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Spin Trapping Pharmaceutical Compositions and Methods for Use Thereof

John M. Carney
University of Kentucky

Robert A. Floyd
University of Kentucky

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US005622994A

United States Patent [19]

[11] Patent Number: **5,622,994**

Carney et al.

[45] Date of Patent: **Apr. 22, 1997**

[54] **SPIN TRAPPING PHARMACEUTICAL COMPOSITIONS AND METHODS FOR USE THEREOF**

[75] Inventors: **John M. Carney**, Lexington, Ky.;
Robert A. Floyd, Oklahoma City, Okla.

[73] Assignees: **Oklahoma Medical Research Foundation**, Oklahoma City, Okla.;
University of Kentucky Research Foundation, Lexington, Ky.

[21] Appl. No.: **212,800**

[22] Filed: **Mar. 15, 1994**

Related U.S. Application Data

[63] Continuation of Ser. No. 52,870, Apr. 26, 1993, abandoned, which is a continuation of Ser. No. 716,952, Jun. 18, 1991, abandoned, which is a continuation-in-part of Ser. No. 589,177, Sep. 27, 1990, abandoned, which is a continuation-in-part of Ser. No. 422,651, Oct. 17, 1989, Pat. No. 5,025, 032.

[51] **Int. Cl.⁶** **A61K 31/255**

[52] **U.S. Cl.** **514/643; 514/59; 514/226.2; 514/315; 514/399; 514/400; 514/422; 514/428; 514/517; 514/518; 514/642; 514/645; 514/708; 514/709**

[58] **Field of Search** **514/640, 641, 514/59, 226.2, 399, 400, 422, 428, 315, 645, 517, 642, 643, 518, 708, 709**

[56] References Cited

U.S. PATENT DOCUMENTS

5,508,305 4/1996 Carney 514/517

OTHER PUBLICATIONS

Royston, *Anaesthesia* 43: 315-320 (1988).
Plummer et al. *Anesthesiology* 57 :160-166 (1982).
Janzen et al. *Free Rad. Res. Comms.* 9(3-6)325-35 (1990).
Websters New World Dictionary (3rd Ed.) 1986 p. 17.

Monti et al., "Protective Effects of Spin-Trapping Agents on Adriamycin-Induced Cardiotoxicity in Isolated Rat Atria", *Free. Rad. Res. Comms.*, vol. 14, No. 1, pp. 41-45 (1991).

Jotti et al., "Cardiotoxicity Induced by Doxorubicin in vivo: Protective Activity of the Spin Trap Alpha-phenyl-tert-Butyl Nitron", *Pharmacological Research*, vol. 26, No. 2, 1992.

Paracchini et al., "The Spin Trap Alpha-phenyl-tert-butyl Nitron Protects Against Myelotoxicity and Cardiotoxicity of Adriamycin While Preserving the Cytotoxic Activity", *Anticancer Research*, vol. 13, pp. 1607-1612 (1993).

Primary Examiner—Brian M. Burn

[57] ABSTRACT

Spin trapping compositions in general have now been discovered to be effective in treating a variety of disorders, including disorders such as those arising from ischemia, infection, inflammation, exposure to radiation or cytotoxic compounds, not just of the central and peripheral nervous systems but of peripheral organ disease having a wide variety of etiologies. In the preferred embodiment, the compositions for treating tissue damage from ischemia contain PBN, or active derivatives thereof, in a suitable pharmaceutical carrier for intravenous, oral, topical, or nasal/pulmonary administration. Many different disorders can be treated using these compounds, including diseases or disorders of the central and peripheral nervous systems, and disorders arising from ischemia, infection, inflammation, oxidation from exposure to radiation or cytotoxic compounds, as well as due to naturally occurring processes such as aging.

36 Claims, No Drawings

SPIN TRAPPING PHARMACEUTICAL COMPOSITIONS AND METHODS FOR USE THEREOF

This is a continuation of application Ser. No. 08/052,870 filed on Apr. 26, 1993, (now abandoned) which is a CONT of Ser. No. 07/716,952, filed Jun. 18, 1991, (now abandoned) which is a CIP of Ser. No. 07/589,177, filed Sep. 27, 1990, (now abandoned) which is a CIP of Ser. No. 07/422,651, filed Oct. 17, 1989, now U.S. Pat. 5,025,032.

BACKGROUND OF THE INVENTION

The present invention is a method and compositions containing spin trapping agents for the treatment of dysfunctions and disease conditions arising from oxidative damage.

As first described in U.S. Pat. Ser. No. 07/422,651 (U.S. Pat. No. 5,025,032), oxygenated tissue suffers damage, in many cases permanent damage, if it becomes ischemic and is then reperfused. Brain appears to be uniquely susceptible to ischemia/reperfusion injury. Certain areas of the brain, for example, the hippocampus and spinal cord, are more susceptible than other regions of the brain. As a result, ischemia/reperfusion injury to brain may have a multiplicative effect simply because of the necessity for complete integrity of all regions in order to have proper functioning.

Free radicals have been postulated to be mediators of reperfusion damage. The important production sites of such radicals as the superoxide (O_2^-) and hydroxyl ($OH\cdot$) species are the mitochondrial respiratory chain and the sequences catalyzed by cyclooxygenase and lipoxygenase. However, radicals are also formed during autoxidation of many compounds (e.g., catecholamines). Several ischemic events favor a spurt of free-radical formation, such as those causing oxidation of polyenoic free fatty acids, release and reuptake of catecholamines, and oxidation of hypoxanthine by xanthine oxidase. Despite these events occurring during recirculation, when the O_2 supply is restored, they represent metabolic cascades triggered by agonist-receptor interactions, energy failure, and/or calcium influx during the insult.

Although free radical formation was postulated to be a likely cause of ischemic damage, it was difficult to directly demonstrate that such formation occurs and/or that it was sufficiently pronounced to overwhelm the antioxidative defense of the tissue, as reviewed by Curran, et al., *Mol. Cell. Biol.* 5, 167-172 (1985). Phenyl butyl nitron (PBN) has been used in a number of these in vitro research studies using spin trapping to look for free radicals, but until demonstrated by the data in U.S. Ser. No. 07/422,651, (U.S. Pat. No. 5,025,032) there has been no data to support the proposition that it could be useful in vivo, particularly with respect to treatment of tissue damage in the central nervous system. In vivo, the drug must be able to both cross the blood brain barrier and act in a manner which reduces tissue damage during or following ischemia.

In U.S. Ser. No. 07/589,177, (now abandoned) the use of PBN and related compounds, as well as 5,5-dimethyl pyrrolone N-oxide (DMPO) and α -(4-pyridyl-1-oxide)-N-tert-butyl nitron (POBN), for treatment of aging was described. Age related changes in central nervous system function have generally been associated with the loss of cells, a widening of lateral ventricles and deficits in short term memory. The precise mechanisms of functional changes as a result of aging, or other diseases associated with aging, have not generally been agreed upon, including several mechanisms

for the generation of oxidized material in the brain. A marked reduction in certain neurotransmitter receptor systems has been associated with increased oxidation of proteins. For example, decreases in muscarinic receptors and other cholinergic systems have been characterized as they relate to alterations in functions in Alzheimers disease. It has also been hypothesized that aging is associated with multiple minor periods of ischemia (multi-infarct conditions or transient ischemia attacks) which, over a period of time, may give rise to the production of oxidized protein.

