (m, 2H), 1.79 (d, $J = 12.3$ Hz, 2H), 1.61 - 1.54 (m, 5H), 1.49 - 1.46 (m, 2H), 1.29 - 1.23 (m, 1H), 1.14 - 1.03 (m, 4H). ^{13}C NMR (201 MHz, CDCl_3) δ 156.97, 141.98, 134.13, 123.79, 117.86, 114.77, 109.13, 101.78, 98.74, 65.67, 59.95, 56.46, 55.91, 52.87, 49.61, 49.50, 46.01, 44.66, 40.82, 35.49, 33.77, 33.60, 31.90, 27.43, 25.39, 24.25. HR-MS (ESI, m/z): $\text{C}_{27}\text{H}_{40}\text{N}_5\text{O}^+[\text{M}+\text{H}]^+$, calculated: 450.3227; found: 450.3227.

Example 13: N-(4-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)trans-cyclohexyl)-1H-indole-2-carboxamide (Compound I-13)



[0153] Step 1: methyl 2-(4-aminotrans-cyclohexyl)acetate (0.19 g, 1.02 mmol) was dissolved in tetrahydrofuran (5 mL) in a round bottom flask, then HATU (0.505 g, 1.33 mmol), DIPEA (1 mL) and 1H-indole-2-carboxylic acid (0.214 g, 1.33 mmol) were added, and the reaction system was stirred overnight at room temperature. The solvent was evaporated under reduced pressure, and the residue was purified by silica gel column chromatography (eluent: petroleum ether containing 40-50% ethyl acetate) to obtain intermediate **whb108** (0.30 g, 90%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 9.41 (d, $J = 62.1$ Hz, 1H), 7.64 (d, $J = 8.0$ Hz, 1H), 7.43 (d, $J = 8.2$ Hz, 1H), 7.28 (d, $J = 8.3$ Hz, 1H), 7.13 (t, $J = 7.4$ Hz, 1H), 6.85 (d, $J = 4.9$ Hz, 1H), 6.16 (d, $J = 33.4$ Hz, 1H), 4.14 (q, $J = 7.1$ Hz, 2H), 3.98 - 3.93 (m, 1H), 2.24 (dd, $J = 13.8, 7.0$ Hz, 2H), 2.12 (d, $J = 13.4$ Hz, 2H), 1.86 (d, $J = 13.4$ Hz, 2H), 1.83 - 1.79 (m, 1H), 1.31 (q, $J = 12.8$ Hz, 2H), 1.26 (t, $J = 7.2$ Hz, 3H), 1.21 - 1.17 (q, $J = 12.8$ Hz, 2H). HR-MS (ESI, m/z): $\text{C}_{19}\text{H}_{25}\text{N}_2\text{O}_3^+[\text{M}+\text{H}]^+$, calculated: 329.1860; found: 329.1795.

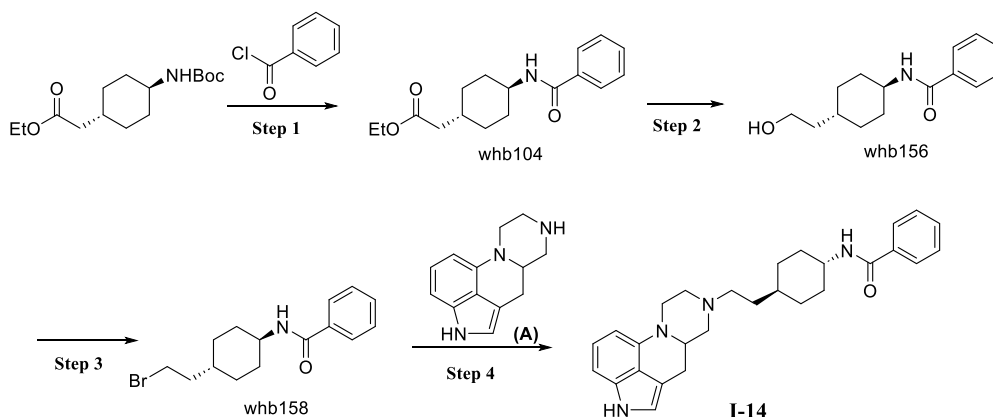
[0154] Step 2: Following the method described in step 3 of example 10, the intermediate

whb108 was reduced to obtain intermediate **whb149** (80 mg, 47%) as a white solid. ¹H NMR (800 MHz, CDCl₃) δ 9.23 (s, 1H), 7.64 (d, J = 8.0 Hz, 1H), 7.43 (d, J = 8.3 Hz, 1H), 7.28 (t, J = 8.2 Hz, 1H), 7.14 (t, J = 7.8 Hz, 1H), 6.82 - 6.79 (m, 1H), 3.97 - 3.93 (m, 1H), 3.72 (t, J = 6.6 Hz, 2H), 2.15 - 2.10 (m, 2H), 1.89 - 1.83 (m, 2H), 1.54 - 1.51 (m, 2H), 1.49 - 1.43 (m, 1H), 1.31 - 1.23 (m, 2H), 1.18 - 1.13 (m, 2H). HR-MS (ESI, m/z): C₁₇H₂₃N₂O₂⁺ [M+H]⁺, calculated: 287.1754; found: 287.1752.

[0155] Step 3: Following the method of step 4 of example 10, the alcohol intermediate **whb149** was converted into bromide **whb150** (0.11 g, 45%) as a white solid. ¹H NMR (800 MHz, CDCl₃) δ 9.31 (s, 1H), 7.64 (d, J = 8.0 Hz, 1H), 7.43 (d, J = 8.4 Hz, 1H), 7.31 - 7.27 (m, 1H), 7.13 (t, J = 7.12 Hz, 1H), 6.84 (d, J = 2.2 Hz, 1H), 6.10 (d, J = 8.2 Hz, 1H), 3.97 - 3.91 (m, 1H), 3.46 (t, J = 7.0 Hz, 2H), 2.13 (d, J = 13.4 Hz, 2H), 1.88 - 1.83 (m, 2H), 1.81 (q, J = 6.9 Hz, 2H), 1.55 - 1.51 (m, 1H), 1.33 - 1.29 (m, 2H), 1.16 - 1.11 (m, 2H). HR-MS (ESI, m/z): C₁₇H₂₂BrN₂O⁺ [M+H]⁺, calculated: 349.0910; found: 349.0901 and 351.0884.

[0156] Step 4: Following the method of step 5 of example 10, **whb150** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-13** (33 mg, yield 30%) as a white solid. ¹H NMR (800 MHz, CDCl₃) δ 9.16 (s, 1H), 7.83 (s, 1H), 7.64 (dd, J = 8.0, 1.1 Hz, 1H), 7.43 (dd, J = 8.3, 1.1 Hz, 1H), 7.28 (dd, J = 8.2, 7.0 Hz, 1H), 7.14 (dd, J = 8.0, 7.0 Hz, 1H), 7.08 (t, J = 7.8 Hz, 1H), 6.82 - 6.79 (m, 2H), 6.73 (d, J = 1.9 Hz, 1H), 6.34 (d, J = 7.6 Hz, 1H), 5.95 (d, J = 8.2 Hz, 1H), 3.97 - 3.93 (m, 1H), 3.82 - 3.78 (m, 1H), 3.21 (s, 1H), 3.08 (d, J = 10.8 Hz, 2H), 2.98 (dd, J = 15.2, 3.8 Hz, 1H), 2.94 (t, J = 11.8 Hz, 1H), 2.83 (dd, J = 15.2, 11.1 Hz, 1H), 2.46 (t, J = 7.9 Hz, 2H), 2.35 - 2.30 (m, 1H), 2.16 - 2.06 (m, 3H), 1.87 (d, J = 11.96 Hz, 2H), 1.52 - 1.50 (m, 2H), 1.36 - 1.32 (m, 1H), 1.29 - 1.24 (m, 2H), 1.20 - 1.14 (m, 2H). ¹³C NMR (201 MHz, DMSO-d₆) δ 160.22, 141.98, 136.35, 134.02, 132.02, 127.10, 123.11, 122.97, 121.39, 119.61, 117.86, 115.54, 112.26, 107.69, 102.46, 102.05, 98.00, 59.62, 56.07, 55.75, 52.55, 48.21, 45.92, 34.90, 33.46, 32.35, 31.74, 27.12. HR-MS (ESI, m/z): C₃₀H₃₆N₅O⁺ [M+H]⁺, calculated: 482.2914; found: 482.2918.

Example 14: N-(4-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)trans-cyclohexyl)benzamide (Compound **I-14**)



[0157] Step 1: Using "ethyl 2-(4-((tert-butoxycarbonylamino-trans-cyclohexyl) acetate" as a raw material, following the method of step 2 of example 10 and replacing "dimethylcarbamoyl chloride" with "benzoyl chloride", intermediate **whb104** (0.20 g, yield 69%) was obtained as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.74 (d, $J = 7.6$ Hz, 2H), 7.49 (t, $J = 7.4$ Hz, 1H), 7.42 (t, $J = 7.5$ Hz, 2H), 5.95 - 5.91 (br, 1H), 4.14 (q, $J = 7.1$ Hz, 2H), 3.96 - 3.91 (m, 1H), 2.23 (dd, $J = 13.9, 7.0$ Hz, 2H), 2.11 (d, $J = 12.2$ Hz, 2H), 1.85 (d, $J = 13.3$ Hz, 2H), 1.82 - 1.77 (m, 1H), 1.30 - 1.23 (m, 5H), 1.21 - 1.16 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{17}\text{H}_{24}\text{NO}_3^+$ $[\text{M}+\text{H}]^+$, calculated: 290.1751; found: 290.1748 and 312.1526 ($\text{M}+\text{Na}^+$).

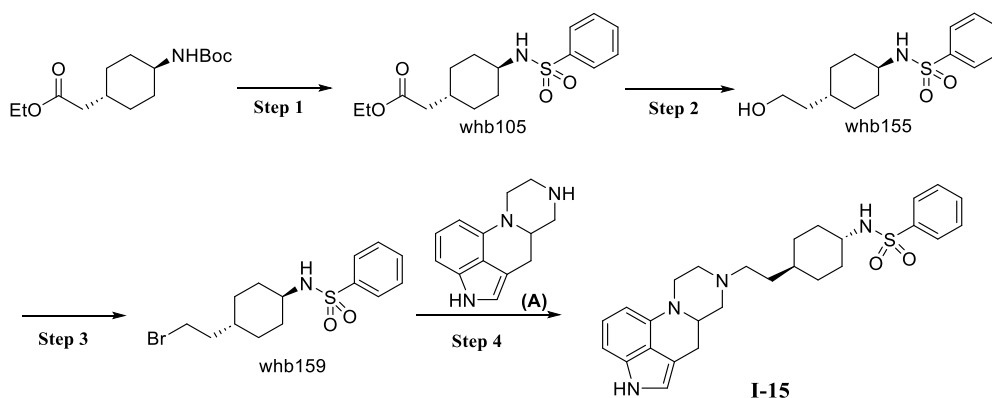
[0158] Step 2: Following the method described in step 3 of example 10, the intermediate **whb104** was reduced to obtain intermediate **whb156** (0.11 g, yield 65%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.77 - 7.73 (m, 2H), 7.51 - 7.46 (m, 1H), 7.45 - 7.40 (m, 2H), 5.89 (d, $J = 8.1$ Hz, 1H), 3.96 - 3.91 (m, 1H), 3.71 (t, $J = 6.8$ Hz, 2H), 2.14 - 2.09 (m, 2H), 1.87 - 1.83 (m, 2H), 1.53 - 1.50 (m, 2H), 1.47 - 1.42 (m, 1H), 1.28 - 1.20 (m, 2H), 1.18 - 1.11 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{15}\text{H}_{22}\text{NO}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 248.1645; found: 248.1772.

[0159] Step 3: Following the method of step 4 of example 10, the alcohol intermediate **whb156** was converted into bromide **whb158** (78 mg, 57%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.76 - 7.73 (m, 2H), 7.51 - 7.47 (m, 1H), 7.43 (dd, $J = 8.3, 7.1$ Hz, 2H), 5.89 (d, $J = 8.1$ Hz, 1H), 3.97 - 3.90 (m, 1H), 3.46 (t, $J = 7.0$ Hz, 2H), 2.13 (d, $J = 13.2$ Hz, 2H), 1.87 - 1.82 (m, 2H), 1.81 - 1.79 (m, 2H), 1.54 - 1.48 (m, 1H), 1.27 - 1.22 (m, 2H), 1.16 - 1.11 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{15}\text{H}_{21}\text{BrNO}^+$ $[\text{M}+\text{H}]^+$, calculated: 310.0801; found: 310.0792 and 312.0772.

[0160] Step 4: Following the method of step 5 of example 10, the **whb158** and the starting

material (**A**) were subjected to alkylation reaction to obtain compound **I-14** (30 mg, yield 32%) as a yellow solid. ^1H NMR (800 MHz, CDCl_3) δ 7.84 (s, 1H), 7.76 - 7.73 (m, 2H), 7.52 - 7.46 (m, 1H), 7.43 (dd, J = 8.3, 7.1 Hz, 2H), 7.08 (t, J = 7.8 Hz, 1H), 6.80 (d, J = 8.1 Hz, 1H), 6.73 (d, J = 1.9 Hz, 1H), 6.34 (d, J = 7.5 Hz, 1H), 5.89 (d, J = 8.1 Hz, 1H), 3.97 - 3.92 (m, 1H), 3.81 (d, J = 11.7 Hz, 1H), 3.25 - 3.21 (m, 1H), 3.08 (d, J = 10.9 Hz, 2H), 2.99 - 2.93 (m, 2H), 2.83 (dd, J = 15.3, 11.0 Hz, 1H), 2.48 - 2.44 (s, 2H), 2.36 - 2.32 (m, 1H), 2.12 (dd, J = 12.1, 3.8 Hz, 3H), 1.85 (d, J = 12.8 Hz, 2H), 1.53 - 1.50 (m, 2H), 1.37 - 1.30 (m, 1H), 1.26 - 1.13 (m, 4H). ^{13}C NMR (201 MHz, DMSO-d_6) δ 165.87, 142.44, 135.36, 134.48, 131.38, 128.59, 127.71, 123.43, 118.32, 116.02, 108.13, 102.53, 98.47, 56.51, 56.20, 53.01, 49.04, 46.36, 40.91, 35.37, 33.88, 32.65, 32.23, 27.58. HR-MS (ESI, m/z): $\text{C}_{28}\text{H}_{35}\text{N}_4\text{O}^+$ $[\text{M}+\text{H}]^+$, calculated: 443.2805; found: 443.2807.

