

THRB RECEPTOR AGONIST COMPOUND AND PREPARATION METHOD AND USE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Chinese Patent Application No. 201811527414.4, filed December 13, 2018, the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] The present invention relates to the field of pharmaceutical syntheses, and particularly to a compound that can serve as a novel agonist of THR β receptors, and a preparation method and use thereof.

BACKGROUND

[0003] Thyroid hormone (TH) is synthesized in the thyroid gland in response to the thyroid stimulating hormone (TSH) secreted by the pituitary. Thyroxine plays a rather important role in regulating body growth, development, metabolism, and body balance. Thyroid hormones mainly include two types: 3,5,3'-triiodo-L-thyroxine (T3) and thyroxine (T4). Human bodies mainly secrete T4. In peripheral organs, T4 is transformed by deiodinase into T3 having greater activity. T3 and T4 produced by the thyroid gland are under negative feedback control. Thyrotropin (TSH) is responsible for the normal thyroid function and thyroid hormone secretion. Thyrotropin is synthesized in the anterior pituitary gland, and its secretion is controlled by the thyroid releasing hormone (TRH) synthesized in the hypothalamus.

[0004] Thyroid hormones function by binding to the thyroid hormone receptors (THR). The thyroid hormone receptor belongs to a family of nuclear receptors and regulates the target gene expressions. Thyroid hormone receptors include two different subtypes, i.e., THR α and THR β . THR α is mainly distributed in cardiac tissues and plays an important role in regulating heart function. The THR β subtype is mainly expressed in the liver and the pituitary, and regulates cholesterol metabolism and thyrotropin secretion.

[0005] At normal levels, thyroid hormones THs maintain body weight, metabolic rate, body temperature, and mood, and are responsible for regulating serum cholesterol. Attempts have been

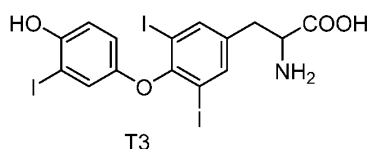
made to use thyroid hormones to regulate serum cholesterol. However, given the possible side effects on the heart from taking natural thyroid hormone (e.g., tachycardia and arrhythmia, heart failure, and thyroid axis function, muscle metabolism, and osteoporosis,) thyroid hormones are unsuitable for treating high cholesterol and obesity. Research results regarding the study of animals with selective knock-out of the THR gene, and research results of some selective THR ligands show that the side effects on the heart caused by these thyroid hormones can be attributed to THR α .

[0006] The pathway of the thyroid hormone receptor regulates metabolism of lipids, including cholesterol, triglyceride, and lipoprotein. It has been clinically shown that lowering the low-density cholesterol can reduce the incidence of cardiovascular diseases.

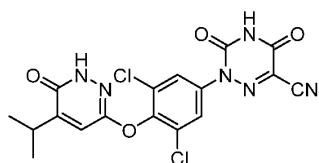
[0007] Non-alcoholic fatty liver disease (NAFLD) is also a type of metabolic disorder disease caused by excessive accumulation of triglycerides in the liver, which can further cause liver cell damage and inflammation, leading to non-alcoholic steatohepatitis (NASH). NASH patients usually have type 2 diabetes, high cholesterol, hyperlipaemia, and obesity along with NASH. Furthermore, they are more likely to develop hepatocirrhosis, liver failure and, eventually, liver cancer. In the field, currently drugs that effectively treat NASH are limited. Given the thyroid hormone's function of regulating the lipid metabolism, the thyroid receptor pathway becomes a potential target for the treatment of NASH and NAFLD. It has been proven in animal bodies that thyroid hormone analogues can significantly reduce fatty levels in animal livers.

[0008] Selective THR β agonists can be used to avoid side effects on the heart that result from conventional THR receptor agonists, and selectively to only activate THR β , thereby improving cell lipid metabolism, and achieve the function of lowering cholesterol and blood fat. However, selective THR β agonists may also inhibit the thyroid axis, leading to depression, fatigue, osteoporosis, and other side effects. Therefore, it is desired to develop a selective THR β agonist to activate THR β , but to also reduce the inhibition of the thyroid axis, so as to avoid the side effects accompanying the thyroid axis inhibition.

[0009] Patents such as WO03094845, WO2007009913, WO2010122980, and WO2011038207 reveal some THR receptor agonists. Structures of these agonists are almost all designed and developed based on the natural ligand T3 of the THR receptor. Based on such background, it is still desired to develop selective THR β receptor agonists which not only have the beneficial therapeutic effects of thyroid hormones, but also avoid side effects affecting the heart.



[0010] Structural modification is carried out in the present invention also on the basis of the natural ligand T3 of the THR receptor. The present inventors unexpectedly found that, most of the modified compounds maintain good agonistic activity toward the THR β receptor, and some compounds also have improved selectivity toward THR α as compared with **Comparative compound 53** in the reference documents (“Discovery of 2-[3,5-Dichloro-4-(5-isopropyl-6-oxo-1,6-dihydropyridazin-3-yloxy)phenyl]-3,5-dioxo-2,3,4,5-tetrahydro[1,2,4]triazine-6-carbonitrile (MGL-3196), a Highly Selective Thyroid Hormone Receptor β Agonist in Clinical Trials for the Treatment of Dyslipidemia,” Martha et al., *Journal of Medicinal Chemistry*, 2014, 3912-3923). At the same time, some compounds of the present invention also show very desirable pharmacokinetic properties. The pharmacokinetic properties of some preferred compounds are significantly better than those of the comparative compound, thus improving the properties of the finished drug.

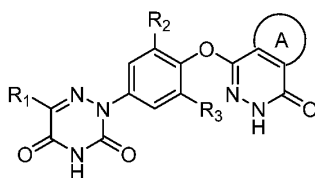


Comparative Compound 53

SUMMARY

[0011] In order to solve the above technical problem, the present invention employs the following technical solutions:

[0012] According to one aspect of the present invention, the present invention provides a compound represented by the following Formula (I) and a pharmaceutically acceptable salt thereof,



(I)

wherein,

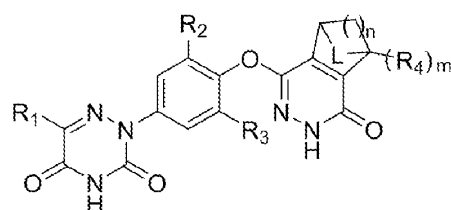
R₁ is selected from the group consisting of hydrogen, cyano, substituted or unsubstituted C₁₋₆ alkyl, or substituted or unsubstituted C₃₋₆ cycloalkyl, the substituent being selected from the group consisting of halogen atoms, hydroxy, and C₁₋₆ alkoxy;

R₂ and R₃ are each independently selected from the group consisting of halogen atoms or substituted or unsubstituted C₁₋₆ alkyl, the substituent being selected from the group consisting of halogen atoms, hydroxy, and C₁₋₆ alkoxy;

ring A is a substituted or unsubstituted saturated or unsaturated C₅₋₁₀ aliphatic ring, or a substituted or unsubstituted C₅₋₁₀ aromatic ring, the substituent being one or more substances selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, -NH₂, -NHC₁₋₄ alkyl, -N(C₁₋₄ alkyl)₂, -CONH₂, -CONHC₁₋₄ alkyl, -CON(C₁₋₄ alkyl)₂, -NHCOC₁₋₄ alkyl, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl, and when two substituents are contained, the two substituents can form a ring structure together with the carbon connected thereto; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

[0013] The compound according to the present invention has a structure as shown in the following Formula (II):



(II)

wherein,

R₁ to R₃ are defined as described in the above Formula (I);

L is not present or is selected from the group consisting of -CH₂- and -CH₂CH₂-;

R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, -NH₂, -NHC₁₋₄ alkyl, -N(C₁₋₄ alkyl)₂, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl;

n is an integer from the range 1 to 4;

m is an integer from the range 1 to 4; and

when L is not present, the ring may have two or more substituents R₄ thereon; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

Preferably, in the structure as shown in Formula (II), R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, C₁₋₃ alkyl, C₁₋₃ alkoxy or C₃₋₆ cycloalkyl;

L is not present or is selected from the group consisting of -CH₂- or -CH₂CH₂-;

n is 1, 2 or 3; and

m is 1 or 2.

Further preferably, in the structure as shown in Formula (II), R₄ is selected from the group consisting of hydrogen or C₁₋₃ alkyl;

L is -CH₂- or -CH₂CH₂-;

n is 1, 2 or 3; and

m is 1 or 2.

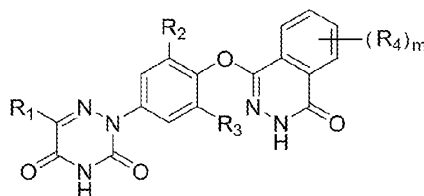
Further preferably, in the structure as shown in Formula (II), R₄ is selected from the group consisting of hydrogen or C₁₋₃ alkyl;

L is not present;

n is 1, 2 or 3; and

m is 1 or 2.

[0014] The compound according to the present invention has a structure as shown in the following Formula (III):



wherein,

R₁ to R₃ are defined as described in the above Formula (I);

R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, -NH₂, -NHC₁₋₄ alkyl, -N(C₁₋₄ alkyl)₂, -CONH₂, -CONHC₁₋₄ alkyl, -CON(C₁₋₄ alkyl)₂, -NHCOC₁₋₄ alkyl, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl;

m is an integer from the range 1 to 4; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

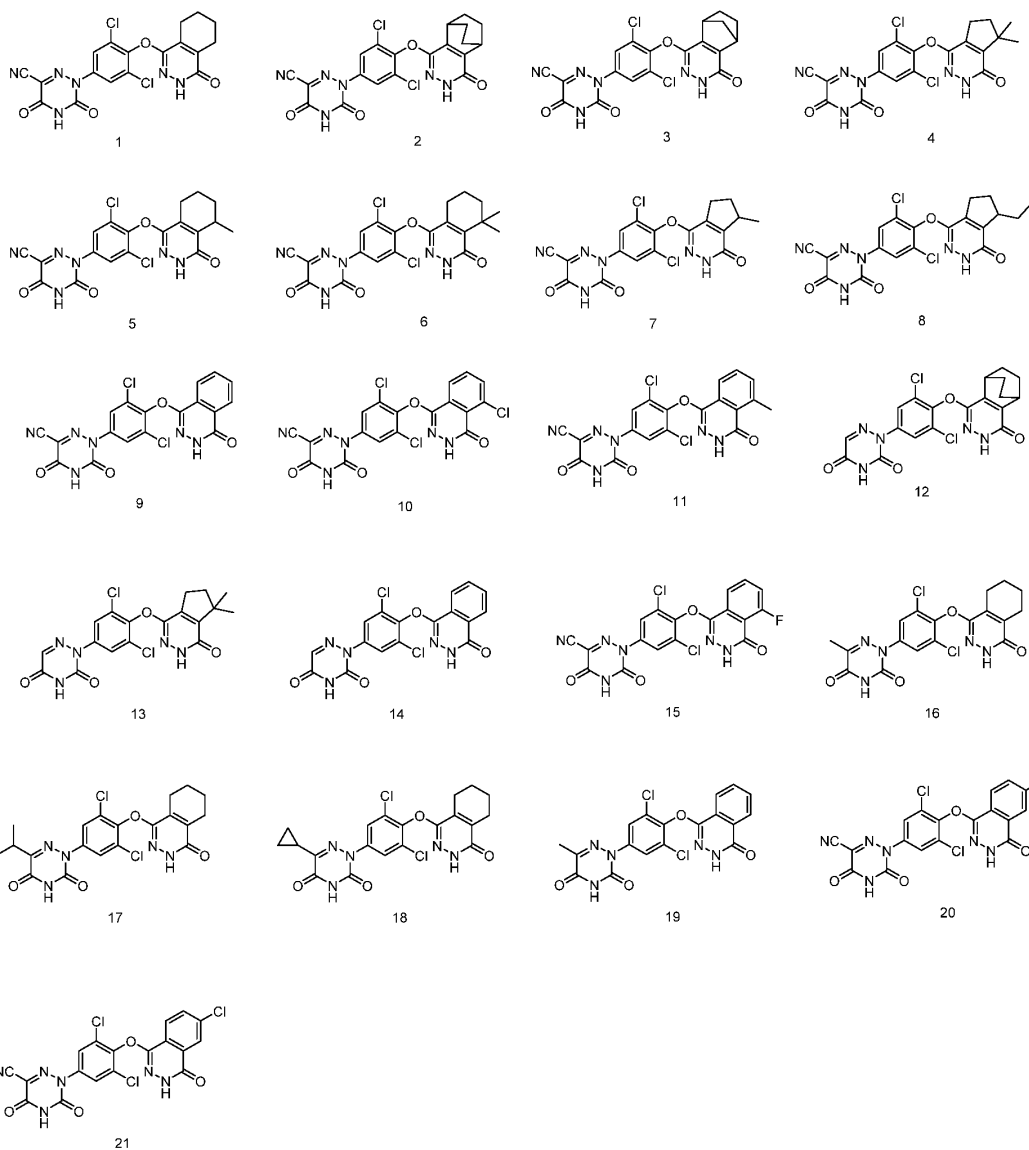
[0015] Preferably, in the structure as shown in Formula (III), R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl; and m is an integer from the range 1 to 3.

[0016] Preferably, in the structure as shown in Formula (III), R₄ is selected from the group consisting of hydrogen, halogen atoms or C₁₋₃ alkyl; and m is 1 or 2.

