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(54) Title: TRIPTOLIDE LACTONE RING DERIVATIVES AS IMMUNOMODULATORS AND ANTICANCER AGENTS

(57) Abstract: Disclosed are compounds based on lactone ring modifications of triptolide and hydroxylated triptolide, for use in therapy, such as antiproliferative, anticancer, and immunosuppressive therapy.

Triptolide Lactone Ring Derivatives as Immunomodulators and Anticancer Agents

Field of the Invention

The present invention relates to compounds useful as immunosuppressive, anti-inflammatory and anticancer agents.

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Background of the Invention

Immunosuppressive agents are widely used in the treatment of autoimmune disease and in treating or preventing transplantation rejection, including the treatment of graft-versus-host disease (GVHD). Common immunosuppressive agents include azathioprine, corticosteroids, cyclophosphamide, methotrexate, 6-mercaptopurine, vincristine, and cyclosporin A. In general, none of these drugs are completely effective, and most are limited by severe toxicity. For example, cyclosporin A, a widely used agent, is significantly toxic to the kidney. In addition, doses needed for effective treatment may increase the patient's susceptibility to infection by a variety of opportunistic invaders.

The compound triptolide, obtained from the Chinese medicinal plant *Tripterygium wilfordii* (TW), and certain derivatives and prodrugs thereof, have been identified as having immunosuppressive activity, *e.g.* in the treatment of autoimmune disease, and in treating or preventing transplantation rejection, including the treatment of graft-versus-host disease (GVHD). See, for example, co-owned U.S. Patent Nos. 5,962,516 (Immunosuppressive compounds and methods), 5,843,452 (Immunotherapy composition and method), 5,759,550 (Method for suppressing xenograft rejection), 5,663,335 (Immunosuppressive compounds and methods), 5,648,376 (Immunosuppressant diterpene compound), and 6,150,539 (Triptolide prodrugs having high aqueous solubility), which are incorporated by reference. Triptolide and certain derivatives and prodrugs thereof have also been reported to show anticancer activity; see, for example, Kupchan *et* al., 1972, 1977, as well as co-owned U.S. Patent No. 6,620,843 (Sep 2003), which is hereby incorporated by reference.

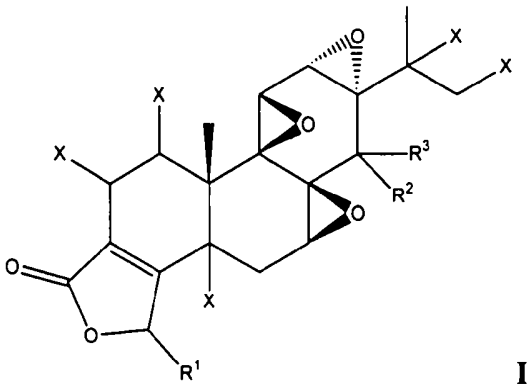
Although derivatives and prodrugs of triptolide have provided benefits relative to native triptolide in areas such as pharmacokinetics or biodistribution, *e.g.* by virtue of differences in lipid or aqueous solubility, or via their activity as prodrugs, the biological activity per se of triptolide derivatives is often significantly less than that of native triptolide.

Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed before the priority date of each claim of this application.

Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

Summary of the Invention

In one embodiment the present invention provides a compound having the structure **I**:



I

where

R^1 is alkyl, alkenyl, alkynyl, arylalkyl, aryl, arylacyl, or $C(OH)R^4R^5$,

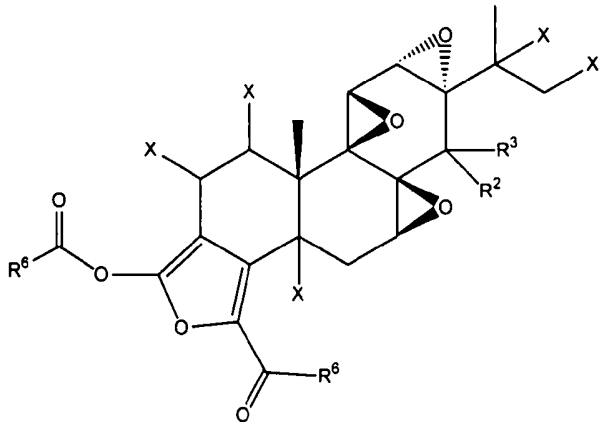
wherein arylacyl is -C(O)R and R is aryl;

wherein R^4 and R^5 are independently hydrogen, alkyl, cycloalkyl, alkenyl, or cycloalkenyl, any of which, excepting hydrogen, may be substituted with alkoxy, hydroxy, acyloxy, or aryl, wherein each said alkyl, alkenyl, alkynyl, alkoxy, and acyloxy includes at most four carbon atoms, each said cycloalkyl and cycloalkenyl includes at most six carbon atoms, and each said aryl is monocyclic and non-heterocyclic;

