

## PERIPHERAL OPIOID RECEPTOR ANTAGONISTS AND USES THEREOF

### CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to United States provisional patent applications serial number 61/101,201, filed September 30, 2008, 61/226,581, filed July 17, 2009, and 61/237,428, filed August 27, 2009, the entirety of each of which is hereby incorporated herein by reference.

### BACKGROUND OF THE INVENTION

[0002] Opioids are widely used in patients with advanced cancers and other terminal diseases to reduce suffering. Opioids are narcotic medications that activate opioid receptors located in the central nervous system to relieve pain. Opioids, however, also react with receptors outside of the central nervous system, resulting in side effects including constipation, nausea, vomiting, urinary retention, and severe itching. Most notable are the effects in the gastrointestinal tract (GI) where opioids inhibit gastric emptying and propulsive motor activity of the intestine, thereby decreasing the rate of intestinal transit and producing constipation. The effectiveness of opioids for pain is often limited due to resultant side effects, which can be debilitating and often cause patients to cease use of opioid analgesics.

[0003] In addition to analgesic opioid induced side effects, studies have suggested that endogenous opioid compounds and receptors may also affect activity of the gastrointestinal (GI) tract and may be involved in normal regulation of intestinal motility and mucosal transport of fluids in both animals and man. (Koch, T. R, et al, Digestive Diseases and Sciences 1991, 36, 712-728; Schuller, A.G.P., et al., Society of Neuroscience Abstracts 1998, 24, 524, Reisine, T., and Pasternak, G., Goodman & Gilman's The Pharmacological Basis of Therapeutics Ninth Edition 1996, 521-555 and Bagnol, D., et al., Regul. Pept. 1993, 47, 259-273). Thus, an abnormal physiological level of endogenous compounds and/or receptor activity may lead to bowel dysfunction.

[0004] For example, patients who have undergone surgical procedures, especially surgery of the abdomen, often suffer from a particular bowel dysfunction, called post-operative (or post-surgical) ileus, that may be caused by fluctuations in natural opioid levels. Similarly, women who have recently given birth commonly suffer from post-partum ileus, which is thought

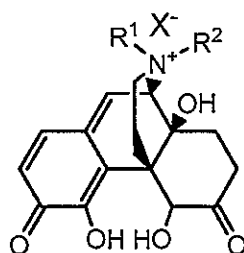
to be caused by similar natural opioid fluctuations as a result of birthing stress. Gastrointestinal dysfunction associated with post-operative or post partum ileus can typically last for 3 to 5 days, with some severe cases lasting more than a week. Administration of opioid analgesics to a patient after surgery, which is now an almost universal practice, may exacerbate bowel dysfunction, thereby delaying recovery of normal bowel function, prolonging hospital stays, and increasing medical care costs.

[0005] Methylnaltrexone ("MNTX") is a derivative of the opioid antagonist, naltrexone, whereby the amine is quarternized. MNTX is commonly provided as a salt, for example, a bromide salt. The bromide salt of MNTX is also known in the literature as: methylnaltrexone bromide; *N*-methylnaltrexone bromide; naltrexone methobromide; naltrexone methyl bromide; and MRZ 2663BR. MNTX was first reported by Goldberg et al. as described in U.S. Patent No. 4,176,186. It is believed that addition of the methyl group to the ring nitrogen of naltrexone forms a charged compound with greater polarity and less liposolubility than naltrexone, preventing MNTX from crossing the blood-brain barrier in humans. As a consequence, MNTX exerts its effects in the periphery rather than in the central nervous system with the advantage that it does not counteract the analgesic effects of opioids on the central nervous system.

[0006] Generally, pharmaceutical compositions require a high level of purity to meet regulated standards for drug quality and purity. For example, during synthesis and/or storage of MNTX, impurities may form which may hinder the therapeutic effects of MNTX and/or may be toxic if present in high enough quantity. As such, it is desirable to have the ability to determine the purity of MNTX. To that end, it is important to identify, isolate, and chemically characterize impurities and degradants which can be used in chromatographic procedures as standards to confirm the purity of MNTX.

## SUMMARY

[0007] In certain embodiments, the present invention relates to the identification, purification, and synthesis of an impurity of MNTX. It has been discovered that this compound can arise as an impurity either in the process for manufacturing MNTX or as a degradant when certain solutions of MNTX are stored under certain conditions. Accordingly, in certain embodiments, the present invention provides a compound of formula I:

**I**

wherein  $X^-$ ,  $R^1$ , and  $R^2$  are as defined and described herein. In some embodiments, provided compounds are peripheral  $\mu$  opioid receptor antagonists. Other uses of provided compounds are set forth *infra*.

[0008] The present invention also provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone. In some embodiments, a prefilled syringe is substantially free of tungsten, or a derivative thereof. Such prefilled syringes, and uses thereof, are described in detail herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0009] **Figure 1** depicts the LC/MS result of a stability study of a methylnaltrexone pre-filled syringe at 40 °C and 75% relative humidity after 6 months..

[0010] **Figure 2** depicts the total ion chromatogram (TIC), UV chromatogram ( $\lambda = 280$  nm), mass and UV spectra obtained for the RRT 0.60 peak.

[0011] **Figure 3** depicts the effect of pH on reaction of compound **III-1** with  $H_2O_2$  to form compound **II-1**.

[0012] **Figure 4** shows the UV chromatogram of a stability sample and the chromatogram of a stability sample spiked with compound **II-1** prepared according to Example 2.

[0013] **Figure 5** depicts the fragmentation assignments of compound **II-1** with the chemical structure based on NMR data.

[0014] **Figure 6** depicts the COSY spectrum of compound **II-1**.

[0015] **Figure 7** depicts the HSQC spectrum of compound **II-1**.

[0016] **Figure 8** depicts the  $^1H$  NMR spectrum of compound **II-1**.

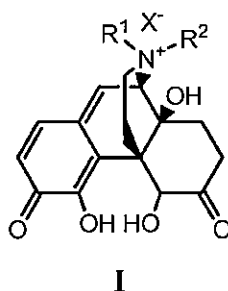
[0017] **Figure 9** depicts the HMBC spectrum of compound **II-1**.

- [0018] Figure 10 depicts the ROESY spectrum of compound II-1.
- [0019] Figure 11 depicts the  $^{13}\text{C}$  NMR spectrum of compound II-1.
- [0020] Figure 12 depicts the X-ray diffraction pattern of crystalline compound II-1.
- [0021] Figure 13 depicts the mass spectrogram and mass measurement of the M+H ion of compound II-1 crystals.
- [0022] Figure 14 depicts the  $^1\text{H}$  NMR spectrum of compound II-1.
- [0023] Figure 15 depicts the X-ray diffraction pattern of crystalline compound II-1.

## DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS OF THE INVENTION

### 1. Compounds and Definitions:

- [0024] In certain embodiments, the present invention provides a compound of formula I:



wherein:

$\text{R}^1$  and  $\text{R}^2$  are each independently  $\text{C}_{1-6}$  aliphatic; and

$\text{X}^-$  is a suitable anion.

[0025] The term “aliphatic” or “aliphatic group”, as used herein, means a straight-chain (i.e., unbranched) or branched hydrocarbon chain that is completely saturated or that contains one or more units of unsaturation, or a monocyclic hydrocarbon that is completely saturated or that contains one or more units of unsaturation, but which is not aromatic (also referred to herein as “carbocycle” “cycloaliphatic” or “cycloalkyl”), that has a single point of attachment to the rest of the molecule. In certain embodiments, an aliphatic group contains 1-4 aliphatic carbon atoms, and in yet other embodiments, an aliphatic group contains 1-3 aliphatic carbon atoms. In some embodiments, “cycloaliphatic” (or “carbocycle”) refers to a monocyclic  $\text{C}_3\text{-C}_6$  hydrocarbon that is completely saturated or that contains one or more units of unsaturation, but which is not aromatic, that has a single point of attachment to the rest of the molecule. Such cycloaliphatic groups include cycloalkyl, cycloalkenyl, and cycloalkynyl groups. Suitable aliphatic groups

include, but are not limited to, linear or branched alkyl, alkenyl, alkynyl groups and hybrids thereof such as (cycloalkyl)alkyl, (cycloalkenyl)alkyl or (cycloalkyl)alkenyl. Exemplary aliphatic groups include allyl, vinyl, cyclopropylmethyl, methyl, ethyl, isopropyl, and the like.

[0026] The term “unsaturated,” as used herein, means that a moiety has one or more units of unsaturation.

[0027] The term “lower alkyl,” as used herein, refers to a hydrocarbon chain having up to 4 carbon atoms, preferably 1 to 3 carbon atoms, and more preferably 1 to 2 carbon atoms. The term “alkyl” includes, but is not limited to, straight and branched chains such as methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, or t-butyl.

[0028] As used herein, an “effective amount” of a compound or pharmaceutically acceptable composition can achieve a desired therapeutic and/or prophylactic effect. In some embodiments, an “effective amount” is at least a minimal amount of a compound, or composition containing a compound, which is sufficient for treating one or more symptoms of a disorder or condition associated with modulation of peripheral  $\mu$  opioid receptors, such as side effects associated with opioid analgesic therapy (e.g., gastrointestinal dysfunction (e.g., dysmotility constipation, etc.), nausea, emesis, (e.g., nausea), etc.). In certain embodiments, an “effective amount” of a compound, or composition containing a compound, is sufficient for treating one or more symptoms associated with, a disease associated with aberrant endogenous peripheral opioid or  $\mu$  opioid receptor activity (e.g., idiopathic constipation, ileus, etc.).

[0029] The term “prefilled syringe” refers to a syringe that contains a drug product such as a solution of methylnaltrexone and is pre-packaged for use by a subject such as for self-administration or administration by another such as a medical professional. In certain embodiments, a prefilled syringe is provided in a sterile package. In some embodiments, such a package contains a plurality of prefilled syringes.

[0030] The term “subject”, as used herein, means a mammal and includes human and animal subjects, such as domestic animals (e.g., horses, dogs, cats, etc.).

[0031] The terms “suffer” or “suffering” as used herein refers to one or more conditions that a patient has been diagnosed with, or is suspected to have.

[0032] The terms “treat” or “treating,” as used herein, refers to partially or completely alleviating, inhibiting, delaying onset of, preventing, ameliorating and/or relieving a disorder or condition, or one or more symptoms of the disorder or condition.

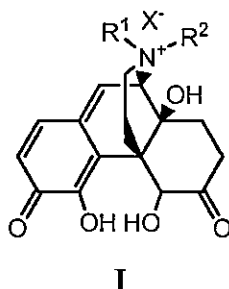
[0033] “Therapeutically active agent” or “active agent” refers to a substance, including a biologically active substance, that is useful for therapy (e.g., human therapy, veterinary therapy), including prophylactic and therapeutic treatment. Therapeutically active agents include organic molecules that are drug compounds, peptides, proteins, carbohydrates, monosaccharides, oligosaccharides, polysaccharides, nucleoprotein, mucoprotein, lipoprotein, synthetic polypeptide or protein, small molecules linked to a protein, glycoprotein, steroid, nucleic acid, DNA, RNA, nucleotide, nucleoside, oligonucleotides, antisense oligonucleotides, lipid, hormone, and vitamin. Therapeutically active agents include any substance used as a medicine for treatment, prevention, delay, reduction or amelioration of a disease, condition, or disorder. Among therapeutically active agents useful in the formulations of the present invention are opioid receptor antagonist compounds, opioid analgesic compounds, and the like. Further detailed description of compounds useful as therapeutically active agents is provided below. A therapeutically active agent includes a compound that increases the effect or effectiveness of a second compound, for example, by enhancing potency or reducing adverse effects of a second compound.

[0034] “Tungsten, or a derivative thereof” refers to tungsten, a salt thereof, an oxidized form thereof, or a tungsten-containing alloy. The term “tungsten” is used interchangeably with the phrase “tungsten, or a derivative thereof.”

[0035] The expression “unit dosage form” as used herein refers to a physically discrete unit of inventive formulation appropriate for administration to a subject to be treated. It will be understood, however, that the total daily usage of the compositions of the present invention will be decided by the attending physician within the scope of sound medical judgment. The specific effective dose level for any particular subject or organism will depend upon a variety of factors including the disorder being treated and the severity of the disorder; activity of specific active agent employed; specific composition employed; age, body weight, general health, sex and diet of the subject; time of administration, and rate of excretion of the specific active agent employed; duration of the treatment; drugs and/or additional therapies used in combination or coincidental with specific compound(s) employed, and like factors well known in the medical arts.

## 2. Description of Exemplary Compounds:

[0036] As described generally above, the present invention provides a compound of formula I:



wherein:

$R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and

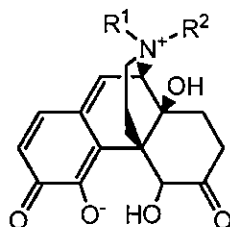
$X^-$  is a suitable anion.

[0037] One of ordinary skill in the art will recognize that the nitrogen atom depicted in formula I is a chiral center and, therefore, can exist in either the (R) or (S) configuration. According to one aspect, the present invention provides a compound of formula I wherein the compound is in the (R) configuration with respect to the nitrogen. In certain embodiments of the present invention, at least about 99.6%, 99.7%, 99.8%, 99.85%, 99.9%, or 99.95% of a compound of formula I is in the (R) configuration with respect to nitrogen.

[0038] As defined generally above, the  $X^-$  group of formula I is a suitable anion. In certain embodiments,  $X^-$  is the anion of a suitable Brønsted acid. Exemplary Brønsted acids include hydrogen halides, carboxylic acids, sulfonic acids, sulfuric acid, and phosphoric acid. In certain embodiments,  $X^-$  is chloride, bromide, iodide, fluoride, sulfate, bisulfate, tartrate, nitrate, citrate, bitartrate, carbonate, phosphate, malate, maleate, fumarate sulfonate, methylsulfonate, formate, carboxylate, sulfate, methylsulfate or succinate salt. In certain embodiments,  $X^-$  is trifluoroacetate. According to one aspect,  $X^-$  is bromide.

[0039] It is readily apparent that a compound of formula I contains both a quaternized nitrogen group and a phenolic hydroxyl group. One of ordinary skill in the art will recognize that the phenolic hydroxyl group of a compound of formula I can form a salt with the quaternized nitrogen of a compound of formula I. Such salts can form between two molecules of a compound of formula I *via* an intermolecular interaction or can form between those groups of the same compound *via* an intramolecular interaction. The present invention contemplates

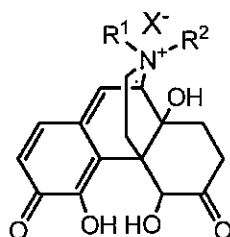
both such salt forms. Thus, in certain embodiments, the present invention provides a compound of formula **I-a**:



**I-a**

wherein  $R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic.

[0040] In some embodiments, the present invention provides a compound of formula **I-b**:

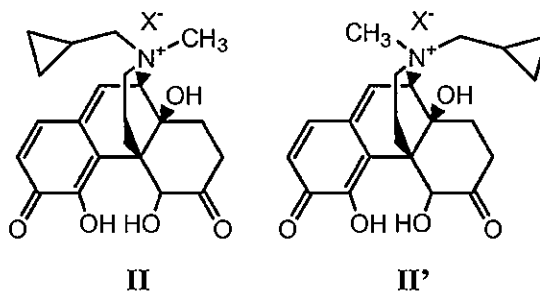


**I-b**

wherein  $R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and  $X^-$  is a suitable anion.

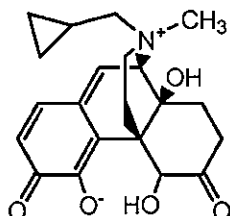
[0041] In certain embodiments, the present invention provides a compound of formula **I** wherein  $R^1$  is  $C_{1-4}$  aliphatic and  $R^2$  is lower alkyl. In other embodiments, the  $R^1$  group is a (cycloalkyl)alkyl group or alkenyl group. According to certain embodiments,  $R^1$  is cyclopropyl methyl or allyl. In other embodiments,  $R^1$  is cyclopropyl methyl or allyl and  $R^2$  is methyl. In some embodiments,  $R^1$  is methyl and  $R^2$  is cyclopropyl methyl or allyl.

[0042] According to one embodiment, the present invention provides a compound of formula **II** or **II'**:



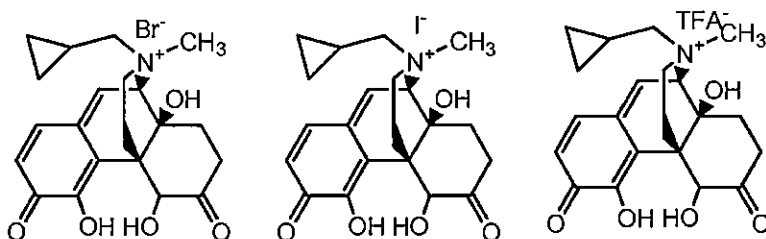
wherein each  $X^-$  is a suitable anion as described herein.