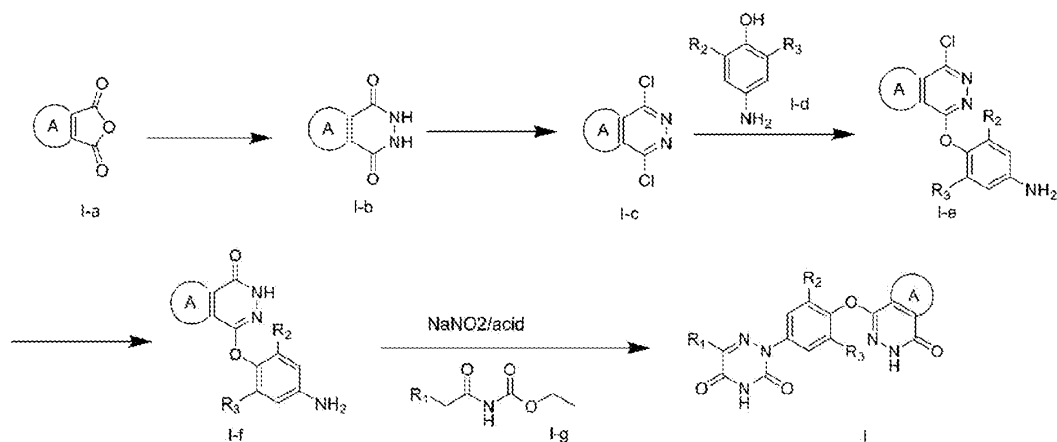
[0017] Preferably, in the above compound having the structure of Formula (I), (II) or (III) according to the present invention, R₁ is selected from the group consisting of hydrogen, cyano, substituted or unsubstituted C₁₋₆ alkyl; further preferably, R₁ is selected from the group consisting of cyano or C₁₋₃ alkyl; and still further preferably, R₁ is cyano.

[0018] Preferably, in the above compound having the structure of Formula (I), (II) or (III) according to the present invention, R₂ and R₃ are each independently selected from the group consisting of F, Cl or Br, and further preferably, both R₂ and R₃ are Cl.

[0019] Preferably, the compound and pharmaceutically acceptable salt thereof according to the invention are one of the following compounds:

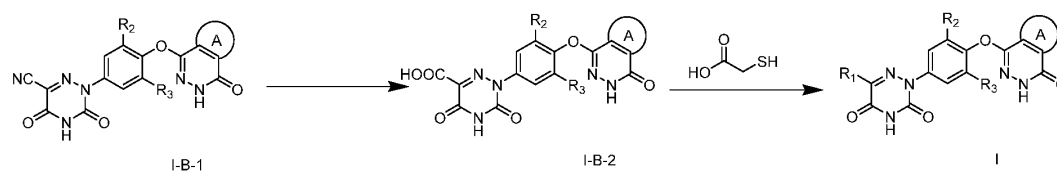


[0020] According to another aspect of the present invention, the present invention provides a method for preparing the compound, the preparation method comprising the following steps:



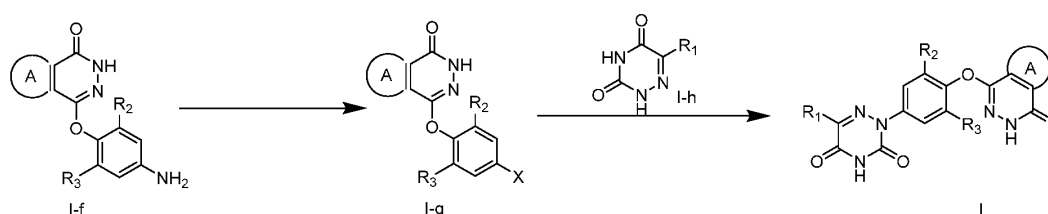
- 1) reacting the internal anhydride compound I-a with hydrazine hydrochloride, to obtain a compound of the general formula I-b;
- 2) heating the obtained compound of the general formula I-b in phosphorus oxychloride, to form a compound of the general formula I-c;
- 3) subjecting the obtained compound of the general formula I-c and the compound I-d to coupling reaction at high temperature, to obtain a compound of the general formula I-e, where the catalyst at this condition is preferably cuprous iodide;
- 4) reacting the obtained compound of the general formula I-e at acidic or alkaline high temperature, to obtain a compound of the general formula I-f; and
- 5) reacting the obtained compound of the general formula I-f with sodium nitrite in an aqueous acidic solution, followed by the addition of a compound I-g for further reaction and ring closing at high temperature, to obtain a compound of the general formula I, where the acid is preferably hydrochloric acid under this condition.

[0021] The compound of the general formula I according to the present invention may also be prepared as follows:



[0022] The compound of the general formula I-B-1 is subjected to high-temperature hydrolysis in an aqueous acidic solution, to obtain a compound of the general formula I-B-2, where the acid is preferably hydrochloric acid under this condition; and the obtained compound of the general formula I-B-2 is reacted in the presence of mercaptoacetic acid at a high temperature to eliminate carboxy, to obtain the compound of the general formula I.

[0023] The compound of the general formula I according to the present invention may also be prepared through the following method:



[0024] The compound of the general formula I-f is reacted with sodium nitrite under an acidic condition, to form a diazonium salt compound, followed by the addition of a halide anion, to obtain a compound of the general formula I-g; and under the catalysis of a transition metal, the obtained compound of the general formula I-g is coupled with the intermediate I-h, to obtain the compound of the general formula I.

[0025] According to another aspect of the present invention, the present invention provides use of the compound in the preparation of a therapeutic drug for a metabolism-related disease.

[0026] According to another aspect of the present invention, the present invention provides a pharmaceutical composition comprising a therapeutically effective amount of the compound according to the present invention and a pharmaceutically acceptable salt thereof as an active ingredient, and a pharmaceutically acceptable adjuvant.

[0027] Preferably, the metabolism-related disease is selected from the group consisting of obesity, hyperlipidemia, hypercholesterolemia, diabetes, and non-alcoholic steatohepatitis (NASH),

steatosis of liver, atherosclerosis, hypothyroidism, and thyroid cancer; and preferably, the metabolism-related disease is selected from the group consisting of non-alcoholic steatohepatitis (NASH), hypothyroidism and thyroid cancer.

[0028] According to another aspect of the present invention, the present invention provides a method for treating a metabolism-related disease, the method comprising administering to the subject an effective amount of the compound according to the present invention or a pharmaceutical composition comprising the compound and pharmaceutically acceptable salt thereof as an active ingredient.

[0029] Preferably, according to the method for treating the metabolism-related disease, the metabolism-related disease is selected from the group consisting of: obesity, hyperlipidemia, hypercholesterolemia, diabetes, and non-alcoholic steatohepatitis (NASH), steatosis of liver, atherosclerosis, hypothyroidism, and thyroid cancer; and preferably, the metabolism-related disease is selected from the group consisting of non-alcoholic steatohepatitis (NASH), hypothyroidism and thyroid cancer.

DETAILED DESCRIPTION

[0030] The present invention is described below in detail. Prior to the description, it should be understood that, the terms used in the specification and the appended claims shall not be interpreted to be limited to the general meaning and dictionary meaning, but shall be interpreted according to the corresponding meaning and concepts in the technical aspects of the present invention on the basis of the principle that the inventor is allowed to properly define the terms for the best interpretation. Therefore, the description proposed here is only a preferred example for the purpose of illustration, and is not intended to limit the scope of the invention. Hence it should be understood that other equivalents or improvements can be obtained from it without departing from the spirit and scope of the present invention.

[0031] According to the present invention, all terms quoted herein have the same meaning as those skilled in the art that understand the invention, unless otherwise specified.

[0032] As used herein, the term “salt” refers to a compound containing cations and anions, which can be formed by protonation of a site that can accept protons and/or proton abstraction of a site that can supply protons. It is worth noting that the protonation of the site that can accept protons

leads to the formation of a cationic substance, and the charge thereof is balanced by the presence of physiological anions, whereas the proton abstraction of the site that can supply protons leads to the formation of an anionic substance, and the charge thereof is balanced by the presence of physiological cations.

[0033] The term “pharmaceutically acceptable salt” refers that the salt is pharmaceutically acceptable. Examples of the pharmaceutically acceptable salt include, but are not limited to: (1) acid addition salts, formed with inorganic acid, e.g., hydrochloric acid, hydrobromic acid, sulfuric acid, nitric acid, and phosphoric acid; or formed with organic acid, e.g., glycolic acid, pyruvic acid, lactic acid, malonic acid, malic acid, maleic acid, fumaric acid, tartaric acid, citric acid, 3-(4-hydroxybenzoyl)benzoic acid, cinnamic acid, mandelic acid, methanesulfonic acid, ethanesulfonic acid, 1,2-ethane-disulfonic acid, 2-hydroxyethane sulfonic acid, benzene sulfonic acid, 4-chlorobenzenesulfonic acid, 2-naphthalenesulfonic acid, 4-paratoluenesulfonic acid, camphoric acid, dodecylsulfuric acid, gluconic acid, glutamic acid, salicylic acid, and cis-muconic acid; or (2) alkali addition salts, formed with any conjugate base of the above inorganic acids, where the conjugate base comprises a cationic component selected from the group consisting of Na^+ , K^+ , Mg^{2+} , Ca^{2+} , and $\text{NH}_x\text{R}_{4-x}^+$, where $\text{NH}_x\text{R}_{4-x}^+$ (R is C_{1-4} alkyl, and the subscript x is an integer selected from the group consisting of 0, 1, 2, 3 or 4) represents the cation in the quaternary ammonium salt. It should be understood that, all pharmaceutically acceptable salts involved include the solvent addition form (solvate) or crystal form (polymorphic substance) as defined herein for the same acid addition salt.

[0034] The term “ C_{1-M} alkyl” refers to alkyl comprising 1 to M carbon atoms, e.g., where M is an integer having the following numerical value: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 or 30. For example, the term “ C_{1-6} alkyl” refers to alkyl containing 1 to 6 carbon atoms. Examples of alkyl include, but are not limited to lower alkyl, including methyl, ethyl, propyl, i-propyl, n-butyl, i-butyl, t-butyl or amyl, i-amyl, neopentyl, hexyl, heptyl and octyl.

[0035] The term “aromatic group” refers to an aromatic system, which may be a monocyclic ring, or a poly-aromatic ring originally fused or joined together such that at least a part of the fused or joined rings form a conjugated aromatic system. Aryl groups include, but are not limited to: phenyl, naphthyl and tetralyl. Aryl may be optionally substituted by, e.g., 1 to 4 aryl groups or heterocyclic

rings substituted by a group selected from the group consisting of: halogen, -CN, -OH, -NO₂, amino, alkyl, cycloalkyl, alkenyl, alkynyl, alkoxy, aryloxy, substituted alkoxy, alkylcarbonyl, alkylcarboxy, alkylamino, or arylthio.

[0036] The term “substitute” refers that the reference group can be substituted by one or a plurality of additional groups, where the additional groups are separately and independently selected from the group consisting of alkyl, cycloalkyl, aryl, heteroaryl, heteroalicyclic hydrocarbon, hydroxy, alkoxy, alkylthiol, arylthio, alkylsulfinyl, arylsulfinyl, alkylsulfonyl, arylsulfonyl, cyano, halo, carbonyl, thiocarbonyl, nitro, haloalkyl, fluoroalkyl and amino, including monosubstituted and disubstituted amino groups and derivatives protected by them.

[0037] The compound represented by Formula (I) or pharmaceutically acceptable salt thereof provided by the present invention, and pharmaceutical compositions containing the compound may be in various forms, such as tablets, capsules, powders, syrups, solutions, suspensions and aerosols, etc., and may exist in a suitable solid or liquid carrier or diluent, and in a disinfectant suitable for injection or infusion.

[0038] Various dosage forms of the pharmaceutical composition of the present invention can be prepared according to preparation methods conventional in the field of pharmacy. For example, the unit dose of the preparation formula contains 0.05 to 200 mg of the compound of Formula (I) or pharmaceutically acceptable salt thereof, and preferably, the unit dose of the preparation formula contains 0.1 to 100 mg of the compound of Formula (I).

[0039] The compound represented by the general formula (I) or pharmaceutical compositions provided by the present invention can be used clinically in mammals, including humans and animals, through dosage routes such as oral, nasal, transdermal, transpulmonary or gastrointestinal tract routes. Oral administration is the most preferred. The most preferred daily dose is 0.01 to 200 mg/kg of weight per single administration, or 0.01 to 100 mg/kg of weight per separate administration. Regardless of the administration method, the best dose for an individual should be decided on the basis of the specific treatment. Usually administration starts at a small dose and increases gradually until the most suitable dose is found.

[0040] In the present invention, the term “effective amount” may refer to the effective amount for the dose and time period required to achieve the expected effect. This effective dose may vary differently due to certain factors, such as the disease type, symptoms of the disease at the time of

treatment; the structure of the specific target organ to be administered; the individual height and weight of the patient, or the severity of the disease or symptom. Those of ordinary skill in the art can determine, by experience, the effective amount of a specific compound without conducting unneeded experiments.

[0041] A typical formula is prepared by mixing the compound represented by the general formula (I) of the invention, and a carrier, a diluent or an excipient. Suitable carriers, diluents or excipients are well known to those of skill in the art, including substances such as carbohydrates, waxes, water-soluble and/or expandable polymers, hydrophilic or hydrophobic substances, gelatin, oil, solvents, and water.

[0042] The specific carrier, diluent or excipient to be used shall be decided according to the usage and purpose of the compound of the present invention. Generally, the solvent is selected on the basis of the solvents which can be safely and effectively dosed to mammals according to those skilled in the art. In general, safe solvents are non-toxic aqueous solvents such as water and other non-toxic solvents that are soluble in or miscible with water. Suitable aqueous solvents include one or a plurality of water, ethanol, propylene glycol, polyethylene glycol (such as PEG400, and PEG300) and the like. The formula may also include one or a plurality of buffers, stabilizers, surfactants, wetting agents, lubricants, emulsifiers, suspending agents, preservatives, antioxidants, light-screening agents, flow aids, processing aids, colorants, sweeteners, fragrances, flavoring agents or other known additives, to enable the drug to be manufactured or used in an acceptable form.

[0043] When the compound of Formula (I) of the present invention is used in combination with at least one other drug, the two or more drugs can be used separately or in combination, preferably in the form of a pharmaceutical composition. The compound of Formula (I) or the pharmaceutical composition according to the present invention can be dosed to the subject separately or together, in any known oral, intravenous, rectal, vaginal, transdermal, other topical or systemic dosage forms.