Example 15: N-(4-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)cyclohexyl)phenylsulfonamide (Compound I-15)



[0161] Step 1: Using "ethyl 2-(4-((tert-butoxycarbonylamino-trans-cyclohexyl) acetate" as a raw material, following the method of step 2 of example 10 and replacing "dimethylcarbamoyl chloride" with "benzenesulfonyl chloride", intermediate **whb105** (0.30 g, yield 89%) was obtained as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.88 (d, J = 7.7 Hz, 2H), 7.57 (t, J = 7.4 Hz, 1H), 7.51 (t, J = 7.6 Hz, 2H), 4.51 (br, 1H), 4.09 (q, J = 7.1 Hz, 2H), 3.1 - 3.07 (m, 1H), 2.14 (dd, J = 14.4, 6.9 Hz, 2H), 1.83 (d, J = 13.3 Hz, 2H), 1.72 (d, J = 13.6 Hz, 2H), 1.69 - 1.65 (m, 1H), 1.23 (t, J = 7.1 Hz, 3H), 1.20 - 1.15 (m, 2H), 1.00 - 0.96 (m, 2H). HR-MS (ESI, m/z): $[\text{C}_{16}\text{H}_{23}\text{NO}_4\text{S}+\text{Na}]^+$ $[\text{M}+\text{Na}]^+$, calculated: 348.1240; found: 348.1245.

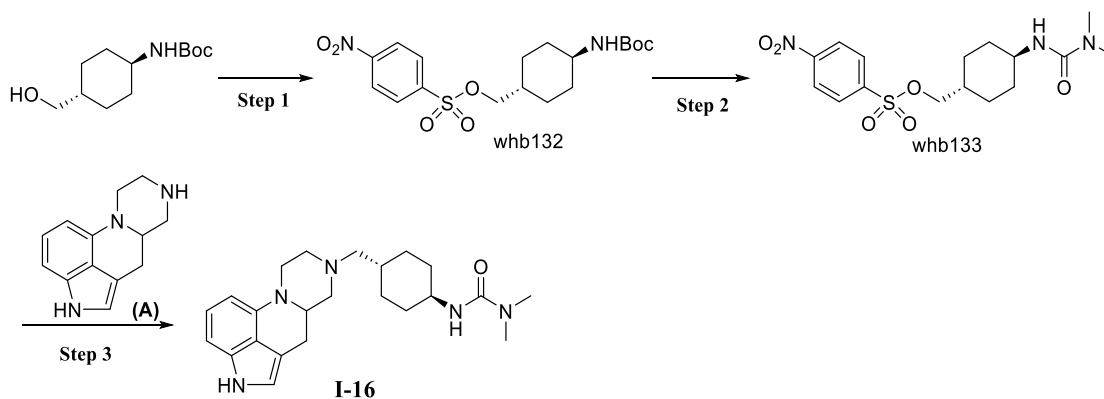
[0162] Step 2: Following the method described in step 3 of example 10, intermediate **whb105** was reduced to obtain intermediate **whb155** (0.22 g, 87%) as a white solid. ^1H NMR (800

MHz, CDCl₃) δ 7.90 - 7.86 (m, 2H), 7.59 - 7.55 (m, 1H), 7.51 (dd, J = 8.4, 7.1 Hz, 2H), 4.34 (s, NH, 1H), 3.64 (t, J = 6.6 Hz, 2H), 3.11 - 3.06 (m, 1H), 1.86 - 1.82 (m, 2H), 1.72 (d, J = 13.2 Hz, 2H), 1.42 (q, J = 6.7 Hz, 2H), 1.36 - 1.28 (m, 1H), 1.16 - 1.11 (m, 2H), 0.96 - 0.90 (m, 2H). HR-MS (ESI, m/z): C₁₄H₂₂NO₃S⁺ [M+H]⁺, calculated: 284.1315; found: 284.1332.

[0163] Step 3: Following the method of step 4 of example 10, the alcohol intermediate **whb155** was converted into bromide **whb159** (0.10 g, 37%) as a white solid. ¹H NMR (800 MHz, CDCl₃) δ 7.90 - 7.86 (m, 2H), 7.59 - 7.55 (m, 1H), 7.53 - 7.49 (m, 2H), 4.38 (br, 1H), 3.38 (t, J = 7.0 Hz, 2H), 3.12 - 3.07 (m, 1H), 1.88 - 1.82 (m, 2H), 1.74 - 1.68 (m, 4H), 1.43 - 1.35 (m, 1H), 1.19 - 1.12 (m, 2H), 0.96 - 0.86 (m, 2H). HR-MS (ESI, m/z): C₁₄H₂₁BrNO₂S⁺ [M+H]⁺, calculated: 346.0471; found: 346.0457 and 348.0435.

[0164] Step 4: Following the method of step 5 of example 10, the **whb159** and the starting material (**A**) were subjected to alkylation reaction to obtain compound **I-15** (40 mg, 98%) as a pale yellow solid. ¹H NMR (800 MHz, CDCl₃) δ 7.90 - 7.86 (m, 2H), 7.83 (s, 1H), 7.59 - 7.55 (m, 1H), 7.51 (dd, J = 8.3, 7.1 Hz, 2H), 7.07 (t, J = 7.8 Hz, 1H), 6.80 (d, J = 8.1 Hz, 1H), 6.72 (s, 1H), 6.32 (d, J = 7.6 Hz, 1H), 4.28 (d, J = 7.6 Hz, 1H), 3.80 - 3.77 (s, 1H), 3.23 - 3.16 (m, 1H), 3.12 - 3.08 (m, 1H), 3.06 - 3.01 (m, 2H), 2.97 (d, J = 15.0 Hz, 1H), 2.80 (dd, J = 15.3, 10.6 Hz, 1H), 2.43-2.36 (s, 2H), 2.31 (s, 1H), 2.08-2.04 (s, 1H), 1.84 (d, J = 12.8 Hz, 3H), 1.73 (d, J = 13.4 Hz, 2H), 1.45-1.39 (m, 2H), 1.23-1.19 (m, 1H), 1.17 - 1.09 (m, 2H), 0.99 - 0.92 (m, 2H). ¹³C NMR (201 MHz, CDCl₃) δ 142.12, 141.61, 141.59, 134.37, 132.46, 129.10, 126.89, 123.98, 118.12, 115.15, 109.17, 102.19, 99.00, 60.04, 56.50, 56.09, 53.20, 52.98, 46.17, 40.89, 35.08, 33.88, 33.48, 31.90, 27.65. HR-MS (ESI, m/z): C₂₇H₃₅N₄O₂S⁺ [M+H]⁺, calculated: 479.2475; found: 479.2487.

Example 16: 3-(4-((4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)methyl)trans-cyclohexyl)-1,1-dimethylurea (Compound I-16)

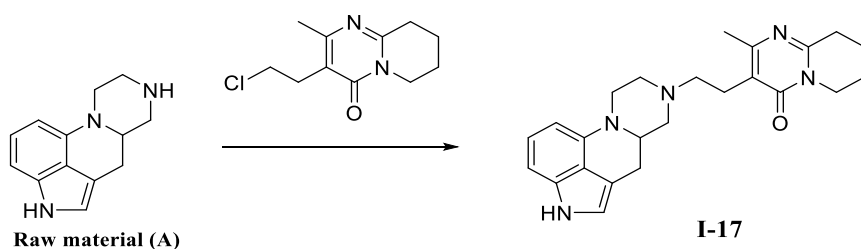


[0165] Step 1: tert-butyl(4-(hydroxymethyl)trans-cyclohexyl)carbamate (0.23 g, 1 mmol) was dissolved in DMF (5 mL), then triethylamine (1 mL) and 4-nitrobenzenesulfonyl chloride (0.27 g, 1.2 mmol) were successively added, and the reaction system was stirred overnight at room temperature. After the reaction was completed, the reaction was concentrated under reduced pressure, and the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 0-10% methanol) to obtain intermediate **whb132** (0.12 g, 29%) as a white solid. ^1H NMR (800 MHz, CDCl_3) δ 8.43 - 8.38 (m, 2H), 8.12 - 8.08 (m, 2H), 3.93 (d, J = 6.5 Hz, 2H), 3.42 - 3.29 (m, 1H), 2.06 - 2.00 (m, 2H), 1.78 - 1.76 (m, 2H), 1.70 - 1.65 (m, 1H), 1.43 (s, 9H), 1.17 - 1.07 (m, 4H). HR-MS (ESI, m/z): $\text{C}_{18}\text{H}_{26}\text{N}_2\text{O}_7\text{SNa}^+ [\text{M}+\text{Na}]^+$, calculated: 437.1358; found: 437.1323.

[0166] Step 2: the intermediate **whb132** (0.12 g, 0.29 mmol) was dissolved in dichloromethane (3 mL), and trifluoroacetic acid (1.5 mL) was added and stirred at room temperature for 3 hours. After the reaction was completed, the reaction was concentrated under reduced pressure, and the residue was dissolved in tetrahydrofuran (5 mL), then triethylamine (2 mL) and dimethylcarbamoyl chloride (37 mg, 0.35 mmol) were added, and the reaction system was stirred overnight at room temperature. After the reaction was completed, the reaction was concentrated under reduced pressure, and the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 10-20% methanol) to obtain intermediate **whb133** (30 mg, 27%) as a white solid. ^1H NMR (800 MHz, $\text{DMSO}-d_6$) δ 8.48 - 8.43 (m, 2H), 8.21 - 8.17 (m, 2H), 5.86 (d, J = 7.8 Hz, 1H), 3.98 (d, J = 6.4 Hz, 2H), 3.29 - 3.25 (m, 1H), 2.73 (s, 6H), 1.76 - 1.71 (m, 2H), 1.66 - 1.60 (m, 2H), 1.57 - 1.51 (m, 1H), 1.17 - 1.12 (m, 2H), 0.97 - 0.92 (m, 2H). HR-MS (ESI, m/z): $\text{C}_{16}\text{H}_{24}\text{N}_3\text{O}_6\text{S}^+ [\text{M}+\text{H}]^+$, calculated: 386.1380; found: 386.1391.

[0167] Step 3: the starting material (**A**) (50 mg, 0.23 mmol), the intermediate **whb133** (30 mg, 0.078 mmol) and K_2CO_3 (127 mg, 0.92 mmol) were added into a round bottom flask, then solvents tetrahydrofuran (3 mL) and dimethyl sulfoxide (1 mL) were added. The reaction system was heated and stirred at 60 °C for 16 hours. After the reaction was completed, the reaction was concentrated under reduced pressure, and the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 0-10% methanol) to obtain compound **I-16** (12 mg, 13%) as an off-white solid. 1H NMR (800 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.06 (t, J = 7.8 Hz, 1H), 6.79 (d, J = 8.1 Hz, 1H), 6.71 (d, J = 1.8 Hz, 1H), 6.32 (d, J = 7.6 Hz, 1H), 4.14 (d, J = 7.6 Hz, 1H), 3.76 (d, J = 11.8 Hz, 1H), 3.63 - 3.58 (m, 1H), 3.26 - 3.21 (m, 1H), 3.03 - 2.94 (m, 3H), 2.88 (s, 6H), 2.80 (dd, J = 15.3, 10.9 Hz, 1H), 2.34 - 2.30 (m, 1H), 2.24 - 2.21 (m, 2H), 2.11 - 2.07 (m, 1H), 2.07 - 2.03 (m, 2H), 1.91 - 1.85 (m, 2H), 1.55 - 1.50 (m, 1H), 1.14 - 1.02 (m, 4H). ^{13}C NMR (201 MHz, $CDCl_3$) δ 157.94, 142.25, 134.37, 123.81, 118.13, 115.09, 109.13, 102.07, 98.78, 65.01, 60.65, 56.13, 53.38, 50.10, 46.23, 40.93, 36.19, 34.49, 33.83, 30.61, 27.62. HR-MS (ESI, m/z): $C_{23}H_{34}N_5O^+$ $[M+H]^+$, calculated: 396.2758; found: 396.2755.

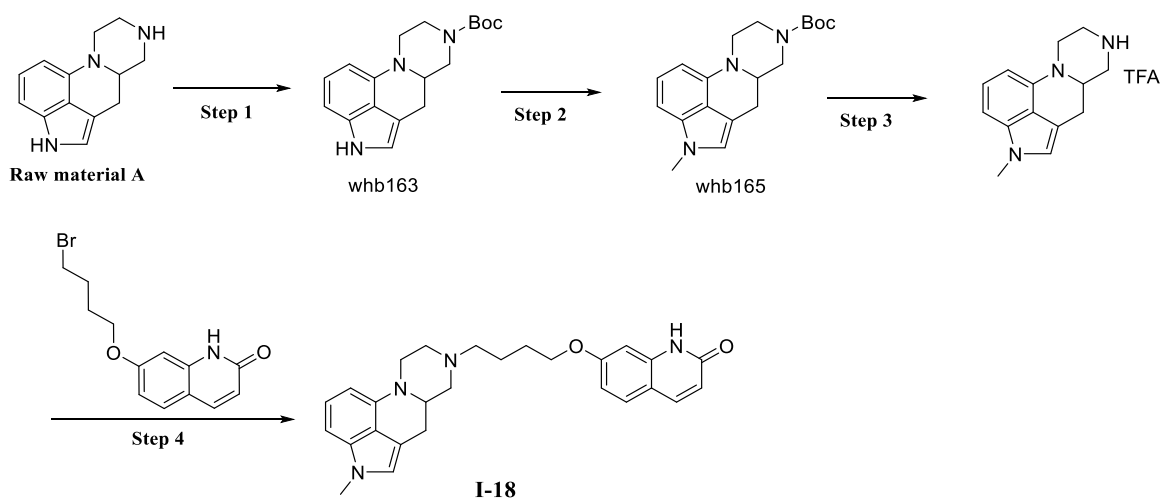
Example 17: 3-(2-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)-2-methyl-6,7,8,9-tetrahydro-4H-pyrido[1,2-a]pyrimidin-4-one (Compound I-17)



[0168] Following the method of step 2 of example 1, the starting material (**A**) and "3-(2-chloroethyl)-2-methyl-6,7,8,9-tetrahydro-4H-pyrido[1,2-a]pyrimidin-4-one" (cas#63234-80-0, commercially available) were subjected to alkylation reaction to prepare compound **I-17** as a dark green solid, which was further purified by preparative HPLC (mobile phase: 20-80% MeOH/ H_2O), t_R = 16 min, to obtain 10 mg (yield 10%). 1H NMR (800 MHz, $DMSO-d_6$) δ 10.68 (s, 1H), 10.03 (s, 1H), 6.97 - 6.92 (m, 1H), 6.90 (s, 1H), 6.80 (d, J = 8.1 Hz, 1H), 6.33 (d, J = 7.5 Hz, 1H), 4.11 - 4.05 (m, 1H), 3.90 - 3.82 (m, 2H), 3.80 (t, J = 6.2 Hz, 2H), 3.23 - 3.15 (m, 2H), 3.08 (d, J = 15.4 Hz, 2H), 3.00 - 2.95 (m, 1H), 2.93 - 2.84 (m, 2H), 2.79 (t, J =

6.7 Hz, 2H), 2.75 (dd, $J = 15.4, 9.2$ Hz, 1H), 2.26 (s, 3H), 2.03 - 1.96 (m, 1H), 1.88 - 1.85 (m, 2H), 1.79 - 1.75 (m, 2H), 1.48 - 1.43 (m, 1H). ^{13}C NMR (201 MHz, DMSO- d_6) δ 161.57, 158.89, 157.56, 139.89, 134.14, 123.03, 117.65, 116.57, 114.91, 105.99, 103.20, 98.97, 54.84, 53.65, 50.49, 43.45, 42.42, 30.65, 26.26, 21.14, 21.12, 20.79, 20.76, 18.35. HR-MS (ESI, m/z): $\text{C}_{24}\text{H}_{30}\text{N}_5\text{O}^+ [\text{M}+\text{H}]^+$, calculated: 404.2445; found: 404.2444.