The demonstration in a variety of systems, both neural and nonneural, that there is an age related enhancement of the level of oxidized protein in tissue gives rise to the possibility that age related dysfunctions in the central nervous system may be associated with the build-up of oxidized proteins and oxidized macromolecules within neurons throughout the central nervous system. The hypothesis is that cells which have a buildup of oxidized protein are less functional and less able to maintain the specified role of those cells in that particular area of the central nervous system. The data presented in U.S. Ser. No. 07/589,177 (now abandoned) was the first report of substantial investigations in which alterations in the oxidized protein burden of the central nervous system was manipulated and correlated with a functional outcome on the part of the animal.

There are a number of other disorders and diseases which have now been postulated to be associated with oxidation of proteins, including many central nervous system (CNS) diseases besides stroke and aging, including Parkinsonism, trauma, vascular headaches, and neuroanesthesia adjunct, as well as peripheral nervous system diseases such as diabetic peripheral neuropathy and traumatic nerve damage, as well as peripheral organ diseases. Examples of peripheral organ diseases include atherosclerosis, pulmonary fibrosis, pancreatitis, angioplasty, multiple organ failure, burns, and ischemic bowel disease.

It is therefore an object of the present invention to provide spin-trapping composition and methods for use thereof which are useful in preventing or reversing ischemic damage in vivo, in the (CNS, resulting from diseases such as stroke, aging, Parkinsonism, concussion, Berry aneurysm, ventricular hemorrhage and associated vasospasm, spinal cord trauma, vascular headaches, and neuroanesthesia adjunct.

It is another object of the present invention to provide spin-trapping compositions, and methods for use thereof, which are useful in treating damage in vivo resulting from peripheral nervous system diseases, including diabetic peripheral neuropathy and traumatic nerve damage.

It is still another object of the present invention to provide spin-trapping compositions, and methods for use thereof, which are useful in preventing or reversing free radical damage in vivo resulting from injury, infection and inflammation, especially peripheral organ diseases such as chronic obstructive pulmonary disease (COPD), atherosclerosis (both diabetic and spontaneous), pulmonary fibrosis due to anti-cancer, pancreatitis, angioplasty, multi-organ failure following trauma, burns, and ischemic bowel disease.

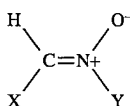
It is a further object of the present invention to treat disorders not associated with oxidation, such as undesirable HDL/LDL ratios, as well as the treatment of damage arising from exposure to cytotoxic compounds and radiation.

SUMMARY OF THE INVENTION

Spin trapping compositions in general have now been discovered to be effective in treating a variety of disorders,

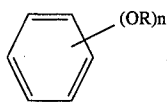
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including disorders such as those arising from ischemia, infection, inflammation, exposure to radiation or cytotoxic compounds, not just of the central and peripheral nervous systems but of peripheral organ disease having a wide variety of etiologies. In the preferred embodiment, the compositions for treating tissue damage from ischemia contain PBN, or active derivatives thereof, having the following general formula, in a suitable pharmaceutical carrier for intravenous, oral, topical, or nasal/pulmonary administration.



wherein:

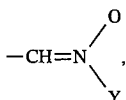
X is phenyl or



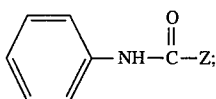
wherein R is H,



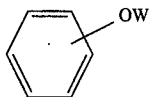
or Z; or



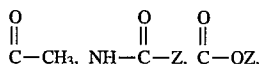
and n is a whole integer from 1 to 5; or



Y is a tert-butyl group that can be hydroxylated or acetylated on one or more positions; phenyl; or



wherein W is



or Z; and

Z is a C₁ to C₅ straight or branched alkyl group.

Other preferred spin-trapping agents include 5,5-dimethyl pyrroline N-oxide (DMPO), α -(4-pyridyl 1-oxide)-N-tert-butyl nitron (POBN), and (TEMPO) and spin-trapping derivatives thereof. Examples of useful derivatives of PBN include imidazole PBN, phenothiazinyl PBN, nitrosobenzene PBN, 2 methyl-nitrosopropane PBN, halogenated derivatives, bifunctional derivatives, conjugates, dimers and cyclodextran polymers of PBN. Conjugates of calcium channel blockers such as nimodipine, nicardipine, nife-

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dipine, nitrendipine, diltrazam, and flunarazine, digitalis, propranolol, desferal, and lazaroids, antiinflammatories such as prednisone, antioxidants such as vitamin E, and neuroactive compounds such as L-DOPA and acetaminophen are possible, although in some cases spacers will be required between the spin-trap and the conjugated compound in order to preserve maximum activity. The essential criteria for the selection of the spin trap is that it actively trap free radicals without cytotoxicity, and that in the applications where access to the CNS is required for efficacy, that the compounds pass through the blood brain barrier.

Many different disorders can be treated using these compounds, including diseases or disorders of the central and peripheral nervous systems, and disorders arising from ischemia, infection, inflammation, oxidation from exposure to radiation or cytotoxic compounds, as well as due to naturally occurring processes such as aging.

DETAILED DESCRIPTION OF THE INVENTION

it has now been discovered that, further to the methods using PBN, DMPO, and POBN, and their derivatives for the treatment and prevention of ischemic damage described and claimed in U.S. Ser. No. 07/422,651 filed Oct. 17, 1989 (now U.S. Pat. No. 5,025,032) and U.S. Ser. No. 07/589,177 filed Sep. 27, 1990, (now abandoned) the teachings of which are specifically incorporated herein, spin-trapping agents are generally useful in preventing or treating symptoms associated with a very wide range of disorders of the central and peripheral nervous system, as well as peripheral organ dysfunction and disease, including not just aging, trauma, ischemia, but disorders as disparate as undesirable ratios of lipoproteins, ulcerative colitis, and damage arising from exposure to radiation and cytotoxic compounds (chemotherapeutic compounds, in most instances).

As used herein, a free radical scavenger or spin-trap reagent is a molecule that will form a stable complex with a free radical. A free radical carbon trap is a molecule in which the free radical is localized on a carbon atom or a nitrogen atom. As a result of this chemical bond formation, the free radical is no longer damaging to the cell.

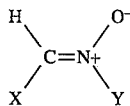
Useful Spin-Trapping Compounds

POBN and Derivatives Thereof

The preferred spin-trapping compounds are phenyl N-tert-butyl nitron, also referred to as α -phenyl t-butyl nitron (PBN), and derivatives thereof. PBN is the most preferred compound at this time, having no measurable effect on normal or uninjured cells, although a number of derivatives are also useful, including hydroxy derivatives, especially 2-, 3- or 4-hydroxy PBN and mono-, di- and trihydroxy tert-butyl nitron; esters, especially esters which release 2-, 3, or 4-hydroxyphenyl t-butyl nitron such as the acetoxy derivative, 2-, 3-, or 4-carboxyphenyl t-butyl nitron, such as the ethyl derivative, or phenyl hydroxybutyl nitron, such as the acetoxy derivative; alkoxy derivatives, especially alkoxy derivatives which release 2-, or 4-hydroxyphenyl t-butyl nitron, such as the methyl derivative; and acetamide derivatives, especially acetamide derivatives which release 2-, or 4 aminophenyl t-butyl nitron, such as the acetyl derivative; diphenyl nitron (PPN) and the analogous diphenyl nitron derivatives. As used herein, "PBN" refers to both phenyl N-tert-butyl nitron and derivatives thereof, unless otherwise stated.