[0044] These pharmaceutical compositions may also contain one or a plurality of buffers, stabilizers, surfactants, wetting agents, lubricants, emulsifiers, suspending agents, preservatives, antioxidants, light-screening agents, flow aids, processing aids, colorants, sweeteners, fragrances,

flavoring agents, or other known additives, to enable the pharmaceutical compositions to be manufactured or used in an acceptable form.

[0045] The oral dosage route is preferred for the drug of the present invention. The solid dosage form for oral dosage may include capsules, tablets, powders or particle formulations. In the solid dosage form, the compound or pharmaceutical composition according to the present invention is mixed with at least one inert excipient, diluent, or carrier. Suitable excipients, diluents, or carriers include substances such as sodium citrate or dicalcium phosphate, or starch, lactose, sucrose, mannitol, silicic acid, and the like; adhesives such as carboxymethyl cellulose, alginate, gelatin, polyvinyl pyrrolidone, sucrose, and Arabia gum; wetting agents such as glycerol; disintegrating agents such as agar, calcium carbonate, potato or cassava starch, alginic acid, specific complex silicate, and sodium carbonate; solution blockers such as paraffin; absorption promoters such as quaternary ammonium compounds; adsorbents such as kaolin and bentonite; and lubricants such as talc, calcium stearate, magnesium stearate, solid polyethylene glycol, and sodium lauryl sulfate. In the case of capsules and tablets, the dosage form may also include buffers. Similar types of solid compositions may also be used as fillers in soft and hard filled gelatin capsules, which use lactose and high molecular weight polyethylene glycol as excipients.

[0046] Liquid dosage forms for oral administration include pharmaceutically acceptable emulsions, solutions, suspensions, and syrups and elixirs. In addition to the compound or the pharmaceutical composition thereof according to the present invention, the liquid dosage form may contain inert diluents commonly used in the art, such as water or other solvents; solubilizers and emulsifiers such as ethanol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butanediol, dimethylformamide; oils (e.g., cotton seed oil, peanut oil, corn germ oil, olive oil, castor oil, and sesame oil); glycerol; tetrahydrofurfuryl alcohol; fatty acid esters of polyethylene glycol and sorbitan; or mixtures of several of these substances, etc.

[0047] In addition to these inert diluents, the composition may also include an excipient, such as one or a plurality of wetting agents, emulsifiers, suspending agents, sweeteners, flavoring agents, and fragrances.

[0048] In terms of the suspension, in addition to the compound represented by the general formula (I) or pharmaceutically acceptable salt thereof or the pharmaceutical composition comprising the

same according to the present invention, the suspension may further contain carriers such as suspending agents, for example, ethoxylated isostearyl, polyoxyethylene sorbitol, sorbitan ester, microcrystalline cellulose, aluminum metahydroxide, bentonite, agar and tragacanth gum, or mixtures of several of these substances, etc.

[0049] The compound represented by the general formula (I) or a pharmaceutically acceptable salt thereof or the pharmaceutical composition comprising the same according to the present invention may be dosed using other topical dosage forms, including ointments, powders, sprays and inhalants. This drug can be mixed under sterile conditions with pharmaceutically acceptable excipients, diluents or carriers and any preservatives, buffers or propellants required. Ophthalmic formulae, ophthalmic ointments, powders, and solutions are also intended to be encompassed in the scope of the present invention.

[0050] In addition, the present disclosure further encompasses kits (e.g., pharmaceutical packages). The kit provided may comprise the pharmaceutical composition or the compound described herein and containers (e.g., drug bottles, ampoules, bottles, syringes and/or subpackages or other suitable containers). In some embodiments, the kit provided may optionally further include a second container comprising a pharmaceutical excipient for diluting or suspending the pharmaceutical composition or the compound described herein. In some embodiments, the pharmaceutical composition or the compound described herein provided in the first and the second containers are combined to form a unit dosage form.

[0051] In some embodiments, the kit described herein further includes instructions of use of the compound or the pharmaceutical composition comprised in the kit. The kit described herein may also include information required by regulatory agencies such as the US Food and Drug Administration (FDA). In some embodiments, the information included in the kit is formula information. In some embodiments, the kit and the instructions are provided for the treatment of a proliferative disease in subjects in need thereof and/or prevention of a proliferative disease of subjects in need thereof. The kit described herein may comprise one or a plurality of additional pharmaceutical preparations as separate compositions.

[0052] The present invention will be further described below in detail in combination with particular embodiments, but the present invention is not limited to the following embodiments which serve the purpose of better explaining specific embodiments of the present invention and

should not be interpreted as limiting the scope of the invention in any way. The conditions not noted in the embodiments are conventional conditions. Unless stated particularly, the reagents and apparatuses used in the following embodiments are all commercially available products.

[0053] The structures of the compounds in the following embodiments are determined by nuclear magnetic resonance (NMR) or/and mass spectrometry (MS). The NMR displacement (δ) is given in the unit of 10⁻⁶ (ppm). For the determination by NMR, a Bruker AVANCE-400 nuclear magnetic instrument is used. Solvents are deuterated dimethyl sulfoxide (DMSO-d₆), deuterated chloroform (CDCl₃) and deuterated methanol (CD₃OD), and the internal standard is tetramethylsilane (TMS).

[0054] For determination by MS, a FINNIGAN LCQAd (ESI) mass spectrometer (manufacturer: Thermo, model: Finnigan LCQ advance max) is used.

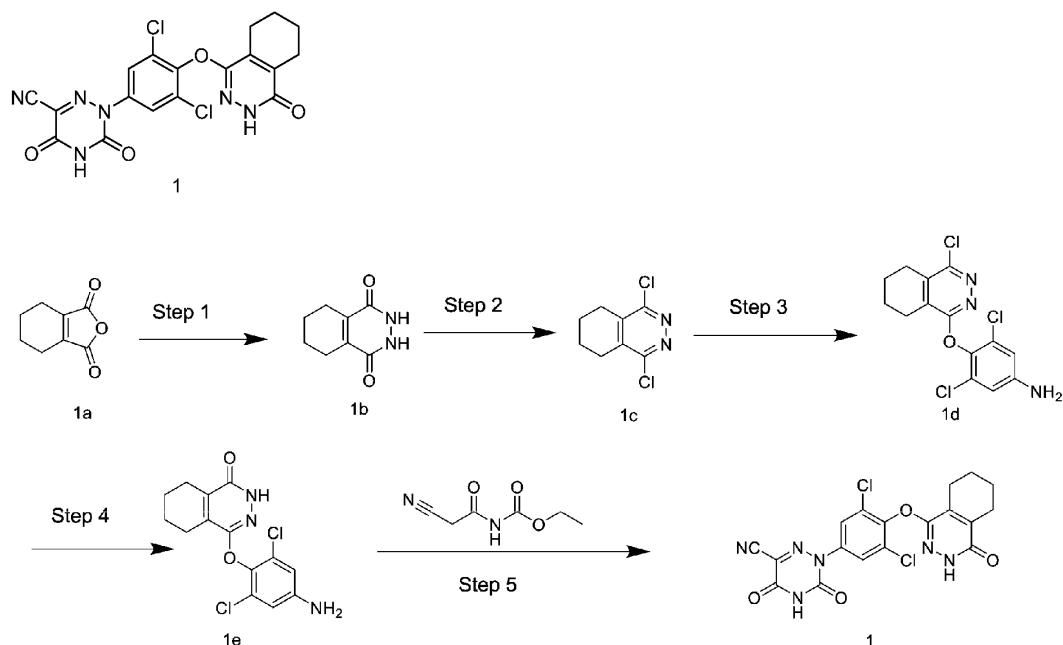
[0055] Yantai Huanghai HSGF254 or Qingdao GF254 silica gel plates are used as the silica gel plates for the thin-layer chromatography. The specification of the silica gel plate for the thin-layer chromatography (TLC) is 0.15 mm to 0.2 mm, and the specification for that in the thin-layer chromatography for separation and purification of products is 0.4 mm to 0.5 mm.

[0056] Column chromatography generally uses Yantai Huanghai silica gel 200-300 mesh silica gel as the carrier.

[0057] When no special description in the embodiments exists, the reaction temperature is room temperature, i.e., 20 °C to 30 °C.

[0058] The thin-layer chromatography (TLC) is employed to detect the reaction process in the embodiments. The developer system used and the eluent system of column chromatography employed for purifying the compound include: A: a dichloromethane and methanol system; B: a n-hexane and ethyl acetate system; C: a petroleum ether and ethyl acetate system; D: an acetone and petroleum ether system, where the ratio by volume of the solvents is adjusted according to different polarities of the compounds.

[0059] Embodiment 1: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile



[0060] Step 1: Preparation of 2,3,5,6,7,8-hexahydrophthalazin-1,4-dione (compound 1b)

[0061] Sodium acetate (3.69 g, 45 mmol) and hydrazine hydrochloride (3.08 g, 45 mmol) were successively added into a solution of a compound 3,4,5,6-tetrahydrophthalic anhydride **1a** (4.56 g, 30 mmol) in acetic acid (50 ml) and water (100 ml). After the addition, the mixture was warmed up to a temperature of 100 °C and stirred for 3 h. The reaction was stopped and naturally cooled to room temperature. A solid was precipitated and filtered out to obtain a compound 1b (4.2 g), and the product was directly used in the next reaction.

[0062] ¹H NMR (400 MHz, DMSO-*d*₆): 11.26 (s, 2H), 2.36 (s, 4H), 1.65 (s, 4H).

[0063] Step 2: Preparation of 1,4-dichloro-5,6,7,8-tetrahydrophthalazine (compound 1c)

[0064] The compound 1b (1 g, 6.02 mmol) was dissolved into phosphorus oxychloride (8 ml). The air in the system was replaced 3 times with nitrogen gas. The system was warmed up to a temperature of 110 °C and stirred for 3 h. The reaction was stopped and then naturally cooled. The reaction solution was slowly dripped into ice water. The mixture was adjusted to pH 10 with a 1N sodium hydroxide aqueous solution and extracted 3 times with ethyl acetate. Organic phases were combined, and the organic phase was washed with saturated brine and concentrated to dry, to obtain a compound 1c (1.1 g). The product was directly used in the next reaction.

[0065] Step 3: Preparation of 3,5-dichloro-4-((4-chloro-5,6,7,8-tetrahydrophthalazin-1-yl)oxy)aniline (compound 1d)

[0066] Dimethyl sulfoxide (8 ml) was added into the mixture of the compound 1c (1.0 g, 5.0 mmol), 2,6-dichloro-4-aminophenol (0.93 g, 6 mmol), potassium carbonate (2.76 g, 20 mmol), and CuI (0.57 g, 3 mmol). The air in the system was replaced 3 times with nitrogen gas. The system was warmed up to a temperature of 100 °C and stirred for 3 h. After the reaction was stopped, it was cooled. The solid in the reaction solution was filtered out first, and the filter residue was washed repeatedly with ethyl acetate. 80 ml of water was added into the filtrate, and then the aqueous phase was extracted with ethyl acetate reaction. The organic phases were combined and washed with saturated brine. A compound 1d (450 mg) was obtained by column chromatography after filtration and solvent concentration.

[0067] Step 4: Preparation of 4-(4-amino-2,6-dichlorophenoxy)-5,6,7,8-tetrahydrophthalazin-1(2H)-one (compound 1e)

[0068] The compound 1d (100 mg, 0.3 mmol) was dissolved into acetic acid (4 ml), and sodium acetate (200 mg, 2.5 mmol) was added therein. The mixture was heated to a temperature of 120 °C and stirred for 12 h. After the reaction was stopped, the solvent was removed under reduced pressure. 10 ml of water was added therein, and then a 1N sodium hydroxide aqueous solution was added to adjust the pH to 8. Then extraction was carried out with ethyl acetate (10 ml × 3), and organic phases were combined. The organic phase was washed with a saturated aqueous sodium bicarbonate solution and saturated brine respectively, and concentrated under reduced pressure to obtain a gray solid. 10 ml of methanol and 10 ml of a 1N sodium hydroxide aqueous solution were added into the solid obtained, and the mixture was heated to a temperature of 120 °C and stirred for 12 h. After the reaction was stopped, methanol was concentrated under reduced pressure. The remaining aqueous phase was extracted 3 times with ethyl acetate repeatedly, and organic phases were combined. After the solvent was concentrated under reduced pressure, compound 1e (80 mg) was obtained by separation and purification through thin-layer chromatography.

[0069] Step 5: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 1)

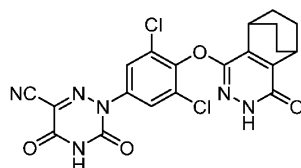
[0070] Sodium nitrite (16 mg) was dissolved into water (0.5 mL). Under ice bath conditions, this solution was slowly added dropwise into a mixture of a compound 1e (60 mg, 0.185 mmol), water

(2.5 mL) and a saturated aqueous hydrochloric acid solution (1.25 mL), and stirred for 0.5 h with the ice bath conditions maintained, until the solution became clear. At this temperature, a mixed solution of N-cyanoacetylurethane (32 mg) in water (4.2 ml) and pyridine (1.3 ml) was additionally added dropwise, and stirred overnight after the dropwise addition. After the reaction was stopped, a yellow solid was filtered out, and washed with water and petroleum ether. Acetic acid (5 ml) and sodium acetate (160 mg, 2 mmol) were added into the solid obtained. The mixture was heated to a temperature of 120°C and stirred for 6 h, then cooled to room temperature. 100 ml of water was added therein to precipitate a light yellow solid. After separation and purification through thin-layer chromatography (DCM:MeOH=8:1), compound 1 (12.0 mg) was obtained.

[0071] ¹H NMR (400 MHz, DMSO-*d*₆) δ 12.03 (s, 1H), 7.75 (s, 2H), 2.68-2.63 (m, 2H), 2.45-2.39 (m, 2H), 1.80-1.67 (m, 4H).

[0072] MS m/z (ESI): 447.4 [M+1].

[0073] **Embodiment 2:** Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 2b).



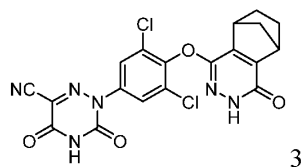
2

[0074] The synthetic route of Embodiment 1 was employed, except that the raw material 3,4,5,6-tetrahydrophthalic anhydride **1a** in Step 1 was replaced with bicyclo[2.2.2]oct-2-ene-2,3-dicarboxylic anhydride, to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 2).