[0043] In certain embodiments, the present invention provides compound **II-a**:



**II-a**

[0044] Exemplary compounds of formula **II** include compound **II-1**, **II-2**, and **II-3**:



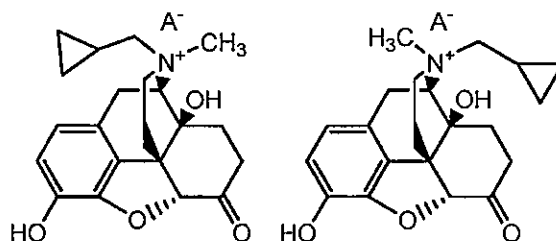
**II-1**

**II-2**

**II-3**

[0045] According to another aspect, the present invention provides a composition comprising:

(a) a compound of formula **III** or **III'**:

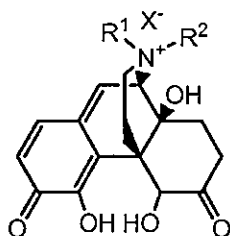


**III**

**III'**

wherein  $A^-$  is a suitable anion,

(b) at least one compound of formula **I**:



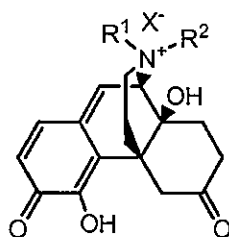
**I**

wherein:

$R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and

$X^-$  is a suitable anion; and

(c) optionally, a compound of formula **IV**:

**IV**

wherein:

$R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and

$X^-$  is a suitable anion.

[0046] In some embodiments, provided compositions are formulated for oral administration. In certain embodiments, a provided composition comprising a compound of formula **III**, a compound of formula **I**, and, optionally, a compound of formula **IV** is a solid composition wherein:

- (a) at least about 99.6%, 99.7%, 99.8%, 99.85%, 99.9%, or 99.95% of the compound of formula **III** is in the (R) configuration with respect to nitrogen; and
- (b) the compound of formula **I** is present in an amount of 60, 10, 5, 3.3, 2.5, 1 ppm or less.

[0047] In other embodiments, the present invention provides a composition comprising a compound of formula **III**, a compound of formula **I**, and a compound of formula **IV**, wherein the compounds of formula **I** and **IV** are present in amount of less than about 60, about 10, about 5, about 3.3, about 2.5, or about 1 ppm total. In some embodiments, provided solid formulations comprise from about 7% to about 75% or about 25% to about 65% or about 25% to about 55%. or about 40% to about 50% or about 20% to about 40% of a compound of formula **III**, based upon total weight of the solid formulation. In certain embodiments, provided solid formulations comprise from about 7%, about 8%, about 10%, about 20%, about 30%, about 40%, about 50%,

about 60%, about 70%, or about 75% a compound of formula **III**, based upon total weight of the solid formulation.

**[0048]** In some embodiments, an oral solid formulation contains 50 mg, 75 mg, 100 mg, 125 mg, 150 mg, 175 mg, 200 mg, 225 mg, 250 mg, 275 mg, 300 mg, 325 mg, 350 mg, 375 mg, 400 mg, 425 mg, 450 mg, 475 mg, or 500 mg, 525 mg, 550 mg, 575 mg, 600 mg, 625 mg, 650 mg, 675 mg, 700 mg, 725 mg, 750 mg, 775 mg, 800 mg, 825 mg, 850 mg, 875 mg, 900 mg, 925 mg, 950 mg, 975 mg, 1000 mg, 1025 mg, 1050 mg, 1075 mg, 1100 mg, 1125 mg, 1150 mg, 1175 mg, 1200 mg, 1225 mg, 1250 mg, 1275 mg, 1300 mg, 1325 mg, 1350 mg, 1375 mg, 1400 mg, 1425 mg, 1450 mg, 1475 mg, 1500 mg of a compound of formula **III**. In some embodiments, an oral solid formulation contains between 50 mg and 900 mg, inclusive, or between 150 mg and 450 mg, inclusive, of a compound of formula **III**. In some embodiments, an oral solid formulation contains 75 mg, 150 mg, 225 mg, 300 mg, 450 mg, 600 mg, or 900 mg of a compound of formula **III**. In certain embodiments, any such oral solid formulation wherein the compounds of formula **I** and **IV** are present in amount of less than about 60, about 10, about 5, about 3.3, about 2.5, or about 1 ppm total.

**[0049]** In some embodiments, the present invention provides a solid formulation for oral administration wherein said formulation comprises a compound of formula **III**, a compound of formula **II**, and optionally a compound of formula **IV** wherein the formulation provides no more than 1.5 micrograms of a compound of formula **II** per dose. In certain embodiments, the present invention provides a solid formulation for oral administration wherein said formulation comprises a compound of formula **III**, a compound of formula **II**, and a compound of formula **IV** wherein the formulation provides no more than 1.5 micrograms total of a compound of formula **II** and a compound of formula **IV** per dose.

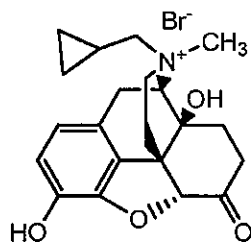
**[0050]** In certain embodiments, such compositions are formulated in a liquid formulation. Such liquid formulations are described in detail in WO2008/019115, published February 14, 2008, the entirety of which is hereby incorporated herein by reference. In some embodiments, the present invention provides a composition comprising a compound of formula **III** and a compound of formula **I**, where the amount of compound of formula **I** in the composition is less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In some embodiments, the present invention provides a composition comprising a compound of formula **III**, a compound of formula **I**, and a compound of formula **IV**, wherein the compounds

of formula **I** and **IV** are present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total.

[0051] As defined generally above, the  $A^-$  group of formula **III** is a suitable anion. In certain embodiments,  $A^-$  is the anion of a suitable Brønsted acid. Exemplary Brønsted acids include hydrogen halides, carboxylic acids, sulfonic acids, sulfuric acid, and phosphoric acid. In certain embodiments,  $A^-$  is chloride, bromide, iodide, fluoride, sulfate, bisulfate, tartrate, nitrate, citrate, bitartrate, carbonate, phosphate, malate, maleate, fumarate sulfonate, methylsulfonate, formate, carboxylate, sulfate, methylsulfate or succinate salt. In certain embodiments,  $X^-$  is trifluoroacetate. According to one aspect,  $X^-$  is bromide.

[0052] It is readily apparent that a compound of formula **III** contains both a quaternized nitrogen group and a phenolic hydroxyl group. One of ordinary skill in the art will recognize that the phenolic hydroxyl group of a compound of formula **III** can form a salt with the quaternized nitrogen of a compound of formula **III**. Such salts can form between two molecules of a compound of formula **III** *via* an intermolecular interaction or can form between those groups of the same compound *via* an intramolecular interaction. The present invention contemplates both such salt forms.

[0053] International patent application publication number WO2006/127899 describes Compound **III-1**, (R)-*N*-methylnaltrexone bromide, which has the following structure:

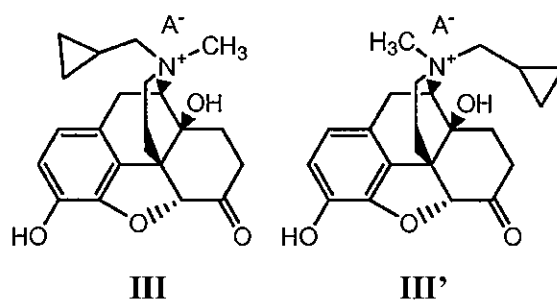


**III-1**

where the compound is in the (R) configuration with respect to the nitrogen. In certain embodiments of the present invention, at least about 99.6%, 99.7%, 99.8%, 99.85%, 99.9%, or 99.95% of Compound **III-1** is in the (R) configuration with respect to nitrogen. Methods for determining the amount of (R)-*N*-methylnaltrexone bromide, present in a sample as compared to the amount of (S)-*N*-methylnaltrexone bromide present in that same sample, are described in detail in WO2006/127899, the entirety of which is hereby incorporated herein by reference. In other embodiments, Compound **III-1** contains 0.15% or less (S)-*N*-methylnaltrexone bromide.

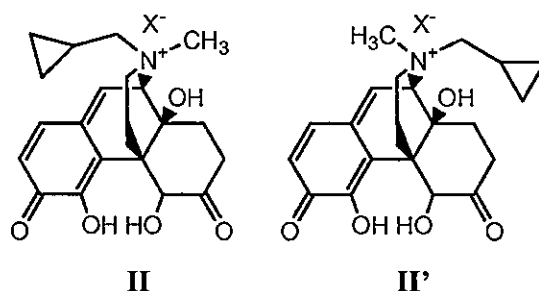
[0054] In certain embodiments, the present invention provides a compound of the present invention in isolated form. As used herein, the term “isolated” means that a compound is provided in a form that is separated from other components that might be present in that compound’s usual environment (e.g., a reaction mixture, a chromatography eluent, a pharmaceutical composition, etc.). In certain embodiments, an isolated compound is in solid form. In some embodiments, an isolated compound is at least about 50% pure as determined by a suitable HPLC method. In certain embodiments, an isolated compound is at least about 60%, 70%, 80%, 90%, 95%, 98%, or 99% as determined by a suitable HPLC method.

[0055] In certain embodiments, the present invention provides a composition comprising:  
 (a) a compound of formula **III** and/or **III'**:



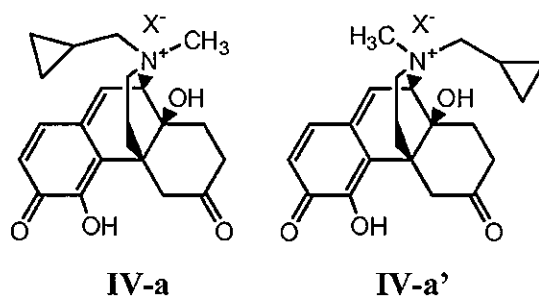
wherein A<sup>-</sup> is a suitable anion,

(b) at least one compound of formula **II** and/or **II'**:



wherein X<sup>-</sup> is a suitable anion as described herein; and

(c) optionally, a compound of formula **IV-a** and/or **IV-a'**:



wherein  $X^-$  is a suitable anion as described herein.

[0056] In certain embodiments, the present invention provides a solid composition comprising a compound of formula **III**, a compound of formula **II**, and, optionally, a compound of formula **IV-a** wherein:

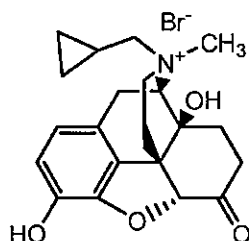
- (a) at least about 99.6%, 99.7%, 99.8%, 99.85%, 99.9%, or 99.95% of the compound of formula **III** is in the (R) configuration with respect to nitrogen; and
- (b) the compound of formula **II** is present in an amount of 60, 10, 5, 3.3, 2.5, 1 ppm or less.

[0057] In other embodiments, the present invention provides a composition comprising a compound of formula **III**, a compound of formula **II**, and, optionally, a compound of formula **IV-a**, wherein the compounds of formula **II** and **IV-a** are present in amount of less than about 60, about 10, about 5, about 3.3, about 2.5, or about 1 ppm total.

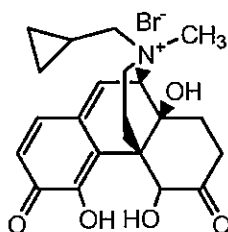
[0058] In certain embodiments, such compositions are formulated in a liquid formulation. In some embodiments, the present invention provides a liquid composition comprising a compound of formula **III** and a compound of formula **II** where the amount of compound of formula **II** in the composition is less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In some embodiments, the present invention provides a composition comprising a compound of formula **III**, a compound of formula **II**, and, optionally, a compound of formula **IV-a**, wherein the compounds of formula **II** and **IV-a**, when present, are present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total.

[0059] In other embodiments, the present invention provides a composition comprising:

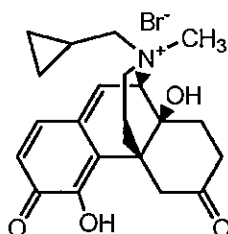
- (a) compound **III-1**:

**III-1**

(b) compound **II-1**:

**II-1**

and (c) optionally, compound **IV-1**:

**IV-1**

[0060] In other embodiments, the present invention provides a solid composition comprising compound **III-1**, a **II-1**, and, optionally, compound **IV-1**, wherein at least about 99.6%, 99.7%, 99.8%, 99.85%, 99.9%, or 99.95% of the compound **III-1** is in the (R) configuration with respect to nitrogen and compound **II-1** is present in an amount of 60, 10, 5, 3.3, 2.5, 1 ppm or less. In other embodiments, the present invention provides a composition comprising compound **III-1**, compound **II-1**, and, optionally, compound **IV-1**, wherein the compounds **II-1** and **IV-1** are present in amount of less than about 60, about 10, about 5, about 3.3, about 2.5, or about 1 ppm total.

[0061] In some embodiments, the present invention provides a liquid composition comprising compound **III-1** and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In

some embodiments, the present invention provides a liquid composition comprising compound **III-1**, compound **II-1**, and, optionally, compound **IV-1**, wherein the compounds **II-1** and **IV-1** are present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total.

**[0062]** In certain embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone. Nonlimiting examples of such liquid compositions are described in detail in United States published patent application number US 2008-0070975, the entirety of which is hereby incorporated herein by reference. In some embodiments, the present invention provides a prefilled syringe comprising a unit dosage of a liquid composition which comprises methylnaltrexone or a pharmaceutically acceptable salt thereof, a calcium salt, and a chelating agent. In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition which comprises methylnaltrexone, a calcium chelating agent, and a buffering agent. In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition which comprises methylnaltrexone, a calcium chelating agent, a buffering agent, and an isotonicity agent. In some embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition which comprises methylnaltrexone bromide, edetate calcium disodium, and glycine hydrochloride. In some embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition which comprises methylnaltrexone bromide, edetate calcium disodium, glycine hydrochloride, and sodium chloride.

**[0063]** In certain embodiments, the liquid composition has a pH of between about pH 2.0 and about pH 6.0. In some embodiments, the pH of the formulation is between about pH 2.6 and about pH 5.0. In some embodiments, the pH of the formulation is between about pH 3.0 and about pH 4.0. In some embodiments, the pH of the formulation is between about pH 3.4 and about pH 3.6. In some embodiments, the pH of the formulation is about pH 3.5. In certain embodiments, the liquid composition has a pH of about 2.5 to about 6.

**[0064]** In some embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone in an amount from about 0.5 mg to about 200 mg, about 1 mg to about 80 mg, from about 5 mg to about 40 mg, or

methylnaltrexone bromide in an amount of about 8 mg, about 12 mg, about 16 mg, about 18 mg, or about 24 mg.

[0065] In some embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone and a chelating agent in an amount from about 0.01 mg/mL to about 2 mg/mL or about 0.1 mg/mL to about 1 mg/mL in the formulation, or about 0.2 mg/mL to about 0.8 mg/mL of the formulation. In some embodiments, a chelating agent may be present in an amount from about 0.2 mg/mL, about 0.3 mg/mL, about 0.4 mg/mL, about 0.5 mg/mL, or about 0.6 mg/mL, in the formulation.

[0066] Exemplary chelating agents include ethylenediaminetetraacetic acid (also synonymous with EDTA, edetic acid, versene acid, and sequestrene), and EDTA derivatives, such as sodium EDTA, and potassium EDTA, diammonium EDTA, dipotassium EDTA, disodium EDTA, TEA-EDTA, tetrasodium EDTA, tripotassium EDTA, trisodium EDTA, HEDTA, and trisodium HEDTA, and related salts thereof. Other chelating agents include niacinamide and derivatives thereof and sodium desoxycholate and derivatives thereof, ethylene glycol-bis-(2-aminoethyl)-N,N,N', N'-tetraacetic acid (EGTA) and derivatives thereof, diethylenetriaminepentaacetic acid (DTPA) and derivatives thereof, N,N-bis(carboxymethyl)glycine (NTA) and derivatives thereof, nitrilotriacetic acid and derivatives thereof. Still other chelating agents include citric acid and derivatives thereof. Citric acid also is known as citric acid monohydrate. Derivatives of citric acid include anhydrous citric acid and trisodiumcitrate-dihydrate. In some embodiments, chelating agent is selected from EDTA or an EDTA derivative or EGTA or an EGTA derivative. In some embodiments chelating agent is EDTA disodium such as, for example, EDTA disodium hydrate.

[0067] In some embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone and a calcium salt in an amount from about 0.01 mg/mL to about 2 mg/mL or about 0.1 mg/mL to about 1 mg/mL, or about 0.2 mg/mL to about 0.8 mg/mL, about 0.2 mg/mL, about 0.3 mg/mL, about 0.4 mg/mL, about 0.5 mg/mL, or about 0.6 mg/mL.

[0068] Exemplary of calcium salts include, but are not limited to calcium chloride, calcium acetate, calcium citrate, calcium sulfate, etc.

[0069] In some embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone and a calcium salt chelating agent

in an amount from about 0.01 mg/mL to about 2 mg/mL or about 0.1 mg/mL to about 1 mg/mL, or about 0.2 mg/mL to about 0.8 mg/mL. In some embodiments, calcium salt chelating agent may be present in an amount from about 0.2 mg/mL, about 0.3 mg/mL, about 0.4 mg/mL, about 0.5 mg/mL, or about 0.6 mg/mL.

[0070] Common calcium salt chelating agents include, but are not limited to calcium ethylenediaminetetra acetic acid (EDTA) and calcium salt EDTA derivatives, calcium ethylene glycol-bis-(2-aminoethyl)-N,N,N', N'-tetraacetic acid (EGTA) and calcium salt EGTA derivatives, calcium diethylenetriaminepentaacetic acid (DTPA) and calcium salt DTPA derivatives, calcium N,N-bis(carboxymethyl)glycine (NTA) and calcium salt NTA derivatives, and calcium citrate and derivatives thereof. In some embodiments, chelating agent is selected from calcium EDTA or a calcium salt EDTA derivative or calcium EGTA or a calcium salt EGTA derivative. In some embodiments chelating agent is calcium EDTA disodium such as, for example, calcium EDTA disodium hydrate.