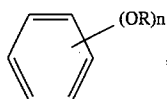
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The general formula for PBN and useful derivatives thereof is:



wherein:

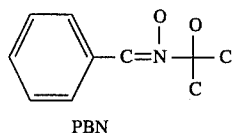
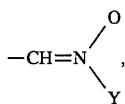
X is phenyl or



wherein R is H,

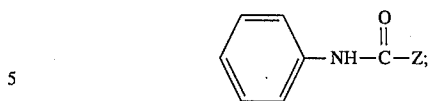


or Z; or



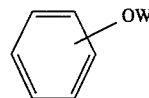
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and n is a whole integer from 1 to 5; or



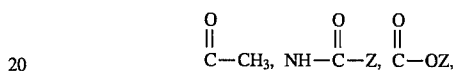
Y is a tert-butyl group that can be hydroxylated or acetylated on one or more positions; phenyl; or

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wherein W is



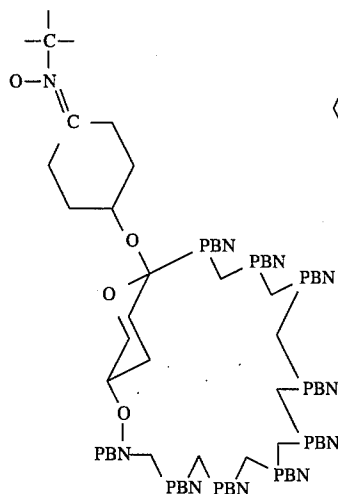
or Z; and

Z is a C₁ to C₅ straight or branched alkyl group.

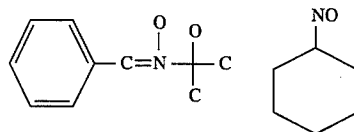
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The formulas for PBN and specific derivatives thereof are:

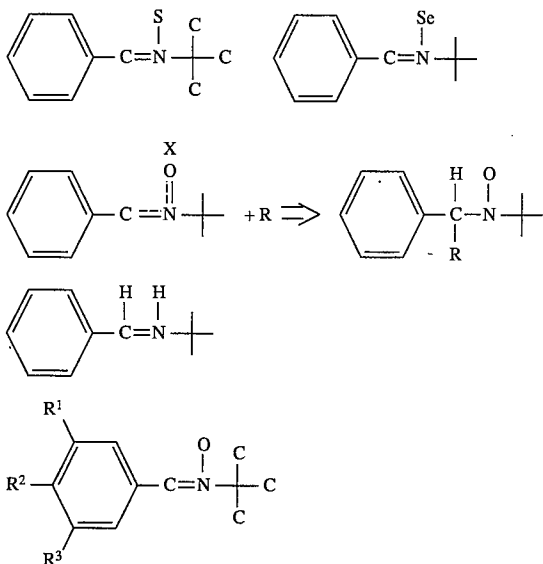
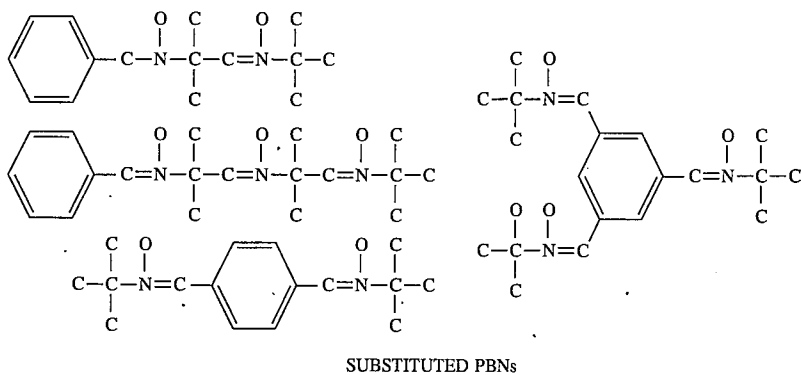
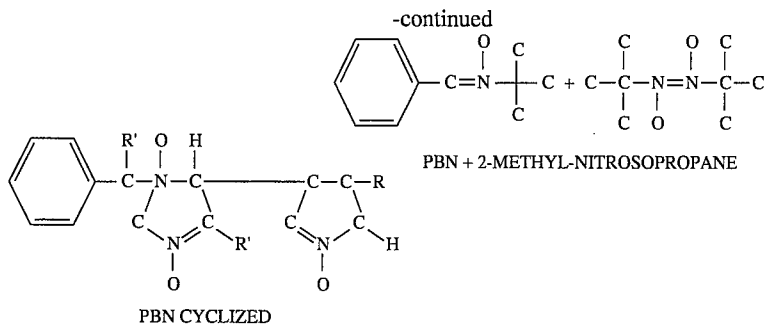
DERIVATIVES OF PBN



PBN CYCLODEXTRAN POLYMER



PBN + NITROSOBENZENE

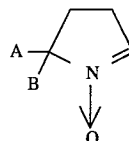


Other spin-trapping agents can also be used, such as 5,5-dimethyl pyrroline N-oxide (DMPO), α -(4-pyridyl 1-oxide)-N-tert-butyl nitron (POBN), N-tert-butyl- α -(4-nitro-phenyl)nitron, N-tert-butyl- α -(2-sulfophenyl)nitron, 3,3,5,5-tetramethyl-1-pyrroline N-oxide, and 2,4,6-tri-tert-butyl nitrosobenzene (BNB), and spin-trapping derivatives thereof. Derivatives are made using standard techniques, for example, by substitution of the methyl groups, for example, with halogens or sulfur. Many compounds are commercially available or can be synthesized using methods known to those skilled in the art. α -phenyl-N-phenylnitron compounds for use as topical antiinflammatories are described

55 by U.S. Pat. No. 4,224,340 to Campbell, et al., the teachings of which are incorporated herein.

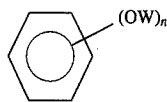
DMPO and Derivatives Thereof

The general formula for DMPO, and specific derivatives are:



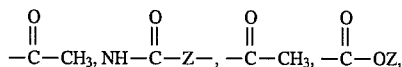
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wherein A and B are independently CH₃, CH₂ OH, CH₂OW, or



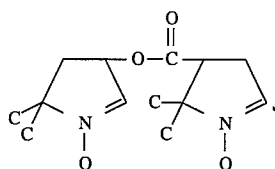
n is an integer from 1 to 5

wherein W is

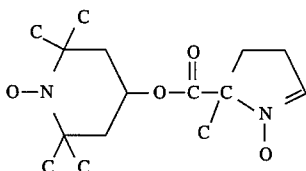


or Z; and

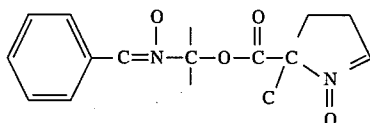
Z is a C₁ to C₅ straight or branched alkyl group.



DMPO dimer



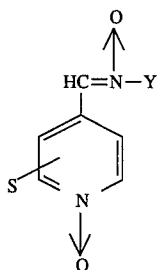
DMPO conjugated to TEMPO



PBN conjugated to DMPO

POBN and Derivatives Thereof

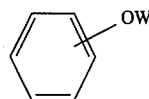
The general formula for POBN is:



wherein

Y is a tert-butyl group that can be hydroxylated or acetylated on one or more positions; phenyl; or

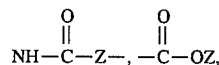
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wherein W is $-\overset{\text{O}}{\parallel}{\text{C}}-\text{CH}_3$,

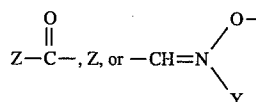
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or Z; and

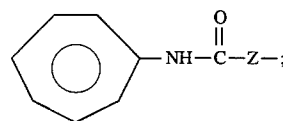
S=H, (OR)_n, wherein R is H,

15



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n is a whole number from 1 to 4, or



25

Z is a C₁ to C₅ straight or branched alkyl group.