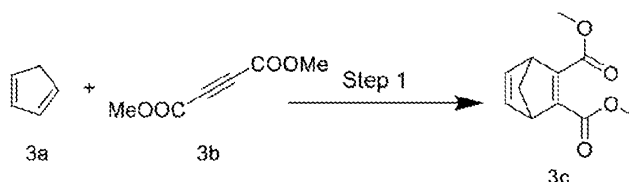
[0075] ¹H NMR (400 MHz, DMSO-*d*₆): 12.13 (s, 1H), 7.77 (s, 2H), 1.88-1.73 (m, 4H), 1.39-1.17 (m, 6H).

[0076] MS m/z (ESI): 473.2 [M+1].

[0077] Embodiment 3: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-methanophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 3).

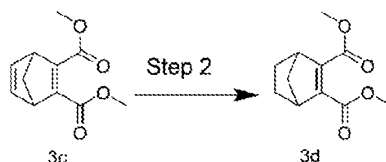


[0078] Step 1: Preparation of dimethyl-bicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate



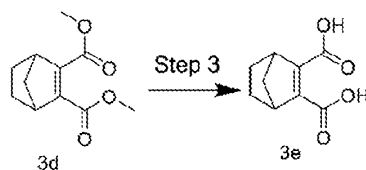
[0079] Dimethyl acetylenedicarboxylate (compound 3b) (2.75 ml, 22.3 mmol) was slowly dripped into cyclopentadiene (compound 3a) (1.475 g, 22.3 mmol), and stirred for 2 h at room temperature after the addition. The reaction was stopped, and an oily product 3c (4.0 g) was obtained. The crude product was directly used in the next reaction without purification.

[0080] Step 2: Preparation of dimethyl-bicyclo[2.2.1]hepta-2-ene-2,3-dicarboxylate:



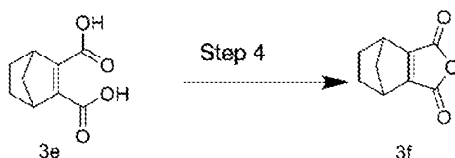
[0081] The compound 3c (1.0 g, 4.8 mmol), palladium carbon (0.05 g) and 15 ml of acetone were placed into a reaction flask, and replacement was performed 3 times under a hydrogen balloon. The system was stirred for 1 h at room temperature. Filtration was carried out, and the solvent was concentrated to dry under reduced pressure, to obtain a light green liquid product 3d (0.9 g).

[0082] Step 3: Preparation of bicyclo[2.2.1]hepta-2-ene-2,3-diacid:



[0083] Tetrahydrofuran (20 ml) and water (20 ml) were added into a mixture of the compound 3d (3.0 g, 14.3 mmol) and lithium hydroxide monohydrate (1.54 g, 35.8 mmol), and stirred for 2 h at room temperature. The solution was adjusted to pH 1 with 2N dilute hydrochloric acid, extracted 3 times with ethyl acetate, dried over anhydrous sodium sulfate, filtered, and concentrated under reduced pressure to obtain a white solid compound 3e (2.0 g).

[0084] Step 4: Preparation of 4,5,6,7-tetrahydro-4,7-methanoisophenylfuran1,3-dione:



[0085] Acetic anhydride (10 mL) was added into the compound 3e (200 mg, 1.1 mmol). The mixture was heated to a temperature of 100 °C and stirred for 2 h. The solvent was removed by concentration under reduced pressure, to obtain a crude product of a solid compound **3f** (200 mg).

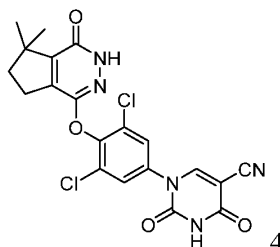
[0086] Step 5: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-methanophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile:

[0087] The synthetic route of Embodiment 1 was employed, except that the raw material 4,5,6,7-tetrahydroisobenzofuran-1,3-dione (compound **1a**) in Step 1 was replaced with 4,5,6,7-tetrahydro-4,7-methanoisophenylfuran 1,3-dione (compound **3f**), to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-methanophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **3**).

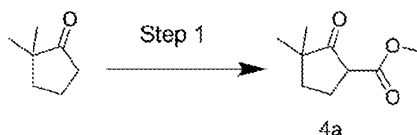
[0088] ¹H NMR (400 MHz, DMSO-*d*₆) δ 12.08 (s, 1H), 7.77 (s, 2H), 2.75-2.65 (m, 2H), 1.80-1.72 (m, 4H), 1.55-1.50 (m, 2H).

[0089] MS *m/z* (ESI): 459.0 [M+1].

[0090] Embodiment 4: Preparation of 1-(3,5-dichloro-4-((7,7-dimethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentane[d]pyridazin-4-yl)oxy)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 4)

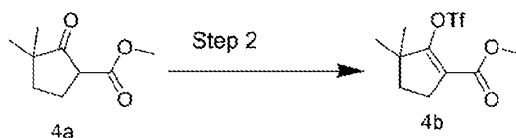


[0091] Step 1: Preparation of methyl 3,3-dimethyl-2-oxocyclopentyl-1-carboxylate



[0092] NaH (480 mg, 12 mmol) was added into a solution of a compound 2,2-dimethylcyclopentane-1-one (1.12 g, 10 mmol) and MeOH (0.5 ml) in DMC (11 ml). The mixture was heated to a temperature of 82 °C, stirred for 3 h, and cooled. Methanol (0.5 ml) and acetic acid (1 ml) were successively added into the system, then the system was poured into ice water, extracted with dichloromethane, dried, and subjected to removal of the solvent under reduced pressure, to obtain a colorless oily compound 4a (1.7 g) directly used in the next step.

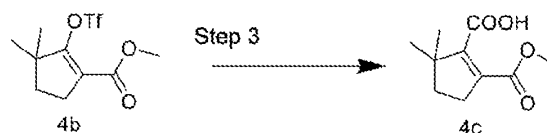
[0093] Step 2: Preparation of methyl 3,3-dimethyl-2-(((trifluoromethyl)sulfo)oxo)cyclopent-1-ene-1-carboxylate



[0094] At -60 °C, trifluoroacetic anhydride (2 ml, 12 mmol) was added dropwise into a solution of the compound 4a (1.7 g, 10 mmol) and diisopropylethylamine (8.2 ml, 50 mmol) in dichloromethane (17 ml). After the addition, the mixture was slowly warmed up to room temperature and stirred for 16 h. 50 ml of water was added therein, and the mixture was extracted

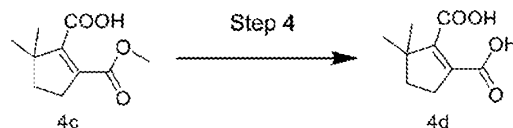
with ethyl acetate, subjected to removal of the solvent under reduced pressure, and purified through column chromatography (PE:EA=50:1), to obtain a colorless oily compound 4b (1.8 g).

[0095] Step 3: Preparation of 2-(methoxycarbonyl)-5,5-dimethylcyclopent-1-ene-1-carboxylic acid



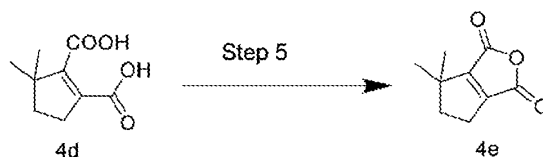
[0096] Under the atmosphere of a nitrogen gas balloon, DMF (25 ml) was added into a mixture of 4b (1.8 g, 5.96 mmol), diisopropylethylamine (1.97 ml, 11.92 mmol), acetic anhydride (1.13 ml, 11.92 mmol), sodium formate (1.22 g, 5.96 mmol), palladium diacetate (66.9 mg, 0.30 mmol), and lithium chloride (758 mg, 17.88 mmol). The system was stirred for 16 h at room temperature after the addition, and 300 ml of ethyl acetate was added into the system. The system was washed with water and saturated brine once each. The solvent was removed under reduced pressure, to obtain a colorless oil 4c (1.2 g).

[0097] Step 4: Preparation of 3,3-dimethylcyclopent-1-ene-1,2-dicarboxylic acid



[0098] Methanol (6 ml) and water (6 ml) were added into a mixture of 4c (1.2 g, 6 mmol) and lithium hydroxide monohydrate (756 mg, 18 mmol), and stirred for 3 h at room temperature. Methanol was removed under reduced pressure, then the solution was adjusted to pH 1 with concentrated hydrochloric acid and extracted with ethyl acetate, and the solvent was removed under reduced pressure, to obtain a white solid compound 4d (1.0 g).

[0099] Step 5: Preparation of 4,4-dimethyl-5,6-dihydro-1H-cyclopentyl[c]furan-1,3(4H)-dione



[0100] Acetic anhydride (10 ml) was added into the compound 4d (1.0 g, 5.43 mmol). The mixture was warmed up to a temperature of 100 °C, stirred for 3 h, and cooled. Superfluous acetic anhydride was removed under reduced pressure, to obtain a light brown liquid compound 4e (875 mg), which was directly used in the next synthesis.

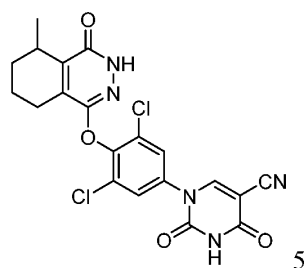
[0101] Step 6: Preparation of 1-(3,5-dichloro-4-((7,7-dimethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentane[d]pyridazin-4-yl)oxy)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile

[0102] The synthetic route of Embodiment 1 was employed, except that the raw material 3,4,5,6-tetrahydrophthalic anhydride (compound 1a) in Step 1 was replaced with 4,4-dimethyl-5,6-dihydro-1H-cyclopentyl[c]furan-1,3(4H)-dione (compound 4e), to produce the title product 1-(3,5-dichloro-4-((7,7-dimethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentane[d]pyridazin-4-yl)oxy)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 4).

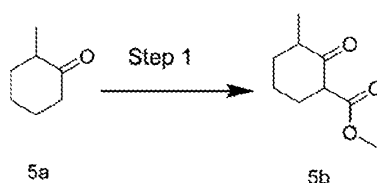
[0103] ¹H NMR (400 MHz, DMSO-*d*₆) δ 12.09 (s, 1H), 7.79 (s, 2H), 2.97-2.93 (m, 2H), 2.01-1.98 (m, 2H), 1.34-1.20 (m, 6H).

[0104] MS *m/z* (ESI): 460.9 [M+1].

[0105] **Embodiment 5:** Preparation of 1-(3,5-dichloro-4-((5-methyl-4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 5)

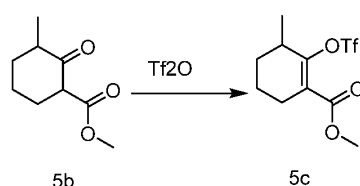


[0106] Step 1: Preparation of methyl 3-methyl-2-oxocyclohexane-1-carboxylate 5b:



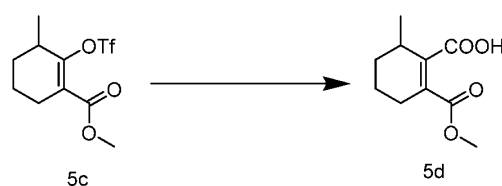
[0107] NaH (60% content, 1.92 g, 48 mmol) was added into a solution of 2-methylcyclohexanone (compound 5a) (4.48 g, 40 mmol) in dichloromethane (50 ml). The mixture was heated to reflux, stirred for 3 h, and cooled. The mixture was roughly quenched with methanol (0.5 ml) and acetic acid (1 ml). The reaction system was added into an ice bath and extracted with dichloromethane. The solvent was removed under reduced pressure, and an oil (compound 5b) (5.6 g) was obtained by purification through column chromatography.

[0108] Step 2: Preparation of methyl 3-methyl-2-(((trifluoromethyl)sulfo)oxo)cyclohexyl-1-ene-1-carboxylate



[0109] Under ice bath conditions, NaH (60% content, 600 mg, 25 mmol) was added into compound 5b (0.85g, 5 mmol) in ethyl ether (20 ml), and stirred for 0.5 h. Then trifluoromethanesulfonic anhydride (2.8 g, 10 mmol) was added dropwise into the system and further stirred for 1 h at a temperature of 0 °C. The system was quenched with H₂O (50 ml) added, adjusted to pH 1 with 1N HCl added, and extracted with dichloromethane. The solvent was removed under reduced pressure, and a colorless oily compound 5c (1.04 g) was obtained by purification through column chromatography (PE:EA=20:1).

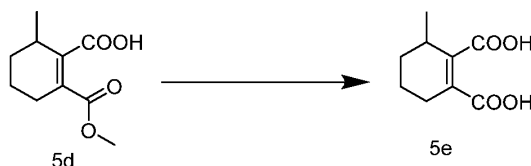
[0110] Step 3: Preparation of 2-(methoxycarbonyl)-6-methylcyclohexyl-1-ene-1-carboxylic acid



[0111] Under a nitrogen atmosphere, diisopropylethylamine (0.714 g, 7.00 mmol) and acetic anhydride (0.903 g, 7.00 mmol) were successively added dropwise into a solution of the compound 5c (0.714 g, 10.5 mmol) and sodium formate (0.714 g, 10.50 mmol) in N,N-dimethyl formamide (15 ml), and stirred for 1 h at room temperature. Then palladium acetate (40 mg, 0.18 mmol) and lithium chloride (445 mg, 10.50 mmol) were added, and the system was stirred overnight at room

temperature. Ethyl acetate (30 ml) was added therein, and the mixture was washed with water. The solvent was removed under reduced pressure, to obtain a light yellow oily compound 5d (590 mg).