[0071] In some embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone and an isotonic agent. Common isotonic agents include agents selected from the group consisting of sodium chloride, mannitol, lactose, dextrose (hydrous or anhydrous), sucrose, glycerol, and sorbitol, and solutions thereof.

[0072] In some embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising methylnaltrexone and a stabilizing agent in an amount from about 0.01 mg/mL to about 2 mg/mL or about 0.05 mg/mL to about 1 mg/mL, or about 0.1 mg/mL to about 0.8 mg/mL. In some embodiments, stabilizing agent may be present in an amount from about 0.15 mg/mL, about 0.2 mg/mL, about 0.25 mg/mL, about 0.3 mg/mL, about 0.35 mg/mL, or about 0.4 mg/mL.

[0073] Exemplary stabilizing agents include glycine, benzoic acid, citric, glycolic, lactic, malic, and maleic acid. In some embodiments, the formulation comprises glycine. In some embodiments, glycine comprises glycine-HCl.

[0074] In certain embodiments, the present invention provides a prefilled syringe comprising a liquid composition comprising a compound of formula **III** and a compound of formula **II**, wherein the compound of formula **II** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In some embodiments, the present invention provides a liquid composition comprising a compound of formula **III**, a

compound of formula **II**, and, optionally, a compound of formula **IV**, wherein the compounds of formulae **II** and **IV** are present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total.

[0075] In some embodiments, a syringe, for use in preparing prefilled syringes in accordance with the present invention, is “tungsten free” or “substantially free” from tungsten. In some embodiments, a “tungsten free” or substantially free from tungsten syringe is commercially available from Becton Dickinson, Schott, and others. Such syringes may be referred to as “Ultra Low” Tungsten Syringes or “tungsten free”.

[0076] In certain embodiments, “substantially free” from tungsten means a level of tungsten less than an amount that contributes to degradation of a compound of formula **III**. In certain embodiments, a syringe that is substantially free from tungsten contains tungsten in an amount of less than about 60 parts per billion, or less than about 50 parts per billion, or less than about 40 parts per billion. In some embodiments, a syringe that is substantially free from tungsten contains tungsten in an amount of less than about 12 parts per billion. It will be appreciated that syringes designated as “substantially free” from tungsten include those that are tungsten free. Levels of tungsten in the syringe can be measured by variety of techniques known to those skilled in the art such as those described in US 20080103438 and, in more detail, in Example 8, *infra*.

[0077] In some embodiments a syringe for use in preparing prefilled syringes in accordance with the present invention is a prefillable glass and/or polymer syringe. Such syringes are commercially available, for example, from Schott. In some embodiments, the polymer syringe is made of cycloolefin polymer.

[0078] Without wishing to be bound by any particular theory, it is believed that the presence of tungsten in a syringe contributes to the degradation of methylnaltrexone solution stored in such a syringe. Such degradation includes formation of a compound of formula **I**. Thus, in some aspects of the present invention, a methylnaltrexone solution is stored in a manner whereby the solution is isolated from tungsten (i.e., methylnaltrexone is not in contact with tungsten). In certain embodiments, the present invention provides a methylnaltrexone prefilled syringe that is free from tungsten, or a derivative thereof, or contains tungsten in an amount of less than about 60 parts per billion or less than about 50 parts per billion or less than about 40

parts per billion or less than about 12 parts per billion. Levels of tungsten can be measured for example by ICP-MS.

[0079] In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a liquid composition comprising compound **III-1** and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In some embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, liquid composition comprising compound **III-1**, compound **II-1**, and, optionally, compound **IV-1**, wherein the compounds **II-1** and **IV-1** are present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total.

[0080] In some embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a liquid composition comprising about 8 mg of compound **III-1** in about 0.4 mL water, and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising: (a) 8 mg of compound **III-1**; (b) 0.16 mg edetate calcium disodium; and (c) 0.12 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising: (a) 8 mg of compound **III-1**; (b) 0.4 mL water; (c) 2.6 mg sodium chloride; (d) 0.16 mg edetate calcium disodium; and (e) 0.12 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm.

[0081] In some embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising a liquid composition comprising about 12 mg of compound **III-1** in about 0.6 mL water, and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm. In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising: (a) 12 mg of compound **III-1**; (b) 0.24 mg edetate calcium disodium; and (c) 0.18 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25, about 100, about 125, about 150,

about 185, about 187, or about 190 ppm. In certain embodiments, the present invention provides a prefilled syringe, substantially free from tungsten, comprising: (a) 12 mg of compound **III-1**; (b) 0.6 mL water; (c) 3.9 mg sodium chloride; (d) 0.24 mg edetate calcium disodium; and (e) 0.18 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm.

[0082] In some embodiments, one or more provided prefilled syringes that are substantially free from tungsten and contains methylnaltrexone, as described herein, are stored in a container that shields the syringe from light. In certain embodiments, one or more prefilled syringes are stored in a blister pack which shields the syringes from light. In some embodiments, one or more prefilled syringes are stored in a box which shields the syringe from light.

[0083] In some embodiments, a prefilled syringe, that is substantially free from tungsten and contains methylnaltrexone, as described herein, provides a unit dosage of methylnaltrexone that is stable to degradation under typical ambient storage conditions for at least 9 months or at least 12 months, or at least 18 months or at least 24 months. As used herein, the term “typical ambient storage conditions” refers to 25°C/60%RH. In certain embodiments, the present invention provides a prefilled syringe, as described herein, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25 ppm for at least 9 months, at least 12 months, at least 14 months, at least 16 months, at least 18 months, or at least 24 months. In certain embodiments, the present invention provides a prefilled syringe, as described herein, wherein said prefilled syringe comprises compounds **II-1** and/or **IV-1** in an amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total for at least 9 months, at least 12 months, at least 14 months, at least 16 months, at least 18 months, or at least about 24 months.

[0084] In certain embodiments, the present invention provides compound **II-1** as a crystalline solid. In some embodiments, compound **II-1** is provided as an amorphous solid.

[0085] As used herein, the term “substantially free of amorphous compound **II-1**” means that the crystalline solid contains no significant amount of amorphous compound **II-1**. In certain embodiments of the present invention, the term “substantially free of amorphous compound **II-1**” means that at least about 95% by weight of compound **II-1** in the solid is in crystalline form.

In certain embodiments of the invention, the term “substantially free of amorphous compound **II-1**” means that at least about 99% by weight of Compound **1** in the solid is in crystalline form.

[0086] As used herein, the term “substantially free of other forms of compound **II-1**” means that the solid contains no significant amount of another solid form of compound **II-1**. In certain embodiments of the present invention, the term “substantially free of other forms of compound **II-1**” means that at least about 95% by weight of compound **II-1** is in the specified solid form. In certain embodiments of the invention, the term “substantially free of another form of compound **II-1**” means that at least about 99% by weight of compound **II-1** is in the specified solid form.

[0087] The powder XRD of compound **II-1** polymorph contained peaks at 9.8, 10.8, 12.7, 14.7, 15.0, 15.9, 16.7, 17.5, 18.7, 19.4, 20.5, 21.0, 21.7, 22.6, 23.0, 24.3, 24.8, 25.5, 25.9, 26.8, 27.2, 28.2, 28.8, 29.5, 30.1, 31.2, 32.1, 32.9, 33.5, 34.9, 36.0 and 38.5 degrees 2 theta. In certain embodiments, the present invention provides a crystalline form of compound **II-1** characterized in that said form has one or more peaks in its powder X-ray diffraction pattern selected from 9.8, 10.8, 12.7, 14.7, 15.0, 15.9, 16.7, 17.5, 18.7, 19.4, 20.5, 21.0, 21.7, 22.6, 23.0, 24.3, 24.8, 25.5, 25.9, 26.8, 27.2, 28.2, 28.8, 29.5, 30.1, 31.2, 32.1, 32.9, 33.5, 34.9, 36.0 and 38.5 degrees 2 theta. In certain embodiments, the present invention provides a crystalline form of compound **II-1** characterized in that said form has two or more peaks in its powder X-ray diffraction pattern selected from 9.8, 10.8, 12.7, 14.7, 15.0, 15.9, 16.7, 17.5, 18.7, 19.4, 20.5, 21.0, 21.7, 22.6, 23.0, 24.3, 24.8, 25.5, 25.9, 26.8, 27.2, 28.2, 28.8, 29.5, 30.1, 31.2, 32.1, 32.9, 33.5, 34.9, 36.0 and 38.5 degrees 2 theta. In certain embodiments, the present invention provides a crystalline form of compound **II-1** characterized in that said form has substantially all of the peaks in its powder X-ray diffraction pattern selected from 9.8, 10.8, 12.7, 14.7, 15.0, 15.9, 16.7, 17.5, 18.7, 19.4, 20.5, 21.0, 21.7, 22.6, 23.0, 24.3, 24.8, 25.5, 25.9, 26.8, 27.2, 28.2, 28.8, 29.5, 30.1, 31.2, 32.1, 32.9, 33.5, 34.9, 36.0 and 38.5 degrees 2 theta.

[0088] According to one aspect, compound **II-1** polymorph has an XRD pattern containing substantially all of the peaks depicted in **Figure 15**. As used herein, the phrase “substantially all of the peaks” means that the compound exhibits, in its XRD, at least about 80% of the peaks listed. In other embodiments, the phrase “substantially all of the peaks” means that the compound exhibits, in its XRD, at least about 85, 90, 95, 97, 98, or 99% of the peaks listed.

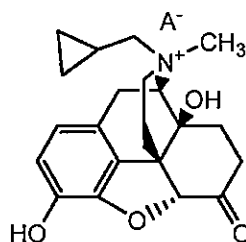
[0089] According to another embodiment, the present invention provides compound **II-1** as an amorphous solid. Amorphous solids are well known to one of ordinary skill in the art and are typically prepared by such methods as lyophilization, melting, and precipitation from supercritical fluid, among others. Methods of preparing amorphous compound **II-1** are described in the Examples section, *infra*.

[0090] In certain embodiments, the present invention provides amorphous compound **II-1** substantially free of crystalline compound **II-1**. As used herein, the term “substantially free of crystalline compound **II-1**” means that the compound contains no significant amount of crystalline compound **II-1**. In certain embodiments of the present invention, at least about 95% by weight of compound **II-1** present is amorphous compound **II-1**. In still other embodiments of the invention, at least about 99% by weight of compound **II-1** present is amorphous compound **II-1**.

[0091] In other embodiments, the present invention provides a composition comprising amorphous compound **II-1** and at least one crystalline form of compound **II-1**. Such crystalline forms of compound **II-1** include compound **II-1** polymorph as described herein or other crystalline forms of compound **II-1** that may result from the preparation of, and/or isolation of, amorphous compound **II-1**. In certain embodiments, the present invention provides a composition comprising amorphous compound **II-1** and at least one crystalline form of compound **II-1** as described herein.

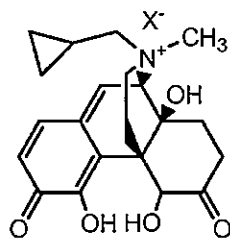
[0092] In some embodiments, the present invention provides a method comprising the steps of:

(a) providing a compound of formula **III**:



wherein A<sup>-</sup> is a suitable anion; and

(b) treating the compound of formula **III** with an oxidizing agent to form a compound of formula **II**:

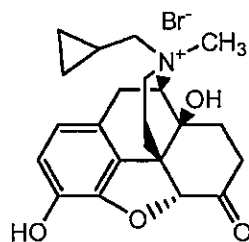
**II**

wherein  $X^-$  is a suitable anion.

[0093] Oxidizing agents suitable for the reaction with a compound of formula **III** to form a compound of formula **II** are well known to one of ordinary skill in the art. In some embodiments, the oxidizing agent is a peroxide, a benzoquinone, or a peracid. In certain embodiments, the oxidizing agent is hydrogen peroxide, t-butyl hydrogen peroxide, MCPBA (meta-chloroperoxybenzoic acid), peracetic acid, oxone (potassium peroxymonosulfate), or DDQ (2,3-dichloro-5,6-dicyanobenzoquinone).

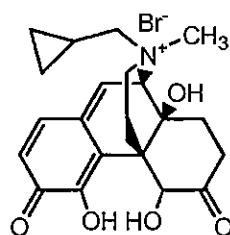
[0094] In certain embodiments, the present invention provides a method comprising the steps of:

(a) providing compound **III-1**:

**III-1**

and

(b) treating the compound **III-1** with an oxidizing agent to form compound **II-1**:

**II-1.**

[0095] In some embodiments, the method for preparing compound **II-1** from **III-1**, via oxidation reaction, further comprises the step of performing a salt exchange to afford compound **II-3**:

[0096] One of ordinary skill in the art will appreciate that compound **II-3** is readily prepared from compound **II-1** by, for example, HPLC purification utilizing an eluent that contains trifluoroacetic acid.

#### 4. *Uses, Formulation and Administration*

[0097] Compound **II-1** was identified as a new degradation product of (R)-*N*-methylnaltrexone bromide. Specifically, a stability study performed on (R)-*N*-methylnaltrexone bromide pre-filled syringes resulted in a new, unknown impurity. This impurity was identified by LC/MS as a new peak eluting at RRT 0.60. The peak was isolated by preparative HPLC, as detailed at Example 1. One of ordinary skill in the art would recognize that the compound of formula **II** isolated from the preparative HPLC, using the solvent eluent as described in the Exemplification, was the trifluoroacetic acid salt, compound **II-3**. In addition, compound **II-1** was synthesized to confirm its structural identity. Thus, compounds of the present invention are useful as analytical standards for use in determining the purity of (R)-*N*-methylnaltrexone bromide as an active pharmaceutical ingredient.

[0098] In certain embodiments, the present invention provides a method comprising the steps of:

- (a) providing a sample of (R)-*N*-methylnaltrexone bromide;
- (b) performing an analysis of the sample of (R)-*N*-methylnaltrexone bromide; and
- (c) determining the amount of compound **II-1** in the sample of (R)-*N*-methylnaltrexone bromide.

[0099] In certain embodiments, the present invention provides a method comprising the steps of:

- (a) providing a sample of (R)-*N*-methylnaltrexone bromide;
- (b) performing an analysis of the sample of (R)-*N*-methylnaltrexone bromide; and
- (c) determining the amount of compound **II-1** and compound **IV** in the sample of (R)-*N*-methylnaltrexone bromide.

[00100] In certain embodiments, the present invention provides a method comprising the steps of:

- (a) providing a sample of (R)-*N*-methylnaltrexone bromide;
- (b) providing a sample of compound **II-1**; and
- (c) performing HPLC analysis of the sample of (R)-*N*-methylnaltrexone bromide and the sample of compound **II-1**; and
- (d) determining the amount of compound **II-1** in the sample of (R)-*N*-methylnaltrexone bromide.

[00101] In certain embodiments, step (d) comprises determining that the amount of compound **II-1** (or compound **II-3**, as appropriate) in the sample of (R)-*N*-methylnaltrexone bromide is less than about 60 ppm, about 10 ppm, about 5 ppm, about 3.3 ppm, about 2.5 ppm, or about 1.0 ppm. In some embodiments, step (d) comprises determining that the amount of compound **II-1** (or compound **II-3**, as appropriate) in the sample of (R)-*N*-methylnaltrexone bromide is less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm.

[00102] In some embodiments, the present invention provides a method comprising the steps of:

- (a) providing an HPLC chromatogram of a sample of (R)-*N*-methylnaltrexone bromide;
- (b) providing an HPLC chromatogram of a sample of compound **II-1**;
- (c) comparing the HPLC chromatograms and determining the amount of compound **II-1** in the sample of (R)-*N*-methylnaltrexone bromide.

[00103] In certain embodiments, step (c) comprises determining that the amount of compound **II-1** (or compound **II-3**, as appropriate) in the sample of (R)-*N*-methylnaltrexone bromide is less than about 60 ppm, about 10 ppm, about 5 ppm, about 3.3 ppm, about 2.5 ppm, or about 1.0 ppm. In some embodiments, step (c) comprises determining that the amount of compound **II-1** (or compound **II-3**, as appropriate) in the sample of (R)-*N*-methylnaltrexone bromide is less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm.

[00104] In certain embodiments, step (b) further comprises providing a sample of compound **IV-1** and step (c) further comprises determining the amount of compound **IV-1** in the sample of (R)-*N*-methylnaltrexone bromide. In certain embodiments, step (c) comprises

determining that the amount of compound **II-1** and compound **IV-1** in the sample of (R)-*N*-methylnaltrexone bromide is less than about 60 ppm, about 10 ppm, about 5 ppm, about 3.3 ppm, about 2.5 ppm, or about 1 ppm total. In certain embodiments, step (c) comprises determining that the amount of compound **II-1** and compound **IV-1** in the sample of (R)-*N*-methylnaltrexone bromide is less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm.

[00105] In some embodiments, step (c) comprises determining that the sample of (R)-*N*-methylnaltrexone bromide provides no more than 1.5 micrograms of compound **II-1** and compound **IV-1** per dose (i.e., per day).

[00106] In certain embodiments, compounds of the present invention are useful for the study of peripheral mu opioid antagonists in biological and pathological phenomena and the comparative evaluation of peripheral mu opioid antagonists.