CR^2R^3 is CHOH or C=O; and

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

In one embodiment the present invention provides a compound having the structure **II**:



II

where

each R^6 is independently selected from alkyl, alkenyl, alkynyl, or aryl;

wherein each said alkyl, alkenyl, and alkynyl includes at most four carbon atoms, and each said aryl is monocyclic and non-heterocyclic;

CR^2R^3 is CHOH or C=O;

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

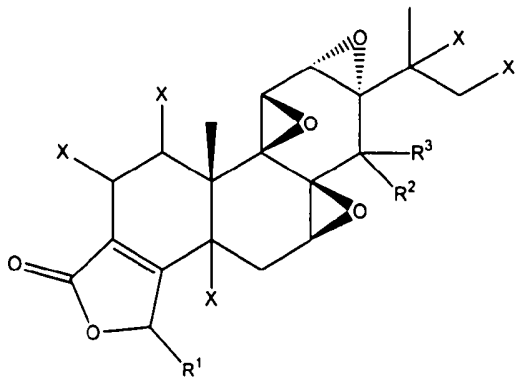
In one embodiment the present invention provides a method of effecting immunosuppression, comprising administering to a subject in need of such treatment, in a pharmaceutically acceptable vehicle, an effective amount of a compound according to a compound of the present invention.

In one embodiment the present invention provides a method of inducing apoptosis in a cell, comprising contacting said cell with an effective amount of a compound according to a compound of the present invention.

In one embodiment the present invention provides a use of a compound according to a compound of the present invention, in a pharmaceutically acceptable vehicle, for effecting immunosuppression in a subject, by administering an effective amount of said compound to said subject.

In one embodiment the present invention provides a use of a compound according to a compound of the present invention for inducing apoptosis in a cell, by contacting said cell with an effective amount of said compound.

In one aspect, the invention provides compounds which are useful for immunosuppressive, anti-inflammatory and anticancer therapy. The compounds are derivatives of triptolide represented by formula **I**:



where

R^1 is alkyl, alkenyl, alkynyl, arylalkyl, aryl, arylacyl, or $C(OH)R^4R^5$,

wherein R^4 and R^5 are independently hydrogen, alkyl, cycloalkyl, alkenyl, or cycloalkenyl, any of which, excepting hydrogen, may be substituted with alkoxy, hydroxy, acyloxy, or aryl;

CR^2R^3 is CHOH or C=O, and

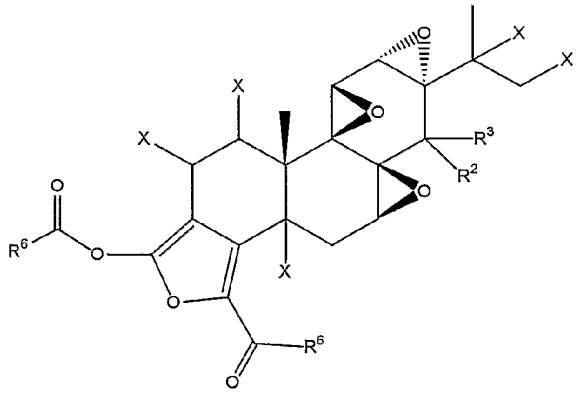
at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

In preferred embodiments of structure **I**, CR^2R^3 is CHOH, preferably having the β-hydroxy configuration. In further embodiments, each group X is hydrogen.

Preferably, each said alkyl, alkenyl, alkynyl, alkoxy, and acyloxy moiety present in a compound of structure **I** includes at most four carbon atoms, each said cycloalkyl and cycloalkenyl moiety includes at most six carbon atoms, and each said aryl moiety is monocyclic and non-heterocyclic (i.e.; consists of hydrogen and carbon atoms).