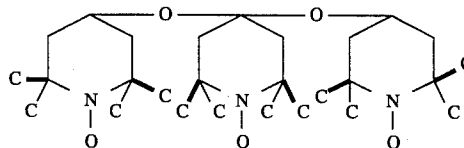
TEMPO and Derivatives Thereof

2,2,6,6-tetramethyl piperidinoxy (TEMPO) is a nitroxide organic free radical trap. The synthesis and chemistry of nitroxide free radicals is referenced by Galfney, B. J., pp. 184-238 in *Spin Labeling in Pharmacology* Berliner, L. H., (Academic Press, NY, N.Y. 1976), the teachings of which are incorporated herein. TEMPO and several derivatives thereof can be purchased from Aldrich Chemical Co., as can many other spin traps such as PBN, DMPO, and POBN and some of their derivatives.

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DERIVATIVES OF TEMPO

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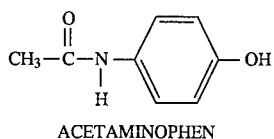


As discussed above, the important criteria for these compounds is that they must trap free radicals, especially hydroxy and superoxide radicals, while remaining non-toxic to normal cells. In those applications where the compound must reach the brain and other parts of the CNS, the compound must also be low molecular weight to pass through the blood brain barrier. In some applications, the higher molecular weight dimers and polymers of the spin trap may have advantages.

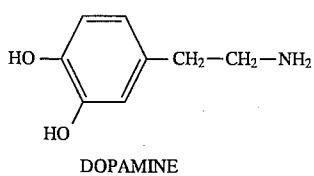
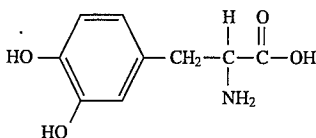
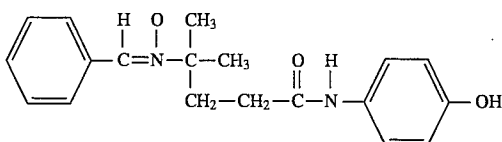
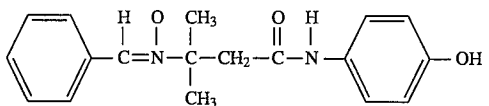
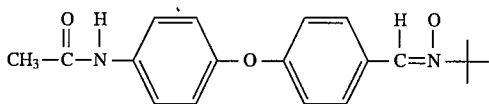
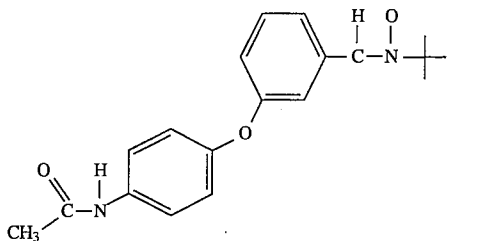
Conjugates and Polymers of Spin Trapping Compounds

Examples of other useful compounds include conjugates of spin traps with known biologically active compounds, including drugs such as antiinflammatories, neuroactive compounds, antioxidants, and calcium channel blockers. Examples include conjugates of acetaminophen, dopamine (or DOPA), vitamin E, and nifediphenyl:

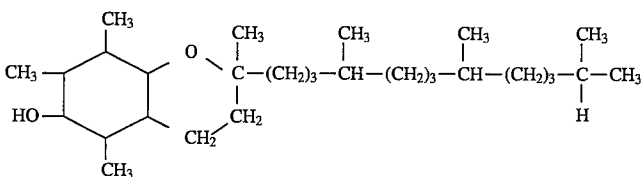
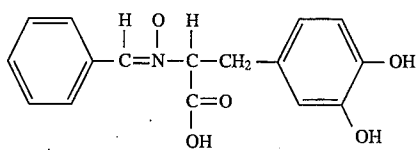
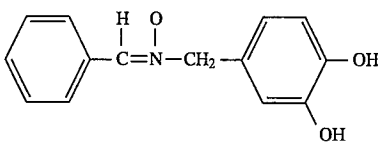
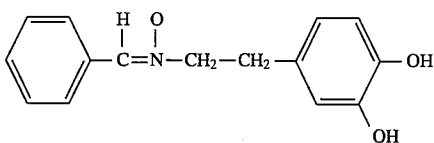
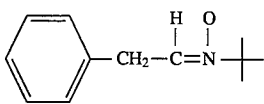
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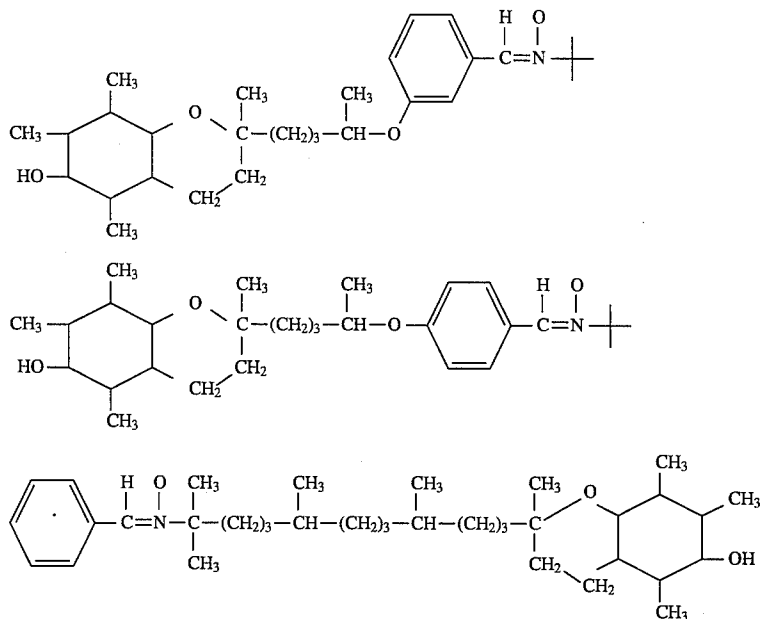
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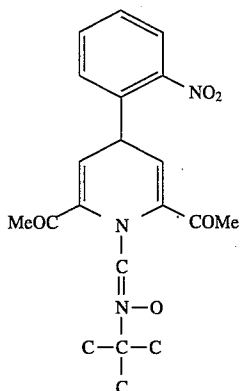
Derivatives of DOPA



-continued
VITAMIN E AND ANALOGUES THEREOF



NIFEDIPHENYL PBN



Other drugs that can be conjugated to the spin traps include diltiazem, calcium channel blockers such as nifedipine, nifedipine and nitrendipine, flunarazine, digitalis analogues, propranolol, desferal, and lazaroids. Conjugates with other types of biologically active molecules can also be made, for example, with antibodies or ligands for specific receptors (such as certain hormones, enzymes, or even specific sugars or carbohydrates) which are used to "target" or otherwise concentrate the spin trapping compound. Depending on the structure of the spin trap, as well as the biologically active compound, it may be necessary to insert a spacer between the spin trap and the biologically active compound.

Indications that the compositions are useful in treating.

The spin trap or free-radical scavenger compositions are useful in treating a variety of dysfunctions or disorders characterized by oxidized proteins or lipids in the tissues, cells, or associated fluids (such as the blood). Oxidation of cytosolic protein has been demonstrated to occur in a wide variety of pathological conditions. Accordingly, compounds which have as their fundamental mechanism of action the interference of production of oxidized protein should be useful in the treatment of a wide variety of diseases having what appears at first glance to be widely dissimilar etiolo-

gies, because the fundamental cause of the condition is oxidation of protein, nucleic acids, or lipids.