[00107] In certain embodiments, a compound of formula **I** is useful as a peripheral mu opioid receptor antagonist. According to another aspect of the present invention, pharmaceutically acceptable compositions are provided, comprising a compound of formula **I**, as described herein, and optionally comprising a pharmaceutically acceptable carrier, adjuvant, or vehicle. In certain embodiments of the present invention, such pharmaceutically acceptable compositions optionally further comprise one or more additional therapeutic agents.

[00108] As described above, the pharmaceutically acceptable compositions of the present invention additionally comprise a pharmaceutically acceptable carrier, adjuvant, or vehicle, which, as used herein, includes any and all solvents, diluents, or other liquid vehicle, dispersion or suspension aids, surface active agents, isotonic agents, thickening or emulsifying agents, preservatives, solid binders, lubricants and the like, as suited to the particular dosage form desired. *Remingtons Pharmaceutical Sciences*, 17th edition, ed. Alfonso R. Gennaro, Mack Publishing Company, Easton, PA (1985) discloses various carriers used in formulating pharmaceutically acceptable compositions and known techniques for the preparation thereof. Except insofar as any conventional carrier medium is incompatible with the salt of the invention, such as by producing any undesirable biological effect or otherwise interacting in a deleterious manner with any other component(s) of the pharmaceutically acceptable composition, its use is contemplated to be within the scope of this invention. Some examples of materials which can serve as pharmaceutically acceptable carriers include, but are not limited to, ion exchangers,

alumina, aluminum stearate, lecithin, serum proteins, such as human serum albumin, buffer substances such as phosphates, glycine, sorbic acid, or potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts or electrolytes, such as protamine sulfate, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, polyacrylates, waxes, polyethylene-polyoxypropylene-block polymers, wool fat, sugars such as lactose, glucose and sucrose; starches such as corn starch and potato starch; cellulose and its derivatives such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; powdered tragacanth; malt; gelatin; talc; excipients such as cocoa butter and suppository waxes; oils such as peanut oil, cottonseed oil; safflower oil; sesame oil; olive oil; corn oil and soybean oil; glycols; such as propylene glycol or polyethylene glycol; esters such as ethyl oleate and ethyl laurate; agar; buffering agents such as magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer's solution; ethyl alcohol, and phosphate buffer solutions, as well as other non-toxic compatible lubricants such as sodium lauryl sulfate and magnesium stearate, as well as coloring agents, releasing agents, coating agents, sweetening, flavoring and perfuming agents, preservatives and antioxidants can also be present in the composition, according to the judgment of the formulator.

[00109] In certain embodiments, the invention relates to compositions comprising at least one compound of formula I and one or more pharmaceutically acceptable carriers, excipients, or diluents. Such compositions are prepared in accordance with acceptable pharmaceutical procedures, such as, for example, those described in *Remington's*, which is incorporated herein by reference in its entirety. Pharmaceutically acceptable carriers are those carriers that are compatible with the other ingredients in the formulation and are biologically acceptable.

[00110] The compositions of the present invention are administered orally or parenterally, neat, or in combination with conventional pharmaceutical carriers. Applicable solid carriers can include one or more substances that can also act as flavoring agents, lubricants, solubilizers, suspending agents, fillers, glidants, compression aids, binders, tablet-disintegrating agents, or encapsulating materials. In powders, the carrier is a finely divided solid that is in admixture with the finely divided active ingredient. In tablets, the active ingredient is mixed with a carrier having the necessary compression properties in suitable proportions and compacted in the shape and size desired. Suitable solid carriers include, for example, calcium phosphate, magnesium

stearate, talc, sugars, lactose, dextrin, starch, gelatin, cellulose, methyl cellulose, sodium carboxymethyl cellulose, polyvinylpyrrolidone, low melting waxes and ion exchange resins.

[00111] Liquid carriers can be used in preparing solutions, suspensions, emulsions, syrups and elixirs. The active ingredient can be dissolved or suspended in a pharmaceutically acceptable liquid carrier such as water, an organic solvent, a mixture of both, or a pharmaceutically acceptable oil or fat. The liquid carrier can contain other suitable pharmaceutical additives such as, for example, solubilizers, emulsifiers, buffers, preservatives, sweeteners, flavoring agents, suspending agents, thickening agents, colors, viscosity regulators, stabilizers or osmo-regulators. Suitable examples of liquid carriers for oral and parenteral administration include water (particularly containing additives as above, e.g. cellulose derivatives, preferably sodium carboxymethyl cellulose solution), alcohols (including monohydric alcohols and polyhydric alcohols e.g. glycols) and their derivatives, and oils (e.g. fractionated coconut oil and arachis oil). For parenteral administration, the carrier can also be an oily ester such as ethyl oleate and isopropyl myristate. Sterile liquid carriers are used in sterile liquid form compositions for parenteral administration. The liquid carrier for pressurized compositions can be halogenated hydrocarbon or other pharmaceutically acceptable propellant.

[00112] Liquid pharmaceutical compositions that are sterile solutions or suspensions can be administered by, for example, intramuscular, intraperitoneal or subcutaneous injection. Sterile solutions can also be administered intravenously. Compositions for oral administration can be in either liquid or solid form.

[00113] In certain embodiments, the compositions of the present invention are administered rectally or vaginally in the form of a conventional suppository. For administration by intranasal or intrabronchial inhalation or insufflation, the compositions of the present invention can be formulated into an aqueous or partially aqueous solution, which can then be utilized in the form of an aerosol. The compositions of the present invention can also be administered transdermally through the use of a transdermal patch containing the active compound and a carrier that is inert to the active compound, is non-toxic to the skin, and allows delivery of the agent for systemic absorption into the blood stream via the skin. The carrier can take any number of forms such as creams and ointments, pastes, gels, and occlusive devices. The creams and ointments can be viscous liquid or semisolid emulsions of either the oil-in-water or water-in-oil type. Pastes comprised of absorptive powders dispersed in petroleum or

hydrophilic petroleum containing the active ingredient can also be suitable. A variety of occlusive devices can be used to release the active ingredient into the blood stream such as a semipermeable membrane covering a reservoir containing the active ingredient with or without a carrier, or a matrix containing the active ingredient. Other occlusive devices are known in the literature.

[00114] In some embodiments, the pharmaceutical composition is in unit dosage form, e.g. as tablets, capsules, powders, solutions, suspensions, emulsions, granules, or suppositories. In such form, the composition is sub-divided in unit dose containing appropriate quantities of the active ingredient; the unit dosage forms can be packaged compositions, for example, packeted powders, vials, ampoules, prefilled syringes or sachets containing liquids. The unit dosage form can be, for example, a capsule or tablet itself, or it can be the appropriate number of any such compositions in package form.

[00115] The amount of composition of the present invention provided to a subject will vary depending upon what is being administered, the purpose of the administration, such as prophylaxis or therapy, the state of the subject, the manner of administration, and the like. In therapeutic applications, compositions of the present invention are provided to a subject suffering from a condition in an amount sufficient to treat or at least partially treat the symptoms of the condition and its complications. An amount adequate to accomplish this is a "therapeutically effective amount" as described previously herein. The dosage to be used in the treatment of a specific case must be subjectively determined by the attending physician. The variables involved include the specific condition and the size, age, and response pattern of the subject. The treatment of substance abuse follows the same method of subjective drug administration under the guidance of the attending physician. Generally, a starting dose is about 5 mg per day with gradual increase in the daily dose to about 150 mg per day, to provide the desired dosage level in the subject.

[00116] In some embodiments, the present invention provides a method comprising administering to a subject an 8mg or 12 mg dose of a compound of formula **III** via subcutaneous injection. In certain embodiments, the present invention provides a method comprising the steps of:

- (i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising 8 mg of compound **III-1** and compound **II-**

1, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00117] In certain embodiments, the present invention provides a method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising 8 mg of compound **III-1** in 0.4 mL water, and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00118] In certain embodiments, the present invention provides a method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising: (a) 8 mg of compound **III-1**; (b) 0.16 mg edetate calcium disodium; and (c) 0.12 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00119] In certain embodiments, the present invention provides a method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a composition comprising: (a) 8 mg of compound **III-1**; (b) 0.4 mL water; (c) 2.6 mg sodium chloride; (d) 0.16 mg edetate calcium disodium; and (e) 0.12 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of

less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00120] In certain embodiments, the present invention provides a method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising 12 mg of compound **III-1** and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00121] In certain embodiments, the present invention provides a method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising 12 mg of compound **III-1** in 0.6 mL water, and compound **II-1**, wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00122] In certain embodiments, the present invention provides a method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising: (a) 12 mg of compound **III-1**; (b) 0.24 mg edetate calcium disodium; and (c) 0.18 mg glycine hydrochloride, wherein said prefilled syringe comprises compound **II-1** in an amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and/or where the

amount of compound **II-1** and compound **IV-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in total;

(ii) administering the unit dosage to a subject via subcutaneous injection.

[00123] In certain embodiments, a subject weighs between about 62 and about 114 kg. In some embodiments, the subject is suffering from opioid induced constipation, including but not limited to, for example, subjects who are terminally ill or suffer from chronic pain.

[00124] In other embodiments of the present invention, the compositions contain a compound of either of formula **I** or **II**, in an amount of at least about 97, 97.5, 98, 98.5, 99, 99.5, 99.8 weight percent where the percentages are based on the free base of said compound and on the total weight of the composition. In other embodiments, the composition containing a compound of either of formula **I** or **II** contains no more than about 2.0 area percent HPLC of total organic impurities and more preferably no more than about 1.5 area percent HPLC total organic impurities relative to the total area of the HPLC chromatogram.

[00125] In other embodiments of the present invention, a composition is provided comprising a compound of formula **III**, at least one compound of formula **I** or **II**, and at least one pharmaceutically acceptable carrier. In some embodiments, such compositions contain a compound of formula **I** or **II** in an amount of about 1 weight percent to about 99 weight percent, where the percentages are based on the free base of said compound and on the total weight of the composition. In other embodiments, the composition containing a compound of formula **I** or **II** contains no more than about 2.0 area percent HPLC of total organic impurities and more preferably no more than about 1.5 area percent HPLC total organic impurities relative to the total area of the HPLC chromatogram.

[00126] In certain embodiments, the present invention is directed to a composition, as described herein, comprising a prodrug of a compound of formula **I**. The term "prodrug," as used herein, means a compound that is convertible *in vivo* by metabolic means (e.g. by hydrolysis) to a compound of formula **I**. Various forms of prodrugs are known in the art such as those discussed in, for example, Bundgaard, (ed.), Design of Prodrugs, Elsevier (1985); Widder, et al. (ed.), Methods in Enzymology, vol. 4, Academic Press (1985); Krogsgaard-Larsen, et al., (ed). "Design and Application of Prodrugs, Textbook of Drug Design and Development, Chapter 5, 113-191 (1991), Bundgaard, et al., Journal of Drug Delivery Reviews, 8:1-38(1992), Bundgaard, J. of Pharmaceutical Sciences, 77:285 et seq. (1988); and Higuchi and Stella (eds.)

Prodrugs as Novel Drug Delivery Systems, American Chemical Society (1975), each of which is hereby incorporated by reference in its entirety.

***Combination Products and Combined Administration***

[00127] In certain embodiments, inventive compositions, and formulations thereof, may be administered alone to treat one or more disorders as described herein, or alternatively may be administered in combination with (whether simultaneously or sequentially) one or more other active agents useful to treat one or more disorders as described herein. Thus, an inventive composition, or formulation thereof, can be administered concurrently with, prior to, or subsequent to, one or more active agents.

[00128] In certain embodiments, inventive compositions include one or more other active agents in addition to a compound of formula I that is not a compound of formula I. In certain embodiments, the present invention provides a formulation that delivers a compound of formula I and at least one additional active agent.

[00129] In some embodiments, inventive formulations comprise both an opioid and a compound of formula I. Such combination products, containing both an opioid and a compound of formula I would allow simultaneous relief of pain and minimization of opioid-associated side effects (e.g., gastrointestinal effects (e.g., delayed gastric emptying, altered GI tract motility), etc.).

[00130] Opioids useful in treatment of analgesia are known in the art. For example, opioid compounds include, but are not limited to, alfentanil, anileridine, asimadoline, bremazocine, buprenorphine, butorphanol, codeine, dezocine, diacetylmorphine (heroin), dihydrocodeine, diphenoxylate, ethylmorphine, fedotozine, fentanyl, funaltrexamine, hydrocodone, hydromorphone, levallorphan, levomethadyl acetate, levorphanol, loperamide, meperidine (pethidine), methadone, morphine, morphine-6-glucuronide, nalbuphine, nalorphine, nicomorphine, opium, oxycodone, oxymorphone, papaveretum, pentazocine, propiram, propoxyphene, remifentanyl, sufentanil, tilidine, trimebutine, and tramadol. In some embodiments the opioid is at least one opioid selected from alfentanil, buprenorphine, butorphanol, codeine, dezocine, dihydrocodeine, fentanyl, hydrocodone, hydromorphone, levorphanol, meperidine (pethidine), methadone, morphine, nalbuphine, nicomorphine, oxycodone, oxymorphone, papaveretum, pentazocine, propiram, propoxyphene, sufentanil

and/or tramadol. In certain embodiments of the present invention, the opioid is selected from morphine, codeine, oxycodone, hydrocodone, dihydrocodeine, propoxyphene, fentanyl, tramadol, and mixtures thereof. In a particular embodiment, the opioid is loperamide. In other embodiments, the opioid is a mixed agonist such as butorphanol. In some embodiments, the subjects are administered more than one opioid, for example, morphine and heroin or methadone and heroin.

**[00131]** The amount of additional active agent(s) present in combination compositions of this invention will typically be no more than the amount that would normally be administered in a composition comprising that active agent as the only therapeutic agent. In certain embodiments of the present invention, the amount of additional active agent will range from about 50% to 100% of the amount normally present in a composition comprising that compound as the only therapeutic agent.

**[00132]** In certain embodiments, inventive formulations may also be used in conjunction with and/or in combination with conventional therapies for gastrointestinal dysfunction to aid in the amelioration of constipation and bowel dysfunction. For example, conventional therapies include, but may not be limited to functional stimulation of the intestinal tract, stool softening agents, laxatives (e.g., diphelymethane laxatives, cathartic laxatives, osmotic laxatives, saline laxatives, etc), bulk forming agents and laxatives, lubricants, intravenous hydration, and nasogastric decompression.

#### ***Uses and Kits of Inventive Formulations***

**[00133]** As discussed above, the present invention provides compounds and compositions useful in antagonizing undesirable side effects of opioid analgesic therapy (e.g., gastrointestinal effects (e.g., delayed gastric emptying, altered GI tract motility), etc.). Furthermore, a provided compound or composition may be used as to treat subjects having disease states that are ameliorated by binding  $\mu$  opioid receptors, or in any treatment wherein temporary suppression of the  $\mu$  opioid receptor system is desired (e.g., ileus, etc.). In certain embodiments of the present invention, methods of use of formulations are in human subjects.

**[00134]** Accordingly, administration of provided compound or composition may be advantageous for treatment, prevention, amelioration, delay or reduction of side effects of opioid use, such as, for example, gastrointestinal dysfunction (e.g., inhibition of intestinal motility,

constipation, GI sphincter constriction, nausea, emesis (vomiting), biliary spasm, opioid bowel dysfunction, colic, dysphoria, pruritus, urinary retention, depression of respiration, papillary constriction, cardiovascular effects, chest wall rigidity and cough suppression, depression of stress response, and immune suppression associated with use of narcotic analgesia, etc, or combinations thereof. Use of a provided compound or composition may thus be beneficial from a quality of life standpoint for subjects receiving opioids, as well as to reduce complications arising from chronic constipation, such as hemorrhoids, appetite suppression, mucosal breakdown, sepsis, colon cancer risk, and myocardial infarction.

[00135] In some embodiments, a provided compound or composition is useful for administration to a subject receiving acute opioid administration. In some embodiments, a provided compound or composition is useful for administration to subjects suffering from post-operative gastrointestinal dysfunction.

[00136] In other embodiments, a provided compound or composition is also useful for administration to subjects receiving chronic opioid administration (e.g., terminally ill patients receiving opioid therapy such as an AIDS patient, a cancer patient, a cardiovascular patient; subjects receiving chronic opioid therapy for pain management; subjects receiving opioid therapy for maintenance of opioid withdrawal). In some embodiments, the subject is a subject using opioid for chronic pain management. In some embodiments, the subject is a terminally ill patient. In other embodiments the subject is a person receiving opioid withdrawal maintenance therapy.

[00137] Alternative or additional uses for a provided compound or composition may be to treat, reduce, inhibit, or prevent effects of opioid use including, e.g., aberrant migration or proliferation of endothelial cells (e.g., vascular endothelial cells), increased angiogenesis, and increase in lethal factor production from opportunistic infectious agents (e.g., *Pseudomonas aeruginosa*). Additional advantageous uses of a provided compound or composition include treatment of opioid-induced immune suppression, inhibition of angiogenesis, inhibition of vascular proliferation, treatment of pain, treatment of inflammatory conditions such as inflammatory bowel syndrome, treatment of infectious diseases and diseases of the musculoskeletal system such as osteoporosis, arthritis, osteitis, periostitis, myopathies, and treatment of autoimmune diseases.