In selected embodiments of structure **I**, R^1 is alkyl, alkenyl or $C(OH)R^4R^5$, where, preferably, each of R^4 and R^5 is independently hydrogen, alkyl or alkenyl. In further embodiments, R^1 is alkyl, preferably C_1-C_3 alkyl, or hydroxyalkyl. In one embodiment, R^1 is methyl. In another embodiment, R^1 is arylacyl, preferably benzoyl ($C(O)C_6H_5$).

In a related aspect, the invention provides compounds of structure **II**:



II

where

each R^6 is independently selected from alkyl, alkenyl, alkynyl, or aryl;

CR^2R^3 is CHOH or C=O;

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

In preferred embodiments of structure **II**, CR^2R^3 is CHOH, preferably having the β-hydroxy configuration. In further embodiments, each group X is hydrogen.

Preferably, each said alkyl, alkenyl, and alkynyl moiety present in a compound of

structure **II** includes at most four carbon atoms, and each said aryl moiety is monocyclic and non-heterocyclic; *e.g.* substituted or unsubstituted phenyl.

In selected embodiments of structure **II**, each R^6 is aryl; preferably, each R^6 is unsubstituted phenyl.

In another aspect, the invention provides a method of effecting immunosuppression in a subject, by administering to a subject in need of such treatment an effective amount of a compound having the structure **I** or **II** as described above. In a further aspect, the invention provides a method of inducing apoptosis in a cell, which is useful in antiproliferative therapy, especially anticancer therapy. In accordance with this method, the cell is contacted with an effective amount of a compound having the structure **I** or **II** as described above. Alternatively, the invention encompasses the use of a compound of structure **I** or **II** for effecting immunosuppression or for inducing apoptosis in a cell, or for preparation of a medicament for effecting immunosuppression or for inducing apoptosis in a cell. The compound is typically provided in a pharmaceutically acceptable carrier. Specific embodiments of the methods and uses may employ any of the specific embodiments of formulas **I** and **II** described above.

These and other objects and features of the invention will become more fully apparent when the following detailed description of the invention is read in conjunction with the accompanying drawings.

Brief Description of the Drawings

Fig. 1 shows the cytotoxic effect in Jurkat cells of a compound of the invention, 19-methyl triptolide (designated PG795), in comparison with triptolide (designated PG490) (Example 3);

Fig. 2 shows the cytotoxic effect in Jurkat cells of a compound of the invention, 18-deoxo-19-dehydro-18-benzoyloxy-19-benzoyl triptolide (designated PG796), in comparison with triptolide 14-succinate (designated PG490-88), with and without pre-incubation in mouse or human serum (Example 3);

Fig. 3 shows inhibition of IL-2 production in Jurkat cells by a compound of the invention, 19-methyl triptolide (designated PG795), in comparison with triptolide (Example 4); and

Fig. 4 shows inhibition of IL-2 production in Jurkat cells by PG796, in comparison

with triptolide 14-succinate, with and without pre-incubation in mouse or human serum (Example 4).

Detailed Description of the Invention

I. Definitions

"Alkyl" refers to a saturated acyclic monovalent radical containing carbon and hydrogen, which may be linear or branched. Examples of alkyl groups are methyl, ethyl, n-butyl, t-butyl, n-heptyl, and isopropyl. "Cycloalkyl" refers to a fully saturated cyclic monovalent radical containing carbon and hydrogen, which may be further substituted with alkyl. Examples of cycloalkyl groups are cyclopropyl, methyl cyclopropyl, cyclobutyl, cyclopentyl, ethylcyclopentyl, and cyclohexyl. "Lower alkyl" refers to such a group having one to six carbon atoms, preferably one to four carbon atoms.

"Alkenyl" refers to an acyclic monovalent radical containing carbon and hydrogen, which may be linear or branched, and which contains at least one carbon-carbon double bond (C=C). "Alkynyl" refers to an acyclic monovalent radical containing carbon and hydrogen, which may be linear or branched, and which contains at least one carbon-carbon triple bond (C≡C). "Lower alkenyl" or "lower alkynyl" such a group having two to six carbon atoms, preferably two to four carbon atoms.