[0112] Step 4: Preparation of 3-methylcyclohexyl-1-ene-1,2-diacid 5e



[0113] Lithium hydroxide monohydrate (0.375 g, 8.94 mmol) was added into a solution of the compound 5d (0.590 g, 2.98 mmol) in methanol (3 ml) and water (3 ml), and stirred for 3 h at room temperature. Then methanol was removed under reduced pressure. The system was adjusted to pH 1 with a 1N aqueous hydrochloric acid solution added, and extracted 3 times with ethyl acetate. The organic phases were combined, and concentrated under reduced pressure to remove the solvent, to obtain an oily compound 5e (0.550 g).

[0114] Step 5: Preparation of 4-methyl-4,5,6,7-tetrahydroisophenylfuran-1,3-dione 5f



[0115] Acetic anhydride (6 ml) was added into the compound 5e (0.550 g, 2.99 mmol). The mixture was warmed up to a temperature of 100 °C, and stirred for 2 h. The system was cooled, and the solvent was removed under reduced pressure, to obtain a brown oily compound 5f (0.34 g) directly used in the next synthesis.

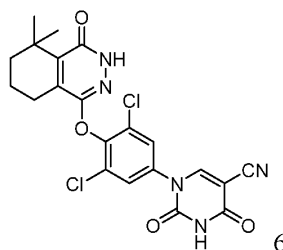
[0116] Step 6: Preparation of 1-(3,5-dichloro-4-((5-methyl-4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 5)

[0117] The synthetic route of Embodiment 1 was employed, except that the raw material 3,4,5,6-tetrahydrophthalic anhydride (compound 1a) in Step 1 was replaced with 4-methyl-4,5,6,7-tetrahydroisophenylfuran-1,3-dione (compound 5f), to produce the title product 1-(3,5-dichloro-

4-((5-methyl-4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 5).

[0118] MS m/z (ESI): 460.1 [M+1]

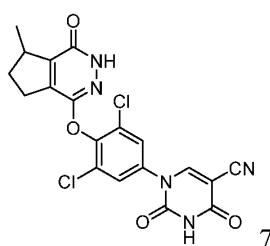
[0119] **Embodiment 6:** Preparation of 1-(3,5-dichloro-4-((5,5-dimethyl-4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile



[0120] The synthetic route of Embodiment 5 was employed, except that the raw material 2-methylcyclohexanone (compound 5a) in Step 1 was replaced with 2,2-dimethylcyclohexanone, to produce the title product 1-(3,5-dichloro-4-((5,5-dimethyl-4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 6).

[0121] MS m/z (ESI): 474.1 [M+1]

[0122] **Embodiment 7:** Preparation of 1-(3,5-dichloro-4-((7-methyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentyl[d]pyridazin-4-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 7)

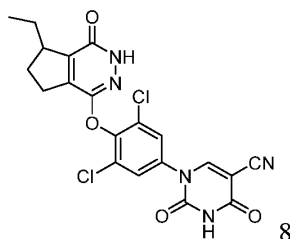


[0123] The synthetic route of Embodiment 5 was employed, except that the raw material 2-methylcyclohexanone (compound 5a) in Step 1 was replaced with 2-methylcyclopentanone, to produce the title product 1-(3,5-dichloro-4-((7-methyl-1-oxo-2,5,6,7-tetrahydro-1H-

cyclopentyl[d]pyridazin-4-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 7).

[0124] MS m/z (ESI): 446.0 [M+1]

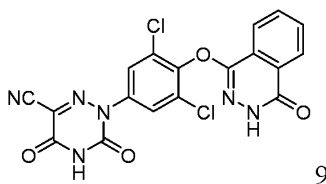
[0125] **Embodiment 8:** Preparation of 1-(3,5-dichloro-4-((7-ethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentane[d]pyridazin-4-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 8)



[0126] The synthetic route of Embodiment 5 was employed, except that the raw material 2-methylcyclohexanone (compound 5a) in Step 1 was replaced with 2-ethylcyclopentanone, to produce the title product 1-(3,5-dichloro-4-((7-ethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentane[d]pyridazin-4-yl)oxo)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 8).

[0127] MS m/z (ESI): 460.1 [M+1]

[0128] **Embodiment 9:** Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 9)

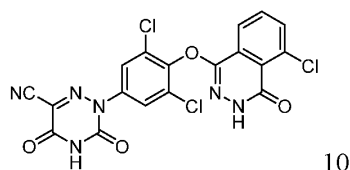


[0129] The synthetic route of Embodiment 1 was employed, except that the raw material 1,4-dichloro-5,6,7,8-tetrahydrophthalazine (compound 1c) in Step 3 was replaced with 1,4-dichlorophthalazine, to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 9).

[0130] ^1H NMR (400 MHz, $\text{DMSO-}d_6$): 12.00(s, 1H), 8.31(d, $J=8.0\text{Hz}$, 1H), 8.26 (d, $J=8.0\text{Hz}$, 1H), 8.09 (t, $J=12.0\text{Hz}$ 1H), 8.03 (t, $J=16.0\text{Hz}$ 1H), 7.81 (s, 2H).

[0131] MS m/z (ESI): 443.0 $[\text{M}+1]$.

[0132] **Embodiment 10:** Preparation of 2-(3,5-dichloro-4-((5-chloro-4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 10)

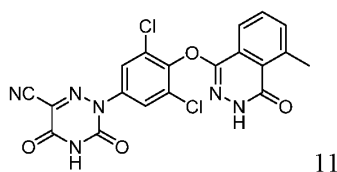


[0133] The synthetic route of Embodiment 1 was employed, except that the raw material 3,4,5,6-tetrahydrophthalic anhydride (compound **1a**) in Step 1 was replaced with 3-chlorophthalic anhydride, to produce the title product 2-(3,5-dichloro-4-((5-chloro-4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **10**)

[0134] ^1H NMR (400 MHz, $\text{DMSO-}d_6$): 12.00(s, 1H), 8.30 (d, $J=8.0\text{Hz}$, 1H), 8.15 (d, $J=8.0\text{Hz}$, 1H), 7.95 (m, 1H), 7.80 (s, 2H).

[0135] MS m/z (ESI): 477.0 $[\text{M}+1]$.

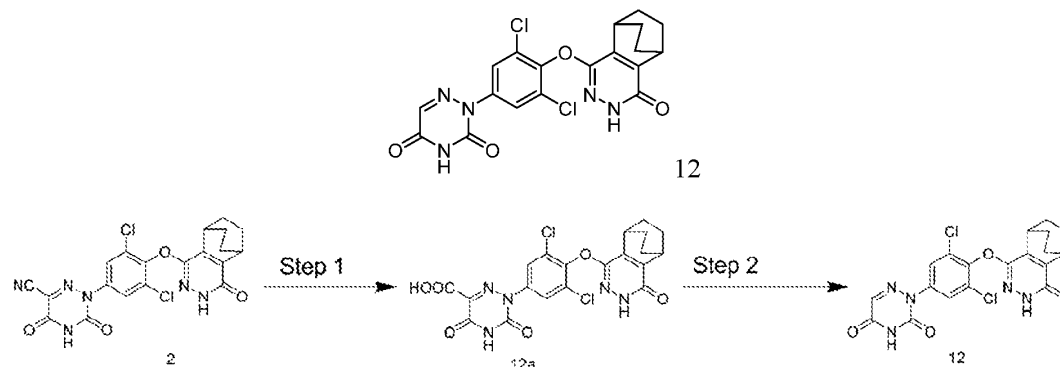
[0136] **Embodiment 11:** Preparation of 2-(3,5-dichloro-4-((5-methyl-4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 11):



[0137] The synthetic route of Embodiment 1 was employed, except that the raw material 3,4,5,6-tetrahydrophthalic anhydride (compound **1a**) in Step 1 was replaced with 3-methylphthalic anhydride, to produce the title product 2-(3,5-dichloro-4-((5-methyl-4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **11**).

[0138] MS m/z (ESI): 456.9 [M+1].

[0139] **Embodiment 12:** Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxo)phenyl)-1,2,4-triazine-3,5(2H,4H)-dione (compound 12):



[0140] Step 1: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-carboxylic acid

[0141] Acetic acid (4 ml) and concentrated hydrochloric acid (1 ml) were respectively added into the compound 2 (77 mg), heated to a temperature of 120 °C, stirred for 5 h, and cooled. The reaction solution was diluted with water. The solid obtained was filtered, washed with water, and washed with petroleum ether, to obtain a solid compound 12a (35 mg) directly used in the next reaction.

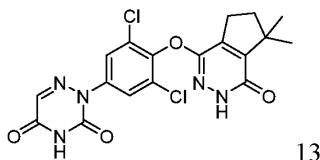
[0142] Step 2: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxo)phenyl)-1,2,4-triazine-3,5(2H,4H)-dione

[0143] Mercaptoacetic acid (2 ml) was added into the compound 12a (35.0 mg), and the mixture was heated to a temperature of 170 °C and stirred for 2 h. The mixture was cooled, adjusted to pH 8 with a 1N aqueous sodium hydroxide solution, and extracted 3 times with ethyl acetate. Organic phases were combined. The solvent was removed under reduced pressure, and a compound 12 (10.0 mg) was obtained by separation and purification through thin-layer chromatography (DCM:MeOH=8:1).

[0144] ¹H NMR (400 MHz, DMSO-*d*₆): 12.10 (s, 1H), 7.77 (s, 2H), 7.33 (s, 1H), 2.01 (m, 2H), 1.93-1.75 (m, 4H), 1.39-1.27 (m, 4H).

[0145] MS m/z (ESI): 448.0 [M+1].

[0146] Embodiment 13: Preparation of 2-(3,5-dichloro-4-((7,7-dimethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentyl[d]pyridazin-4-yl)oxy)phenyl)-1,2,4-triazine-3,5(2H,4H)-dione (compound 13)



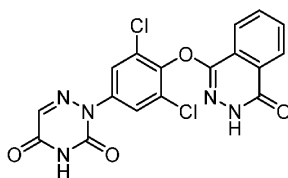
13

[0147] The synthetic route of Embodiment 12 was employed, except that the raw material 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 2) in Step 1 was replaced with 1-(3,5-dichloro-4-((7,7-dimethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentane[d]pyridazin-4-yl)oxy)phenyl)-2,4-dioxo-1,2,3,4-tetrahydropyrimidine-5-nitrile (compound 4), to produce the title product 2-(3,5-dichloro-4-((7,7-dimethyl-1-oxo-2,5,6,7-tetrahydro-1H-cyclopentyl[d]pyridazin-4-yl)oxy)phenyl)-1,2,4-triazine-3,5(2H,4H)-dione (compound 13).

[0148] ^1H NMR (400 MHz, DMSO- d_6): 12.02 (s, 1H), 7.77 (s, 2H), 7.35 (s, 1H), 2.94-2.90 (m, 2H), 1.99-1.95 (m, 2H), 1.32 (d, 6H).

[0149] MS m/z (ESI): 436.0 $[\text{M}+1]$.

[0150] Embodiment 14: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-1,2,4-triazine-3,5-(2H,4H)dione (compound 14)



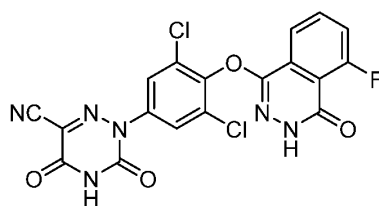
14

[0151] The synthetic route of Embodiment 12 was employed, except that the raw material 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydro-5,8-ethanophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 2) in Step 1 was replaced with 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound 9), to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-1,2,4-triazine-3,5-(2H,4H)dione (compound 14).

[0152] ^1H NMR (400 MHz, $\text{DMSO}-d_6$): 12.00 (s, 1H), 8.30-8.23 (m, 2H), 8.09-7.99 (m, 2H), 7.18 (s, 1H).

[0153] MS m/z (ESI): 418.0 $[\text{M}+1]$.

[0154] **Embodiment 15:** Preparation of 2-(3,5-dichloro-4-((5-fluoro-4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **15**)

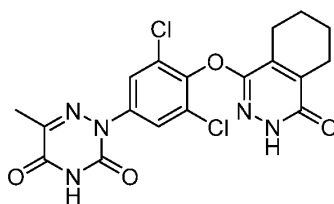


15

[0155] The synthetic route of Embodiment 1 was employed, except that the raw material 3,4,5,6-tetrahydrophthalic anhydride (compound **1a**) in Step 1 was replaced with 3-fluorophthalic anhydride, to produce the title product 2-(3,5-dichloro-4-((5-fluoro-4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **15**).

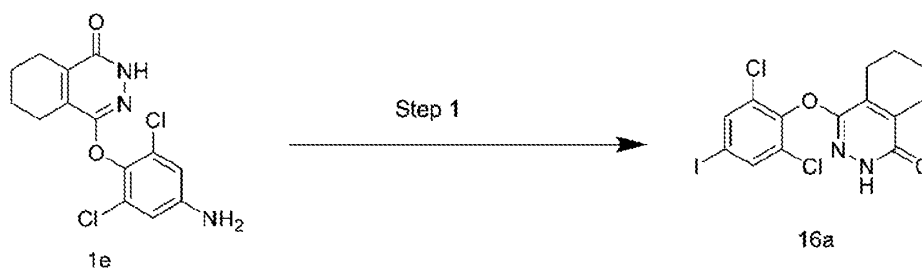
[0156] MS m/z (ESI): 461.0 $[\text{M}+1]$.

[0157] **Embodiment 16:** Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-6-methyl-1,2,4-triazine-3,5(2H,4H)-dione (compound **16**)



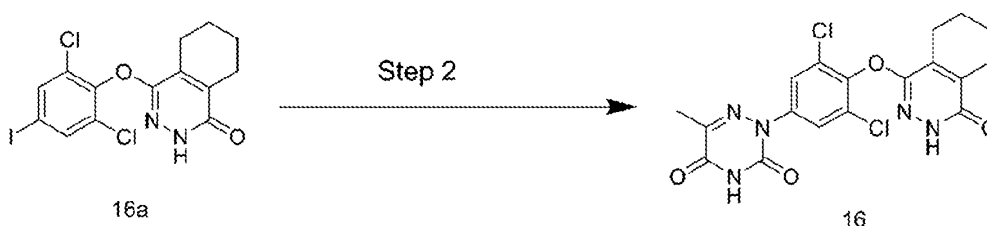
16

[0158] Step 1: Preparation of 4-(2,6-dichloro-4-iodophenoxy)-5,6,7,8-tetrahydrophthalazin-1(2H)-one (compound 16a)



[0159] Under ice bath conditions, water (4 ml) and concentrated hydrochloric acid (2 ml) were successively added into **1e** (100 mg), followed by the dropwise addition of a solution of sodium nitrite (30 mg) in water (2 ml). The reaction was stirred for 1 h under the maintained ice bath conditions. Potassium iodide (104 mg) was added dropwise, and the mixture was warmed up to room temperature and stirred for 16 h. The mixture was extracted with dichloromethane, and the solvent was removed under reduced pressure, to obtain a yellow solid **16a** (100 mg), directly used in the next reaction.