Disorders are generally divided into disorders of the central and peripheral nervous system and disorders of the peripheral organs.

Disorders of the CNS include stroke, aging, Parkinsonism, concussion, aneurysm, ventricular hemorrhage and associated vasospasm, migraine and other vascular headaches, spinal cord trauma, and neuroanesthesia adjunct. Disorders of the peripheral nervous system include diabetic peripheral neuropathy and traumatic nerve damage.

Peripheral organ disease includes atherosclerosis (both diabetic and spontaneous), chronic obstructive pulmonary disease (COPD), pancreatitis, pulmonary fibrosis due to chemotherapeutic agents, angioplasty, trauma, burns, ischemic bowel disease, wounds, ulcers and bed sores, lupus, ulcerative colitis, organ transplantation, renal hypertension, overexertion of skeletal muscle, and epistaxis (pulmonary bleeding).

Other conditions associated: with excessive oxidation of proteins or lipids that can be treated include undesirable or altered oxidation of low density lipoprotein, and dysfunction from exposure to radiation, including x-ray, ultraviolet, gamma and beta radiation, and cytotoxic compounds,

including those used for chemotherapy for cancer and viral infections.

Treatment of Central Nervous System Diseases

Stroke.

Multiple in vitro studies, as well as the in vivo data presented in U.S. Ser. No. 07/589,177 (now abandoned) and U.S. Ser. No. 07/422,651 (U.S. Pat. No. 5,025,032) have demonstrated that there are a series of biochemical changes that result in the production of free radicals following ischemia. PBN and other spin-trapping compounds can covalently bind to these radicals and prevent the peroxidation of cellular proteins and fatty acids. The consequence of the trapping of these carbon-centered and oxygen-centered radicals is the termination of the propagation phase of free radical production within the neuron. This interruption of free radical production can decrease the mortality and morbidity seen in strokes.

Aging

Aging has been demonstrated to be associated with the production of abnormally high levels of oxidized proteins. The consequence of this increased level of protein oxidation is an abnormally low level of critical enzymes in the affected cells. While not all cells have been evaluated, it appears from the in vivo data presented in U.S. Ser. No. 07/589,177 (now abandoned) and U.S. Ser. No. 07/422,651, (U.S. Pat. No. 5,225,032) and reports of in vitro studies, that most, if not all, cells in the body will undergo abnormally high levels of protein oxidation. Decreases in antioxidant systems and abnormally low levels of mitochondrial function have been described. The protein oxidation is thought to arise from oxygen free radicals, largely generated via a metal catalyzed reaction within the cell. Studies have now been conducted that daily administration of a free radical spin trapping compound, PBN, for fourteen days completely reverses this process. Not only is the level of protein oxidation decreased, but the abnormally low level of enzyme activity is restored to normal.

Parkinsonism

Research has indicated that one of the principle sources of dopaminergic damage to the striatum is via free radical mediated oxidation. Dopamine can be oxidized to the neurotoxin 6-OH dopamine within the neuron. This neurotoxin is activated by a second oxidation. Both of these reactions are thought to occur as a result of oxygen free radical production and attack on the dopamine, a naturally occurring neurotransmitter. These oxygen radical mediated oxidations are thought to occur at a relatively slow rate and to be responsible for the progressive loss of motor function in Parkinsonism and related conditions. Based upon the demonstration that chronic administration of PBN can decrease the progressive oxidation that occurs following a stroke, it is believed that PBN and other spin-trapping compounds will be effective in limiting the production of the neurotoxic dopamine oxidation products.

Concussion.

The majority of the research literature indicates that concussion produces the bulk of its long term effects via interruption of brain and spinal cord microcirculation, producing localized ischemia. This interruption in blood flow can be the result of the initial trauma and shearing of capillaries or the consequence of the brain edema and compression of the blood vessels. In any event, spin trapping compounds should be of therapeutic value as they have been demonstrated to be in models of stroke.

Berry Aneurysm and other types of Aneurysm.

This vascular problem results in bleeding on the brain and presents as a serious and chronic headache or other neurologic symptom. The condition is ultimately treated by surgical repair of the vessel that has developed a weak wall. However, this condition oftentimes results in hemorrhage and neural damage due to the bleeding. In addition, the presence of blood on the outside of the vessel sensitizes the vessels to spasm and increases the risk of a stroke, as is also true in concussion and other traumatic conditions. In addition to the radicals generated by spasm and stroke, the iron or other metal catalyzed generation of oxygen free radicals, similar to what has been proposed for ischemia and concussion, also represents a second source of free radicals.

Ventricular Hemorrhage and Associated Vasospasm.

The same biochemical and physiological conditions as described for Berry Aneurysm and their management by spin trapping compounds will apply for these conditions.

Migraine and other Vascular Headaches

Migraines are thought to arise in part from vasodilation and compression of the microcirculation of the cortex. This is another form of ischemia/reperfusion injury. While spin-trapping compounds will not prevent the initial occurrence of these vascular headaches, they should limit the extent or frequency by trapping the free radicals that are generated during the ischemia phase.

Spinal Cord Trauma.

Spinal cord trauma involves the interruption of the normal vascular supply due to shearing forces at the time of the initial trauma and as a result of the subsequent edema of the tissue. In addition, the hemorrhage that often accompanies such trauma will also generate vasospasm and directly generated oxygen free radicals. Spin trapping compounds should limit this process and terminate the intracellular cascade of lipid and protein oxidation.

Neuroanesthesia Adjunct.

Several procedures involve resection of brain tissue which will result in hemorrhage in the immediate area. Other surgical procedures may be associated with increased risk of cerebral blood flow interruption, either as a natural consequence of the procedure, e.g., cardiac surgery or heart transplantation, or due to the unexpected interruption of flow, e.g., hemorrhage, clot following angioplasty, cardiac arrest during surgery. In all of these conditions, spin-trapping compounds will limit free radical mediated damage.

Peripheral Nervous System Diseases

Diabetics are well known for their tendencies to develop peripheral neuropathies and progressively lose sensation in limbs. In addition, diabetics have a higher risk to develop atherosclerosis, which may affect microvascular function. One of the most frequently seen biochemical consequences of diabetes is excessive glycation of proteins. Following glycation, there is a burst of protein oxidation that is mediated by oxygen free radicals. It is thought that this process of excessive glycation is critical in the development of damage to neurons and axons in the diabetic. Since spin trapping compounds are quite effective in limiting intracellular free radical mediated damage, such compounds should be useful in the chronic management of diabetic neuropathies and other long term adverse consequences of diabetes.

Traumatic Nerve Damage.

Crushing injury to peripheral nerves, as in the hands, arms, and legs, involves interruption of blood flow (ischemia) and edema. Effective and prompt repair is depen-

dent on the re-establishment of an effective oxygen and nutrient supply. Oftert recovering tissue tertds to outgrow its blood supply and is restricted in recovery by the ischemia that occurs as the tissue outgrows the vascular supply. Spin-trapping compounds should provide greater tolerance of partial hypoxia as vascular supply grows to reach the healing tissue. In addition, the same ischemia/hypoxia protection that occurs in the non-vascular tissue may also enhance the growth of the endothelia as the revascularization process occurs.

Peripheral Organ Diseases

Atherosclerosis (Both Diabetic and Spontaneous).