Example 18: 7-(4-(4-methyl-4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)butoxy)quinolin-2(1H)-one (Compound I-18)



[0169] Step 1: the starting material (A) (0.20 g, 0.94 mmol), triethylamine (0.4 g, 3.76 mmol), DMAP (12 mg, 0.094 mmol) and solvent DMF (5 mL) were added into a round bottom flask, then Boc_2O (0.23 g, 1.03 mmol) was added and stirred at room temperature for 12 hours. After the reaction was completed, the reaction was concentrated under reduced pressure to remove the solvent, and the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 0-10% methanol) to obtain intermediate **whb163** (0.22 g, 75%) as an off-white solid. ^1H NMR (800 MHz, CDCl_3) δ 7.85 (s, 1H), 7.09 (t, $J = 7.8$ Hz, 1H), 6.82 (d, $J = 8.0$ Hz, 1H), 6.75 (d, $J = 1.9$ Hz, 1H), 6.35 (d, $J = 7.6$ Hz, 1H), 4.31 - 4.21 (m, 1H), 4.20 - 4.08 (m, 1H), 3.81 (d, $J = 11.9$ Hz, 1H), 3.19 - 3.11 (m, 1H), 3.11 - 3.01 (m, 2H), 2.94 - 2.72 (m, 3H), 1.49 (s, 9H). HR-MS (ESI, m/z): $\text{C}_{18}\text{H}_{24}\text{N}_3\text{O}_2^+ [\text{M}+\text{H}]^+$, calculated: 314.1863; found: 314.1862.

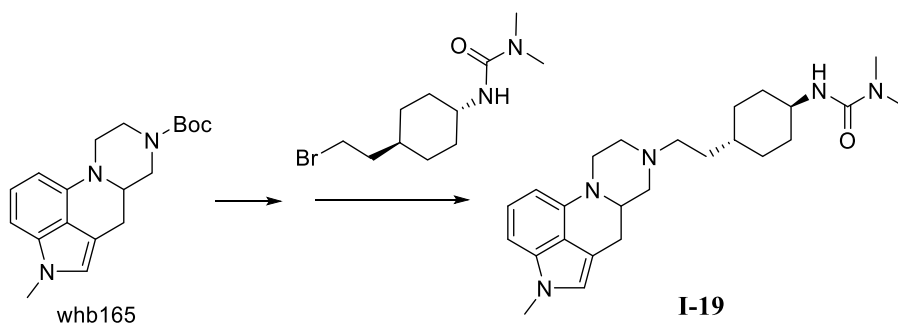
[0170] Step 2: the intermediate **whb163** (0.21 g, 0.67 mmol), potassium tert-butoxide (0.091 g, 0.81 mmol) and DMF (8 mL) were added into a round bottom flask, and stirred for 30 minutes. Iodomethane (0.19 g, 1.34 mmol) was added and further stirred at room temperature

for 3 hours. After the reaction was completed, water (3 mL) was added to the reaction system to quench the reaction, and a solid was precipitated out. Crude intermediate **whb165** (0.18 g, 82%) was obtained by filtration as a yellow solid, which was directly used in the next step. ^1H NMR (800 MHz, CDCl_3) δ 7.13 - 7.08 (m, 1H), 6.75 (d, J = 8.1 Hz, 1H), 6.59 (s, 1H), 6.33 (d, J = 7.6 Hz, 1H), 4.29 - 4.24 (m, 1H), 4.21 - 4.08 (m, 2H), 3.82 - 3.80 (m, 1H), 3.73 (s, 3H), 3.17 - 3.10 (m, 1H), 3.09 - 3.04 (m, 1H), 3.01 (d, J = 15.2 Hz, 1H), 2.80 (t, J = 13.0 Hz, 2H), 1.48 (s, 9H). HR-MS (ESI, m/z): $\text{C}_{19}\text{H}_{26}\text{N}_3\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 328.2020; found: 328.1990.

[0171] Step 3: the intermediate **whb165** (50 mg) was dissolved in dichloromethane (3 mL), and TFA (1 mL) was added and stirred at room temperature for 1 hour. The solvent was evaporated under reduced pressure to obtain a crude product, which was directly used in the next step.

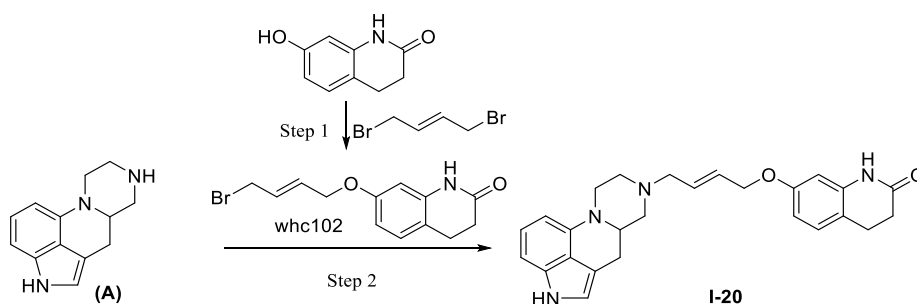
[0172] Step 4: the crude product obtained in step 3 was dissolved in tetrahydrofuran THF (3 mL), then DMSO (1.5 mL), K_2CO_3 (0.12 g, 0.87 mmol) and the intermediate **wha70** of example 2 (49 mg, 0.17 mmol) were added, heated and stirred at 60 °C for 16 hours. The solvent was evaporated under reduced pressure, and the residue was purified by silica gel column chromatography (eluent: dichloromethane containing 0-10% methanol) to obtain compound I-18 of interest (30 mg, 45%) as a pale yellow solid. ^1H NMR (800 MHz, CD_3OD) δ 7.89 (d, J = 9.4 Hz, 1H), 7.59 (d, J = 8.7 Hz, 1H), 7.03 (t, J = 7.8 Hz, 1H), 6.91 (dd, J = 8.7, 2.4 Hz, 1H), 6.87 (d, J = 2.4 Hz, 1H), 6.78 (d, J = 8.2 Hz, 1H), 6.67 (s, 1H), 6.45 (d, J = 9.4 Hz, 1H), 6.34 (d, J = 7.5 Hz, 1H), 4.18 - 4.14 (m, 2H), 3.85 (d, J = 12.0 Hz, 1H), 3.74 (s, 3H), 3.21 - 3.16 (s, 2H), 3.11 - 3.05 (m, 1H), 2.96 (d, J = 15.3 Hz, 1H), 2.87 (t, J = 12.0 Hz, 1H), 2.80 - 2.76 (m, 1H), 2.63 - 2.57 (m, 2H), 2.46 - 2.40 (m, 1H), 2.23 - 2.16 (m, 1H), 1.94 - 1.90 (m, 2H), 1.86 - 1.81 (m, 2H). ^{13}C NMR (201 MHz, CDCl_3) δ 165.14, 161.51, 142.23, 141.00, 140.50, 135.48, 129.14, 123.76, 119.86, 118.39, 117.98, 114.32, 112.78, 108.19, 100.42, 99.15, 98.64, 68.23, 60.01, 58.27, 56.31, 53.00, 46.31, 32.96, 27.67, 27.28, 23.39. HR-MS (ESI, m/z): $\text{C}_{27}\text{H}_{31}\text{N}_4\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 443.2442; found: 443.2445.

Example 19: 1,1-dimethyl-3-(4-(2-(4-methyl-4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)ethyl)trans-cyclohexyl)urea (Compound I-19)



[0173] Using the method similar to that of example 17, the **whb165** was subjected to removal of Boc protecting group first, and then subjected to alkylation reaction with the intermediate whb60 to obtain the compound **I-19** (50 mg, 79%) as a pale yellow solid, which was further purified by HPLC (mobile phase: 20-80% MeOH/H₂O), $t_R = 19.5$ min, to obtain 40 mg. ¹H NMR (800 MHz, CD₃OD) δ 7.08 - 7.04 (m, 1H), 6.83 (d, $J = 8.2$ Hz, 1H), 6.75 (s, 1H), 6.39 (d, $J = 7.6$ Hz, 1H), 4.15 (d, $J = 14.1$ Hz, 1H), 3.73 (s, 3H), 3.73 - 3.68 (m, 2H), 3.51 - 3.47 (m, 1H), 3.37 - 3.32 (m, 1H), 3.26 - 3.20 (m, 3H), 3.15 - 3.12 (m, 1H), 3.05 (t, $J = 13.32$ Hz, 1H), 3.00 (t, $J = 11.9$ Hz, 1H), 2.87 (s, 6H), 2.87 - 2.81 (m, 1H), 1.95 - 1.89 (m, 2H), 1.85 - 1.84 (m, 2H), 1.74 - 1.65 (m, 2H), 1.39 - 1.32 (m, 1H), 1.32 - 1.26 (m, 2H), 1.16 - 1.10 (m, 2H). ¹³C NMR (201 MHz, CD₃OD) δ 159.12, 139.54, 135.63, 123.24, 120.54, 118.09, 105.75, 101.38, 99.12, 55.68, 55.45, 54.33, 50.96, 49.78, 43.76, 35.04, 34.70, 32.64, 31.54, 31.52, 30.33, 26.24. HR-MS (ESI, m/z): C₂₅H₃₈N₅O⁺ [M+H]⁺, calculated: 424.3071; found: 424.3089.

Example 20: (E)-7-((4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)-2-buten-1-yl)oxy)-3,4-dihydroquinolin-2(1H)-one (Compound I-20)

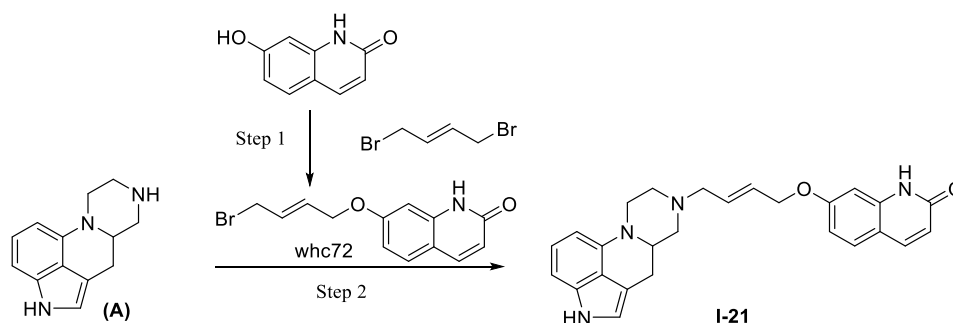


[0174] Step 1: following the method of step 1 of example 1, the alkylation reaction was carried out using 7-hydroxy-3,4-dihydroquinolin-2(1H)-one and (E)-1,4-dibromo-2-butene as raw materials to prepare intermediate **whc102** (0.82 g, 45%) as a yellow solid. ¹H NMR (800 MHz, CDCl₃) δ 8.45 (s, 1H), 7.05 (d, $J = 8.2$ Hz, 1H), 6.57 - 6.49 (m, 1H), 6.37 (d, $J = 2.5$ Hz, 1H), 6.07 (dt, $J = 15.2, 7.4$ Hz, 1H), 5.97 (dt, $J = 15.2, 5.3$ Hz, 1H), 4.52 (d, $J = 5.4$ Hz, 2H),

3.99 (d, $J = 7.5$ Hz, 2H), 2.90 (t, $J = 7.5$ Hz, 2H), 2.62 (t, $J = 7.5$ Hz, 2H). HR-MS (ESI, m/z): $C_{13}H_{15}BrNO_2^+$ $[M+H]^+$, calculated: 296.0281; found: 296.0294 and 298.0277.

[0175] Step 2: following the method of step 2 of example 1, the intermediate **A** and the **whc102** were subjected to alkylation reaction to obtain the compound **I-20** (40 mg, 33%) as a pale yellow solid. HR-MS (ESI, m/z): $C_{26}H_{29}N_4O_2^+$ $[M+H]^+$, calculated: 429.2285; found: 429.2288.

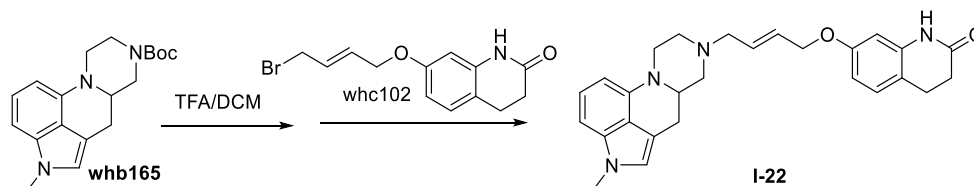
Example 21: (E)-7-((4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)-2-buten-1-yl)oxy)quinolin-2(1H)-one (Compound I-21)



[0176] Step 1: following the method of step 1 of example 1, the alkylation reaction was carried out using 7-hydroxy-quinolin-2(1H)-one and (E)-1,4-dibromo-2-butene as raw materials to prepare intermediate **whc72** (0.25 g, 14%) as a yellow solid. 1H NMR (600 MHz, $CDCl_3$) δ 7.74 (d, $J = 9.4$ Hz, 1H), 7.46 (d, $J = 8.7$ Hz, 1H), 6.88 (d, $J = 2.4$ Hz, 1H), 6.86 - 6.80 (m, 1H), 6.59 - 6.47 (m, 1H), 6.14 (dt, $J = 15.0, 7.4$ Hz, 1H), 6.01 (dt, $J = 15.4, 5.5$ Hz, 1H), 4.66 (d, $J = 5.3$ Hz, 2H), 4.01 (d, $J = 7.5$ Hz, 2H). HR-MS (ESI, m/z): $C_{13}H_{13}BrNO_2^+$ $[M+H]^+$, calculated: 294.0124; found: 294.0124 and 296.0106.