[00138] In certain embodiments, a provided compound or composition may be used in methods for preventing, inhibiting, reducing, delaying, diminishing or treating gastrointestinal dysfunction, including, but not limited to, irritable bowel syndrome, opioid-induced bowel dysfunction, colitis, post-operative or postpartum ileus, nausea and/or vomiting, decreased gastric motility and emptying, inhibition of the stomach, and small and/or large intestinal propulsion, increased amplitude of non-propulsive segmental contractions, constriction of sphincter of Oddi, increased anal sphincter tone, impaired reflex relaxation with rectal distention, diminished gastric, biliary, pancreatic or intestinal secretions, increased absorption of water from bowel contents, gastro-esophageal reflux, gastroparesis, cramping, bloating, abdominal or epigastric pain and discomfort, constipation, idiopathic constipation, post-operative gastrointestinal dysfunction following abdominal surgery (e.g., colectomy (e.g., right hemicolectomy, left hemicolectomy, transverse hemicolectomy, colectomy takedown, low anterior resection)), and delayed absorption of orally administered medications or nutritive substances.

[00139] Provided forms of a provided compound or composition are also useful in treatment of conditions including cancers involving angiogenesis, immune suppression, sickle cell anemia, vascular wounds, and retinopathy, treatment of inflammation associated disorders (e.g., irritable bowel syndrome), immune suppression, chronic inflammation.

[00140] In still further embodiments, veterinary applications (e.g., treatment of domestic animals, e.g. horse, dogs, cats, etc.) of use of a provided compound or composition are provided. Thus, use of provided formulations in veterinary applications analogous to those discussed above for human subjects is contemplated. For example, inhibition of equine gastrointestinal motility, such as colic and constipation, may be fatal to a horse. Resulting pain suffered by the horse with colic can result in a death-inducing shock, while a long-term case of constipation may also cause a horse's death. Treatment of equines with peripheral opioid receptor antagonists has been described, e.g., in U.S. Patent Publication No. 20050124657 published January 20, 2005.

[00141] It will also be appreciated that a provided compound or composition can be employed in combination therapies, that is, a provided compound or composition can be administered concurrently with, prior to, or subsequent to, one or more other desired therapeutics or medical procedures. Particular combination therapies (therapeutics or procedures) to employ in a combination regimen will take into account compatibility of the desired therapeutics and/or

procedures and the desired therapeutic effect to be achieved. It will also be appreciated that therapies employed may achieve a desired effect for the same disorder (for example, a formulation may be administered concurrently with another compound used to treat the same disorder), or they may achieve different effects (e.g., control of any adverse effects). As used herein, additional therapeutic compounds which are normally administered to treat or prevent a particular disease, or condition, are known as “appropriate for the disease, or condition, being treated”.

[00142] In other embodiments, a provided compound or composition and unit dose forms are useful in preparation of medicaments, including, but not limited to medicaments useful in the treatment of side effects of opioid use (e.g., gastrointestinal side effects (e.g., inhibition of intestinal motility, GI sphincter constriction, constipation) nausea, emesis, vomiting, dysphoria, pruritus, etc.) or a combination thereof. Compounds of the present invention, and pharmaceutically acceptable compositions and formulations thereof, are useful for preparations of medicaments, useful in treatment of patients receiving acute opioid therapy (e.g., patients suffering from post-operative gastrointestinal dysfunction receiving acute opioid administration) or subjects using opioids chronically (e.g., terminally ill patients receiving opioid therapy such as an AIDS patient, a cancer patient, a cardiovascular patient; subjects receiving chronic opioid therapy for pain management; or subjects receiving opioid therapy for maintenance of opioid withdrawal). Still further, preparation of medicaments useful in the treatment of pain, treatment of inflammatory conditions such as inflammatory bowel syndrome, treatment of infectious diseases, treatment of diseases of the musculoskeletal system such as osteoporosis, arthritis, osteitis, periostitis, myopathies, treatment of autoimmune diseases and immune suppression, therapy of post-operative gastrointestinal dysfunction following abdominal surgery (e.g., colectomy (e.g., right hemicolectomy, left hemicolectomy, transverse hemicolectomy, colectomy takedown, low anterior resection), idiopathic constipation, and ileus (e.g., post-operative ileus, post-partum ileus), and treatment of disorders such as cancers involving angiogenesis, chronic inflammation and/or chronic pain, sickle cell anemia, vascular wounds, and retinopathy.

[00143] Still further encompassed by the invention are pharmaceutical packs and/or kits comprising a provided compound or composition and a container (e.g., a foil or plastic package, or other suitable container). Optionally instructions for use are additionally provided in such kits.

[00144] As described herein, the present invention provides methods for determining the purity of a sample of (R)-*N*-methylnaltrexone bromide. In certain embodiments, such methods can utilize reference standards. The term “reference standard” as used herein refers to “highly characterized specimens of drug substances, excipients, impurities, degradation products, dietary supplements, compendial reagents and performance calibrators. They are required for use in conducting official USP–NF tests and assays.” as defined by the United States Pharmacopeia. As would be appreciated by one of ordinary skill in the art, USP Reference Standards are also used as calibrators (e.g., particle count, melting point, and standardization of titrants and as blanks and controls). Reference Standards are used mainly in chromatographic and spectrophotometric procedures. In certain embodiments, the present invention provides compound **II-1** as a reference standard. In some embodiments, the present invention provides a kit comprising a compound **II-1** reference standard and optionally one or more reference standards of (R)-*N*-methylnaltrexone bromide, Impurity B, Impurity C, Impurity D, Impurity E, Impurity F, Impurity G, Impurity H, and Impurity I, as described in detail in Example 1, below.

[00145] In order that the invention described herein may be more fully understood, the following examples are set forth. It should be understood that these examples are for illustrative purposes only and are not to be construed as limiting this invention in any manner.

[00146] All features of each of the aspects of the invention apply to all other aspects *mutatis mutandis*.

## EXEMPLIFICATION

### *General Procedures*

[00147] Compound **III-1** can be prepared, for example, according to the methods described in detail in International Patent Application publication number WO2006/127899, the entirety of which is hereby incorporated herein by reference.

[00148] Mass Spectral Analysis was performed using an Agilent 1100 HPLC system coupled with Applied Biosystems-PE SCIEX QSTAR PULSAR *i* quadrupole time-of-flight tandem mass spectrometer equipped with an electrospray ionization ion source operated in the positive ionization mode. The HPLC eluent was split to allow a flow at approximately 50  $\mu$ L/min into the ion source of the mass spectrometer.

[00149] NMR spectroscopic analysis of compound **II-1** was performed in DMSO- $d_6$  and the spectra were acquired on a Bruker DRX-500 NMR spectrometer equipped with a triple

resonance inverse detection (TXI) probe. TMS was used as an internal reference for the proton resonances ( $\delta^1\text{H}$  at 0.00) and the solvent, DMSO- $d_6$ , used as an internal standard for the carbon resonances ( $\delta^{13}\text{C}$  at 39.5).

[00150] The following abbreviations are used herein and have the following meanings:

#### KEY TO ABBREVIATIONS

| Abbreviation |   | Full Description                              |
|--------------|---|-----------------------------------------------|
| $\delta$     | = | Chemical Shift                                |
| 2D           | = | Two Dimensional                               |
| amu          | = | Atomic Mass Units                             |
| COSY         | = | Correlation Spectroscopy                      |
| DMSO- $d_6$  | = | Dimethylsulfoxide- $d_6$                      |
| Da           | = | Daltons                                       |
| dd           | = | Doublet of doublets                           |
| ESI-MS       | = | Electrospray Ionization Mass Spectrometry     |
| HMBC         | = | Heteronuclear Multiple Bond Correlation       |
| HPLC         | = | High Performance Liquid Chromatography        |
| HSQC         | = | Heteronuclear Single Quantum Coherence        |
| M            | = | Mass                                          |
| m/z          | = | mass to charge                                |
| mDa          | = | milliDaltons                                  |
| min          | = | Minutes                                       |
| MNTX         | = | Methylnaltrexone bromide                      |
| MS           | = | Mass Spectrometry                             |
| MS/MS        | = | Mass Spectrometry/ Mass Spectrometry          |
| MV           | = | Millivolts                                    |
| nm           | = | Nanometers                                    |
| NMR          | = | Nuclear Magnetic Resonance                    |
| ppm          | = | parts per million                             |
| ROESY        | = | Rotating Frame Overhauser Effect Spectroscopy |
| td           | = | Triplet of doublets                           |
| TFA          | = | Trifluoroacetic acid                          |
| TMS          | = | Tetramethylsilane                             |
| TRIS         | = | Trishydroxymethylaminomethane                 |
| UV           | = | Ultraviolet                                   |
| UV-VIS       | = | Ultraviolet -Visible                          |

## EXAMPLE 1

*Isolation and Characterization of RRT 0.60*

[00151] Previously, at least three degradation products of methylnaltrexone (compound **III-1**) were identified from HPLC analysis in 20 mg/mL isotonic saline solution (identified as RRT peaks at about 0.72, 0.89, and 1.48 when products were analyzed by HPLC). See, e.g., U.S. Patent Application Publication No. 20040266806, published December 30, 2004, and WO2008/019115, published February 14, 2008. Recently, methylnaltrexone-containing pre-filled syringes were examined for production of degradants. A new degradation product was observed, having a RRT at about 0.60. **Figure 1** depicts the LC/MS result of a stability study of such a pre-filled syringe at 40 °C and 75% relative humidity after 6 months.

[00152] For HPLC analysis a Prodigy ODS-3 15cm X 2.0mm, 3 µm particles (Phenomenex) HPLC column at a flow rate of 0.25 mL/min, using the following eluent:

Mobile Phase: Strength (Isocratic: 75:25 (v/v) 0.1% TFA in Water/Methanol

Purity: (Gradient):

Mobile Phase A = 95:5 (v/v) 0.1% TFA in Water/Methanol

Mobile Phase B = 35:65 (v/v) 0.1% TFA in Water/Methanol

Gradient Program:

| <u>Time</u><br><u>(Min)</u> | <u>% Mobile Phase A</u> |
|-----------------------------|-------------------------|
| 0                           | 100                     |
| 45                          | 50                      |
| 45.1                        | 100                     |
| 60                          | 100                     |

Column Temperature: 50°C

Flow: 0.25 mL/minute

Detection: UV, 280 nm or 310 nm

Injection volume: 20 µL

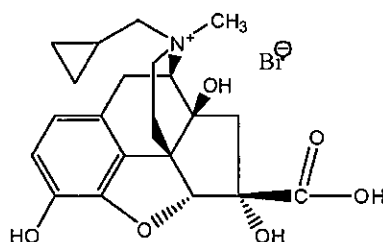
Sample Solvent: 0.05M Dibasic Sodium Phosphate pH 6.8

[00153] The following standards of compounds and known impurities were identified with associated calculated relative retention times ("RRT") and relative response factors ("RRF"):

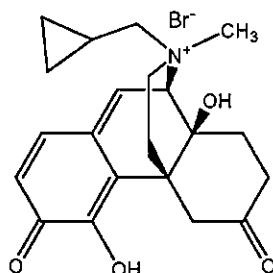
| <u>Compound</u>                                   | <u>RRT</u> | <u>RRF</u> |
|---------------------------------------------------|------------|------------|
| <b>Impurity A:</b> Diol degradant ( <b>II-1</b> ) | 0.60       | 0.0068     |
| <b>Impurity B:</b> Ring contracted                | 0.79       | 1.00       |
| <b>Impurity C:</b> Quinone degradant              | 0.89       | 0.0126     |
| <b>Impurity D:</b> S-Methylnaltrexone bromide     | 0.91       | 1.09       |

|                                                     |      |      |
|-----------------------------------------------------|------|------|
| <b>Methylnaltrexone bromide</b>                     | 1.00 | 1.00 |
| <b>Impurity E:</b> Naltrexone base                  | 1.16 | 0.79 |
| <b>Impurity F:</b> 2,2,bis-methylnaltrexone bromide | 1.45 | 0.54 |
| <b>Impurity G:</b> O-Methylnaltrexone methobromide  | 1.55 | 1.08 |
| <b>Impurity H:</b> Aldol dimer                      | 1.64 | 0.86 |
| <b>Impurity I:</b> Hoffmann elimination             | 2.26 | 0.16 |

[00154] Impurity B, the RRT 0.79 degradant referred to as “Ring contracted,” was identified as a ring contracted form of (R)-N-methylnaltrexone bromide and has the following structure:



[00155] Impurity C, also referred to herein as compound **IV-1**, the RRT 0.89 degradant referred to as “Quinone degradant,” was identified as a light degradation product of (R)-N-methylnaltrexone bromide, and has the following structure:



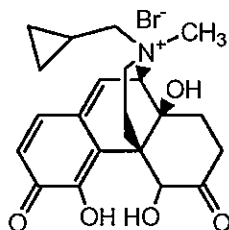
[00156] In certain embodiments, the present invention provides a composition comprising one or more of Impurity A, Impurity B, Impurity C, Impurity D, Impurity E, Impurity F, Impurity G, Impurity H, and Impurity I. In some embodiments, the present invention provides a kit comprising a vial comprising each of (R)-N-methylnaltrexone bromide, Impurity A, Impurity B, Impurity C, Impurity D, Impurity E, Impurity F, Impurity G, Impurity H, and Impurity I. In certain aspects, the present invention provides a kit comprising each of (R)-N-methylnaltrexone bromide, Impurity A, Impurity B, Impurity C, Impurity D, Impurity E, Impurity F, Impurity G, Impurity H, and Impurity I, wherein each impurity compound is contained within a separate vial.

[00157] Impurity A, the RRT 0.60 compound, referred to above as “Diol degradant,” was isolated and characterized and corresponds to compound **II-1**. Specifically, LC/MS was conducted on the unknown peak eluting at RRT 0.60 in the (R)-N-methylnaltrexone pre-filled syringe stability sample. **Figure 2** depicts the total ion chromatogram (TIC), UV chromatogram ( $\lambda = 280$  nm), mass and UV spectra obtained for the RRT 0.60 peak. The UV spectrum has a unique absorption around 310 nm, which is similar to the previously identified quinone compound which has a RRT of about 0.89.

[00158] The measured accurate mass of 372.1809 amu corresponds to the elemental composition of  $C_{21}H_{26}NO_5^+$  (error: 0.4 mDa). Its molecular formula indicates that the unknown peak contains one more oxygen atom than the above-depicted quinone compound.

## EXAMPLE 2

### *Synthetic preparation of compounds II-1 and II-3:*



**II-1**

### Method A

[00159] A solution of compound **III-1** was dissolved in 1M TRIS pH 8 buffer and  $H_2O_2$  (30%) was added in a 1:1.2 molar ratio. Before HPLC injection, the reaction was stopped by addition of TFA and the solution changed from brown/red to yellow. The solution was injected into a preparative HPLC with a Sunfire column (50x250 mm, C18, 5 $\mu$ m), flow rate of 100 mL/min, and a mobile phase that started at 6% MeOH/0.25%TFA for 1 min and then was changed to a gradient of 12% MeOH/0.25%TFA in 30 min. The collected fraction was diluted with two parts of water and the compound was adsorbed onto a reverse phase polymeric sorbent (Strata-X from Phenomenex). The column was placed under vacuum to remove all remaining liquid and acetonitrile was used to elute the compound.

[00160] About 20% water was added to the eluent which was then passed through a strong anion exchange column charged with bromide (Strata-SAX from Phenomenex). Acetonitrile was

removed from the eluent by extraction with dichloromethane. The pH of the aqueous layer was adjusted to 4.2 (the optimum acidity to avoid hydrolysis), and then lyophilized to get a red powder. The compound was crystallized by dissolving the red powder in water and putting the solution in a water bath at 70 °C, which caused crystals to form immediately. The crystals were filtered and dried under vacuum to provide compound **II-1** as red crystals. The X-ray diffraction pattern for the resulting crystalline compound **II-1** is depicted in **Figure 12**. The mass spectrogram of the resulting crystalline compound **II-1** is depicted in **Figure 13**. The <sup>1</sup>H NMR of the resulting crystalline compound **II-1** is depicted in **Figure 14**.

#### Method B

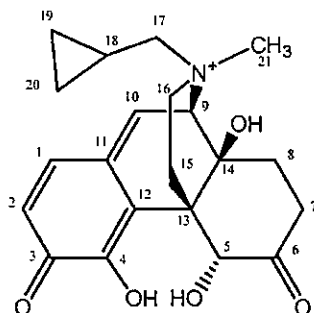
[00161] A solution of compound **III-1** was dissolved in 1M TRIS pH 8 buffer and H<sub>2</sub>O<sub>2</sub> (30%) was added in a 1:2 molar ratio. After about 30 minutes at room temperature, the reaction was stopped by addition of TFA and the solution changed from brown/red to yellow. The solution was injected into a preparative HPLC with a Sunfire column (50x250 mm, C18, 5μm), flow rate of 100 mL/min, and a mobile phase that started at 6% MeOH/0.25%TFA for 1 min and then was changed to a gradient of 12% MeOH/0.25%TFA in 30 min. The collected fraction was immediately frozen and lyophilized to afford compound **II-3** as a yellow solid.

[00162] The reaction of compound **III-1** with H<sub>2</sub>O<sub>2</sub> to form compound **II-3** was performed under different pH conditions to determine the effect of pH upon the reaction. It was found that at acidic pH the reaction of compound **III-1** with H<sub>2</sub>O<sub>2</sub> is very slow, whereas at basic pH the reaction is faster, following increase of pH (see **Figure 3**).

[00163] Structural elucidation of compound **II-3** was determined using: UV spectroscopy; ESI-MS; MS/MS; <sup>1</sup>H NMR, <sup>13</sup>C NMR, and 2 dimensional NMR techniques, as described in detail below. Positional numbering is as depicted below.