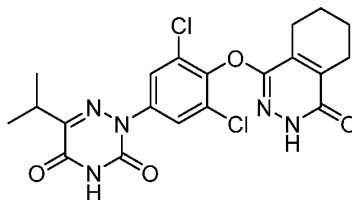
[0160] Step 2: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-6-methyl-1,2,4-triazine-3,5(2H,4H)-dione (compound **16**)



[0161] N,N-dicarbonamide (2.0ml) was added into a mixture of the compound **16a** (20 mg), 6-azathymine (6.6 mg), cuprous iodide (8.9 mg), and potassium carbonate (30 mg), and the system was heated to a temperature of 120° C and stirred for 12 h. The system was cooled, filtered, and separated from water through the addition of ethyl acetate. The solvent was removed from the organic phase under reduced pressure, and a compound **16** (5.0 mg) was obtained by separation and purification through thin-layer chromatography (DCM:MeOH=8:1).

[0162] MS m/z (ESI): 436.1 [M+1].

[0163] Embodiment 17: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-6-isopropyl-1,2,4-triazine-3,5(2H,4H)-dione (compound 17)

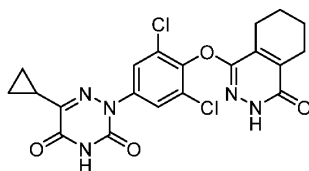


17

[0164] The synthetic route of Embodiment 16 was employed, except that the raw material 6-azathymine in Step 2 was replaced with 6-isopropyl-1,2,4-triazine-3,5(2H,4H)-dione (prepared by employing the well known method “*Chemistry and Biodiversity*, **2012**, 9(3) 536-556”), to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-6-isopropyl-1,2,4-triazine-3,5(2H,4H)-dione (compound 17).

[0165] MS m/z (ESI): 464.1 [M+1].

[0166] Embodiment 18: Preparation of 6-cyclopropyl-2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-1,2,4-triazine-3,5(2H,4H)-dione (compound 18)

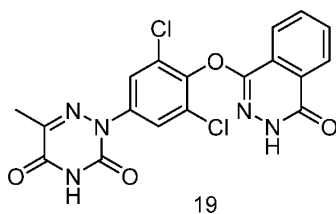


18

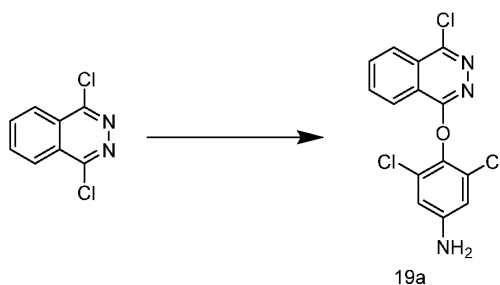
[0167] The synthetic route of Embodiment 16 was employed, except that the raw material 6-azathymine in Step 2 was replaced with 6-cyclopropyl-1,2,4-triazine-3,5(2H,4H)-dione (prepared by employing the well known method found in “*Collection of Czechoslovak Chemical Communications*, **1975**, 40, 1038-1041”), to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4,5,6,7,8-hexahydrophthalazin-1-yl)oxo)phenyl)-6-cyclopropyl-1,2,4-triazine-3,5(2H,4H)-dione (compound 18).

[0168] MS m/z (ESI): 462.1 [M+1].

[0169] **Embodiment 19:** Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-6-methyl-1,2,4-triazine-3,5(2H,4H)-dione (compound **19**)

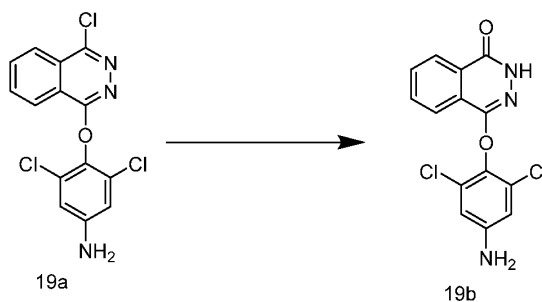


[0170] Step 1: Preparation of 3,5-dichloro-4-((4-chlorophthalazin-1-yl)oxo)aniline (compound **19a**)



[0171] The synthetic route of Intermediate 1d in Step 3 of Embodiment 1 was employed, except that 1,4-dichloro-5,6,7,8-tetrahydrophthalazine (compound **1c**) was replaced with 1,4-dichlorophthalazine, to produce the title product 3,5-dichloro-4-((4-chlorophthalazin-1-yl)oxo)aniline (compound **19a**).

[0172] Step 2: Preparation of 4-(4-amino-2,6-dichlorophenoxy)phthalazin-1(2H)-one (compound **19b**)



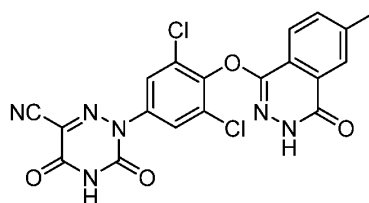
[0173] The synthetic route of Intermediate 1e in Step 4 of Embodiment 1 was employed, except that 3,5-dichloro-4-((4-chloro-5,6,7,8-tetrahydrophthalazin-1-yl)oxy)aniline (compound 1d) was replaced with 3,5-dichloro-4-((4-chlorophthalazin-1-yl)oxo)aniline (compound **19a**), to produce the title product 4-(4-amino-2,6-dichlorophenoxy)phthalazin-1(2H)-one (compound **19b**).

[0174] Step 3: Preparation of 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-6-methyl-1,2,4-triazine-3,5(2H,4H)-dione (compound **19**)

[0175] The synthetic route of Embodiment 16 was employed, except that 4-(2,6-dichloro-4-iodophenoxy)-5,6,7,8-tetrahydrophthalazin-1(2H)-one (compound 16a) in Step 1 was replaced with the compound 4-(4-amino-2,6-dichlorophenoxy)phthalazin-1(2H)-one (compound **19b**), to produce the title product 2-(3,5-dichloro-4-((4-oxo-3,4-dihydrophthalazin-1-yl)oxo)phenyl)-6-methyl-1,2,4-triazine-3,5(2H,4H)-dione (compound **19**).

[0176] MS m/z (ESI): 432.0 [M+1].

[0177] **Embodiment 20:** Preparation of 2-(3,5-dichloro-4-((6-methyl-4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **20**):

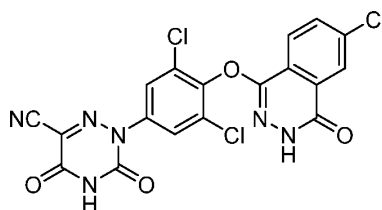


20

[0178] The synthetic route of Embodiment 1 was employed, except that the raw material tetrahydrophthalic anhydride (**1a**) in Step 1 was replaced with 4-methylphthalic anhydride, to produce the title product 2-(3,5-dichloro-4-((6-methyl-4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **20**).

[0179] MS m/z (ESI): 457.0 [M+1].

[0180] **Embodiment 21:** Preparation of 2-(3,5-dichloro-4-((6-chloro-4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **21**):



21

[0181] The synthetic route of Embodiment 1 was employed, except that the raw material tetrahydrophthalic anhydride (**1a**) in Step 1 was replaced with 4-chlorophthalic anhydride, to produce the title product 2-(3,5-dichloro-4-((6-chloro-4-oxo-3,4-dihydrophthalazin-1-yl)oxy)phenyl)-3,5-dioxo-2,3,4,5-tetrahydro-1,2,4-triazine-6-nitrile (compound **21**).

[0182] MS m/z (ESI): 477.0 [M+1].

[0183] Test Embodiment 1: Binding Force of the Compound to TR α Test:

1. Main Experimental Materials and apparatuses:

Envision 2104 microplate reader;

Biotin-SRC2-2 coactivator peptide, commercially available from Sangon Biotech (Shanghai) Co., Ltd.;

TR α LBD, GST, commercially available from ThermoFisher (Art. No. PV4762);

Europium binding anti-glutathione antibody, commercially available from Cisbio (Art. No. 61GSTKLB); and

Streptavidin-D2, commercially available from Cisbio (Art. No. 610SADAB)

2. Preparation and Treatment of Compounds

2.1 Preparation of Stock Solution of the Compound in Dimethyl Sulfoxide

All compounds were dissolved in dimethyl sulfoxide to prepare a 10 mmol stock solution.

2.2 Compound Storage

After the compounds were dissolved in dimethyl sulfoxide, the solution can be stored for 3 months in a desiccator at room temperature. For long-term storage, compounds shall be placed into a refrigerator at -20°C.

3. Experimental Steps

3.1 Preparation of 1x Reaction Buffer

3.2 Compound Screening:

- a) 100% dimethyl sulfoxide was used to dilute the positive drug triiodothyronine (T3) from 10 mmol (100x) or the compound to be tested from 1 mmol (100x), at an equal ratio of 1:3, for a total of 10 concentrations.
- b) a 4x concentration gradient diluted compound was prepared with a 1x reaction buffer.
- c) 5 µl of the 4x concentration gradient diluted compound was added into a 384-well test plate.
- d) 4X TRα LBD and 4X RXRα were prepared with the 1x reaction buffer.
- e) 5 µl of 4x TRα LBD and 4X RXRα were added into the 384-well test plate.
- f) 2X biotin-SRC2-2, 2X Europium binding anti-glutathione antibody, and 2X streptavidin-d2 were prepared with the 1x reaction buffer.
- g) 10 µl of a 2X mixed solution (referring to Step f) was added into the 384-well test plate.
- h) The 384-well test plate was centrifugated for 1000 revolutions within 1 min in a centrifuge.
- i) Incubation at room temperature was performed for 1 h while protected from light.
- j) The fluorescence signal values of each well of the 384-well test plate at the wavelength of 665 nm and 615 nm were recorded with the Envision 2104 microplate reader, and the fluorescence ratio of 665 nm/615 nm was calculated.

4. Data Analysis

4.1 Calculation of Relative Ratio ($\text{ratio}_{665 \text{ nm}/615 \text{ nm}} - \text{ratio}_{\text{blank}}$) of each well

4.2 The Activity Percentage was Calculated as Follows:

$$\text{Activity (\%)} = \left[\frac{\overline{\text{Ratio}}_{\text{compound}} - \overline{\text{Ratio}}_{\text{blank}}}{\overline{\text{Ratio}}_{\text{positive}} - \overline{\text{Ratio}}_{\text{blank}}} \right] * 100$$

$\overline{\text{Ratio}}_{\text{compound}}$: average of relative ratios of wells of embodiment compounds

$\overline{\text{Ratio}}_{\text{positive}}$: average of relative ratios of all positive control wells

$\overline{\text{Ratio}}_{\text{blank}}$: average of relative ratios of all negative control wells

4.3 Curve Plotting and EC50 Calculation:

EC50 was calculated by using Graphpad 5.0 through the nonlinear regression method to fit the relationship between the activity (%) and the logarithm concentration of the compound.

$$Y = \text{bottom} + (\text{top} - \text{bottom}) / (1 + 10^{-(\text{LogEC50} - X) \times \text{slope}})$$

X: Logarithm concentration of the compound Y: Percentage activity

Particular test data are shown in Table 1 as follows.

[0184] Test Embodiment 2: Evaluation of the Agonistic Activity of the Compound toward TR α

1. Main Experimental Materials and Apparatuses:

Envision 2104 microplate reader

HEK293T cell line, commercially available from ATCC (Art. No.: CRL-3216)

pGL4.35[luc2P/9XGAL4 UAS/Hygro], commercially available from Promega (Art. No.: E1370)

pBIND-TR α plasmid, from Pharmaron

pBIND- RXR α plasmid, from Pharmaron

LipoLTX transfection agent, commercially available from ThermoFisher (Art. No.: 15338-100)

2. Compound Preparation

2.1 Compound Dissolution

The compound powder was prepared into a 10 mmol stock solution in dimethyl sulfoxide according to the standard scheme.

2.2 Compound Storage

All compounds dissolved in dimethyl sulfoxide were stored in a desiccator at room temperature for a short term, or stored at -20 °C for a long term.

2.3 Preparation of Experimental Compounds

2.3.1 All the compounds to be tested were diluted with dimethyl sulfoxide at a 3-fold gradient, in 10 dilution gradients, starting from the initial concentration of 10 μmol .

2.3.2 The positive control triiodothyronine (T3) was diluted with dimethyl sulfoxide at a 3-fold gradient, in 10 dilution gradients, starting from the initial concentration of 16.67 μmol .

2.3.3 A 166.7 $\times$ positive control (16.67 μmol , triiodothyronine (T3)) and a 166.7 $\times$ negative control (100% dimethyl sulfoxide) were prepared.

2.4 The compound plate was closed and shaken for 5 min.

3 Experiment Process

3.1 Cell Suspension Preparation and Plate Seeding

a) All cells were cultured according to the ATCC standard operation, and HEK293T was tested in the exponential growth period;

b) The medium was discarded;

c) The cells were washed twice with a phosphate buffer;

d) A trypsinization solution was added to digest the cells, and the digestion was terminated with a complete medium;

- e) The cells were collected and counted, and only when the cell viability was greater than 90% could the experiment be carried out;
- f) 2.5×10^6 HEK293-LUC cells were seeded into a 60-mm cell culture dish; and
- g) The culture dish with cells seeded was placed into an incubator at 37 °C and 5% CO₂ and cultured overnight.