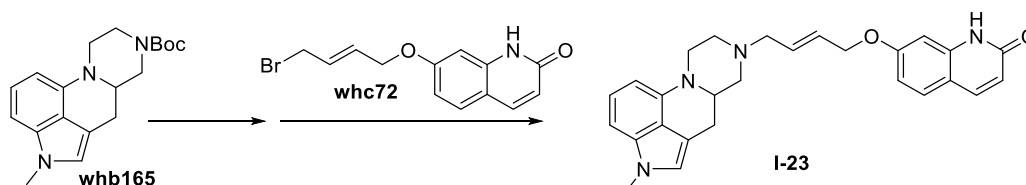
[0177] Step 2: following the method of step 2 of example 1, the intermediate **A** and the **whc72** were subjected to alkylation reaction to obtain the compound **I-21** (50 mg, 51%) as an off-white solid. 1H NMR (800 MHz, $CDCl_3$) δ 10.12 (s, 1H), 7.83 (s, 1H), 7.69 (d, $J = 9.4$ Hz, 1H), 7.45 (d, $J = 8.7$ Hz, 1H), 7.07 (t, $J = 7.8$ Hz, 1H), 6.85 - 6.82 (m, 1H), 6.80 (d, $J = 8.1$ Hz, 1H), 6.72 (d, $J = 2.0$ Hz, 1H), 6.69 (s, 1H), 6.51 (d, $J = 9.4$ Hz, 1H), 6.32 (d, $J = 7.6$ Hz, 1H), 6.03 - 5.98 (m, 1H), 5.95 - 5.91 (m, 1H), 4.65 (d, $J = 5.6$ Hz, 2H), 4.14 - 4.10 (m, 1H), 3.80 (d, $J = 11.7$ Hz, 1H), 3.22 - 3.20 (m, 1H), 3.14 (t, $J = 8.7$ Hz, 1H), 3.07 (t, $J = 14.4$ Hz, 2H), 2.94 (dd, $J = 15.1, 3.7$ Hz, 2H), 2.83 - 2.77 (m, 1H), 2.40 - 2.36 (m, 1H), 2.12 (t, $J = 10.8$ Hz, 1H). HR-MS (ESI, m/z): $C_{26}H_{27}N_4O_2^+$ $[M+H]^+$, calculated: 427.2129; found: 427.2129.

Example 22: (E)-7-((4-(4-methyl-4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)-2-buten-1-yl)oxy)-3,4-dihydroquinolin-2(1H)-one (Compound I-22)



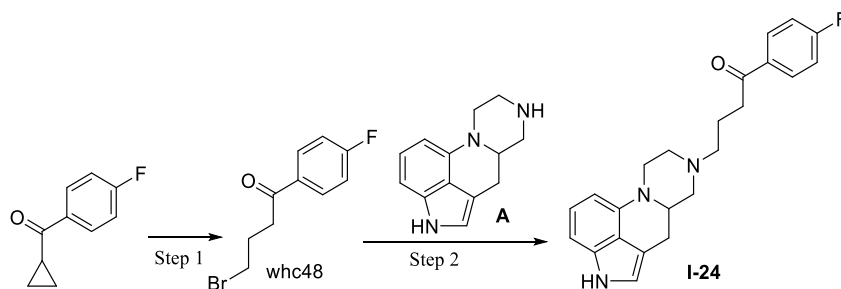
[0178] Following the method of step 3 of example 18, the intermediate **whb165** was subjected to removal of Boc protecting group, and then subjected to alkylation reaction with the intermediate **whc102** to obtain the compound **I-22** of interest (90 mg, 30%) as a brown foamy solid. ^1H NMR (800 MHz, CD_3OD) δ 7.09 - 7.04 (m, 2H), 6.82 (d, J = 8.2 Hz, 1H), 6.72 (s, 1H), 6.58 (dd, J = 8.3, 2.5 Hz, 1H), 6.49 (d, J = 2.5 Hz, 1H), 6.36 (d, J = 7.5 Hz, 1H), 6.26 - 6.22 (m, 1H), 5.97 - 5.93 (m, 1H), 4.66 - 4.62 (m, 2H), 4.11 - 4.05 (m, 1H), 3.84 - 3.75 (m, 2H), 3.71 (s, 3H), 3.64 - 3.59 (m, 1H), 3.56 - 3.52 (m, 1H), 3.13 - 3.09 (m, 1H), 3.08 - 3.00 (m, 2H), 2.82 (t, J = 8.0 Hz, 3H), 2.77 (dd, J = 15.6, 8.0 Hz, 1H), 2.48 (t, J = 8.0 Hz, 2H). HR-MS (ESI, m/z): $\text{C}_{27}\text{H}_{31}\text{N}_4\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 443.2442; found: 443.2442.

Example 23: (E)-7-((4-(4-methyl-4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)-2-buten-1-yl)oxy)quinolin-2(1H)-one (Compound I-23)



[0179] Following the method of step 3 of example 18, the intermediate **whb165** was subjected to removal of Boc protecting group, and then subjected to alkylation reaction with the intermediate **whc72** to obtain the compound **I-23** of interest (23 mg, 20%) as a brown-yellow solid. ^1H NMR (800 MHz, $\text{DMSO}-d_6$) δ 11.60 (s, 1H), 7.80 (d, J = 9.5 Hz, 1H), 7.56 (d, J = 8.3 Hz, 1H), 6.94 (t, J = 7.8 Hz, 1H), 6.84 - 6.80 (m, 2H), 6.76 - 6.71 (m, 2H), 6.31 (d, J = 9.4 Hz, 1H), 6.22 (d, J = 7.5 Hz, 1H), 5.94 - 5.90 (m, 2H), 4.63 (d, J = 5.1 Hz, 2H), 3.72 - 3.69 (m, 1H), 3.68 (s, 3H), 3.06 - 3.02 (m, 2H), 2.98 - 2.94 (m, 3H), 2.82 (d, J = 15.2 Hz, 1H), 2.69 - 2.65 (m, 1H), 2.63 - 2.57 (m, 1H), 2.21 - 2.17 (m, 1H), 1.97 - 1.93 (m, 1H). HR-MS (ESI, m/z): $\text{C}_{27}\text{H}_{29}\text{N}_4\text{O}_2^+$ $[\text{M}+\text{H}]^+$, calculated: 441.2285; found: 441.2286.

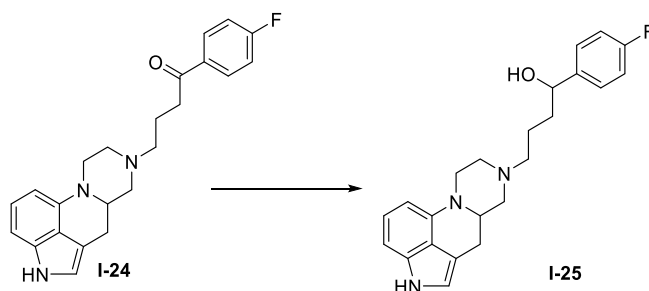
Example 24: 1-(4-fluorobenzene)-4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)-1-butanone (Compound I-24)



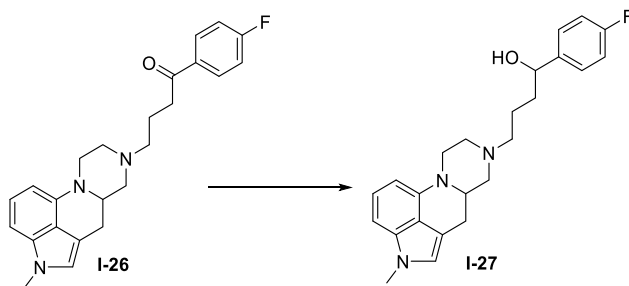
[0180] Step 1: cyclopropyl(4-fluorobenzene)ketone (0.5 g, 3 mmol) and aqueous hydrobromic acid (3 mL) were added to a round bottom flask, and the reaction system was stirred at 80 °C for 2 hours. After the reaction was completed, the reaction was cooled, and water was added and extracted three times with DCM. The organic phases were combined and concentrated under reduced pressure to give crude product **whc48** (0.73 g, 98%) as a yellow liquid. ¹H NMR (800 MHz, CDCl₃) δ 8.04 - 7.99 (m, 2H), 7.17 - 7.12 (m, 2H), 3.55 (t, *J* = 6.3 Hz, 2H), 3.16 (t, *J* = 6.9 Hz, 2H), 2.31 (p, *J* = 6.6 Hz, 2H).

[0181] Step 2: following the method of step 2 of example 1, the intermediate **A** and the **whc48** were subjected to alkylation reaction to obtain the compound **I-24** (0.3 g, 57%) as a pale yellow solid. ¹H NMR (800 MHz, CDCl₃) δ 8.03 - 7.98 (m, 2H), 7.81 (s, 1H), 6.80 (d, *J* = 8.1 Hz, 1H), 6.72 (d, *J* = 1.9 Hz, 1H), 6.32 (d, *J* = 7.6 Hz, 1H), 3.77 (d, *J* = 11.7 Hz, 1H), 3.16 - 3.12 (m, 1H), 3.05 - 3.01 (m, 4H), 2.96 (dd, *J* = 15.2, 3.7 Hz, 1H), 2.88 - 2.78 (m, 2H), 2.49 (t, *J* = 7.1 Hz, 2H), 2.35 (t, *J* = 8.0 Hz, 1H), 2.11 (t, *J* = 8.0 Hz, 1H), 2.03 - 2.00 (m, 2H). HR-MS (ESI, *m/z*): C₂₃H₂₅FN₃O⁺ [M+H]⁺, calculated: 378.1976; found: 378.1976.

Example 25: 1-(4-fluorobenzene)-4-(4,6,6a,7,9,10-hexahydro-8H-pyrazino[1,2-a]pyrrolo[4,3,2-de]quinolin-8-yl)-1-butanol (Compound I-25)



[0182] **I-24** (50 mg, 0.13 mmol) was dissolved in methanol (5 mL), then NaBH₄ (7.6 mg, 0.19 mmol) was added, and the reaction system was stirred at room temperature for 2 hours.



[0184] **I-26** (63 mg, 0.16 mmol) was dissolved in methanol (8 mL), then NaBH_4 (9 mg, 0.24 mmol) was added, and the reaction system was stirred at room temperature for 2 hours. After the reaction was completed, the reaction was quenched by adding water and concentrated under reduced pressure, and the residue was purified by flash silica gel column chromatography (eluent: dichloromethane containing 20-30% methanol) to obtain **I-27** (10 mg, 16%) as a pale yellow solid. ^1H NMR (800 MHz, CDCl_3) δ 7.36 - 7.31 (m, 2H), 7.09 (t, $J = 7.7$ Hz, 1H), 7.00 - 6.97 (m, 2H), 6.73 (d, $J = 7.8$ Hz, 1H), 6.59 - 6.55 (m, 1H), 6.31 (d, $J = 7.7$ Hz, 1H), 4.70 - 4.67 (m, 1H), 3.86 - 3.79 (m, 1H), 3.72 (s, 3H), 3.33 - 3.29 (m, 1H), 3.19 - 3.15 (m, 1H), 3.05 - 2.92 (m, 3 H), 2.85 - 2.76 (m, 1H), 2.52 - 2.48 (m, 2H), 2.43 - 2.39 (m, 1H), 2.19 - 2.15 (m, 1H), 2.00 - 1.96 (m, 1H), 1.87 - 1.83 (m, 1H), 1.77 - 1.73 (m, 1H), 1.72 - 1.68 (m, 1H). HR-MS (ESI, m/z): $\text{C}_{24}\text{H}_{29}\text{FN}_3\text{O}^+ [\text{M}+\text{H}]^+$, calculated: 394.2289; found: 394.2297.

Test example 1: Test of the affinity of the compounds of the present invention for dopamine D_2 receptors

[0185] The affinity of the compounds of the present invention for the dopamine D_2 receptors was determined by the method of radioligand competition experiment. In the first step, a cell membrane component containing specific dopamine D_2 receptors was prepared. A 10 cm dish was used for transfection with 10 ng of the dopamine D_2 receptors and 40 μL of PEI. After 48 hours, the 10 cm dish was taken out from the cell culture room and the cultured cells had expressed the dopamine D_2 receptors. A vacuum pump was used to suck off the culture medium, 3 mL of lysis buffer was added to each well, and the cells were placed in a 4 $^\circ\text{C}$ freezer for 10 minutes. After the cells were detached, the cells were transferred to a 15 mL centrifuge tube and centrifuged at 1500 rpm for 5 minutes at 4 $^\circ\text{C}$, and the supernatant was discarded. The cell pellet was transferred to a tissue homogenizer, and 3 mL of lysis buffer was added and fully ground until the cells were broken. Then, cell suspension was equally divided into several EP tubes, centrifuged at 4 $^\circ\text{C}$ and 12000 rpm for 5 min, and the supernatant was

discarded. The precipitate was the cell membrane component containing the dopamine D₂ receptors. In the second step, a ligand-receptor binding experiment was performed on HEK-293T membrane component transiently expressing the dopamine D₂ receptors. First, a standard binding buffer was added to the cell membrane component containing the dopamine D₂ receptors, and the cell membrane was disrupted and resuspended with an electric tissue homogenizer. 30 μ L of membrane protein suspension was added to each well of a 96-well plate. Then, 30 μ L of different drugs were added to the 96-well plate from left to right to ensure that the final drug concentrations were 10⁻⁵ M, 10⁻⁶ M, 10⁻⁷ M, 10⁻⁸ M, 10⁻⁹ M and 0 M, with two replicates per treatment. Next, 30 μ L [³H]-Methylspiperone was added to each well of the 96-well plate. The plate was incubated for 2 hours at room temperature in the dark. Detection. The machine reading value reflected the amount of [³H]-Methylspiperone bound on the membrane, and after further data processing, the affinity K_i value of different compounds for dopamine D₂ receptors was obtained.

[0186] The results are shown in Table 1. The results show that compound I-1 to compound I-27 have certain affinity activity for dopamine D₂ receptors, and it can be seen that the compounds of the invention have certain affinity activity for dopamine D₂ receptors.