Diabetic atherosclerosis involves the abnormal and excessive glycation of protein in the vascular wall. As discussed above for diabetic neuropathy, this involves oxygen radical production and consequent further damage to cytosolic proteins. Spin-trapping compounds will prevent this abnormal processing of cellular protein and other cellular constituents. In vitro studies have been conducted that demonstrate that PBN inhibits or reduces oxidation of low density lipoprotein in plasma. Plasma samples were tested for oxidation of lipid measured using thiobarbituric acid reactive substance (T_{BAR} , nM) and % inhibition of oxidation calculated. Phosphate buffered saline (PBS) was added to controls, 0.1 mM PBN was added to test samples, and the controls and sealed samples incubated at 4° C. for seven weeks.

The results are shown in Table 1.

TABLE 1

Testing of antioxidation activity of PBN.			
sample	control + PBS	Test (nM/ml)	% inhibition*
NP132 plasma	0.55	0.45	18.2
NP134 plasma	0.18	0.14	22.2
NP135 plasma	0.32	0.25	21.9
NP133 LDL	0.54	0.28	48.1
NP135 LDL	0.33	0.11	66.7

*The actual percent inhibition in the presence of PBN is greater than the measured value due to interference in the assay by the PBN.

Chronic Obstructive Pulmonary Disease (COPD).

COPD has been demonstrated to involve the attack of interstitial alveolar macrophages on pulmonary tissue. Animals models of this clinical condition have demonstrated that increases or decreases in superoxide dismutase activity in the lung can result in decreases or increases in pulmonary pathology, respectively. An alternative approach is to provide to the pulmonary tissue, either via the pulmonary vascular supply or via the airway, radical spin-trapping compounds which will limit the peroxidation of pulmonary tissue and the consequent loss of alveolar tissue.

Pancreatitis.

Pancreatitis is believed to be the result of ischemic or chemically derived peroxidation of pancreatic parenchyma. Alcoholic pancreatitis is probably due to the direct effects of the ethanol radical and the indirect vascular effects of acetaldehyde mediated direct damage to proteins and indirect damage via catecholamine release and mitochondrial metabolism. There is currently no treatment for acute pancreatitis. If the condition does not abate, it is generally regarded as fatal in the severe form. Spin-trapping agents may mediate the acute reaction, allowing the patient time to recover.

Angioplasty.

In the process of re-expanding or laser removal of atheroma, there are periods of ischemia and reperfusion of the vessel. Recent studies have demonstrated that during this period, superoxide and nitric oxide are produced. These products have been demonstrated to further damage the endothelium and may also remove or damage the natural relaxant systems that locally control the vascular tone. If uncontrolled, such changes are likely to result in an increased risk of re-occlusion of the same vessel. Spin-trapping compounds can prevent the generation of the oxy-radical cascade and thereby reduce the likelihood of reocclusion following angioplasty.

Multi-organ Failure Following Trauma.

A characteristic problem following extreme trauma is the development in the patient of a negative nitrogen balance, poor protein synthetic capacity, pulmonary dysfunction, and abnormal cytokine production. Tumor necrosis factor (TNF) is excessively elevated during this process. TNF is associated with the cellular generation of oxygen free radicals in tissue and may be one of the primary causes of this condition. The activation of macrophages and lymphocytes also plays a critical role in the condition. Free radical production by the white cells is part of the process of multiple organ damage. Spin-trapping compounds can prevent the propagation phase of this condition and limit the extert of cachexia and organ damage following severe trauma.

Diabetic Retinopathy.

Diabetes is a disease of abnormal glycation and partial ischemia. Both conditions promote free radical production. The relatively common condition of diabetic retinopathy is thought to involve a microvascular and protein dysfunction of the retina. Spin-trapping compounds can limit the glycation mediated production of free radicals and the damage caused by microvascular interruptions.

Burn Treatment and Healing.

Healing from serious burns is limited by the inability of the repairing vascular system to supply the rapidly growing cutaneum. Periods of ischemia in the dermis will occur as the growing skin cannot be adequately supplied. This hypoxia or ischemia results in the production of oxygen free radicals and either limits the rate of recovery and/or promotes the generation of scar tissue. Systemic and topical spin-trapping compounds should improve the rate of healing and decrease scar formation.

Ischemic Bowel Disease

Strangulation of the bowel is a condition that is frequently fatal in both humans and animals such as dogs, horses and cattle. Even after resection and anastomosis of the intestine, the prognosis is not good. The generation of ischemia derived oxygen radicals and damage to the intestine is considered to be the primary cause. There is no effective treatment to date.

Studies have demonstrated that ischemia induced intestinal edema can be prevented or reduced by a number of different spin-trapping compounds.

Endotoxin is a primary factor in the pathophysiology of equine gastrointestinal disorders and gram negative bacterial infections. The pathophysiological is similar to that characterizing colitis, salmonellosis, and neonatal septicemia. It is hypothesized that endotoxin produces its toxic effects by triggering "oxidative bursts" from sensitized macrophages. These bursts of O_2 radicals are interded to kill invading bacteria associated with the presence of endotoxin. However, they have the adverse effect of damaging the tissues in

which they are produced and this tissue damage is presumably the molecular basis of the pathological changes associated with endotoxin shock. Spin-trapping compounds have the ability to trap radicals and alleviate many of the toxic effects associated with radical formation. Additionally, recent experiments demonstrate that spin trap molecules protect rats against endotoxin administration.

Wound and Ulcer Healing.

Tissue healing oftent involves periods of hypoxia or ischemia as the recovering tissue outgrows the vascular supply. Spin-trapping compounds can decrease the damage associated with this period of ischemia.

Infections as consequence of the development of decubitus ulcers is the number one cause of death in the elderly. The general clinical impression is that elderly patients are much more likely to develop these ulcers, compared to young adults. Pressure sores develop as a result of the interruption of blood flow to the skin. This process is identical to the process of ischemia/reperfusion oxidation of brain and other tissues. In the geriatric patient, pressure sores may rapidly develop due to the enhanced oxidation of cells in the skin. Based upon the observations that spin-trapping compounds can prevent ischemia/reperfusion injury to both brain and intestine, it is expected that spin trapping compounds will reduce or prevent pressure sores. In addition, these compounds should be useful systemically or topically in enhancing recovery.

Reduction in Side-effects of Cancer Chemotherapy.

A number of cancer chemotherapeutic agents produce their cytotoxic effects via the production of oxygen free radicals within the cell. The limiting side effects of these, compounds are also the result of oxygen free radical production in normal cells. Bleomycin produces pulmonary and cutaneous toxicities as a result of hydroxyl free radical production. Adriamycin produces cardiac and gastrointestinal side-effects. The spin-trapping compound PBN has been demonstrated to trap the free radicals produced by adriamycin in heart, brain and other organs of research animals, using the spin-trapping compound PBN. These spin-trapping compounds should be useful in limiting side effects in tissues, such as the brain, that the especially vulnerable to develop free radicals without compromising the therapeutic value of the chemotherapeutic agent.

Skin, Muscle Flap and Organ Survival Following Transplantation.

Autologous (self) transplantation of skeletal muscles from area to the other should not involve any immunologic incompatibilities. However, estimates from surgeons suggest that the success rate is more in the area of 50% success. Acceptance of skin flap grafts has an equally low success rate. It is postulated much of the problem arises a result of ischemia and reperfusion during the surgical procedures for removal and implantation. Following ischemia these tissues undergo calcium loading and eventually necrosis, as in strokes. Spin-trapping compounds should therefore be equally effective in limiting the damage undergone by these tissues, as well as other organs, during surgery associated with transplantation.