3.2 Cell Transfection

- a) The LipoLTX transfection agent was placed at room temperature for balancing;
- b) 6 µl of Plus agent and 6 µg of DNA were added into 250 µl of Opti-MEM™ medium without contacting the tube wall, and they were mixed uniformly through blowing and pipetting by a pipetting gun, and
Plasmid: 2.5 µg of pBIND-TRα, 2.5 µg of pBIND-RXRα and 1 µg of pGL4.35 plasmid were respectively added therein;
- c) 12 µl of Lipo LTX and 250 µl of Opti-MEM™ medium were added without contacting the tube wall, and they were mixed uniformly through blowing and pipetting by a pipetting gun;
- d) the agent mixed with DNA Plus (see Step 3.2.b) was added into the diluted LipoLTX (see Step 3.2.c) transfection agent, and stood still for 15 min at room temperature;
- e) the transfection agent mixed with DNA was added to a 60-mm cell culture dish (see Step 3.1); and
- f) the culture dish was placed into an incubator at 37 °C and 5% CO₂ and cultured for 5 h.

3.3 Compound Treatment

- a) 150 nl of the diluted compound (see Step 2.3) was transferred by Echo550 to a cell culture plate (6007680-50, PE);
- b) the cells (see Step 3.2) were seeded to a 384 cell culture plate (6007680-50, PE), with 15,000 cells and 25 µl of the medium containing 5% fetal bovine serum per well; and
- c) the cells were cultured overnight in an incubator at 37 °C and 5% CO₂.

3.4 Compound Detection

- a) The Steady-Glo™ detection agent was placed at room temperature;
- b) the 384 cell plate (see Step 3.3) was placed at room temperature;
- c) 25 µl of the Steady-Glo™ detection agent per well was added into the cell culture plate (see Step 3.4b);
- d) the plate was placed on a shaker and shaken for 5 min while protected from light; and
- e) the chemiluminescence value was detected with the Envision 2104 microplate reader.

4. Data Analysis

4.1 Calculation of Activity (%):

$$\text{Activity (\%)} = \left[\frac{\text{RLU}_{\text{compound}} - \overline{\text{RLU}}_{\text{blank}}}{\overline{\text{RLU}}_{\text{positive}} - \overline{\text{RLU}}_{\text{blank}}} \right] \times 100$$

RLU: Fluorescence generated

$\overline{\text{RLU}}_{\text{compound}}$: Well average of embodiment compounds

$\overline{\text{RLU}}_{\text{positive}}$: positive control average

$\overline{\text{RLU}}_{\text{blank}}$: negative control average

4.2 EC50 Calculation and Plotting of Dose-effect Curve of the Compound

EC50 of the the compound was calculated by using Graphpad 5.0 to fit the activity (%) and the logarithm concentration of the compound.

$$Y = \text{bottom} + (\text{top} - \text{bottom}) / (1 + 10^{((\text{LogIC50} - X) \times \text{slope})})$$

X: Logarithm concentration of the compound Y: Percentage inhibition rate

[0185] Particular test data are shown in Table 1 as follows.

[0186] Test Embodiment 3: Binding Force of the Compound to TRβ Test

1. Main Experimental Material and Apparatus:

Envision 2104 microplate reader,

Biotin-SRC2-2 coactivator peptide, commercially available from Sangon Biotech (Shanghai) Co., Ltd.

TR β LBD, GST, commercially available from ThermoFisher (Art. No. PV4762)

Europium binding anti-glutathione antibody, commercially available from Cisbio (Art. No. 61GSTKLB)

Streptavidin-D2, commercially available from Cisbio (Art. No. 610SADAB)

2. Preparation and Treatment of Compounds

2.1 Preparation of Stock Solution of the Compound in Dimethyl Sulfoxide

All compounds were dissolved in dimethyl sulfoxide to prepare a 10 mmol stock solution.

2.2 Compound Storage

After the compounds were dissolved in dimethyl sulfoxide, the solution can be stored for 3 months in a desiccator at room temperature. For long-term storage, compounds shall be placed into a refrigerator at -20 °C.

3. Experimental Steps

3.1 Preparation of 1x Reaction Buffer

3.2 Compound Screening:

a) 100% dimethyl sulfoxide was used to dilute the positive drug triiodothyronine (T3) from 10 μ mol (100x) or the compound to be tested from 1 mmol (100x), at an equal ratio of 1:3, totally in 10 concentrations;

b) A 4x concentration gradient diluted compound was prepared with a 1x reaction buffer;

c) 5 μ l of the 4x concentration gradient diluted compound was added into a 384-well test plate;

d) 4X TR β LBD and 4X RXR β were prepared with the 1x reaction buffer;

e) 5 μ l of 4x TR β LBD and 4X RXR β were added into the 384-well test plate;

f) 2X biotin-SRC2-2, 2X Europium binding anti-glutathione antibody and 2X streptavidin-d2 were prepared with the 1x reaction buffer;

- g) 10 μ l of a 2X mixed solution (referring to Step f) was added into the 384-well test plate;
- h) The 384-well test plate was centrifugated for 1000 revolutions within 1 min in a centrifuge;
- i) Incubation at room temperature was performed for 1 h, while protected from light; and
- j) The fluorescence signal values of each well of the 384-well test plate at the wavelength of 665 nm and 615 nm were recorded with the Envision 2104 microplate reader, and the fluorescence ratio of 665 nm/615 nm was calculated.

4. Data Analysis

4.1 Calculation of Relative Ratio (ratio_{665 nm/615 nm} - ratio_{blank}) of Each Well

4.2 The Activity Percentage was Calculated as Follows:

$$\text{Activity (\%)} = \left[\frac{\text{Ratio}_{\text{compound}} - \overline{\text{Ratio}}_{\text{blank}}}{\overline{\text{Ratio}}_{\text{positive}} - \overline{\text{Ratio}}_{\text{blank}}} \right] \times 100$$

$\overline{\text{Ratio}}_{\text{compound}}$: average of relative ratios of wells of embodiment compounds

$\overline{\text{Ratio}}_{\text{positive}}$: average of relative ratios of all positive control wells

$\overline{\text{Ratio}}_{\text{blank}}$: average of relative ratios of all negative control wells

4.3 Curve Plotting and EC50 Calculation:

EC50 was calculated by using Graphpad 5.0 through the nonlinear regression method to fit the relationship between the activity (%) and the logarithm concentration of the compound.

$$Y = \text{bottom} + (\text{top} - \text{bottom}) / (1 + 10^{((\text{LogEC50} - X) \times \text{slope})})$$

X: Logarithm concentration of the compound Y: Percentage activity

[0187] Particular test data are shown in Table 1 as follows.

Table 1 The binding activity of the compound to the thyroxine receptor β is shown as follows:

Embodiments	IC50		THR α / β selectivity (factor)
	THR β binding force (μ M)	THR α binding force (μ M)	
Embodiment 1	1.23	>10	> 8.1
Embodiment 2	2.33	>10	>4.29
Embodiment 3	5.2	>10	>1.92
Embodiment 4	0.36	4.3	>11.9
Embodiment 9	0.17	>10	>58.8
Embodiment 10	1.47	>10	>6.80
Embodiment 11	1.78	>10	5.61
Embodiment 12	0.80	0.2	0.25
Embodiment 13	0.17	1.22	7.17
Embodiment 14	0.262		
Comparative Compound 53	0.26	5.0	19.2
T3	0.00052	0.00026	

[0188] Conclusion: compared with the disclosed comparative compound 53, some of the compounds according to the present invention unexpectedly showed high THR β activity (<0.2 μ M), and some of the compounds showed higher selectivity to THR α than the comparative compound 53.

[0189] Test Embodiment 4: Evaluation of Agonistic Activity of the Compound Toward the TR β Receptor

[0190] Experiment Summary: TR β -LBD and RXR α -LBD coding sequences were inserted into a pBIND plasmid (Promega, E1581) respectively. The expression vector and the reporter vector (pGL4.35 carrying a luciferase reporter gene driven by a stable integrated GAL4 promoter) were co-expressed in the host cell. When the agonist binds to the corresponding chimeric receptor, the chimeric receptor binds to the GAL4 binding site on the reporter gene vector and stimulates the reporter gene expression. According to the intensity of chemiluminescence signals, the agonistic activity of the compound toward the TR β receptor was determined.

[0191] Experimental Materials and Apparatuses:

Envision 2104 microplate reader

HEK293T cell line, commercially available from ATCC (Art. No.: CRL-3216)

pGL4.35[luc2P/9XGAL4 UAS/Hygro], commercially available from Promega (Art. No.: E1370)

pBIND-TR β plasmid, from Pharmaron

pBIND- RXR α plasmid, from Pharmaron

LipoLTX transfection agent, commercially available from ThermoFisher (Art. No.: 15338-100)

Steady-Glo™ luciferase detection kit, commercially available from Promega (Art. No.: E2520)

2.3 Preparation of Experimental Compounds

- ☐ All the compounds to be tested were diluted with dimethyl sulfoxide at a 3-fold gradient, in 10 dilution gradients, starting from the initial concentration of 10 mmol.
- ☐ The positive control triiodothyronine (T3) was diluted with dimethyl sulfoxide at a 3-fold gradient, in 10 dilution gradients, starting from the initial concentration of 16.67 μ mol.
- ☐ A 166.7 $\times$ positive control (16.67 μ mol, triiodothyronine (T3)) and a 166.7 $\times$ negative control (100% dimethyl sulfoxide) were prepared.
- ☐ The compound plate was closed and shaken for 5 min.

Experiment Process

3.1 Cell Suspension Preparation and Plate Seeding

- a) All cells were cultured according to the ATCC standard operation, and HEK293T was tested in the exponential growth period;
- b) The medium was discarded;
- c) The cells were washed twice with a phosphate buffer;
- d) A trypsinization solution was added to digest the cells, and the digestion was terminated with a complete medium;

- e) The cells were collected and counted, and only when the cell viability was greater than 90% could the experiment be carried out;
- f) 2.5×10^6 HEK293-LUC cells were seeded into a 60-mm cell culture dish; and
- g) The culture dish with cells seeded was placed into an incubator at 37 °C and 5% CO₂ and cultured overnight.

3.2 Cell Transfection

- a) The LipoLTX transfection agent was placed at room temperature for balancing;
- b) 6 µl of Plus agent and 6 µg of DNA were added into 250 µl of an Opti-MEM™ medium without contacting the tube wall, and they were mixed uniformly through blowing and pipetting by a pipetting gun; plasmid: 2.5 µg of pBIND-TRβ, 2.5 µg of pBIND-RXRα and 1 µg of pGL4.35 plasmid
- c) 12 µl of Lipo LTX and 250 µl of Opti-MEM™ medium were added without contacting the tube wall, and they were mixed uniformly through blowing and pipetting by a pipetting gun;
- d) the agent mixed with DNA plus (see Step 3.2.b) was added into the diluted LipoLTX (see Step 3.2.c) transfection agent and stood still for 15 min at room temperature;
- e) the transfection agent mixed with DNA was added to a 60-mm cell culture dish (see Step 3.1); and
- f) the culture dish was placed into an incubator at 37 °C and 5% CO₂ and cultured for 5 h.

3.3 Compound Treatment

- a) 150 nl of the diluted compound (see Step 2.3) was transferred by Echo550 to a cell culture plate (6007680-50, PE);
- b) the cells (see Step 3.2) were seeded to a 384 cell culture plate (6007680-50, PE) with 15,000 cells and 25 µl of the medium per well; and
- c) the cells were cultured overnight in an incubator at 37 °C and 5% CO₂.

3.4 Compound Detection

- a) The Steady-Glo™ detection agent was placed at room temperature;

- b) the 384 cell plate (see Step 3.3) was placed at room temperature;
- c) 25 μ l of the Steady-Glo™ detection agent per well was added into the cell culture plate (see Step 3.4b);
- d) the plate was placed on a shaker and shaken for 5 min while protected from light; and
- e) the chemiluminescence value was detected with the Envision 2104 microplate reader.

Data Analysis

4.1 Calculation of Activity (%):

$$\% \text{ Activity} = \left[\frac{\text{RLU}_{\text{compound}} - \overline{\text{RLU}}_{\text{blank}}}{\overline{\text{RLU}}_{\text{positive}} - \overline{\text{RLU}}_{\text{blank}}} \right] \times 100$$

RLU: fluorescence generated

$\overline{\text{RLU}}_{\text{compound}}$: Well average of embodiment compounds

$\overline{\text{RLU}}_{\text{positive}}$: positive control average

$\overline{\text{RLU}}_{\text{blank}}$: negative control average

4.2 EC50 Calculation and Plotting of Dose-effect Curve of the Compound

EC50 of the compound was calculated by using Graphpad 5.0 to fit the activity (%) and the logarithm concentration of the compound.

$$Y = \text{bottom} + (\text{top} - \text{bottom}) / (1 + 10^{((\text{LogIC}_{50} - X) \times \text{slope})})$$

X: Logarithm concentration of the compound Y: Percentage inhibition rate

Table 2: the agonistic activity of the compound of the present invention toward the thyroxine receptor beta is shown as follows:

Embodiments	EC ₅₀	
	THR β agonistic activity (μ M)	THR α agonistic activity (μ M)

Embodiment 4	2.45	4.25
Embodiment 9	1.75	3.98
Embodiment 12	0.79	1.08
Embodiment 13	0.097	0.123
Comparative Compound 53	2.48	4.57
T3	0.001	0.0005

[0192] Conclusion: the compound of the present invention can activate the downstream signal of the thyroid hormone receptor beta.

[0193] Test Embodiment 5: Pharmacokinetic Evaluation:

[0194] Rats were used as test animals. After intragastric infusion of the compounds from Embodiment 4 and Embodiment 9, the drug concentrations in the plasma of the rats at different times were tested. The pharmacokinetic behaviors of the compounds of the present invention in rats were studied, and the pharmaceutical metabolism characteristics thereof were evaluated. In each group of the embodiment, 3 male SD rats with a similar body weight were selected, and the oral dose was 2 mg/kg in a single dose. Blood was collected at time points of 15 min, 30 min, 1 h, 2 h, 4 h, 6 h, 10 h, and 24 h after administration of the dose to the animals. The LC-MS/MS analytical method was employed to detect the content of the compounds in plasma, and the lower limit of quantification of the method was 20 ng/ml. The metakinetik data analysis software WinNonlin 7.0 was used to generate statistics on VT088 and concentration data of the plasma. The non-compartment model method (NCA) was utilized to calculate the pharmacokinetic parameters, particularly as shown in Table 2 below.