Table 1

Compound	Affinity K _i (pK _i $\pm$ SEM)
I-1	33.65 nM (7.47 $\pm$ 0.16)
I-2	9.03 nM (8.04 $\pm$ 0.12)
(+)-I-2	8.87 nM (8.05 $\pm$ 0.05)
(-)-I-2	1.75 nM (8.76 $\pm$ 0.13)
I-3	49.58 nM (7.30 $\pm$ 0.20)
I-4	30.34 nM (7.52 $\pm$ 0.08)
I-5	37.07 nM (7.43 $\pm$ 0.09)
I-6	51.56 nM (7.29 $\pm$ 0.10)
I-7	402.71 nM (6.40 $\pm$ 0.12)
I-8	0.49 nM (9.31 $\pm$ 0.15)
I-9	751.97 nM (6.12 $\pm$ 0.10)

I-10	50.64 nM (7.30 ± 0.08)
(-)-I-10	22.44 nM (7.65 ± 0.08)
(+)-I-10	1135.01 nM (5.95 ± 0.17)
I-11	22.23 nM (7.65 ± 0.06)
I-12	27.14 nM (7.57 ± 0.03)
I-13	16.31 nM (7.79 ± 0.07)
I-14	40.71 nM (7.39 ± 0.05)
I-15	77.45 nM (7.11 ± 0.12)
I-16	1992.20 nM (5.70 ± 0.14)
I-17	55.75 nM (7.25 ± 0.12)
I-18	60.95 nM (7.22 ± 0.02)
I-19	52.68 nM (7.28 ± 0.15)
I-20	70.9 nM
I-21	33.2 nM
I-22	176 nM
I-23	100.5 nM
I-24	32.4 nM
I-25	10.8 nM
I-26	1352 nM
I-27	383.1 nM
Aripiprazole	5.95 nM (8.23 ± 0.08)

[0187] Remark: data use [³H]-Methylspiperone (0.3-0.5 nM) as the average K_i (pK_i ± SEM) of the competitive binding experiment of radioactive ligands. Wherein, all data of compounds I-1 to 19 are mean ± SEM of three independent determinations (n = 3 independent experiments); compounds I-20 to 27 were tested in a single determination, respectively.

Test example 2: Test of the functional activity of the compounds for dopamine D₂ receptors

[0188] To examine downstream G-protein signaling pathway mediated by dopamine D₂ receptors, on the first day, 6 cm dish was used for transfection with 1 µg of dopamine D₂

receptors, 1 μ g of $G_{\alpha i1}$ containing C-terminal seaweed luciferase ($G_{\alpha i1}$ -Rluc), 1 μ g of $G_{\beta 3}$, 1 μ g of $G_{\gamma 9}$ containing C-terminal green fluorescent protein ($G_{\gamma 9}$ -GFP) and 16 μ L of PEI. At the same time, in order to examine the downstream β -arrestin2 signaling pathway mediated by dopamine D_2 receptors, on the first day, 6 cm dish was used for transfection with 500 μ g of dopamine D_2 receptors containing C-terminal seaweed luciferase (D_2 -Rluc), 500 μ g of G protein-coupled receptor kinase 2 (GRK2), 2500 μ g of β -arrestin2 containing N-terminal green fluorescent protein (GFP2-ARRB2) and 14 μ L of PEI. The next day, the overgrown cells were digested and plated a 96-well plate at the amount of cells contained in a 6 cm culture dish with overgrown cells, and 100 μ L of culture medium was added to each well. On the third day, the drugs were added for test. The 96-well plate was taken out from the cell culture room to remove the culture medium, 40 μ L of the substrate coelenterazine 400a (final concentration of 5 μ M) was added to each well, and then 20 μ L of different drugs were added in turn from left to right to ensure that the final concentration of the drugs decreased gradually from bottom to top, and each treatment was repeated twice. Finally, the prepared samples were loaded on machine for test. The machine reading value reflected the intracellular β -arrestin2 on the membrane and the dissociation of G protein trimer. The former indicated the degree of activation of the β -arrestin2 signaling pathway downstream of the dopamine D_2 receptors, and the latter indicated the degree of activation of the G protein signaling pathway downstream of the dopamine D_2 receptors. Thus, the agonistic effect of various compounds on dopamine D_2 receptors can be revealed. The results are shown in Table 2.

[0189] The results show that compounds I-1 to I-25 all have certain agonistic activity for dopamine D_2 receptors.

Table 2

Compound	$G_{\alpha i1}$ BRET EC_{50}^1 ($E_{max}\%^2 \pm SEM$) ($pEC_{50} \pm SEM$)	β -arrestin2 BRET EC_{50} ($E_{max}\% \pm SEM$) ($pEC_{50} \pm SEM$)
I-1	16.21 nM ($100 \pm 2\%$) (7.79 ± 0.03)	56.23 nM ($100 \pm 2\%$) (7.25 ± 0.05)
I-2	14.79 nM ($101 \pm 2\%$) (7.83 ± 0.03)	48.98 nM ($103 \pm 2\%$) (7.31 ± 0.04)
(+)-I-2	1 nM ($95 \pm 2\%$) (9.07 ± 0.01)	16 nM ($89 \pm 5\%$) (7.80 ± 0.05)

(-)-I-2	3 nM (91 ± 3%) (8.56 ± 0.06)	18 nM (76 ± 2%) (7.74 ± 0.08)
I-3	43.65 nM (92 ± 2%) (7.36 ± 0.03)	64.57 nM (93 ± 1%) (7.19 ± 0.03)
I-4	6.68 nM (80 ± 2%) (8.18 ± 0.15)	71.01 nM (66 ± 2%) (7.15 ± 0.13)
I-5	7.44 nM (83 ± 1%) (8.13 ± 0.07)	53.99 nM (61 ± 1%) (7.27 ± 0.06)
I-6	6.64 nM (86 ± 3%) (8.18 ± 0.08)	61.61 nM (61 ± 2%) (7.21 ± 0.09)
I-7	138.04 nM (104 ± 1%) (6.86 ± 0.02)	275.42 nM (97 ± 1%) (6.56 ± 0.10)
I-8	38.90 nM (94 ± 1%) (7.41 ± 0.01)	109.65 nM (98 ± 1%) (6.96 ± 0.11)
I-9	165.96 nM (92 ± 1%) (6.78 ± 0.04)	147.91 nM (96 ± 1%) (6.83 ± 0.12)
I-10	3.89 nM (80 ± 7%) (8.41 ± 0.21)	6.61 nM (84 ± 1%) (8.18 ± 0.20)
(-)-I-10	1.38 nM (78 ± 1%) (8.86 ± 0.01)	2.75 nM (89 ± 1%) (8.56 ± 0.06)
(+)-I-10	9.55 nM (86 ± 1%) (8.02 ± 0.02)	5.25 nM (90 ± 1%) (8.28 ± 0.06)
I-11	9.33 nM (91 ± 1%) (8.03 ± 0.01)	11.22 nM (87 ± 2%) (7.95 ± 0.05)
I-12	17.38 nM (92 ± 1%) (7.76 ± 0.03)	20.42 nM (89 ± 3%) (7.69 ± 0.08)
I-13	6.74 nM (92 ± 3%) (8.17 ± 0.08)	145.80 nM (48 ± 8%) (6.84 ± 0.12)
I-14	1.67 nM (72 ± 3%) (8.78 ± 0.08)	27.71 nM (41 ± 2%) (7.56 ± 0.17)
I-15	2.65 nM (94 ± 2%) (8.58 ± 0.02)	31.55 nM (80 ± 2%) (7.50 ± 0.05)
I-16	58.88 nM (84 ± 1%) (7.23 ± 0.01)	40.74 nM (90 ± 1%) (7.39 ± 0.04)
I-17	32.65 nM (61 ± 2%) (7.49 ± 0.03)	201.84 nM (38 ± 3%) (6.70 ± 0.03)
I-18	11.0 nM (77 ± 4%) (7.96 ± 0.02)	110 nM (50 ± 2%) (6.96 ± 0.11)
I-19	4.0 nM (71 ± 5%) (8.38 ± 0.15)	29 nM (34 ± 4%) (7.54 ± 0.05)
I-20	10.19 nM (74%)	98.22 nM (88%)
I-21	7.71 nM (77%)	61.90 nM (90%)
I-22	38.05 nM (41%)	91.61 nM (32%)
I-23	54.77 nM (38%)	294.40 nM (36%)
I-24	11.41 nM (38%)	10.43 nM (26%)
I-25	7.48 nM (29%)	9.60 nM (30%)
I-26	7621 nM (antagonistic activity)	Inactive
I-27	1204 nM (antagonistic activity)	1540 nM (antagonistic activity)
Aripiprazole	426.58 (60 ± 1%)	309.03 (58 ± 3%)

	(6.37 ± 0.05)	(6.51 ± 0.10)
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[0190] Remark: all data of compounds I-1 to 19 are mean ± SEM of three independent determinations (n = 3 independent experiments); compounds I-20 to 27 were tested in a single determination, respectively. ¹ EC₅₀ is the concentration of a compound that gives half the maximal response in the experiment. ² The E_{max}% in the bracket indicates the percentage of the maximum response intensity (E_{max}) produced by the compound in the experiment relative to the endogenous ligand dopamine.

Example 3: Test of the affinity of the compounds of the present invention for 5-HT_{2A} receptor

[0191] The affinity of the compounds of the present invention for the 5-HT_{2A} receptors was determined by the method of radioligand competition experiment. In the first step, a cell membrane component containing specific 5-HT_{2A} receptor was prepared. A 10 cm dish was used for transfection with 10 ng of the 5-HT_{2A} receptor and 40 μL of PEI. After 48 hours, the 10 cm dish was taken out from the cell culture room and the cultured cells had expressed the 5-HT_{2A} receptor. A vacuum pump was used to suck off the culture medium, 3 mL of lysis buffer was added to each well, and the cells were placed in a 4 °C freezer for 10 minutes. After the cells were detached, the cells were transferred to a 15 mL centrifuge tube and centrifuged at 1500 rpm for 5 minutes at 4 °C, and the supernatant was discarded. The cell pellet was transferred to a tissue homogenizer, and 3 mL of lysis buffer was added and fully ground until the cells were broken. Then, cell suspension was equally divided into several EP tubes, centrifuged at 4 °C and 12000 rpm for 5 min, and the supernatant was discarded. The precipitate was the cell membrane component containing the 5-HT_{2A} receptor. In the second step, a ligand-receptor binding experiment was performed on HEK-293T membrane component transiently expressing the 5-HT_{2A} receptor. First, a standard binding buffer was added to the cell membrane component containing the 5-HT_{2A} receptor, and the cell membrane was disrupted and resuspended with an electric tissue homogenizer. 30 μL of membrane protein suspension was added to each well of a 96-well plate. Then, 30 μL of different drugs were added to the 96-well plate from left to right to ensure that the final drug concentrations were 10⁻⁵ M, 10⁻⁶ M, 10⁻⁷ M, 10⁻⁸ M, 10⁻⁹ M and 0 M, with two replicates per treatment. Next,

30 μ L [3 H]-ketanserin was added to each well of the 96-well plate. The plate was incubated for 2 hours at room temperature in the dark. Detection. The machine reading value reflected the amount of [3 H]-ketanserin bound on the membrane, and after further data processing, the affinity K_i value of different compounds for 5-HT_{2A} receptor was obtained. The results are shown in Table 3.

Table 3

Compound	K_i , nM ($pK_i \pm SEM$)
I-1	3639.15 (5.44 ± 0.02)
I-2	906.78 (6.04 ± 0.01)
I-10	2371.37 (5.63 ± 0.04)
(-)-I-10	2627.24 (5.58 ± 0.09)
(+)-I-10	2480.28 (5.61 ± 0.09)
Aripiprazole	42.17 (7.38 ± 0.03)

[0192] The results in Table 3 show that compounds I-1, I-2, I-10, (-)-I-10 and (+)-I-10 have very weak affinity for 5-HT_{2A} receptor. Comparing the data in Table 1, the binding selectivity of compounds I-1, I-2, (-)-I-10 to 5-HT_{2A} receptor is more than 100 times, it can be seen that the compounds of the invention have good selectivity for dopamine D₂ receptor.

Test example 3: Test of the pharmacokinetic properties of the compounds of the present invention in mice

1. Test of the pharmacokinetic properties of compound (-)-I-10 administered to C57 male mice by single intragastric administration, intraperitoneal injection and intravenous injection

(1) Purpose of the experiment

[0193] Compound (-)-I-10 was administered in a single dose in C57 male mice, and then blood samples were collected at different time points, the concentration of the compound in mouse plasma was determined by LC-MS/MS and the relevant pharmacokinetic parameters were calculated to investigate the pharmacokinetics of the compound in the mice.

(2) Experimental design

[0194] 27 male C57 mice were provided by Suzhou Zhaoyan Experimental Animal Co., Ltd., and the experiment was carried out according to Table 4 below.

Table 4

Group	Test substance	Administration dosage (mg/kg)	Administration concentration (mg/mL)	Administration volume (mL/kg)	Sample collection	Administration mode	Vehicle
G1	(-)-I-10	1.0	0.2	5.0	Plasma	IP	5%
G2	(-)-I-10	5.0	0.5	10.0	Plasma	PO	DMSO+
G3	(-)-I-10	1.0	0.2	5.0	Plasma	IV	95% normal saline

(3) Sample collection

[0195] 0.030 mL of blood was taken from each animal through the orbit each time and anticoagulated with EDTA-K2, and the collection time points were: 0, 5, 15, 30 min, 1, 2, 4, 6, 8, 24 h after administration of the test substance. Blood samples were placed on ice after collection, and the plasma was separated by centrifugation within 30 minutes (centrifugation conditions: 5000 rpm, 10 minutes, 4 °C) and stored at -80 °C until analysis.

(4) Data processing

[0196] Data acquisition and control system software was Analyst 1.5.1 software (Applied Biosystem). The sample peak integration method of the spectrum was automatic integration; the ratio of the peak area of the sample to the peak area of the internal standard was used as an index, and regression was performed with the concentration of the sample. Regression method: linear regression with a weight factor of 1/X². Pharmacokinetic parameters were analyzed using WinNonlin Professional v6.3 (Pharsight, USA) using non-compartmental models. C_{max} was the measured maximum drug concentration in blood, the area under the drug concentration in blood-time curve AUC (0→t) was calculated by the trapezoidal method, and T_{max} was the time to peak of the drug concentration in blood after administration. The experimental data were expressed by "mean ± standard deviation" (Mean ± ICR, n ≥ 3) or "mean" (Mean, n = 2).

(5) Experimental results

[0197] The pharmacokinetic results of compound (-)-I-10 are shown in the table below. It

can be seen that the compound has good pharmacokinetic properties in C57 male mice. See Table 5 for details.

Table 5

Pharmacokinetic parameters		Intravenous injection	Intraperitoneal injection	Oral administration
Administration dosage	mg·kg ⁻¹	1	1	5
Terminal elimination rate K _{el}	h ⁻¹	0.805	0.886	0.604
Terminal elimination half-life t _{1/2}	h	0.861	0.782	1.15
Time to peak t _{max}	h	-	0.0833	0.0833
Drug peak concentration C _{max}	ng·mL ⁻¹	-	271	558
Area under the drug-time curve AUC _{0-t}	h·ng·mL ⁻¹	211	172	591
Area under the drug-time curve AUC _{0-inf}	h·ng·mL ⁻¹	215	175	596
Clearance CL	mL/min/kg	77.6	-	-
Mean residence time MRT _{PO}	h	1.04	0.770	1.49
Apparent volume of distribution V _{dss}	L/kg	4.86	-	-
Bioavailability F	%	-	81.4	55.9

Remark: "--" indicates not applicable.