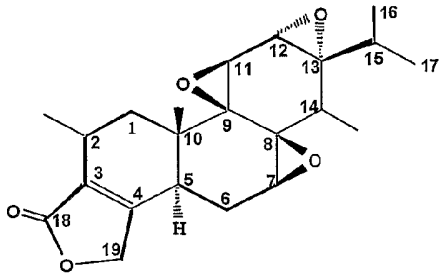
"Acyl" refers to a radical having the form -(C=O)R, where R is alkyl (alkylacyl) or aryl (arylacyl). "Acyloxy" refers to a group having the form -O(C=O)R.

"Aryl" refers to a monovalent aromatic radical having a single ring (*e.g.*, benzene) or two condensed rings (*e.g.*, naphthyl). As used herein, aryl is preferably monocyclic and carbocyclic (non-heterocyclic), *e.g.* a benzene (phenyl) ring or substituted benzene ring. By "substituted" is meant that one or more ring hydrogens is replaced with a group such as a halogen (*e.g.* fluorine, chlorine, or bromine), lower alkyl, nitro, amino, lower alkylamino, hydroxy, lower alkoxy, or halo(lower alkyl).

"Arylalkyl" refers to an alkyl, preferably lower (C_1-C_4, more preferably C_1-C_2) alkyl, substituent which is further substituted with an aryl group; examples are benzyl and phenethyl.

A "heterocycle" refers to a non-aromatic ring, preferably a 5- to 7-membered ring, whose ring atoms are selected from the group consisting of carbon, nitrogen, oxygen and sulfur. Preferably, the ring atoms include 3 to 6 carbon atoms. Such heterocycles include, for example, pyrrolidine, piperidine, piperazine, and morpholine.

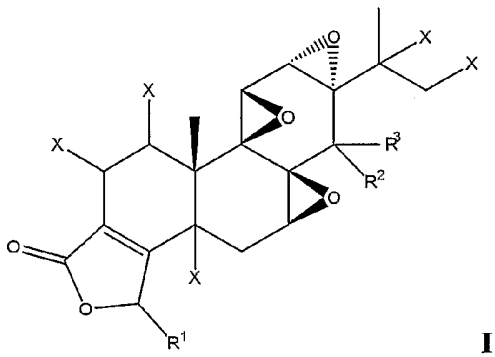
For the purposes of the current disclosure, the following numbering scheme is used for triptolide and triptolide derivatives:



II. Triptolide Derivatives

The compounds of the invention are derivatives of triptolide or hydroxylated triptolides, resulting from alkylation or acylation of the furanoid (lactone) ring, as described below.

More specifically, the invention provides compounds represented by structure **I**:



I

where

R^1 is alkyl, alkenyl, alkynyl, arylalkyl, aryl, arylacyl, or $C(OH)R^4R^5$,

wherein R^4 and R^5 are independently hydrogen, alkyl, cycloalkyl, alkenyl, or cycloalkenyl, any of which, excepting hydrogen, may be substituted with alkoxy, hydroxy, acyloxy, or aryl;

CR^2R^3 is CHOH or C=O, and

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

In preferred embodiments of structure **I**, CR^2R^3 is CHOH, preferably having the β-hydroxy configuration.

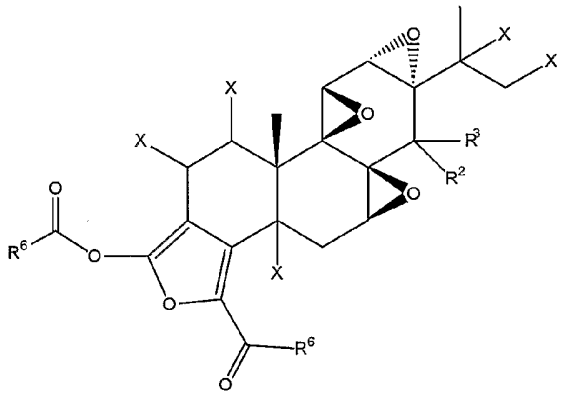
Preferably, each X is hydrogen; however, in selected embodiments, exactly one of the indicated groups X is hydroxyl. Preferred locations for hydroxyl substitution include

carbons 2 and 16, as shown in the numbering scheme above.

Preferably, each said alkyl, alkenyl, alkynyl, alkoxy, and acyloxy moiety present in a compound of structure **I** includes at most four carbon atoms, each said cycloalkyl and cycloalkenyl moiety includes at most six carbon atoms, and each said aryl moiety is monocyclic and non-heterocyclic.