[0195] Experiment Scheme:

[0196] Experiment Drugs: compounds from Embodiment 4 and Embodiment 9.

[0197] Laboratory Animals:

[0198] Six healthy male SD rats, commercially available from Shanghai Sippr-Bk Laboratory Animal Co., Ltd., with an animal production license No.: SCXK(Shanghai) 2008-0016, were divided into 2 groups, 3 in each group.

[0199] Drug Preparation: a certain amount of the drug was taken and added into a 2% Klucel LF + 0.1% Tween 80 aqueous solution, to prepare a clear solution or a uniform suspension.

[0200] Dosage: SD rats were fasted overnight and given the drug by intragastric infusion at an administrated dose of 2 mg/kg and an administrated volume of 10 mL/kg each.

[0201] Operation: rats were dosed by intragastric infusion with the compounds from Embodiment 4 and Embodiment 9. At least 0.2 mL of blood was collected from the vena caudalis at 15 min, 30 min, 1 h, 2 h, 4 h, 6 h, 10 h, and 24 h before and after the dosage; the blood was then placed in heparinized sample tubes, centrifuged at 4 °C and 3500 rpm for 10 min to separate the plasma. The heparinized sample tubes were then stored at -20 °C, and the rats were allowed to eat food 2 h after the dosage.

[0202] Determination of contents of the compounds to be tested in the plasma of rats after intragastric infusion of the drugs at different concentrations: the plasma samples were thawed at room temperature, 50 µL each was taken and added into 130 µL of an internal standard working solution (1000 ng/mL, acetonitrile, tolbutamide), and the mixture was whirled for about 1 min and then centrifuged at 4 °C and 13000 rpm for 10 min. 50 µL of the supernatant was taken and mixed with 100 µL of 50% acetonitrile water, and then introduced for LC/MS/MS analysis.

[0203] Results of the pharmacokinetic parameters are shown in Table 3.

Table 3: Pharmaceutical metabolism data of rats

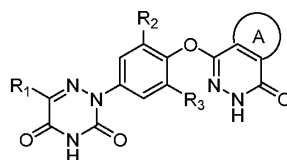
Compound	Dose (mg/kg)	Time to peak (h)	Peak blood drug concentration (ng/mL)	Curve area (ng·h/mL)	Half-life (h)
Embodiment 4	2.0	5.33±1.15	727±183	9242±1245	5.14±0.83
Embodiment 9	2.0	4.67±1.15	2007±106	24790±3704	4.56±0.42
Comparative Compound 53	2.0	5.3±1.15	1163±97.1	12854 ±961	3.53±0.42

[0204] Conclusion: the compounds of the present invention possess good pharmacokinetic absorption and significant pharmacokinetic advantages. Compared with the reported comparative compound 53, some of the compounds of the present invention unexpectedly show higher C_{max} values and exposure amounts at the same dose and preparation. All the above PK results show

that, the compounds provided in the present invention have good PK properties and can be used as a therapeutic drug for a metabolism-related disease.

CLAIMS

1. A compound represented by the following Formula (I) and a pharmaceutically acceptable salt thereof,



(I)

wherein,

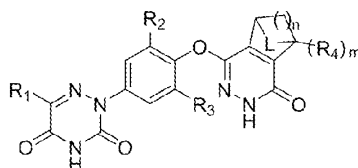
R₁ is selected from the group consisting of hydrogen, cyano, substituted or unsubstituted C₁₋₆ alkyl, or substituted or unsubstituted C₃₋₆ cycloalkyl, the substituent being selected from the group consisting of halogen atoms, hydroxy, and C₁₋₆ alkoxy;

R₂ and R₃ are each independently selected from the group consisting of halogen atoms or substituted or unsubstituted C₁₋₆ alkyl, the substituent being selected from the group consisting of halogen atoms, hydroxy, and C₁₋₆ alkoxy;

ring A is a substituted or unsubstituted saturated or unsaturated C₅₋₁₀ aliphatic ring, or a substituted or unsubstituted C₅₋₁₀ aromatic ring, the substituent being one or more substances selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, -NH₂, -NHC₁₋₄ alkyl, -N(C₁₋₄ alkyl)₂, -CONH₂, -CONHC₁₋₄ alkyl, -CON(C₁₋₄ alkyl)₂, -NHCOC₁₋₄ alkyl, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl, and when two substituents are contained, the two substituents can form a ring structure together with the carbon connected thereto; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

2. The compound and pharmaceutically acceptable salt thereof according to claim 1, wherein the compound has a structure as shown in the following Formula (II):



(II)

wherein,

R₁ to R₃ are defined as described in claim 1;

L is not present or is selected from the group consisting of -CH₂- and -CH₂CH₂-;

R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, -NH₂, -NHC₁₋₄ alkyl, -N(C₁₋₄ alkyl)₂, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl;

n is an integer from the range 1 to 4;

m is an integer from the range 1 to 4;

when L is not present, the ring may have two or more substituents R₄ thereon; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

3. The compound and pharmaceutically acceptable salt thereof according to claim 2, wherein R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, C₁₋₃ alkyl, C₁₋₃ alkoxy or C₃₋₆ cycloalkyl;

L is not present or is selected from the group consisting of -CH₂- or -CH₂CH₂-;

n is 1, 2 or 3; and

m is 1 or 2.

4. The compound and pharmaceutically acceptable salt thereof according to claim 3, wherein R₄ is selected from the group consisting of hydrogen or C₁₋₃ alkyl;

L is not present;

n is 1, 2 or 3; and

m is 1 or 2.

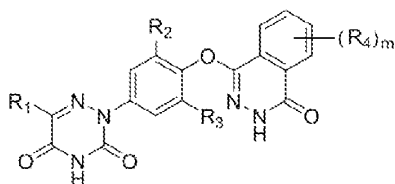
5. The compound and pharmaceutically acceptable salt thereof according to claim 3, wherein R₄ is selected from the group consisting of hydrogen or C₁₋₃ alkyl;

L is selected from the group consisting of -CH₂- or -CH₂CH₂-;

n is 1, 2 or 3; and

m is 1 or 2.

6. The compound and pharmaceutically acceptable salt thereof according to claim 1, wherein the compound has a structure as shown in the following Formula (III):



wherein,

R₁ to R₃ are defined as described in claim 1;

R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, -NH₂, -NHC₁₋₄ alkyl, -N(C₁₋₄ alkyl)₂, -CONH₂, -CONHC₁₋₄ alkyl, -CON(C₁₋₄ alkyl)₂, -NHCOC₁₋₄ alkyl, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl;

m is an integer from the range 1 to 4; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

7. The compound and pharmaceutically acceptable salt thereof according to claim 6, wherein R₄ is selected from the group consisting of hydrogen, halogen atoms, hydroxy, -OCF₃, C₁₋₆ alkyl, C₁₋₆ alkoxy or C₃₋₆ cycloalkyl; and

m is an integer from the range 1 to 3.

8. The compound and pharmaceutically acceptable salt thereof according to claim 7, wherein R₄ is selected from the group consisting of hydrogen, halogen atoms or C₁₋₃ alkyl; and m is 1 or 2.

9. The compound and pharmaceutically acceptable salt thereof according to any one of claims 1 to 8, wherein R₁ is selected from the group consisting of hydrogen, cyano, and substituted or unsubstituted C₁₋₆ alkyl, the substituent being selected from the group consisting of halogen atoms, hydroxy, and C₁₋₆ alkoxy; and

the halogen atoms are selected from the group consisting of F, Cl or Br.

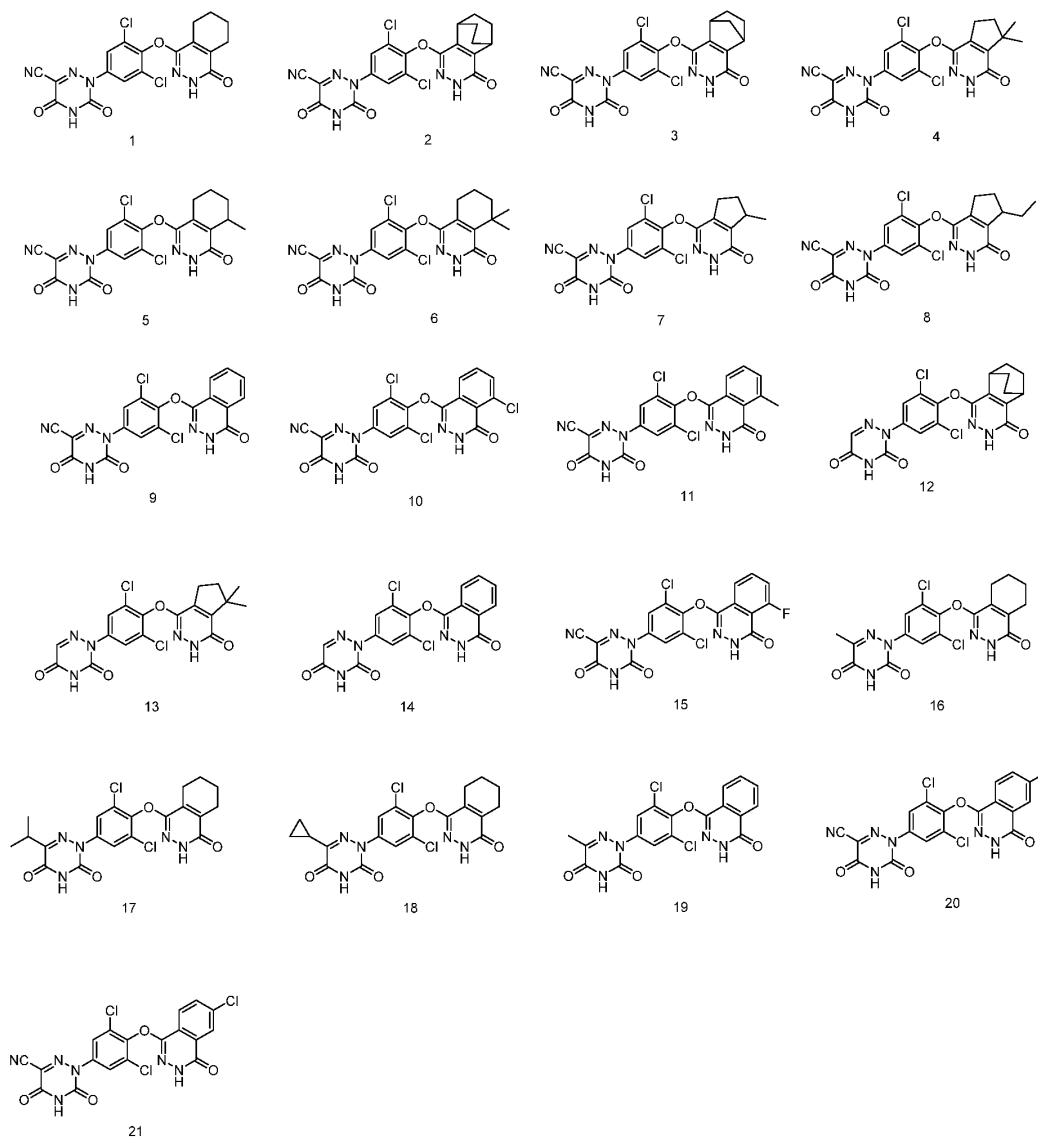
10. The compound and pharmaceutically acceptable salt thereof according to claim 9, wherein R₁ is selected from the group consisting of cyano or C₁₋₃ alkyl.

11. The compound and pharmaceutically acceptable salt thereof according to claim 10, wherein R₁ is cyano.

12. The compound and pharmaceutically acceptable salt thereof according to any one of claims 1 to 8, wherein R₂ and R₃ are each independently selected from the group consisting of F, Cl or Br.

13. The compound and pharmaceutically acceptable salt thereof according to claim 12, wherein R₂ and R₃ are both Cl.

14. The compound and pharmaceutically acceptable salt thereof according to any one of claims 1 to 13, wherein the compound and pharmaceutically acceptable salt thereof are one of the following compounds:



15. Use of the compound and pharmaceutically acceptable salt thereof according to any one of claims 1 to 14 in the preparation of a therapeutic drug for a metabolism-related disease.

16. The use of the compound and pharmaceutically acceptable salt thereof according to claim 15 in the preparation of the therapeutic drug for the metabolism-related disease, wherein the

metabolism-related disease is selected from the group consisting of obesity, hyperlipidemia, hypercholesterolemia, diabetes, and non-alcoholic steatohepatitis (NASH), steatosis of liver, atherosclerosis, hypothyroidism, and thyroid cancer.

17. The use of the compound and pharmaceutically acceptable salt thereof according to claim 16 in the preparation of the therapeutic drug for the metabolism-related disease, wherein the metabolism-related disease is selected from the group consisting of non-alcoholic steatohepatitis (NASH), hypothyroidism, and thyroid cancer.

18. A pharmaceutical composition, comprising a therapeutically effective amount of the compound and pharmaceutically acceptable salt according to any one of claims 1 to 14, and a pharmaceutically acceptable adjuvant.

19. A method for treating a metabolism-related disease, the method comprising administering to the subject an effective amount of the compound according to any of claims 1 to 14, or a pharmaceutical composition containing the compound and pharmaceutically acceptable salt thereof as the active ingredient.

20. The method for treating a metabolism-related disease according to claim 19, wherein the metabolism-related disease is selected from the group consisting of obesity, hyperlipidemia, hypercholesterolemia, diabetes, and non-alcoholic steatohepatitis (NASH), steatosis of liver, atherosclerosis, hypothyroidism, and thyroid cancer.

21. The method for treating a metabolism-related disease according to claim 20, wherein the metabolism-related disease is selected from the group consisting of non-alcoholic steatohepatitis (NASH), hypothyroidism, and thyroid cancer.