2. Test of the brain permeability of compound (-)-I-10 administered to C57 male mice by single intragastric administration, intraperitoneal injection and intravenous injection

[0198] Using the same method as the pharmacokinetic experiment, 0.030 mL of blood was taken from each animal through the orbit at 0.5 and 2.0 hours, respectively, and anticoagulated

with EDTA-K2. Blood samples were placed on ice after collection, and the plasma was separated by centrifugation within 30 minutes (centrifugation conditions: 5000 rpm, 10 minutes, 4 °C) and stored at -80 °C until analysis. After the animal was euthanized by bloodletting, the brain tissue samples were taken, homogenized with 50% methanol according to the body weight of 1 : 3 (m/v = 1 : 3), and stored at -80 °C before homogenate analysis. The drug concentrations in plasma and brain tissue were analyzed by LC/MS/MS and compared. Table 6 shows the drug concentration and ratio of compound (-)-I-10 in plasma and brain tissue at 0.5 and 2.0 h.

Table 6

	Intravenous injection 1 mg/kg	Intraperitoneal injection 1 mg/kg	Oral administration 5 mg/kg
Drug concentration at 0.5 h in brain (ng/mL)	219 ± 21	193 ± 13	346 ± 217
Drug concentration at 0.5 h in plasma (ng/mL)	133 ± 19	124 ± 15	231 ± 153
Brain/blood concentration ratio at 0.5 h	1.65	1.56	1.50
Drug concentration at 2.0 h in brain (ng/mL)	77.0 ± 7.0	42.7 ± 4.0	169 ± 23
Drug concentration at 2.0 h in plasma (ng/mL)	24.9 ± 5.0	13.8 ± 2.7	95 ± 16
Brain/blood concentration ratio at 2.0 h	3.09	3.10	1.78

Test example 4: Pharmacodynamic test of compounds on schizophrenia-like animal behavioral model

1. Open field athletic ability test

[0199] Experimental method: The experimental animals were C57B6 male mice, n = 8 in each group. This model used C57B6 mice as experimental animals. The behavioral representation of hyperkinesia in open field environment in mice was induced by acute injection of NMDA antagonist MK801 and modeled to test the inhibitory effect of different

compounds on hyperkinesia phenotype induced by MK801. All mouse behavior experiments were carried out during the light period of the mice, and the whole experiment was recorded by the camera and automatic tracking and data statistics were carried out by behavioral tracking software. The compound was administered by intraperitoneal injection. Immediately after the injection, the mice entered the open field and their movement trajectories began to record. After 30 minutes, the mice received 0.2 mg/kg of MK801 by intraperitoneal injection and returned to the open field immediately after administration and the movement trajectories were further recorded for 120 min. The accumulative moving distance of the mice was counted at a data sampling point every five minutes. Data statistics were carried out using Student-t-test, $p < 0.05$ was *, $p < 0.01$ was **, $p < 0.001$ was ***, $p < 0.0001$ was ****. The total moving distance of the mice in 0-45 minutes under the combined action of different doses of (-)-I-10 and MK801 (0.2 mg/kg) is shown in Table 7.

[0200] The test results of open field athletic ability show that compound (-)-I-10 at 0.4/0.1/0.025 mg/kg could significantly inhibit the improvement of athletic ability of the mice induced by MK801.

Table 7

Administration condition	Normal saline	MK801 (0.2 mg/kg)				
	Normal saline	Normal saline	(-)-I-10 0.4 mg/kg	(-)-I-10 0.1 mg/kg	(-)-I-10 0.025 mg/kg	(-)-I-10 0.00625 mg/kg
45 minutes moving distance (cm)	3180 ± 406.4	13335 ± 930	2644 ± 294.2	3833 ± 272.7	8643 ± 668.3	11626 ± 1820

2. Animal "depression-like" behavior test

[0201] The experimental animals were C57B6 male mice, $n = 8$ in each group. Firstly, the C57B6 mice were induced to develop depression-related behavioral representations by restraining the mice for 5 hours, and then the effects of the compounds on their "depression-like" behaviors were determined by tail suspension and forced swimming experiments. The

specific experimental procedure was as follows. First, the mice were restrained using a mouse fixator for tail vein injection. During the restraint process, all behavioral abilities of the mice were restricted under the condition of ensuring minimal pain to the mice. The mice were administered intraperitoneally once before and after restraint, respectively. After the restraint, the mice returned to the cage to recover for 30 minutes. After the 30 minutes, the mice in different groups were subjected to tail suspension or forced swimming to detect their "depression-like" behavior, respectively.

[0202] Tail suspension experiment: the tip of the tail of the mouse was fixed on the suspension rod of the iron stand by adhesive tape, and the mouse remained in the hanging position for 6 minutes. The first 2 minutes was the adaptation period, and no data collection was performed, and the time of the intermittent immobility behavior of the mouse was recorded in the next 4 minutes. The duration of this immobility state was used to measure the degree of behavioral despair in the mouse. Data statistics were carried out using Student-t-test, $p < 0.05$ was *, $p < 0.01$ was **, $p < 0.001$ was ***, $p < 0.0001$ was ****.

[0203] Forced swimming experiment: the mouse was placed in a 5 L glass beaker filled with water, the water surface height was 15 cm, and the mouse needed to swim continuously in the beaker for 6 minutes. The first two minutes was the adaptation period and no data collection was performed. The time of the intermittent immobility behavior of the mouse was recorded in the next four minutes, and the immobility behavior of the mouse was defined as: the mouse float passively on the surface of the water without movement, with only small local movements required to maintain afloat. The duration of this immobility state was used to measure the degree of behavioral despair in the mouse. Data statistics were carried out using Student-t-test, $p < 0.05$ was *, $p < 0.01$ was **, $p < 0.001$ was ***, $p < 0.0001$ was ****. The results of statistical data of restrained and unrestrained mouse tail suspension experiment and forced swimming experiment are shown in Table 8.

[0204] The test results of "depression-like" behavior show that compound (-)-I-10 at 0.4 mg/kg and 0.1 mg/kg could significantly inhibit the restraint-induced "depression-like" behavior.

Table 8

Treatment condition		Unrestrained	Restraint for five hours				
		Normal saline	Normal saline	(-)-I-10 10 0.4 mg/kg	(-)-I-10 10 0.1 mg/kg	(-)-I-10 10 0.025 mg/kg	(-)-I-10 0.00625 mg/kg
Immobility time (seconds)	Tail suspension experiment	74.81 ± 11.00	125.4 ± 8.083	72.66 ± 6.486	90.31 ± 10.26	101.8 ± 10.85	132.6 ± 5.708
	Forced swimming experiment	25.40 ± 6.387	81.62 ± 3.242	22.40 ± 5.272	42.76 ± 6.698	56.59 ± 9.965	76.09 ± 5.943

3. Old and novel object recognition

[0205] The experimental animals were C57B6 male mice, n = 8 in each group. Firstly, mice were intraperitoneally injected with MK801 at 0.3 mg/kg twice a day for seven consecutive days to establish a recognition impairment model, and control mice were intraperitoneally injected with normal saline containing the same amount of DMSO. The mice then underwent a seven-day recovery in home cages. After the recovery period expired, the old and novel object distinguishing experiment was performed on the mice to determine the effect of the compounds on the recognition ability of the mice.

[0206] Novel and old object recognition experiment: The experiment was carried out in a low-light environment. Before the experiment started, the mice were placed in the experimental field in advance and adapted to the environment for one hour in the low-light environment. After environmental adaptation, the mice were administered intraperitoneally. 30 minutes after the administration, the mice were put in an open field (diameter of the open field of 40 cm) in which two identical objects had been placed beforehand. The mice explored freely in the open field for 10 minutes, and then were removed from the open field and returned to the cage. After a one-hour interval, the mice returned to the open field, where an old object and a novel object were placed in advance in the same position in the open field. Again, the mice explored freely in the open field for 10 minutes. The distinguishing time of the mice for

the old object and the novel object was recorded separately and the distinguishing index was calculated. The calculation method of the distinguishing index was (exploration time for novel object - exploration time for old object) / (exploration time for novel object + exploration time for old object). Object exploration by the mice was defined as sniffing, climbing, and direct contact with the object. Data statistics were carried out using Student-t-test, $p < 0.05$ was *, $p < 0.01$ was **, $p < 0.001$ was ***, $p < 0.0001$ was ****. Table 9 shows the statistical data results of old and novel object distinguishing index.

[0207] The results of old and novel object distinguishing show that compound (-)-I-10 at 0.1 mg/kg and 0.025 mg/kg could significantly improve MK801-induced recognition impairment in mice.

Table 9

Administration condition	Normal saline	MK801 (0.3 mg/kg) 14 injections in 7 days; 7 days recovery modeling			
	Normal saline	Normal saline	(-)-I-10 0.1 mg/kg	(-)-I-10 0.025 mg/kg	(-)-I-10 0.00625 mg/kg
Distinguishing index (DI)	0.3032 ± 0.04355	0.08611 ± 0.01956	0.2789 ± 0.04036	0.3320 ± 0.06367	0.05971 ± 0.03658

4. Morris water maze

[0208] The experimental animals were C57B6 male mice, $n = 8$ in each group. Firstly, mice were intraperitoneally injected with 0.2 mg/kg of MK801 twice a day for ten consecutive days to establish a recognition impairment model, and control mice were intraperitoneally injected with normal saline containing the same amount of DMSO, and then the mice were subjected to the Morris water maze test.

[0209] Experimental setup: Experiments were conducted in a blue circular water reservoir with a diameter of 130 cm. The reservoir was filled with pure water about 30 cm deep. The reservoir was divided into 4 fan-shaped areas by a cross, and the escape platform (6 cm in diameter) was located in the center of one of the fan-shaped areas and was hidden 0.5 cm below the water surface. The position where the mice entered the water was fixed at the edges of

the other three fan-shaped areas. The position where the mice entered the water was basically consistent with the straight-line distance of the platform.

[0210] Acquisition phase: 30 minutes before the start of the experiment, the mice were administered intraperitoneally. After the experiment started, the mouse was put into the water with its head facing the reservoir wall, and the placement position was randomly selected from one of the three starting positions in the east, west, and south, and the underwater hidden platform was located in the north quadrant. The time taken by the mouse to find the underwater platform was recorded. If the mouse did not find the platform within 1 minute, the mouse was guided to the platform and stayed on the platform for 30 seconds. Then the above steps were repeated 2 times at another starting position. Each animal was trained three times a day for 5 consecutive days.

[0211] Probe trial: on the second day after the last acquisition phase, the platform was removed and a 60-second probe trial began. The animal was placed in the water from the opposite side of the original platform quadrant. The number of times the animal crossed the original platform location was recorded as a detection index of spatial memory. Data statistics were carried out using Student-t-test, $p < 0.05$ was *, $p < 0.01$ was **, $p < 0.001$ was ***, $p < 0.0001$ was ****. For water maze acquisition phase, the results of daily platform exploration time are shown in Table 10.

[0212] The results of Morris water maze show that compound (-)-I-10 at 0.1 mg/kg could significantly improve MK801-induced spatial recognition impairment in mice; compound (-)-I-10 at 0.1 mg/kg and 0.025 mg/kg could significantly improve MK801-induced memory impairment in mice.

Table 10

Administration condition		Normal saline	MK801 (0.2 mg/kg) 20 injections in 10 days for modeling			
		Normal saline	Normal saline	(-)-I-10 0.1 mg/kg	(-)-I-10 0.025 mg/kg	(-)-I-10 0.00625 mg/kg
Platform	First	162.9 ±	160.3 ±	146.2 ±	161.2 ±	173.0 ±

exploration time (seconds)	day	9.672	6.917	9.984	9.932	5.086
	Second	130.3 ±	151.7 ±	128.5 ±	154.0 ±	145.3 ±
	day	15.86	10.57	16.33	11.34	14.15
	Third	95.23 ±	128.3 ±	88.38 ±	96.66 ±	108.1 ±
	day	18.99	11.41	11.66	20.94	18.03
	Fourth	70.60 ±	116.7 ±	68.62 ±	96.66 ±	87.77 ±
	day	13.36	19.28	10.98	19.27	13.59
	Fifth	48.16 ±	109.5 ±	62.86 ±	92.23 ±	97.94 ±
	day	6.160	18.62	12.34	12.25	14.27
Administration condition	Normal saline	MK801 (0.2 mg/kg) 20 injections in 10 days for modeling				
	Normal saline	Normal saline	(-)-I-10 0.1 mg/kg	(-)-I-10 0.025 mg/kg	(-)-I-10 0.00625 mg/kg	
Times of crossing	6.600 ±	1.900 ±	5.800 ±	4.500 ±	2.600 ±	
platform area	0.4989	0.3480	0.7860	0.4282	0.3712	

5. Freezing behavior test

[0213] Experimental method: The experimental animals were C57B6 male mice, n = 8 in each group. Mice were first injected with different compounds, and after a certain period of time (30 min or 60 min), the mice were in an upright and unnatural state by placing their forelimbs on a high glass hanging rod (about 5 cm from the ground). Then the time for the mice to maintain this state was measured, and the length of time was used to determine the freezing effect of the drug on the mice. The test results of the freezing behavior of the mice 30 and 60 minutes after injection of different drugs are shown in Table 11.

[0214] The freezing behavior test show that compound (-)-I-10 at 10 mg/kg has no freezing induction effect on mice.