In selected embodiments of structure **I**, R^1 is alkyl, alkenyl, alkynyl, arylalkyl, aryl, or $C(OH)R^4R^5$, preferably alkyl, alkenyl or $C(OH)R^4R^5$, where, preferably, each of R^4 and R^5 is independently hydrogen, alkyl or alkenyl. In further embodiments, R^1 is alkyl, preferably C_1-C_3 alkyl, or hydroxyalkyl. In one embodiment, which includes the compound designated herein as PG795, R^1 is methyl. In other embodiments, which include the compound 19-benzoyl triptolide, R^1 is arylacyl, preferably benzoyl.

In a related aspect, the invention provides compounds of structure **II**:



II

where

each R^6 is independently selected from alkyl, alkenyl, alkynyl, or aryl;

CR^2R^3 is CHOH or C=O;

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

In preferred embodiments of structure **II**, CR^2R^3 is CHOH, preferably having the β-hydroxy configuration. Preferably, each X is hydrogen; however, in selected embodiments, exactly one of the indicated groups X is hydroxyl. Preferred locations for hydroxyl substitution include carbons 2 and 16, as shown in the numbering scheme above.

Preferably, each said alkyl, alkenyl, and alkynyl moiety present in a compound of structure **II** includes at most four carbon atoms, and each said aryl moiety is monocyclic

and non-heterocyclic; *e.g.* substituted or unsubstituted phenyl.

In selected embodiments of structure **II**, each R^6 is aryl; preferably, each R^6 is phenyl. This includes the compound designated herein as PG796, where each R^6 is unsubstituted phenyl.

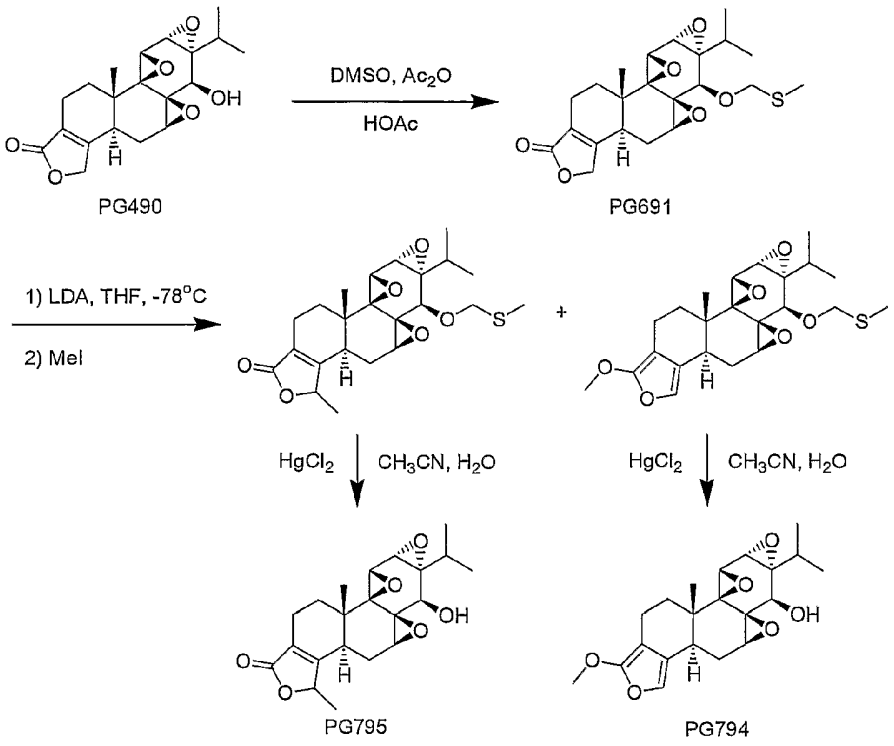
A. Preparation

The compounds of the invention may be prepared from triptolide or its hydroxylated derivatives. The latter include tripdiolide (2-hydroxy triptolide) and 16-hydroxy triptolide, which, along with triptolide, can be obtained from the root xylem of the Chinese medicinal plant *Tripterygium wilfordii* (TW) or from other known sources. The TW plant is found in the Fujian Province and other southern provinces of China; TW plant material can generally be obtained in China or through commercial sources in the United States. Methods for preparing triptolide, tripdiolide and 16-hydroxytriptolide are known in the art and are described, for example, in Kupchan *et al.* (1972, 1977); Lipsky *et al.* (1994); Pu *et al.* (1990); and Ma *et al.* (1992).