#### *NMR results*

[00164] The <sup>1</sup>H and <sup>13</sup>C NMR resonances were assigned using COSY, HSQC, HMBC and ROESY spectra. The assignments are set forth in Table 1, below.

Table 1.  $^1\text{H}$  and  $^{13}\text{C}$  Resonance Assignments for Compound II-1 in  $\text{DMSO}-d_6$ 

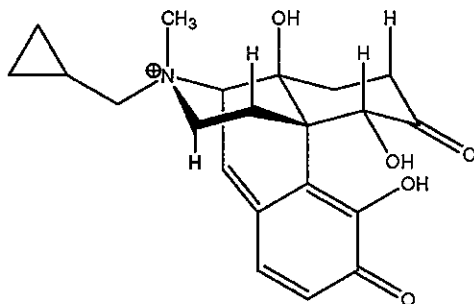
| Position | Group           | Carbon shift <sup>a</sup> | Proton shift <sup>b</sup>                            |
|----------|-----------------|---------------------------|------------------------------------------------------|
| 1        | CH              | 141.0                     | 7.33 (doublet, J=9.6 Hz)                             |
| 2        | CH              | 127.1                     | 6.38 (doublet, J=9.6 Hz)                             |
| 3        | C               | 182.2                     | ---                                                  |
| 4        | C               | 151.1                     | ---                                                  |
| 4-OH     | OH              | ---                       | 12.21                                                |
| 5        | CH              | 74.8                      | 5.08                                                 |
| 6        | C               | 205.7                     | ---                                                  |
| 7        | CH <sub>2</sub> | 35.1                      | 2.70, 2.16                                           |
| 8        | CH <sub>2</sub> | 34.2                      | 1.93                                                 |
| 9        | CH              | 66.7                      | 4.44 (doublet, J=7.0 Hz)                             |
| 10       | CH              | 129.1                     | 6.59 (doublet, J=7.0 Hz)                             |
| 11       | C               | 139.3                     | ---                                                  |
| 12       | C               | 113.5                     | ---                                                  |
| 13       | C               | 48.5                      | ---                                                  |
| 14       | C               | 72.4                      | ---                                                  |
| 14-OH    | OH              | ---                       | 6.82                                                 |
| 15       | CH <sub>2</sub> | 24.8                      | 2.50, 1.95                                           |
| 16       | CH <sub>2</sub> | 53.8                      | 3.35 (dd, J=13.8, 3.3 Hz), 3.01 (td, J=13.8, 3.1 Hz) |
| 17       | CH <sub>2</sub> | 70.7                      | 3.51 (dd, J=13.4, 5.0 Hz), 2.87 (dd, J=13.4, 9.2 Hz) |
| 18       | CH              | 4.0                       | 1.34                                                 |
| 19       | CH <sub>2</sub> | 5.4                       | 0.77, 0.57                                           |
| 20       | CH <sub>2</sub> | 3.2                       | 0.72, 0.40                                           |
| 21       | CH <sub>3</sub> | 49.7                      | 3.59                                                 |

<sup>a</sup> Shifts relative to  $\text{DMSO}-d_6$  ( $\delta^{13}\text{C}=39.5$ ).<sup>b</sup> Shifts relative to TMS ( $\delta^1\text{H}=0.0$ ).

[00165] The COSY spectrum (Figure 6) shows that all the  $^1\text{H}$ - $^1\text{H}$  spin systems are the same as those observed for the quinone compound, Impurity D, except for H-5. In the quinone compound, Impurity D, C-5 is a methylene carbon with two well resolved diastereotopic protons and in compound II-1, H-5 is a methine proton at  $\delta$  5.08. The presence of the C-5 methine was confirmed by the HSQC spectrum (Figure 7) which shows that H-5 is attached to a carbon at  $\delta$  74.8, a typical chemical shift for a carbon attached to oxygen.

[00166] In the  $^1\text{H}$  NMR spectrum (**Figure 8**) there are two hydroxyl protons observed at  $\delta$  12.21 and 8.58, assigned to the C-4 and C-5 OH groups, respectively. Their downfield chemical shifts and broad peak shape imply that they are very close each other, indicating that the C-5 hydroxyl is in the  $\alpha$  orientation as depicted below.

[00167] The HMBC spectrum (**Figure 9**) provides additional evidence that the hydroxyl group at C-5 is facing down. H-5 shows a strong three bond correlation to C-12, requiring their anti-coplanar relationship as depicted below:



[00168] The axial orientation of H-5 is confirmed by the ROESY spectrum (**Figure 10**). H-5 shows 1,3-diaxial type of NOEs to C-14-OH at  $\delta$  6.82, H-8 at  $\delta$  2.70, and H-14 at  $\delta$  2.50. The  $^{13}\text{C}$  NMR spectrum of compound **II-3** is shown in **Figure 11**.

### EXAMPLE 3

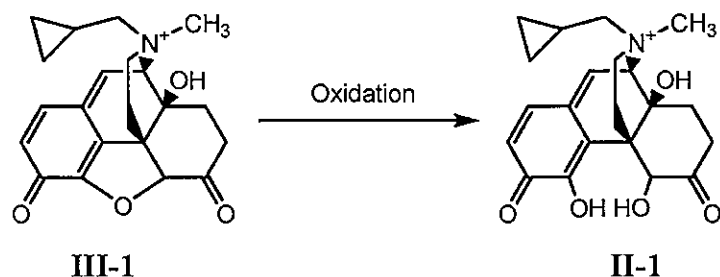
#### *Comparison of Synthetic Compound II-3 and Isolated RRT 0.60*

[00169] Compound **II-3**, prepared according to Example 2, Method B, was analyzed by LC-MS. As depicted in **Figure 2**, the major peak eluting around 9 minutes has the same mass and UV spectra as the RRT 0.60 peak. Also, the measured accurate mass of 372.1785 amu provides the same ionic formula (error: -2.0 mDa). In addition, compound **II-3**, prepared according to Example 2, Method B, was spiked into the sample obtained from the stability study described at Example 1. **Figure 4** shows the UV chromatograms of both the non-spiked and spiked samples. The peak at RRT 0.60 clearly indicates that the synthetic compound **II-3** is the same compound. LC-MS/MS was conducted on the ion of  $m/z$  372 to get structural information. MS/MS data for the RRT 0.60 peak and the synthetic sample are shown in the bottom two boxes in **Figure 4**. Both spectra are quite similar although the synthetic compound provides much better fragment ion intensities. Fragmentation assignments with the chemical structure based on

NMR data are shown in **Figure 5**. The LC/MS data are consistent with the structure as determined by NMR experiments.

#### EXAMPLE 4

##### *Evaluation of Oxidation Method:*



[00170] As described above in Example 2, compound **II-1** was prepared by oxidation of compound **III-1** with  $\text{H}_2\text{O}_2$ . A screen of additional oxidizing reagents was performed to optimize yield and purity of the oxidation reaction. A summary of the reactions performed is set forth in Tables A through E, below. As used herein, the term “SLI” refers to the single largest impurity.

[00171] As summarized in Table A, below, reactions were performed at room temperature using 1 equivalent of different oxidizing agents.

[00172] For each reaction, 0.5 g of **III-1** was combined with 6 mL of TRIS.HCl (1M, pH 8.0) in water. Oxidizing reagent (1 equivalent) was added and the resulting mixture stirred at room temperature for the designated time. All reactions were monitored by HPLC at 280 nM. % values reported as is from the chromatogram

**Table A.**

|   | Oxidant/Rx Conditions                                                            | Time (h) | HPLC % |         |       |              |
|---|----------------------------------------------------------------------------------|----------|--------|---------|-------|--------------|
|   |                                                                                  |          | % II-1 | % III-1 | % SLI | % other imps |
| 1 | 30% $\text{H}_2\text{O}_2$ 0.13 mL                                               | 2.5      | 28     | 64.5    | 3.0   | 4.5          |
|   |                                                                                  | 4.5      | 32     | 60      | 4.0   | 4.0          |
|   |                                                                                  | 20       | 43.6   | 34.2    | 8.0   | 14.2         |
| 2 | 70% tBuOOH 0.16 mL                                                               | 2.5      | 4.7    | 93      | 0.7   | 1.6          |
|   |                                                                                  | 4.5      | 7.1    | 90      | 1.2   | 1.7          |
|   |                                                                                  | 20       | 20     | 70.9    | 3.3   | 5.8          |
| 3 | Oxone+Acetone+ $\text{NaHCO}_3$<br>0.7g Acetone 0.36mL<br>$\text{NaHCO}_3$ 0.33g | 2.5      | 14     | 29      | 16.0  | 41.0         |
|   |                                                                                  | 4.5      | 14     | 29      | 16.0  | 41.0         |
|   |                                                                                  | 20       | 12.8   | 25      | 14.7  | 47.5         |
| 4 | DDQ 0.26 g                                                                       | 2.5      | 0.3    | 11      | 28.0  | 61.7         |
|   |                                                                                  | 4.5      | 0.3    | 11      | 25.0  | 63.7         |

|   |                            |     |      |      |      |      |
|---|----------------------------|-----|------|------|------|------|
|   |                            | 20  | 0.3  | 10.9 | 21.8 | 67.0 |
| 5 | 32% Peracetic acid 0.24 mL | 2.5 | 8.8  | 47   | 10.0 | 34.2 |
|   |                            | 4.5 | 8.8  | 47   | 10.0 | 34.2 |
|   |                            | 20  | 8.4  | 45.6 | 10.8 | 35.2 |
| 6 | 77% mCPBA 0.256g           | 2.5 | 25.1 | 42.9 | 6.9  | 25.1 |
|   |                            | 4.5 | 25   | 42   | 7.1  | 25.9 |
|   |                            | 20  | 25   | 38.4 | 6.3  | 30.3 |

[00173] As summarized in Table B, below, oxidation reactions were performed with varying equivalents of oxidizing reagent (i.e., oxidant) and varying reaction times.

[00174] For each reaction, 0.5 g of **III-1** was combined with 6 mL of TRIS.HCl (1M, pH 8.0) in water and cooled to ~10 °C. Oxidizing reagent (in the specified amount) was added and the resulting mixture stirred at room temperature for the designated time.

**Table B.**

|   | Oxidant                                      | Equivs. | Time (h)  | HPLC % |         |       |              |
|---|----------------------------------------------|---------|-----------|--------|---------|-------|--------------|
|   |                                              |         |           | % II-1 | % III-1 | % SLI | % other imps |
| 1 | 30% H <sub>2</sub> O <sub>2</sub><br>0.26 mL | 2       | 2         | 2      | 91      | 2.5   | 4.5          |
|   |                                              |         | 4         | 2.3    | 87      | 4.4   | 6.3          |
|   |                                              |         | 20        | 3.4    | 84.6    | 4.9   | 7.1          |
| 2 | 30% H <sub>2</sub> O <sub>2</sub><br>0.65 mL | 5       | 2         | 0      | 93      | 2     | 5            |
|   |                                              |         | 4         | 0      | 92      | 2.6   | 4.4          |
|   |                                              |         | 20        | 0      | 92      | 2.6   | 4.4          |
| 3 | 70% tBuOOH<br>0.32 mL                        | 2       | 2         | 7.2    | 90.1    | 1.4   | 1.3          |
|   |                                              |         | 3         | 17.2   | 78      | 2.2   | 2.6          |
|   |                                              |         | 20        | 40.5   | 46.5    | 4.3   | 8.7          |
|   |                                              |         | 1h at 50C | 39.6   | 35.6    | 5.9   | 18.9         |
|   |                                              |         | 44        | 43.1   | 29.1    | 5.3   | 22.5         |
|   |                                              |         | 72        | 43     | 22      | 8.3   | 26.7         |
|   |                                              |         | 90        | 44.3   | 19      | 10.3  | 26.4         |
| 4 | 70% tBuOOH<br>0.8 mL                         | 5       | 2         | 13.3   | 82      | 2.1   | 2.6          |
|   |                                              |         | 4         | 28     | 66      | 2.3   | 3.7          |
|   |                                              |         | 20        | 53.7   | 33.1    | 3.2   | 10           |
|   |                                              |         | 1h at 50C | 49.6   | 25.4    | 9.4   | 15.6         |
|   |                                              |         | 44        | 54     | 19.3    | 9.7   | 17           |
|   |                                              |         | 72        | 55.1   | 12.3    | 6.8   | 25.8         |
|   |                                              |         | 90        | 53.4   | 10.7    | 6.9   | 29           |
| 5 | 77% mCPBA<br>0.512 g                         | 2       | 2         | 24.5   | 38.5    | 9.9   | 27.1         |
|   |                                              |         | 20        | 20.2   | 30.4    | 12.7  | 36.7         |
| 6 | 77% mCPBA<br>1.28 g                          | 5       | 2         | 18.6   | 31.6    | 15.3  | 34.5         |
|   |                                              |         | 20        | 13.8   | 25.7    | 11    | 49.5         |

[00175] As summarized in Table C, below, oxidation reactions were performed with H<sub>2</sub>O<sub>2</sub> and tBHP in varying equivalents and prolonged stirring at room temperature.

[00176] For each reaction, 0.5 g of **III-1** was combined with 6 mL of TRIS.HCl (1M, pH 8.0) in water. The oxidant was added and the resulting mixture stirred for the designated time.

Table C

|   | Oxidant                                        | Equivs.     | Time (h) | HPLC % |         |       |              |
|---|------------------------------------------------|-------------|----------|--------|---------|-------|--------------|
|   |                                                |             |          | % II-1 | % III-1 | % SLI | % Other imps |
| 1 | 30% H <sub>2</sub> O <sub>2</sub><br>(0.13 mL) | 1           | 2        | 22.3   | 72      | 2     | 3.7          |
|   |                                                |             | 18       | 35.4   | 43.8    | 7.1   | 13.7         |
|   |                                                |             | 28       | 40.4   | 32.8    | 8.2   | 17.6         |
|   |                                                |             | 44       | 44.5   | 21.7    | 8.8   | 25           |
| 2 | 30% H <sub>2</sub> O <sub>2</sub>              | 2 (0.26 mL) | 20       | 5.9    | 89.1    | 1.1   | 3.9          |
| 3 | 30% H <sub>2</sub> O <sub>2</sub>              | 5 (0.65mL)  | 20       | 2.1    | 94.3    | 2     | 1.6          |
| 4 | 70% TBHP                                       | 5 (0.8 mL)  | 2        | 15     | 82.8    | 0.9   | 1.3          |
|   |                                                |             | 18       | 54.2   | 37.2    | 2.3   | 6.3          |
|   |                                                |             | 28       | 60     | 28.5    | 2.4   | 9.1          |
|   |                                                |             | 44       | 63.2   | 20.2    | 3.2   | 13.4         |
|   |                                                |             | 92       | 62     | 11.4    | 6.9   | 19.7         |
| 5 | 70% TBHP                                       | 10 (1.6 mL) | 2        | 19.5   | 77.1    | 1.4   | 2            |
|   |                                                |             | 18       | 60.4   | 30      | 2     | 7.6          |
|   |                                                |             | 28       | 64.3   | 22.2    | 3.2   | 10.3         |
|   |                                                |             | 44       | 65.4   | 15.6    | 6.6   | 12.4         |
|   |                                                |             | 92       | 62     | 8.9     | 11.5  | 17.6         |

[00177] As summarized in Table D, below, oxidation reactions were performed with tBHP in varying equivalents and prolonged stirring at elevated temperature (35 °C).

[00178] For each reaction, 0.5 g of **III-1** was combined with 6 mL of TRIS HCl (1M, pH 8.0) in water. Oxidant was added in the designated amount and the reaction stirred for the designated time at 35 °C.

Table D.

|   | Oxidant  | Equivs. | Time (h) | HPLC % |         |       |              |
|---|----------|---------|----------|--------|---------|-------|--------------|
|   |          |         |          | % II-1 | % III-1 | % SLI | % other imps |
| 1 | 70% TBHP | 2       | 2        | 21.7   | 73.1    | 1.3   | 3.9          |
|   |          |         | 18       | 45.3   | 34      | 3.7   | 17           |
| 2 | 70% TBHP | 5       | 2        | 33.8   | 61.6    | 1.5   | 3.1          |
|   |          |         | 18       | 56     | 22.5    | 5.2   | 16.3         |
| 3 | 70% TBHP | 10      | 2        | 40     | 53      | 2.4   | 4.6          |
|   |          |         | 18       | 54.1   | 17.5    | 14.3  | 14.1         |

[00179] As summarized in Table E, below, oxidation reactions were performed with tBHP in varying solvents.

[00180] For each reaction, 0.5 g of **III-1** was combined with 3 mL of TRIS.HCl buffer (1M, pH 8.0) and designated solvent (3 mL). 70% TBHP (5 equivs) was added and the resulting mixture stirred at room temperature for 48 hours.

**Table E.**

|   | Oxidant    | Solvent | HPLC % 280 nM |         |       |              |
|---|------------|---------|---------------|---------|-------|--------------|
|   |            |         | % II-1        | % III-1 | % SLI | % other imps |
| 1 | TBHP, 2eq. | None    | 52            | 36      | 3.5   | 8.5          |
| 2 | TBHP       | None    | 63            | 22.6    | 3.3   | 11.1         |
| 3 | TBHP       | EtOH    | 26            | 61      | 6.6   | 6.4          |
| 4 | TBHP       | NMP     | 15            | 77      | 3.9   | 4.1          |
| 5 | TBHP       | DME     | 23            | 60      | 10    | 7            |
| 6 | TBHP       | THF     | 31            | 47      | 13    | 9            |

#### EXAMPLE 5

##### *Tungstate Stability Studies*

[00181] A short-term evaluation was conducted to investigate the effect of tungstate on methylnaltrexone bromide for the formation of RRT 0.60 under the stressed conditions of high temperature and oxygen exposure. For the stressed sample, the formulation was spiked with 1 mM sodium tungstate and sparged with oxygen for one hour at room temperature. The solution was then autoclaved at 121 °C for one hour. Control samples were also prepared where each solution was prepared without exposure to tungstate, oxygen or heat.