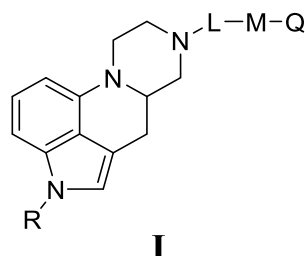
Table 11

	Freezing time (seconds)	
Time after administration (minutes)	Haloperidol (10 mg/kg)	(-)-I-10 (10 mg/kg)

30 minutes	61.05 ± 3.239	2.194 ± 0.2524
60 minutes	53.19 ± 2.443	2.165 ± 0.3256

what is claimed is:

1. A compound as shown in formula I, a pharmaceutically acceptable salt thereof, a solvate thereof or a solvate of the pharmaceutically acceptable salt thereof:



wherein L is C₁₋₁₀ alkylene, C₂₋₁₀ alkenylene, C₂₋₁₀ alkynylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH-, -CH₂-, -(CH-OH)- or -C(=O)-;

Q is C₆₋₁₈ aryl, C₆₋₁₈ aryl substituted with one or more Q¹⁻¹, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²; the heteroatoms in the 5 to 10 membered heteroaryl are one or more of N, S or O, and the number is 1, 2 or 3; the heteroatoms in the 5 to 10 membered heteroaryl substituted with one or more Q¹⁻² are one or more of N, S or O, and the number is 1, 2 or 3;

Q¹⁻¹ is independently halogen or C₁₋₄ alkyl;

Q¹⁻² is independently C₁₋₄ alkyl, oxo or hydroxyl;

R¹ and R² are independently -NR¹⁻¹R¹⁻², 3 to 6 membered heterocycloalkyl, C₆₋₁₈ aryl, C₆₋₁₈ aryl substituted with one or more R¹⁻³, 5 to 10 membered heteroaryl or 5 to 10 membered heteroaryl substituted with one or more R¹⁻⁴; the heteroatoms in the 3 to 6 membered heterocycloalkyl are one or more of N, S or O, and the number is 1, 2 or 3; the heteroatoms in the 5 to 10 membered heteroaryl are one or more of N, S or O, and the number is 1, 2 or 3; the heteroatoms in the 5 to 10 membered heteroaryl substituted with one or more R¹⁻⁴ are one or more of N, S or O, and the number is 1, 2 or 3;

R¹⁻¹, R¹⁻², R¹⁻³ and R¹⁻⁴ are independently C₁₋₄ alkyl;

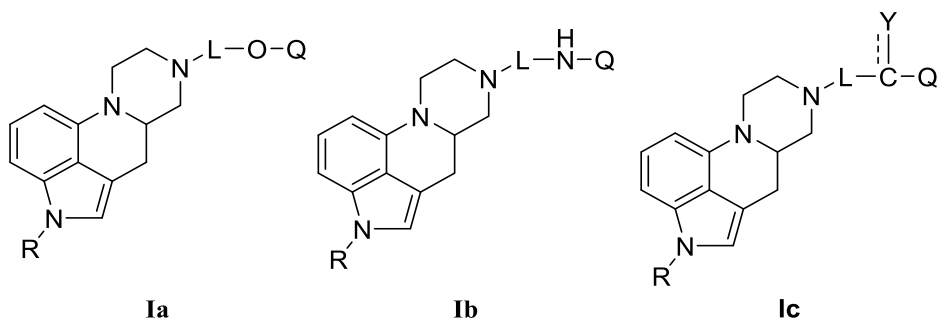
R is hydrogen or C₁₋₄ alkyl.

2. The compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to claim 1, wherein the compound as shown in formula I is described in any one of the following

situations:

situation 1:

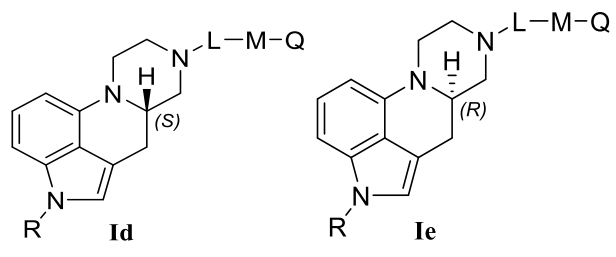
the compound as shown in formula I is a compound as shown in formula Ia, Ib or Ic:



in formula Ic, " $\diagup$ " represents a double bond or a single bond; Y is hydrogen, hydroxyl or oxygen;

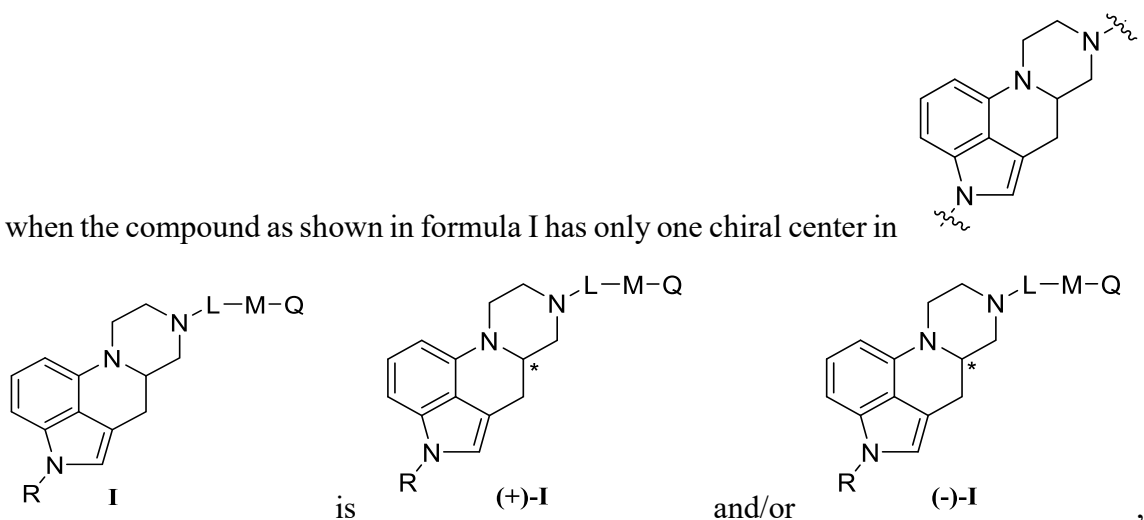
situation 2:

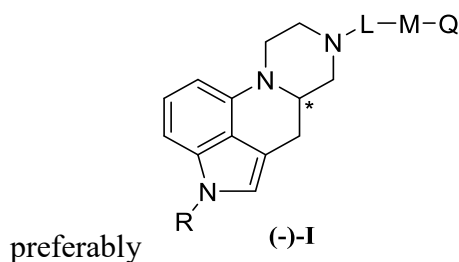
the compound as shown in formula I is a compound as shown in formula Id and/or Ie, preferably a compound as shown in formula Id;



situation 3:

when the compound as shown in formula I has only one chiral center in





3. The compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to claim 1, wherein the compound as shown in formula I is described in any one of the following schemes:

scheme 1:

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH- or -CH₂-;

Q is C₆₋₁₈ aryl, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²;

scheme 2:

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH- or -CH₂-;

Q is C₆₋₁₈ aryl, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²;

when M is -O-, Q¹⁻² is C₁₋₄ alkyl or hydroxyl;

when the heteroatom in the 5 to 10 membered heteroaryl is O, the number of heteroatoms in the 5 to 10 membered heteroaryl is 1;

scheme 3:

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

M is -O-, -NH- or -CH₂-;

Q is C₆₋₁₈ aryl, 5 to 10 membered heteroaryl, 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², -C(=O)R¹ or -S(=O)₂R²;

when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₁₋₆ alkylene in the -C₁₋₆ alkylene-C₃₋₆ cycloalkylene- is ethylene;

scheme 4:

L is C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

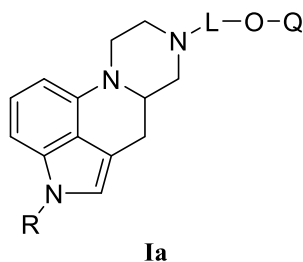
M is -O- or -NH-;

Q is -C(=O)R¹ or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

R¹ is -NR¹⁻¹R¹⁻²;

scheme 5:

the molecular structure of formula I is as shown in formula Ia:



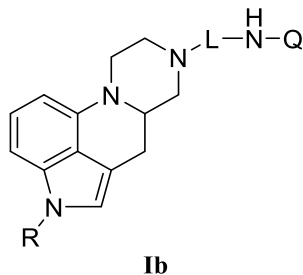
L is C₁₋₁₀ alkylene or C₂₋₁₀ alkenylene;

Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹, 5 to 10 membered heteroaryl or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

Q¹⁻¹ is halogen;

scheme 6:

the molecular structure of formula I is as shown in formula Ib:



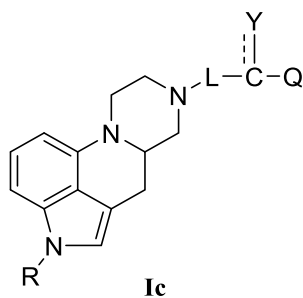
L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

Q is -C(=O)R¹ or -S(=O)₂R²;

R¹ and R² are independently -NR¹⁻¹R¹⁻², 3 to 6 membered heterocycloalkyl, C₆₋₁₈ aryl or 5 to 10 membered heteroaryl;

scheme 7:

the molecular structure of formula I is as shown in formula Ic:



" $\diagup$ " represents a double bond or a single bond;

Y is hydrogen, hydroxyl or oxygen;

L is C₁₋₁₀ alkylene;

Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹ or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

Q¹⁻¹ is halogen;

Q¹⁻² is independently C₁₋₄ alkyl or oxo;

scheme **8**:

L is C₁₋₁₀ alkylene, C₂₋₁₀ alkenylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

when M is -(CH-OH)- or -C(=O)-, R is hydrogen;

scheme **9**:

L is C₁₋₁₀ alkylene;

M is -O-;

Q is 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

scheme **10**:

L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-;

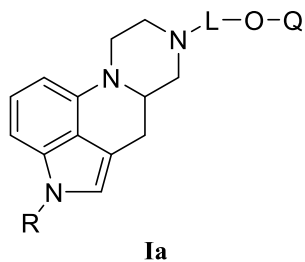
M is -NH-;

Q is -C(=O)R¹;

R¹ is -NR¹⁻¹R¹⁻²;

scheme **11**:

the molecular structure of formula I is as shown in formula Ia:

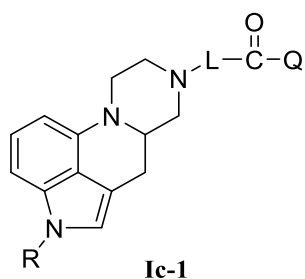


L is C₁₋₁₀ alkylene or C₂₋₁₀ alkenylene;

Q is 5 to 10 membered heteroaryl, or 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

scheme **12**:

the molecular structure of formula I is as shown in formula Ic-1:



L is C₁₋₁₀ alkylene;

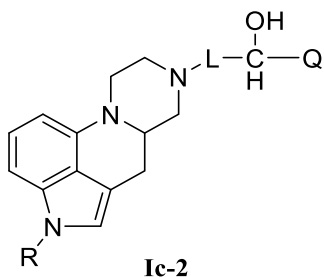
Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹;

Q¹⁻¹ is halogen;

R is hydrogen;

scheme **13**:

the molecular structure of formula I is as shown in formula Ic-2:



L is C₁₋₁₀ alkylene;

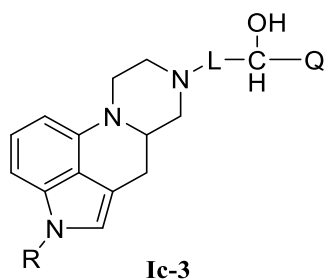
Q is C₆₋₁₈ aryl substituted with one or more Q¹⁻¹;

Q¹⁻¹ is halogen;

R is hydrogen;

scheme **14**:

the molecular structure of formula I is as shown in formula Ic-3:

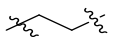
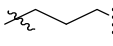
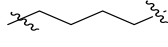
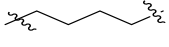


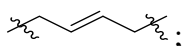
L is C₁₋₁₀ alkylene;

Q is 5 to 10 membered heteroaryl substituted with one or more Q¹⁻²;

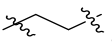
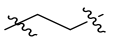
Q¹⁻¹ is C₁₋₄ alkyl or oxo;

R is hydrogen.

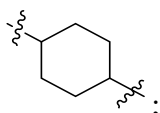
4. The compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to claim 1, wherein when L is C₁₋₁₀ alkylene, the C₁₋₁₀ alkylene is methylene, ethylene, n-propylene, isopropylene, n-butylene, isobutylene or tert-butylene, preferably , , or , more preferably ;

and/or, when L is C₂₋₁₀ alkenylene, the C₂₋₁₀ alkenylene is C₂₋₄ alkenylene, preferably ;

and/or, when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₁₋₆ alkylene is connected to N, and the C₃₋₆ cycloalkylene is connected to Q;

and/or, when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₁₋₆ alkylene in the -C₁₋₆ alkylene-C₃₋₆ cycloalkylene- is methylene, ethylene, n-propylene, isopropylene, n-butylene, isobutylene or tert-butylene, preferably methylene or , more preferably ;

and/or, when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the C₃₋₆ cycloalkylene in the -C₁₋₆ alkylene-C₃₋₆ cycloalkylene- is cyclopropylene, cyclobutylene, cyclopentylene or

cyclohexylene, preferably ;

and/or, when Q is C₆₋₁₈ aryl, the C₆₋₁₈ aryl is phenyl, naphthyl, anthracenyl or phenanthryl, preferably phenyl;

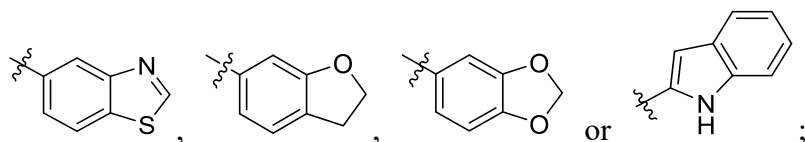
and/or, when Q is C₆₋₁₈ aryl substituted with Q¹⁻¹, the C₆₋₁₈ aryl is phenyl, naphthyl,

anthracenyl or phenanthryl, preferably phenyl;

and/or, when Q is C₆₋₁₈ aryl substituted with Q¹⁻¹, the number of Q¹⁻¹ is 1 or 2;

and/or, when Q¹⁻¹ is halogen, the halogen is F, Cl, Br or I, preferably F;

and/or, when Q is 5 to 10 membered heteroaryl, the 5 to 10 membered heteroaryl is 9 or 10 membered heteroaryl, and the number of heteroatoms is 1 or 2, more preferably



and/or, when Q is 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², the 5 to 10 membered heteroaryl is 9 or 10 membered heteroaryl, the heteroatom is N and/or O, the number of heteroatoms is 1 or 2, preferably tetrahydroquinolyl, quinolinyl, benzoxazolyl, benzisoxazolyl or tetrahydropyridopyrimidinyl;

and/or, when Q is C₆₋₁₈ aryl substituted with Q¹⁻², the number of Q¹⁻² is 1 or 2;

and/or, when Q¹⁻² is C₁₋₄ alkyl, the C₁₋₄ alkyl is methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl or tert-butyl, preferably methyl;

and/or, when R¹ and R² are independently 3 to 6 membered heterocycloalkyl, the 3 to 6 membered heterocycloalkyl is piperidinyl or pyrrolidinyl, preferably pyrrolidinyl;

and/or, when R¹ is 3 to 6 membered heterocycloalkyl, the 3 to 6 membered heterocycloalkyl is connected to carbonyl through a heteroatom;

and/or, when R¹ and R² are independently C₆₋₁₈ aryl, the C₆₋₁₈ aryl is phenyl, naphthyl, anthracenyl or phenanthryl, preferably phenyl;

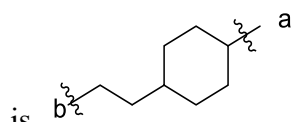
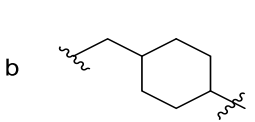
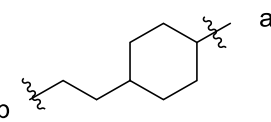
and/or, when R¹ and R² are independently C₆₋₁₈ aryl substituted with R¹⁻³, the C₆₋₁₈ aryl is phenyl, naphthyl, anthracenyl or phenanthryl, preferably phenyl;

and/or, when R¹ and R² are independently 5 to 10 membered heteroaryl, the 5 to 10 membered heteroaryl is 9 or 10 membered heteroaryl, the heteroatom is N, and the number of heteroatoms is 1 or 2, preferably indolyl;

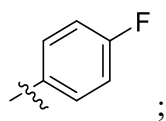
and/or, when R¹⁻¹, R¹⁻², R¹⁻³ and R¹⁻⁴ are independently C₁₋₄ alkyl, the C₁₋₄ alkyl is methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl or tert-butyl, preferably methyl;

and/or, when R is C₁₋₄ alkyl, the C₁₋₄ alkyl is methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl or tert-butyl, preferably methyl.