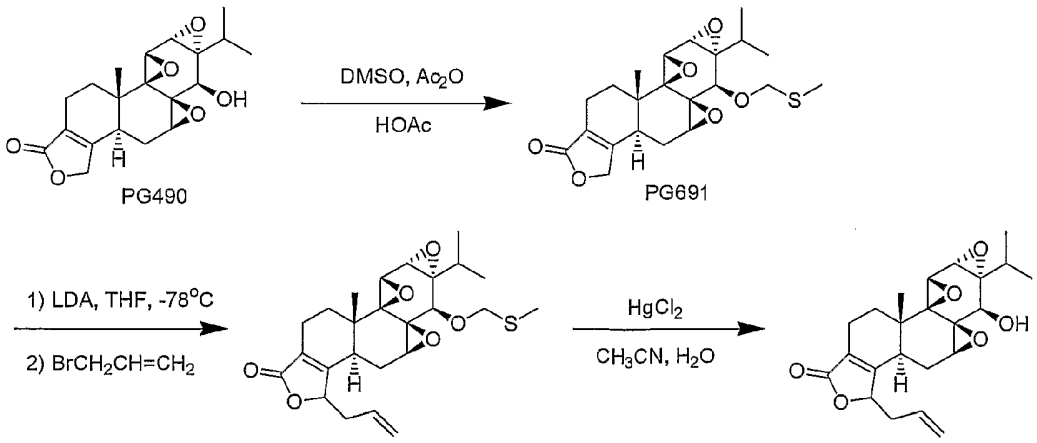
The 5-hydroxy derivative of triptolide can be prepared by selenium dioxide oxidation of triptolide, as described in co-owned U.S. provisional application serial no. 60/532,702. Briefly, in a typical preparation, a solution of triptolide and about 2.2 equivalents of selenium dioxide in dioxane is stirred at about 90°C under N_2 for 72 hrs.

Incubation of triptolide with *Cunninghamella blakesleana*, as described by L. Ning *et al.* (*Tetrahedron* **59**(23):4209-4213, 2003) produces the above hydroxylated derivatives as well as 1β-hydroxytriptolide, triptolidenol (15-hydroxytriptolide), 19α-hydroxytriptolide, and 19β-hydroxytriptolide.

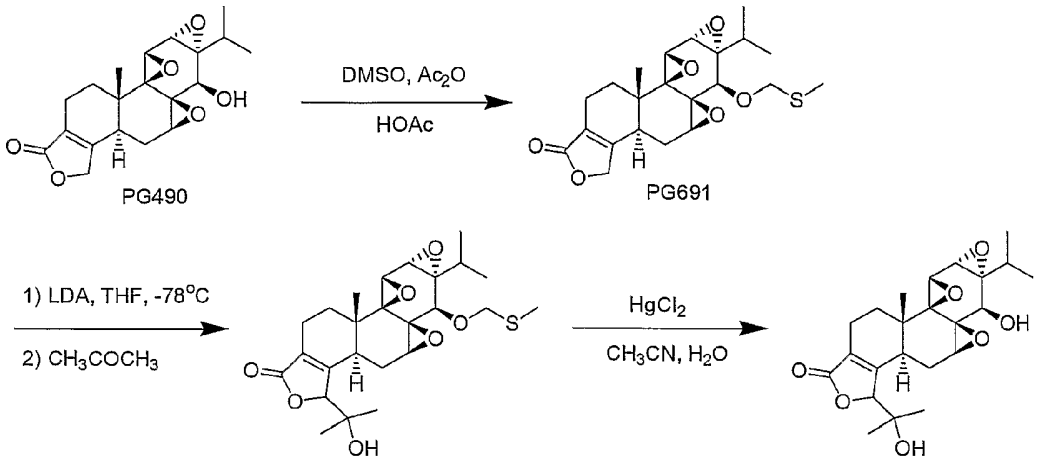
Compounds of formula **I** can be prepared by reaction of hydroxyl-protected triptolide with a strong base, such as LDA, followed by alkylation of the intermediate enolate. As shown in Scheme 1 below, where methyl iodide was used for alkylation, the isomeric furan alkoxide may also be formed. As described in Example 1, these compounds were isolated and separately deprotected by reaction with mercuric chloride.