Organs for transplantation are obtained from donors. The success of the procedure is determined in part by the age (oxidation) related reduction in organ viability, the amount of time the organ is in preservation solution and the status of the recipient. Previous research has demonstrated that spin-trapping compounds can improve the enzymatic status of the aged brain, restoring enzymatic levels to near those of the young adult as early as seven days following initiation of daily treatment with a spin-trapping agent such as PBN.

Organ preservation solutions are designed to prepare the organ to be transplanted for the period of extracorporeal storage. The most recently developed solution contains glutathione as an antioxidant. Spin-trapping compounds differ from glutathione in that they can function both as antioxidants, trapping oxygen free radicals, as well as trapping compounds for both intracellular and extracellular carbon-centered free radicals.

It is believed organ survival would therefore be enhanced by administering spin-trapping compounds to the recipient, as well as adding the compounds to the organ preservation solution.

Ionizing Radiation Prophylaxis.

Ionizing radiation as a therapeutic modality and as an environmental toxicant causes its effects by producing hydroxyl free radicals intracellularly and extracellularly. Ultraviolet radiation acts similarly. The cascade that follows is functionally identical to the process of cellular damage caused by ischemia/reperfusion injury to tissue. By selectively treating with spin-trapping compounds those tissues that are not involved by the cancer, it should be possible to improve the effectiveness and decrease the side effects of radiation therapies. In the case of environmental exposures, spin-trapping compounds should be effective both as a prophylaxis, applied topically or systemically, as well as a post-exposure therapeutic.

Treatment of Renal Hypertension Disorders, resulting from low renal artery flow and high renin.

Renal hypertension develops as a result of reduced blood flow to the kidney. The juxtaglomerular apparatus (JGA) recognizes this hypoperfusion and releases renin, which results in an angiotensin II mediated increase in blood pressure (hypertension). Hypoperfusion (hypoxia) is a condition that is known to result in significant oxygen free radical production, making it probable that oxygen free radicals are likely to be involved in the release of renin by the JGA, and therefore manageable at least in part through administration of spin-trapping compounds.

Exertional Injury to skeletal muscle.

Sore muscles as a result of exercise are thought to be a consequence of free radical mediated peroxidation of skeletal muscle proteins and lipids. Since chronic treatment with spin-trapping compounds decreases cellular oxidations and protects enzymes from oxidative inactivation, daily treatment should improve the process of exercise conditioning (especially in the horse). Moreover, aged skeletal muscle is likely to contain constituents, as do most other cells in the body. Previous work has demonstrated that chronic administration of the spin-trapping compound PBN can return cells to the status of a young adult, spin-trapping compounds should be effective in improving the functional status and exercise condition of skeletal muscle in aged individuals.

Epistaxis (Pulmonary Bleeding in Horses) and Laminitis

Epistaxis (ES) and laminitis are both thought to involve ischemia/reperfusion injury to the alveolar basement membrane and the lamina propria of the hoof, respectively. Since both of these conditions involve the process of reperfusion generation of free radicals, spin-trapping compounds should be effective in the prevention, management of treatment of these conditions.

Pharmaceutical Compositions

The spin trapping compounds are administered topically, locally, or systemically, depending on the application. When administered systemically, the compound is preferably administered orally or intravenously, in an appropriate phar-

maceutical carrier such as saline or phosphate buffered saline (PBS) or in tablet form. For topical application, the compound is preferably administered in an ointment or cream base, or by means of a transdermal patch. The compound can also be administered by controlled delivery devices, such as biodegradable polymers, or by inhalation, insufflation or nasal spray. Suitable carriers are known to those skilled in the pharmaceutical area.

Effective dosages of Spin Trapping Compounds

Exemplary dosages of PBN administered intravenously range from 0.1 to 10 mg/kg of body weight in animals. The effective dosage of PBN in humans for treating age and ischemic related disorders is expected to be between approximately 1 and 10 mg/70 kg body weight. Toxicity tests have demonstrated that the compound is completely innocuous, with such low toxicity that it was not possible to determine an LD₅₀. It is possible to extrapolate from comparative tests using other spin trapping compounds what the effective dosage for these compounds will be.

Since the trapping of endogenous free radicals is specific for only those cells that have been exposed to the conditions that result in the production of free radicals, the traps have little or no effect on normal cells. The beneficial effects occur only in injured cells, and do not require the presence of specific receptors, specific enzymes, and/or specific cell types.

Methods of administration of PBN.

The spin trapping compound is preferably administered systemically, most preferably intravenously or orally, since these are the most rapid and efficient means for delivering the active compound to the site of free radical generation. The spin trapping compound may be administered at once, or may be divided into a number of smaller doses to be administered at varying intervals of time. Other methods of systemic administration can also be used, including inhalation or insufflation, subcutaneous, intravenous, and intraperitoneal administration. The spin trapping compound can also be administered topically, in an ointment, creme, or transdermal patch. The concentration of active compound in the drug composition will depend on absorption, inactivation, and excretion rates of the drug as well as other factors known to those skilled in the art. It is to be noted that dosage values will also vary with the condition of the patient being treated. It is to be further understood that for any particular subject, specific dosage regimens should be adjusted over time according to the individual need and the professional judgment of the person administering or supervising the administration of the compositions, and that the concentration ranges set forth herein are exemplary only and are not intended to limit the scope or practice of the claimed composition.

A preferred mode of administration of the active compound is in a form for oral delivery. Oral compositions will generally include an inert diluent or an edible carrier. Preferred pharmaceutical carriers for intravenous administration are saline or phosphate buffered saline at physiological pH. Since some compounds are pH sensitive, stability of the compound in the carrier should be determined and the pH of the carrier adjusted appropriately, or the compound administered in combination with food, a buffering agent, or in an enteric coating. For oral delivery, the spin trapping compound may be enclosed in capsules, compressed into tablets, microencapsulated, entrapped in liposomes, in solution or suspension, alone or in combination with a substrate immobilizing material such as starch or poorly absorbable salts such as immodium. Pharmaceutically compatible bind-

ing agents can be included as part of the composition. The tablets or capsules may contain, for example, any of the following ingredients, or compounds of a similar nature: a binder such as microcrystalline cellulose, gum tragacanth or gelatin; an excipient such as starch or lactose, a disintegrating agent such as alginic acid, Primogel®, or corn starch; a lubricant such as magnesium stearate or Sterotes; a glidant such as colloidal silicon dioxide; a sweetening agent such as sucrose or saccharin; or a flavoring agent such as peppermint, methyl salicylate, or orange flavoring. When the dosage unit form is a capsule, it can contain, in addition to material of the above type, a liquid carrier. In addition, dosage unit forms can contain various other materials which modify the physical form of the dosage unit, for example, coatings of sugar, shellac, or other enteric agents.

Modifications and variations of the spin trapping compositions for the treatment of a variety of disorders associated with oxidation of proteins and/or lipids will be obvious to those skilled in the art from the foregoing detailed description. Such modifications and variations are intended to come within the scope of the appended claims.