[00182] After the stressed conditions discussed above, the sample exposed to tungsten, oxygen and heat produced 28 ppm of RRT 0.60 degradant. This degradant was observed at lower levels in the control samples. Based on this study, tungsten may aid in catalyzing the formation of the RRT 0.60 degradant. The levels of RRT 0.60 degradant observed in the control samples show that temperature and oxygen content are also contributing factors in this oxidative degradation reaction.

**Tungstate Evaluation – Short-term Stressed Study**

|                 | <b>1mM Tungstate</b> | <b>Oxygen</b> | <b>Autoclave</b> | <b>RRT 0.60 (ppm)</b> |
|-----------------|----------------------|---------------|------------------|-----------------------|
| <b>Sample 1</b> |                      |               |                  | ≤ 7ppm                |
| <b>Sample 2</b> |                      |               | X                | ≤ 7ppm                |
| <b>Sample 3</b> |                      | X             |                  | 9                     |
| <b>Sample 4</b> | X                    | X             |                  | ≤ 7ppm                |
| <b>Sample 5</b> | X                    |               | X                | 17                    |
| <b>Sample 6</b> | X                    | X             | X                | 28                    |

[00183] A long-term evaluation of 18 months was conducted to investigate the effect of tungstate on methylnaltrexone bromide for the formation of RRT 0.60 under standard conditions in standard Sterile, Clean, Ready to Fill (SCF<sup>TM</sup>) syringes (1 mL Becton Dickinson (BD) Syringe, Type 1 borosilicate glass with stainless steel needle 27G x ½ inch, BD Stopper 11510, West 4023/50 grey bromobutyl rubber. Coating: contact side with Daikyo Fluro Tec, remaining part with B2-40 coating, BD Rigid Needle Shield with FM27/0 rubber needle shield and polypropylene rigid shield cover). In this study, syringes containing either an 8 mg methylnaltrexone unit dosage (8 mg methylnaltrexone in 0.4 mL water with 2.6 mg sodium chloride, 0.16 mg edetate calcium disodium, and 0.12 mg glycine hydrochloride) or a 12 mg methylnaltrexone unit dosage (12 mg methylnaltrexone in 0.6 mL water 3.9 mg sodium chloride, 0.24 mg edetate calcium disodium, and 0.18 mg glycine hydrochloride) were stored under the following conditions: 25 °C/60 %RH, 30 °C/75 %RH, and 40 °C/75 %RH. The results of this study show that the RRT 0.60 compounds formed to a level of 40 ppm at 25 °C and 60% RH and up to 204 ppm at 30 °C and 75% RH. After 6 months at 40 °C and 75% RH, 145 ppm was observed. These results are shown in **Table 2**, below.

**Table 2. Amount of RRT 0.60 (ppm) in Standard SCF Syringes\***

| Batch#                       | Time<br>Zero | 1 month | 3 months | 6 months | 9 months | 12months | 18 months |
|------------------------------|--------------|---------|----------|----------|----------|----------|-----------|
| <u>Condition: 25°C/60%RH</u> |              |         |          |          |          |          |           |
| G16 8 mg                     | <7           | 8       | 13       | 13       | 17       | 18       | 26        |
| G17 8 mg                     | <7           | <7      | 16       | 13       | 18       | 19       | 27        |
| G18 8 mg                     | <7           | <7      | 10       | 12       | 15       | 18       | 40        |
| G19 12 mg                    | <7           | <7      | 15       | 14       | 18       | 14       | 36        |
| G20 12 mg                    | <7           | <7      | 14       | 8        | 18       | 19       | 24        |
| G21 12 mg                    | <7           | <7      | 11       | 16       | 16       | 14       | 31        |
| <u>Condition: 30°C/75%RH</u> |              |         |          |          |          |          |           |
| G16 8 mg                     | NA           | 8       | 15       | 16       | 28       | 26       | 101       |
| G17 8 mg                     | NA           | 9       | 12       | 20       | 23       | 22       | 70        |
| G18 8 mg                     | NA           | <7      | 12       | 11       | 28       | 34       | 90        |
| G19 12 mg                    | NA           | 10      | 14       | 12       | 21       | 23       | 55        |
| G20 12 mg                    | NA           | <7      | 18       | 30       | 22       | 29       | 86        |
| G21 12 mg                    | NA           | <7      | 16       | 21       | 28       | 90       | 204       |
| <u>Condition: 40°C/75%RH</u> |              |         |          |          |          |          |           |
| G16 8 mg                     | NA           | 10      | 33       | 100      | NA       | NA       | NA        |
| G17 8 mg                     | NA           | 21      | 57       | 47       | NA       | NA       | NA        |
| G18 8 mg                     | NA           | 14      | 22       | 145      | NA       | NA       | NA        |
| G19 12 mg                    | NA           | 20      | 50       | 121      | NA       | NA       | NA        |
| G20 12 mg                    | NA           | 18      | 47       | 116      | NA       | NA       | NA        |
| G21 12 mg                    | NA           | 11      | 69       | 102      | NA       | NA       | NA        |

Note:

All values reported in ppm, acquired by the 310 nm HPLC method.

LOQ = 7 ppm

NA = not applicable

**[00184]** Another stability study was conducted to investigate the effect of storing methylnaltrexone bromide in an “ultra low” tungsten syringe (Becton Dickenson) for the formation of RRT 0.60 (1 mL BD Syringe, Type 1 borosilicate glass with stainless steel needle 29G x ½ inch, (ultra low tungsten), BD Stopper 11510, West 4023/50 grey bromobutyl rubber, Coating: contact side with Daikyo Fluro Tec, remaining part with B2-40 coating. BD Rigid Needle Shield, with thermoplastic elastomer (TPE) needle shield and polypropylene rigid shield

cover). The results of this study show that no RRT 0.60 compound formed at a level of 25 ppm or greater after 6 months at 40 °C and 75% relative humidity or 9 months at 25 °C and 60% relative humidity. These results are shown in **Table 3**, below.

**Table 3. Amount of RRT 0.60 (ppm) in Ultra Low Tungsten Syringes \***

| Conditions | MNTX | T <sub>0</sub> | 1 mo | 3 mo | 6 mo | 9 mo | 12 mo |
|------------|------|----------------|------|------|------|------|-------|
| 25°C/60%RH | 8 mg | <7             | <7   | <7   | <7   | 7    | 14    |
| 30°C/75%RH | 8 mg | <7             | <7   | 9    | <7   | 11   | 20    |
| 40°C/75%RH | 8 mg | <7             | <7   | 14   | 14   | NA   | NA    |

\* All values reported in ppm, acquired by the 310 nm HPLC method.

LOQ = 7 ppm

NA = not applicable

#### EXAMPLE 6

##### *X-ray Diffraction Study of Compound II-1 Polymorph*

[00185] The powder XRD analysis of compound **II-1** polymorph, prepared according to Example 2, Method A, was performed on a X'PERT-MPD Powder X-ray Diffractometer.

[00186] The samples were ground to a fine powder and packed into a cavity style sample holder with a zero background plate. The peak positions characterized by powder X-ray diffraction of angle position (2θ) are as depicted in **Figure 15**. In certain embodiments, the present invention provides a crystalline form of compound **II-1** characterized in that said form has a powder X-ray diffraction pattern substantially similar to that depicted in **Figure 15**.

#### EXAMPLE 7

##### *HPLC Method*

[00187] As described herein, detection and quantification of potential impurities of methyl naltrexone bromide is an important, and regulated, aspect of drug quality and purity. Another aspect of the invention provides an analytical method useful for detecting Impurity A, also referred to herein as the RRT 0.60 degradant, impurity, or compound and also as compound **II-1**, at levels required by regulatory standards. In certain embodiments, the analytical method is capable of detecting Impurity A at a level of about 2.5 ppm in a sample of N-methyl naltrexone bromide. In some embodiments, the analytical method is capable of detecting Impurity A at a

level of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm in a sample of N-methylnaltrexone bromide. In certain embodiments, such an analytical method is as follows:

Column: Prodigy ODS (3) 15 cm X 4.6 mm, 3  $\mu$ m particles;  
 Flow rate: 1.0 mL/min;  
 Detection: 310 nm UV;  
 Column Temperature: 37 °C;  
 Autosampler Temperature: 5 °C;  
 Sample Solvent: pH 5.0 Sodium Acetate buffer with EDTA (prepared from dissolving about 238 g NaOAc in 3 L of water. Add 45 mL glacial acetic acid and dilute to 50 L with water);  
 Mobile Phase A = 950 mL/ 50 mL/ 1 mL Water/Methanol/TFA;  
 Mobile Phase B = 500 mL/ 500 mL/ 1 mL Water/Methanol/TFA;  
 Gradient Program:

| <u>Time (Min)</u> | <u>% Mobile Phase A</u> | <u>% Mobile Phase B</u> |
|-------------------|-------------------------|-------------------------|
| 0                 | 93                      | 7                       |
| 20                | 73                      | 27                      |
| 20.1              | 0                       | 100                     |
| 25                | 0                       | 100                     |
| 25.1              | 93                      | 7                       |

[00188] Preparation of a standard sample of N-methylnaltrexone bromide, at a concentration of 0.0004 mg/mL, is performed as follows: 20 mg of N-methylnaltrexone bromide is weighed into two separate 100.0 mL volumetric flasks. 50 mL of sample solvent is added to dissolve the N-methylnaltrexone bromide and the resulting solution is diluted to volume with sample solvent. 2.0 mL of the resulting solution are pipetted into the second 100 mL volumetric flask which is then diluted to volume with sample solvent.

[00189] The amount of compound **II-1** present in a sample of (R)-N-methylnaltrexone bromide is calculated using the following equation:

$$\text{Compound II-1 (ppm)} = \frac{(A_i)(C_r)(V)(RF)(1000000)}{(A_r)(W_s)}$$

where:

A<sub>i</sub> = Area of impurity peak from the sample chromatogram;

C<sub>r</sub> = Concentration of (R)-N-methylnaltrexone bromide in the standard preparation (mg/mL);

V = Volume of the sample solution (mL);

RF = Response Factor correction for compound **II-1**;

1000000 = Conversion factor (ppm);

Ar = Average area of (R)-*N*-methylnaltrexone bromide from the standard chromatogram;  
Ws = Sample weight of (R)-*N*-methylnaltrexone bromide (mg).

### EXAMPLE 8

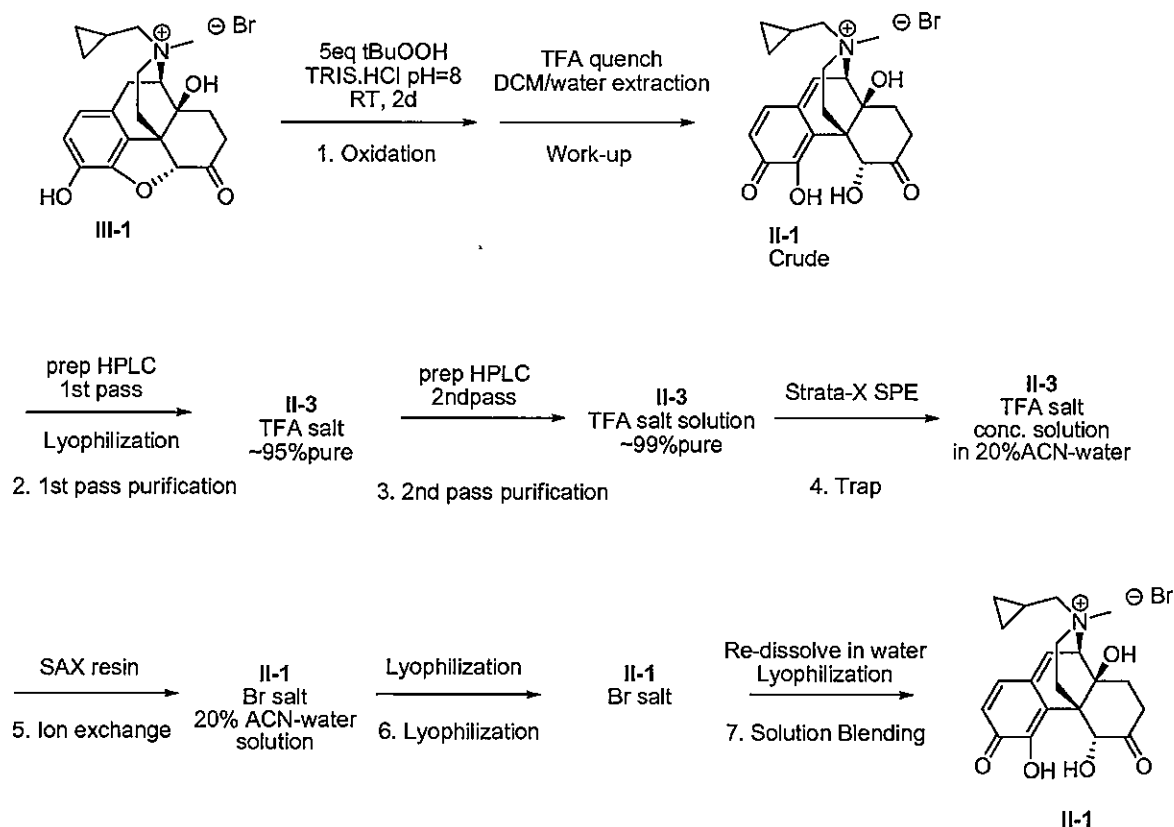
[00190] Levels of tungsten, or derivatives thereof, may be measured by any technique including the method described in US 20080103438. Levels of tungsten, or derivatives thereof, in empty syringes can be determined by extraction followed by ICP-MS analysis. Such extraction and analytical methods are known to one of ordinary skill in the art and include those described in EPA Methods 6020A and 200.8, the entirety of which is hereby incorporated herein by reference.

[00191] Different techniques may provide different results depending on how aggressively the tungsten or derivatives thereof is removed from the glass medical container for testing (i.e., more aggressive techniques, such as with acids, remove higher levels of tungsten residue). For example, a glass medical container can be washed, i.e., extracted, with an acid-containing solution and the extract measured for tungsten such as described in Wang, et al., Journal of Pharmaceutical and Biomedical Analysis, 19 (1999) 937-943, "Determination of Tungsten in Bulk Drug Substance and Intermediates by ICP-AES and ICP-MS", which is incorporated herein by reference in its entirety. Similar methodology can be used for measuring tungsten-containing residue levels.

[00192] The following method is a general method that may be used to determine the amount of tungsten present in an empty syringe:

1. filling a glass medical container (e.g., empty syringe) with purified water (e.g., prepared by laboratory purification system, Millipore Milli Ro 4) and sealing the glass medical container (e.g., with a tip cap);
2. placing the filled glass medical container into an ultrasonic bath containing water at ambient temperature for 60 minutes;
3. removing the glass medical container and dispensing the contained solution into a sample vessel; and
4. measuring the concentration of the tungsten in the solution by Inductively Coupled Plasma Mass Spectrometry (ICP/MS).

## EXAMPLE 9



[00193] According to the general scheme above, a solution of compound **III-1** was dissolved in 1M TRIS pH 8 buffer and t-butyl hydroperoxide (5 molar equivalents) was added and the resulting mixture stirred at room temperature for two days. The reaction was stopped by addition of TFA and the solution was extracted with dichloromethane. The aqueous phase was separated and concentrated for HPLC injections. Preparative HPLC purification was performed on a Sunfire column (50x250 mm, C18, 5 $\mu$ m from Waters) at flow rate of 50 mL/min with a mobile phase that started at 5% ACN/0.1%TFA and was changed to a gradient of 10% ACN/0.1%TFA over 30 min. The collected fractions were lyophilized and subjected to a second pass purification at the same condition as the first pass. The pooled fraction were applied on a reverse phase SPE (solid phase extraction) tube (Strata-X from Phenomenex) which was placed under vacuum to remove all remaining liquid. Then 20% acetonitrile/water was used to elute the compound, which was then passed through a strong anion exchange SPE tube (Strata-SAX from Phenomenex) pretreated with sodium bromide. The collected solution was lyophilized to afford compound **II-1** as a red powder.

[00194] More specifically, 100 g N-(cyclopropylmethyl)-noroxymorphone methobromide (**III-1**) was charged into a magnetically stirred 2 l flask with thermocouple followed by the addition of 600 ml tris (hydroxymethyl) aminoethane. The slurry was then charged with 180 ml 70% t-butyl hydroperoxide (5 equivalents), at which time the slurry becomes solution and gradually darkens in color. The solution was stirred for 69 hours at ambient temperature and was measured at 62-67% conversion by HPLC. The solution was then charged with 20 ml trifluoroacetic acid to pH 2 and was washed with 800 ml methylene chloride. The layers were separated and again the aqueous was washed with 200 ml methylene chloride. The waste organic fractions were combined and back extracted with 2 x 200 ml water. All aqueous fractions were then combined to wash with 2 x 400 ml of fresh methylene chloride. The layers were then separated and the aqueous portion (~1.1L) containing compound **II-3** was isolated (yield unknown) and stored at -20 C to await the purification step. The analytical method utilized to assess % conversion was as follows:

Analytical Method for Crude Aqueous Product

Agilent 1100 HPLC

column: 4.6 mm X 150mm Sunfire C18

$\lambda$  280 nm

flow rate: 1ml/min

Gradient:

| Time | %A water w/0.1%TFA | %B acetonitrile w/0.1%TFA |
|------|--------------------|---------------------------|
| 0    | 95                 | 5                         |
| 10   | 85                 | 15                        |
| 12   | 5                  | 95                        |
| 15   | 5                  | 95                        |
| 16   | 95                 | 5                         |
| 20   | 95                 | 5                         |

[00195] The crude compound **II-3** was purified by preparatory HPLC using the following method.