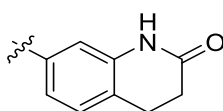
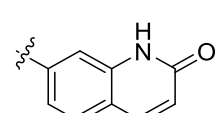
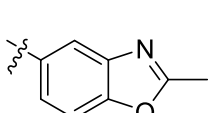
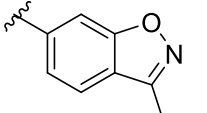
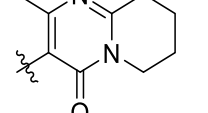
5. The compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to claim 4, wherein when L is -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-, the -C₁₋₆ alkylene-C₃₋₆ cycloalkylene-

is  or , preferably , wherein a end is connected to Q, and b end is connected to N;

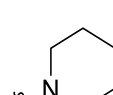
and/or, when Q is C₆₋₁₈ aryl substituted with Q¹⁻¹, the C₆₋₁₈ aryl substituted with Q¹⁻¹ is

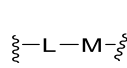
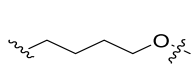
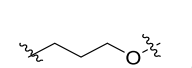
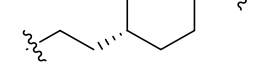
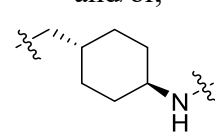
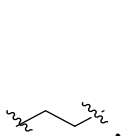
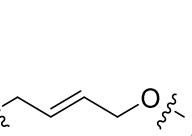
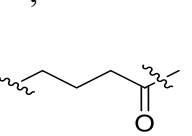
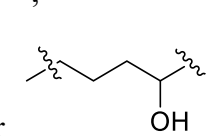


and/or, when Q is 5 to 10 membered heteroaryl substituted with one or more Q¹⁻², the 5 to

10 membered heteroaryl substituted with one or more Q¹⁻² is ,
, ,  or ;

and/or, when R¹ is 3 to 6 membered heterocycloalkyl, the 3 to 6 membered

heterocycloalkyl is  or ;

and/or,  is , , ,
, , ,  or .

6. The compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to claim 1, wherein L is C₁₋₁₀ alkylene, C₂₋₁₀ alkenylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene, preferably C₁₋₁₀ alkylene or -C₁₋₆ alkylene-C₃₋₆ cycloalkylene;

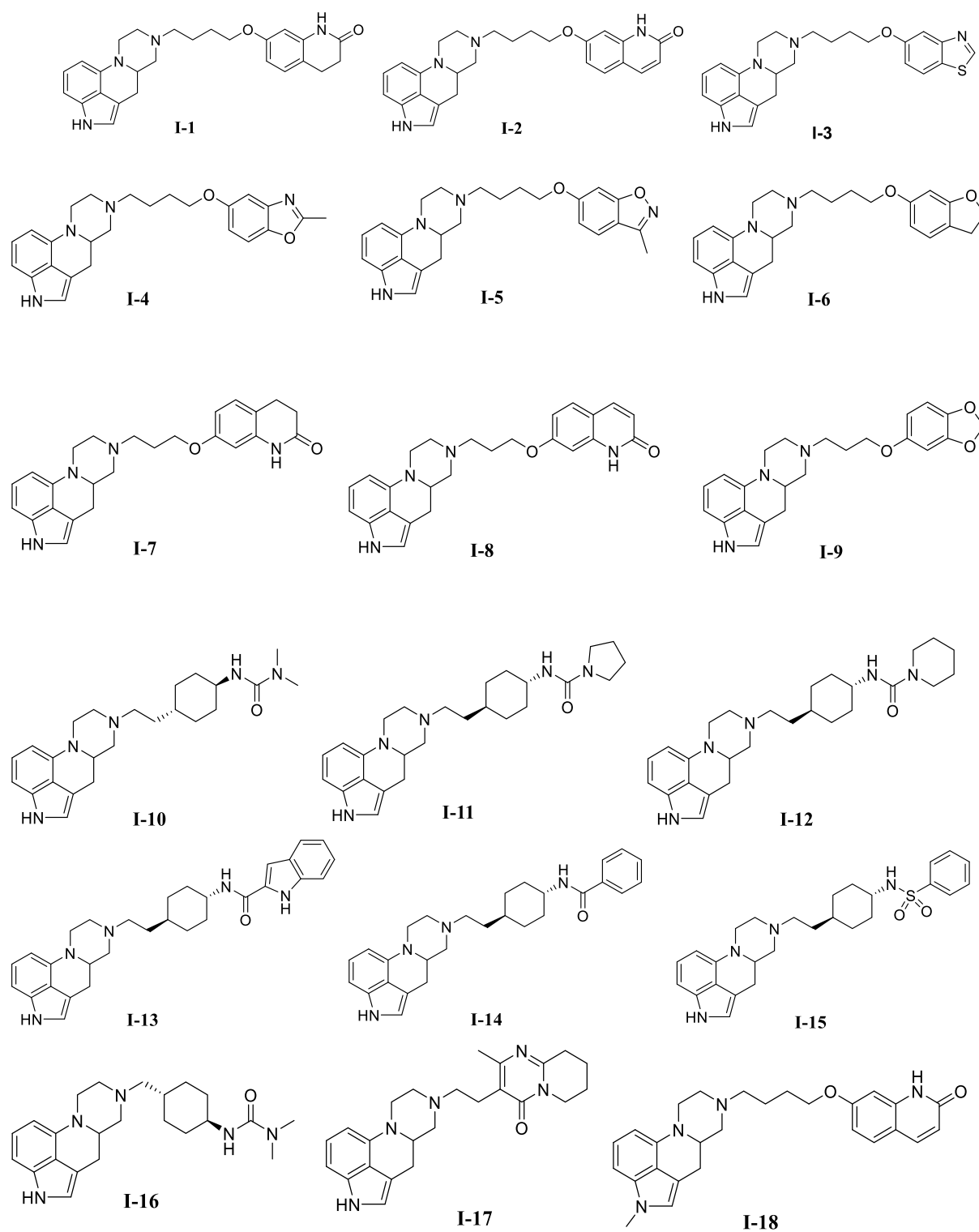
and/or, M is -O-, -NH- or -CH₂-;

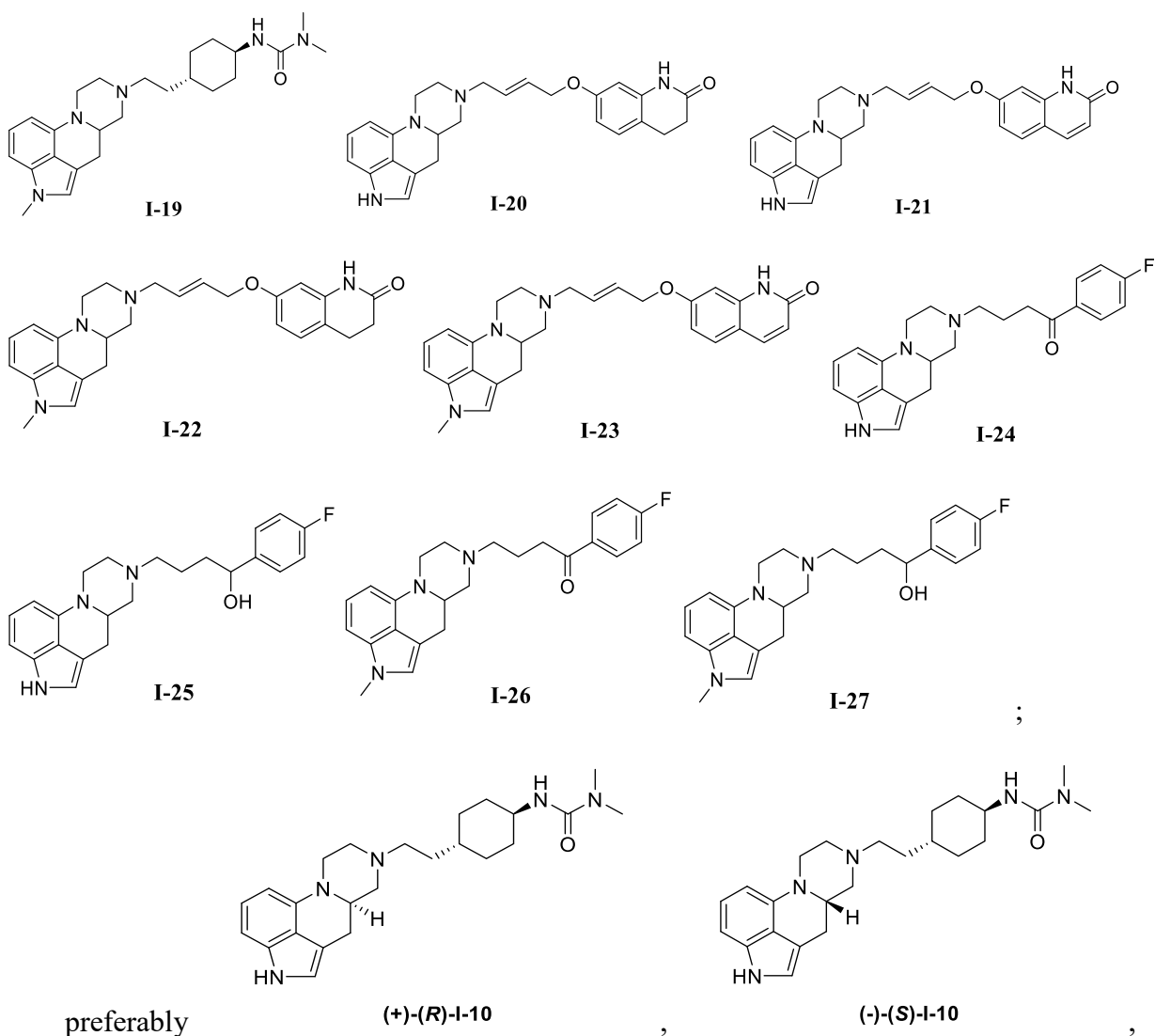
and/or, Q¹⁻¹ is halogen;

and/or, R¹ is -NR¹⁻¹R¹⁻², 3 to 6 membered heterocycloalkyl, C₆₋₁₈ aryl or 5 to 10 membered

heteroaryl, preferably -NR¹⁻¹R¹⁻², 3 to 6 membered heterocycloalkyl or C₆₋₁₈ aryl;
and/or, R is hydrogen.

7. The compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to claim 1, wherein the compound as shown in formula I is any one of the following compounds:



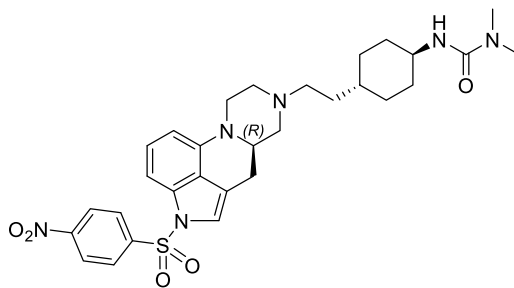


preferably **(+)-(R)-I-10** , **(-)-(S)-I-10** ,
 “ **I-2** with optical rotation of $+50.33^\circ$ and/or retention time of 5.805 min under the following chiral preparation conditions” or

“ **I-2** with optical rotation of -45.00° and/or retention time of 7.60 min under the following chiral preparation conditions”;

the chiral preparation conditions: chromatographic column: chiral column CHIRALCEL OD, column volume: 5.0 cm x 25 cm, 10 μ m filler; mobile phase: MeOH/diethylamine = 100/0.1; flow rate: 30 mL/min; wavelength: UV 214 nm; temperature: 38°C.

8. A crystal as shown in the formula pNs-(+)-I-10, wherein the crystal system of which belongs to the triclinic crystal system, the P1 space group, and the unit cell parameters are $a = 9.315\text{\AA}$, $b = 6.564\text{\AA}$, $c = 23.792\text{\AA}$, $\alpha = 90.15^\circ$, $\beta = 99.368^\circ$, $\gamma = 90.25^\circ$;



pNs-(+)-I-10

9. A pharmaceutical composition, which comprises the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to any one of claims 1 to 7, or the crystal as shown in formula pNs-(+)-I-10 according to claim 8 and a pharmaceutical adjuvant.

10. A use of substance **A**; the use is a use in the preparation of dopamine D2 receptor agonists, drugs for treating and/or preventing diseases related to dopamine D2 receptors, or drugs for treating and/or preventing disease **M**;

the disease **M** is one or more of a neurodegenerative disease, a mental disorder, and a metabolic disease related to a mental disorder;

the substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to any one of claims 1 to 7, the crystal as shown in formula pNs-(+)-I-10 according to claim 8, or the pharmaceutical composition according to claim 9.

11. A method for preventing or treating diseases related to dopamine D2 receptors or disease **M**, which comprises administering to a subject a therapeutically effective amount of substance **A**;

the disease **M** is one or more of a neurodegenerative disease, a mental disorder, and a metabolic disease related to a mental disorder;

the substance **A** is the compound as shown in formula I, the pharmaceutically acceptable salt thereof, the solvate thereof or the solvate of the pharmaceutically acceptable salt thereof according to any one of claims 1 to 7, the crystal as shown in formula pNs-(+)-I-10 according

to claim 8, or the pharmaceutical composition according to claim 9;

in the method, the disease **M** is preferably Parkinson's disease, Alzheimer's disease or dementia, schizophrenia, bipolar disorder, depression, hyperactivity, restless legs syndrome, Huntington's disease, male erectile dysfunction, prolactinoma, or drug addiction.