We claim:

1. A method for ameliorating the side effects caused in a patient by oxidative damage resulting from the administration to said patient of a cancer therapeutic agent, said method comprising administering to said patient an effective side effect-ameliorating amount of an active ingredient selected from the group consisting of:

- (1) phenyl N-tert-butyl nitron (PBN) derivatives selected from the group consisting of hydroxy PBNs, PBN esters, acetoxy PBNs, phenyl PBNs, alkyl PBNs, alkoxy PBNs, acetamide PBNs, and diphenyl PBNs;
- (2) imidazole PBN, phenothiazinyl PBN, nitrosobenzene PBN, 2-methyl nitrosopropane PBN, PBN Cyclodextran polymer and cyclized PBN;
- (3) 5,5-dimethyl pyrroline N-oxide (DMPO) esters, acetoxy DMPOs, phenyl DMPOs, alkyl DMPOs, acetamide DMPOs, diphenyl DMPOs, and DMPO dimers;
- (4) alpha-(4-pyridyl 1-oxide)-N-tert-butyl nitron (POBN) esters, hydroxy POBNs, phenyl POBNs, alkoxy POBNs, and acetamide POBNs;
- (5) N-tert-butyl-alpha-(4-nitro-phenyl)nitron;
- (6) N-tert-butyl-alpha-(2-sulfophenyl)nitron;
- (7) 3,3,5,5-tetramethyl-1-pyrroline N-oxide;
- (8) 2,4,6-tri-tert-butyl nitrosobenzene (BNB); and
- (9) 2,2,6,6-tetramethyl piperidinoxy (TEMPO), optionally in association with a pharmaceutically acceptable carrier.

2. The method of claim 1 wherein said cancer therapeutic agent is selected from the group consisting of bleomycin and adriamycin.

3. The method of claim 1 wherein said active ingredient is a PBN derivative selected from the group consisting of hydroxy PBNs, PBN esters, acetoxy PBNs, phenyl PBNs, alkyl PBNs, alkoxy PBNs, acetamide PBNs, and diphenyl PBNs.

4. The method of claim 1 wherein said active ingredient is a PBN derivative selected from the group consisting of imidazole PBN, phenothiazinyl PBN, nitrosobenzene PBN and 2-methyl nitrosopropane PBN.

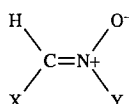
5. The method of claim 1 wherein said active ingredient is selected from the group consisting of DMPO derivatives selected from the group consisting of DMPO esters, acetoxy DMPOs, phenyl DMPOs, alkyl DMPOs, acetamide DMPOs, diphenyl DMPOs, and DMPO dimers.

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6. The method of claim 1 wherein said active ingredient is selected from the group consisting of POBN derivatives selected from the group consisting of POBN esters, hydroxy POBNs, phenyl POBNs, alkoxy POBNs, and acetamide POBNs.

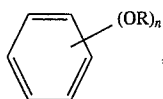
7. The method of claim 1 wherein said active ingredient is administered in association with a pharmaceutically acceptable carrier.

8. A method for ameliorating the side effects caused in a patient by oxidative damage resulting from the administration to said patient of a cancer therapeutic agent, said method comprising administering to said patient an effective side-effect ameliorating amount of an active ingredient defined by the formula:

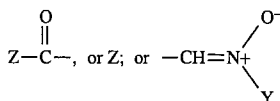


wherein:

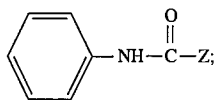
X is phenyl or



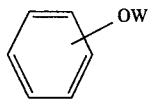
wherein R is H,



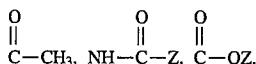
and n is a whole integer from 1 to 5; or



Y is a tert-butyl group that can be hydroxylated or acetylated on one or more positions; phenyl; or



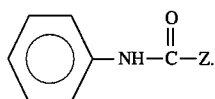
wherein W is



or Z; and

Z is a C₁ to C₅ straight or branched alkyl group, excluding compounds of formula (I) wherein Y is a tert-butyl group when X is phenyl, optionally in association with a pharmaceutically acceptable carrier.

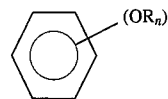
9. The method of claim 8 wherein X is



10. The method of claim 8 wherein Z is methyl.

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11. The method of claim 8 wherein X is

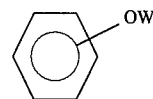


12. The method of claim 8 wherein Y is a tert-butyl group.

13. The method of claim 9 wherein Y is a tert-butyl group.

14. The method of claim 8 wherein Y is phenyl.

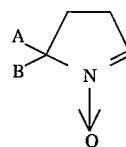
15. The method of claim 8 wherein Y is



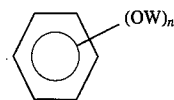
16. The method of claim 8 wherein Z is C₁ to C₅ straight chain alkyl.

17. The method of claim 8 wherein said active ingredient is administered in association with a pharmaceutically acceptable carrier.

18. A method for ameliorating the side effects caused in a patient by oxidative damage resulting from the administration to said patient of a cancer therapeutic agent, said method comprising administering to said patient an effective side effect-ameliorating amount of an active ingredient defined by the formula:

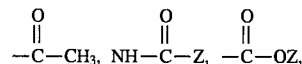


wherein A and B are independently CH₂OH, CH₂OW, or



n is an integer from 1 to 5,

wherein W is

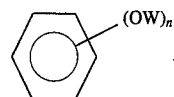


or Z; and

Z is a C₁ to C₅ straight or branched alkyl group, optionally in association with a pharmaceutically acceptable carrier.

19. The method of claim 18 wherein A and B are independently selected from the group consisting of CH₂OH and CH₂OW.

20. The method of claim 18 wherein at least one of A and B is

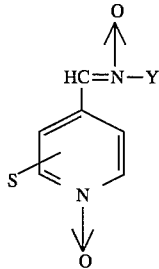


21. The method of claim 18 wherein said active ingredient is administered in association with a pharmaceutically acceptable carrier.

22. A method for ameliorating the side effects caused in a patient by oxidative damage resulting from the adminis-

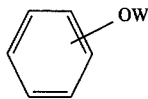
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tration to said patient of a cancer therapeutic agent, said method comprising administering to said patient an effective side effect-ameliorating amount of an active ingredient defined by the formula:

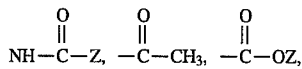


wherein

Y is a tert-butyl group that can be hydroxylated or acetylated on one or more positions; phenyl; or

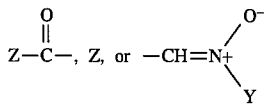


wherein W is

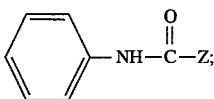


or Z; and

S is $(\text{OR})_n$, wherein R is H,



n is a whole number from 1 to 4, or



and

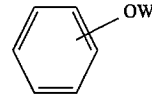
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Z is a C_1 to C_5 straight or branched alkyl group, optionally in association with a pharmaceutically acceptable carrier.

23. The method of claim 22 wherein Y is a tert-butyl group.

24. The method of claim 22 wherein Y is phenyl.

25. The method of claim 22 wherein Y is



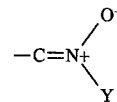
26. The method of claim 22 wherein S is OH.

27. The method of claim 22 wherein Z is a C_1 to C_5 straight alkyl group.

28. The method of claim 22 wherein S is



29. The method of claim 22 wherein S is



30. The method of claim 22 wherein S is a C_1 to C_5 straight or branched alkyl group.

31. The method of claim 22 wherein said active ingredient is administered in association with a pharmaceutically acceptable carrier.

32. The method of claim 1 wherein the active ingredient is N-tert-butyl-alpha-(4-nitro-phenyl) nitron.

33. The method of claim 1 wherein the active ingredient is N-tert-butyl-alpha-(2-sulfophenyl) nitron.

34. The method of claim 1 wherein the active ingredient is 3,3,5,5-tetramethyl-1-pyrroline N-oxide.

35. The method of claim 1 wherein the active ingredient is 2,4,6-tri-tert-butyl nitrosobenzene.

36. The method of claim 1 wherein the active ingredient is 2,2,6,6-tetramethyl piperidinoxy.

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