Varian PrepStar pumps with Varian Prostar 320 Detector

column: 50 mm X 250 mm Sunfire C18 5 micron

$\lambda$  260 nm

flow rate: 50 ml/min

Gradient

| Time | %A water w/0.1%TFA | %B acetonitrile w/0.1%TFA |
|------|--------------------|---------------------------|
| 0    | 95                 | 5 (flow rate =0)          |
| 1    | 95                 | 5 (flow rate = 50 ml/min) |
| 31   | 90                 | 10                        |
| 35   | 10                 | 90                        |
| 40   | 10                 | 90                        |
| 42   | 95                 | 5                         |
| 47   | 95                 | 5                         |
| 48   | 95                 | 5 (flow rate =0)          |

[00196] The first pass preparatory HPLC purification was done by injecting 100 ml per injection and collecting 50 ml fractions with the use of an automated fraction collector. Typically, fractions 15-22 were collected, combined and lyophilized.

[00197] The second pass preparatory HPLC purification was done by loading the collected crude TFA salt material (crude **II-3**), about 2 g each, diluted with 20 ml water, back to the prep column with same gradient and buffer system. Fractions 23-29 were typically collected and combined. This combined fraction was then diluted 1:1 with water, split into 4 equal volumes and then applied onto 4 Strata-X SPE Giga Tube (60ml, reverse phase resin trap) which have been prepared with following procedure:

- Flush procedure for reverse phase column (Strata X 33 micron);
- Elute 3 bed volumes of acetonitrile followed by 3 bed volumes of water; and
- The tube was vacuum dried for 5 min before the desired fraction was eluted by 20% ACN-water and collected (~20ml X 4).

[00198] The combined solution was split into 4 equal volume and applied onto 4 Strata SAX SPE Giga Tube (60ml, strong anion exchange resin) which were prepared with the following procedure:

- Flush procedure for ion exchange column Strata SAX 55 micron; and
- Elute 3 bed volumes of acetonitrile followed by 3 bed volumes of 1M sodium bromide followed by 5 bed volumes of water.

[00199] The desired fraction was collected and the tube was washed by 20% ACN-water until no colored solution was eluted. A total of ~45ml X 4 was collected, pooled and lyophilized.

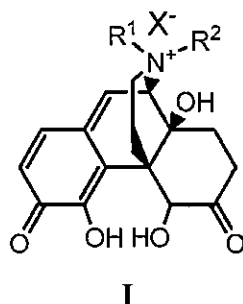
[00200] The multi-lots of lyophilized material were re-dissolved in water (~16g in 150ml of water) and lyophilized to afford 15.9 g of **II-1** as a dark red fluffy solid.

[00201] While we have described a number of embodiments of this invention, it is apparent that our basic examples may be altered to provide other embodiments that utilize the compounds and methods of this invention. Therefore, it will be appreciated that the scope of this invention is to be defined by the appended claims rather than by the specific embodiments that have been represented by way of example.

## CLAIMS

We claim:

1. A compound of formula I:



wherein:

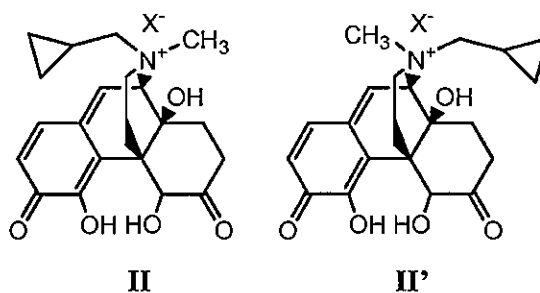
$R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and  
 $X^-$  is a suitable anion.

2. The compound according to claim 1, wherein  $X^-$  is the anion of a suitable Brønsted acid.
3. The compound according to claim 2, wherein the Brønsted acid is a hydrogen halide, a carboxylic acid, a sulfonic acid, a sulfuric acid, or a phosphoric acid.
4. The compound according to claim 2, wherein  $X^-$  is chloride, bromide, iodide, fluoride, sulfate, bisulfate, tartrate, nitrate, citrate, bitartrate, carbonate, phosphate, malate, maleate, fumarate sulfonate, methylsulfonate, formate, carboxylate, sulfate, methylsulfate, trifluoroacetate, or succinate.
5. The compound according to claim 4, wherein  $X^-$  is bromide.
6. The compound according to claim 1, wherein  $R^1$  is  $C_{1-4}$  aliphatic and  $R^2$  is lower alkyl.

7. The compound according to claim 6, wherein  $R^1$  is a (cycloalkyl)alkyl group or alkenyl group.

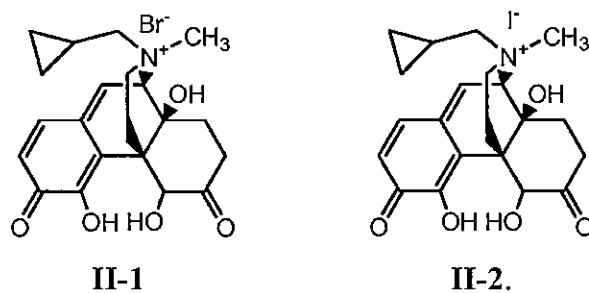
8. The compound according to claim 7, wherein  $R^1$  is cyclopropyl methyl or allyl and  $R^2$  is methyl.

9. The compound according to claim 1, wherein said compound is of formula **II** or **II'**:

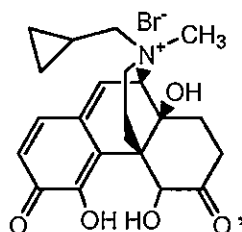


wherein, each X<sup>-</sup> is a suitable anion.

10. The compound according to claim 9, wherein said compound is compound **II-1** or **II-2**:



11. A crystalline form of compound **II-1**:



## II-1.

12. A method comprising the steps of:

- (a) providing a sample of (R)-*N*-methylnaltrexone bromide;
- (b) performing an analysis of the sample of (R)-*N*-methylnaltrexone bromide; and
- (c) determining the amount of compound II-1 in the sample of (R)-*N*-methylnaltrexone bromide.

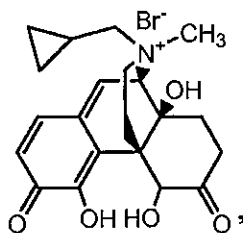
13. The method according to claim 12, wherein step (c) further comprises the step of determining the amount of compound IV-1 in the sample of (R)-*N*-methylnaltrexone bromide.

14. The method according to claim 13, wherein step (c) comprises determining that the amount of compound II-1 and compound IV-1 in the sample of (R)-*N*-methylnaltrexone bromide is less than about 60 ppm, about 10 ppm, about 5 ppm, about 3.3 ppm, about 2.5 ppm, or about 1 ppm total.

15. The method according to claim 13, wherein step (c) comprises determining that the amount of compound II-1 and compound IV-1 in the sample of (R)-*N*-methylnaltrexone bromide is less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total.

16. A method comprising the steps of:

- (a) providing a sample of (R)-*N*-methylnaltrexone bromide;
- (b) providing a sample of compound II-1:



II-1;

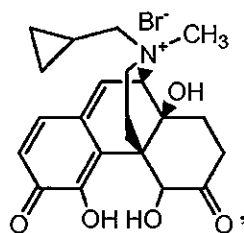
- (c) performing HPLC analysis of the sample of (R)-*N*-methylnaltrexone bromide and the sample of compound II-1; and

(d) determining the amount of compound **II-1** in the sample of (R)-*N*-methylnaltrexone bromide.

17. A method comprising the steps of:

(a) providing an HPLC chromatogram of a sample of (R)-*N*-methylnaltrexone bromide;

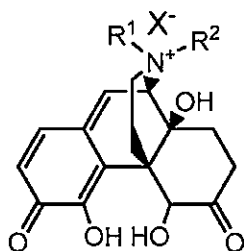
(b) providing an HPLC chromatogram of a sample of compound **II-1**:



**II-1**;

(c) comparing the HPLC chromatograms and determining the amount of compound **II-1** in the sample of (R)-*N*-methylnaltrexone bromide.

18. A kit comprising a compound of formula **I**:



**I**

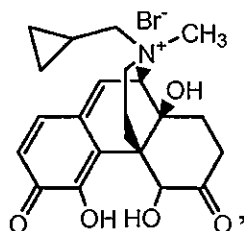
wherein:

$R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and

$X^-$  is a suitable anion,

and a container containing the compound of formula **I**.

19. The kit according to claim 18, wherein the compound is compound **II-1**:



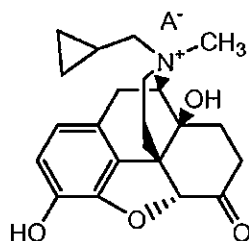
**II-1**

and the kit further comprises one or more reference standards of (R)-*N*-methylnaltrexone bromide, Impurity B, Impurity C, Impurity D, Impurity E, Impurity F, Impurity G, Impurity H, and Impurity I.

20. The kit according to claim 19, wherein each reference standard is provided in a separate vial.

21. The kit according to claim 19, wherein each reference standard is provided together in the same vial.

22. A prefilled syringe comprising a liquid composition comprising a compound of formula **III**:

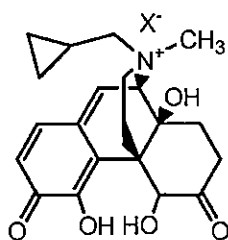


**III**

wherein A<sup>-</sup> is a suitable anion;

and wherein the prefilled syringe is substantially free of tungsten.

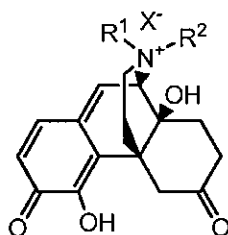
23. The prefilled syringe according to claim 22, wherein the liquid composition comprises less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm of a compound of formula **II**:



**II**

wherein  $X^-$  is a suitable anion.

24. The prefilled syringe according to claim 23, wherein the liquid composition comprises less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total of the compound of formula **II** and a compound of formula **IV**:



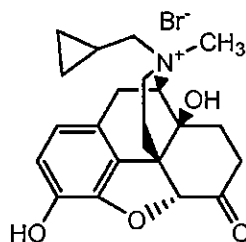
**IV**

wherein:

$R^1$  and  $R^2$  are each independently  $C_{1-6}$  aliphatic; and

$X^-$  is a suitable anion.

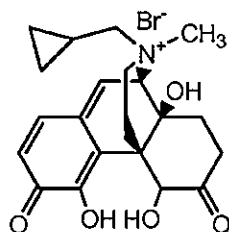
25. A prefilled syringe comprising a liquid composition comprising compound **III-1**:



**III-1**

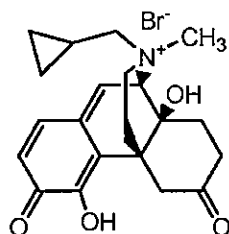
and wherein the prefilled syringe is substantially free of tungsten.

26. The prefilled syringe according to claim 25, wherein the liquid composition comprises less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm of a compound **II-1**:



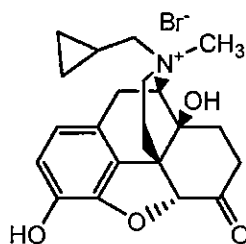
**II-1**

27. The prefilled syringe according to claim 26, comprising less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm total of compound **II-1** and compound **IV-1**:



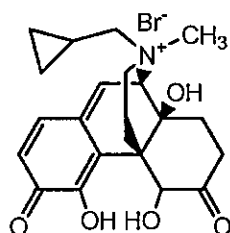
**IV-1.**

28. A prefilled syringe comprising a liquid composition comprising 8 mg of compound **III-1**:



**III-1**

in 0.4 mL water, and compound **II-1**:

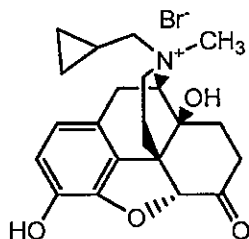


**II-1**

wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and wherein the prefilled syringe is substantially free of tungsten..

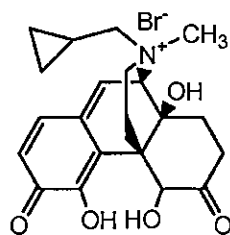
29. The prefilled syringe according to claim 28, wherein the liquid composition further comprises 2.6 mg sodium chloride, 0.16 mg edetate calcium disodium, and 0.12 mg glycine hydrochloride.

30. A prefilled syringe comprising a liquid composition comprising 12 mg of compound **III-1**:



**III-1**

in 0.6 mL water, and compound **II-1**:



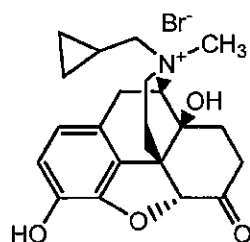
**II-1**

wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm and wherein the prefilled syringe is substantially free of tungsten.

31. The prefilled syringe according to claim 30, wherein the liquid composition further comprises 3.9 mg sodium chloride, 0.24 mg edetate calcium disodium, and 0.18 mg glycine hydrochloride.

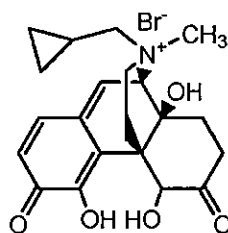
32. A method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising 8 mg of compound **III-1**:



**III-1**

in 0.4 mL water, and compound **II-1**:



**II-1**

wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm;

(ii) administering the unit dosage to a subject via subcutaneous injection.

33. The method according to claim 32, wherein the subject is suffering from opioid induced constipation.

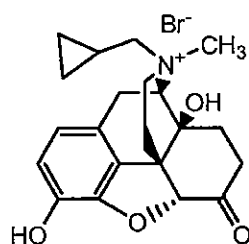
34. The method according to claim 32, wherein the tungsten is present in an amount less than 50 parts per billion.

35. The method according to claim 34, wherein the tungsten is present in an amount of less than 12 parts per billion.

36. The method according to claim 32, wherein the liquid composition further comprises edetate calcium disodium and glycine hydrochloride.

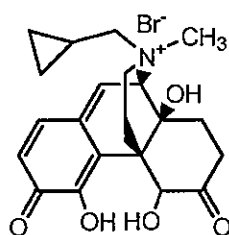
37. A method comprising the steps of:

(i) providing a prefilled syringe, substantially free from tungsten, comprising a unit dosage of a liquid composition comprising 12 mg of compound **III-1**:



**III-1**

in 0.6 mL water, and compound **II-1**:



**II-1**

wherein compound **II-1** is present in amount of less than about 25, about 100, about 125, about 150, about 185, about 187, or about 190 ppm;

(ii) administering the unit dosage to a subject via subcutaneous injection.

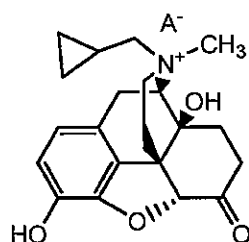
38. The method according to claim 37, wherein the subject is suffering from opioid induced constipation.

39. The method according to claim 37, wherein the tungsten is present in an amount less than 50 parts per billion.

40. The method according to claim 39, wherein the tungsten is present in an amount of less than 12 parts per billion.

41. The method according to claim 37, wherein the liquid composition further comprises edetate calcium disodium and glycine hydrochloride.

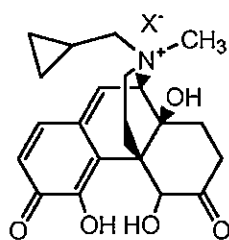
42. A method comprising the steps of:  
(a) providing a compound of formula **III**:



**III**

wherein A<sup>-</sup> is a suitable anion; and

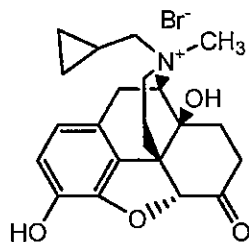
(b) treating the compound of formula **III** with an oxidizing agent to form a compound of formula **II**:



**II**

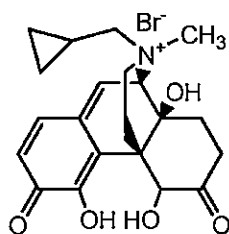
wherein X<sup>-</sup> is a suitable anion.

43. The method according to claim 42, wherein the compound of formula **III** is **III-1**:



**III-1.**

44. The method according to claim 42, wherein the compound of formula **II** is **II-1**:



**II-1.**

45. The method according to claim 42, wherein the oxidizing agent is selected from a peroxide, a benzoquinone, or a peracid.

46. The method according to claim 42, wherein the oxidizing agent is selected from hydrogen peroxide, t-butyl hydrogen peroxide, MCPBA (meta-chloroperbenzoic acid), peracetic acid, oxone (potassium peroxymonosulfate), or DDQ (2,3-dichloro-5,6-dicyanobenzoquinone).