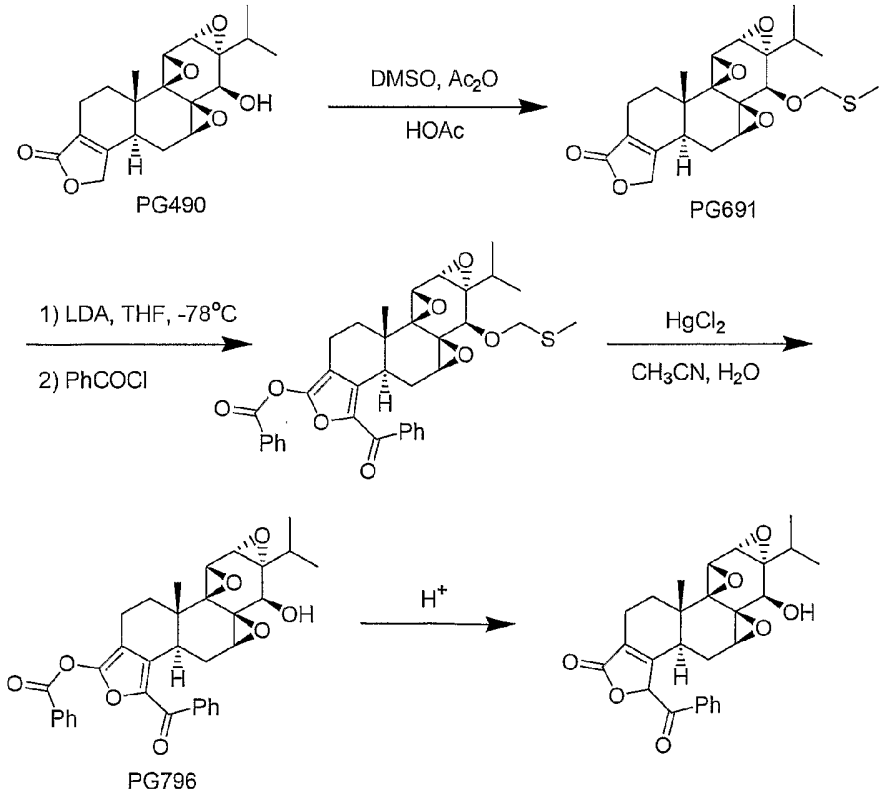
The scheme below illustrates the use of allyl bromide as alkylating agent, to give a compound of formula **I** in which R^1 = allyl ($-CH_2CH=CH_2$). Similarly, benzyl bromide was employed to give a compound of formula **I** in which R^1 = benzyl ($-CH_2C_6H_5$).



Reaction of the intermediate enolate with a ketone, as shown below, can be used to generate an alcohol substituent; *i.e.* a compound of formula **I** in which R^1 is $C(OH)R^4R^5$.



Compounds of formula **II** can be prepared by reaction of the intermediate enolate with an excess of an acylating reagent, such as an acyl halide, as shown in the Scheme below. The disubstituted compound, in this case, can be hydrolyzed with aqueous acid to generate the monoderivatized conjugated enone.



B. Biological Activity

The cytotoxic activity of a compound of formula **I**, 19-methyl triptolide (designated PG795) and a compound of formula **II**, 18-deoxo-19-dehydro-18-benzoyloxy-19-benzoyl triptolide (designated PG796), was evaluated using a standard MTT assay, as described in Example 3. The immunosuppressive activity of these compounds was evaluated in a standard IL-2 inhibition assay, as described in Example 4. The results of these assays are shown in Figures 1-4.

PG795 showed significant activity in both assays, as shown in Figs. 1 and 3, though it was less active than triptolide (designated PG490 in the Figures).

PG796 showed a higher level of activity in both assays than the known prodrug, triptolide 14-succinate (designated PG490-88), as shown in Figs. 2 and 4. In particular, triptolide 14-succinate incubated in human serum was much less active in these assays than triptolide 14-succinate incubated in mouse serum, while PG796 showed high, and essentially equivalent, activity in both cases. (Incubation is expected to convert triptolide 14-succinate to triptolide and PG796 to the monoderivatized compound, 19-benzoyl triptolide, shown in the above synthetic scheme.)

In addition, PG476 showed nearly equivalent activity when unincubated, suggesting that the compound is active in its original (*i.e.* non-hydrolyzed) form.

III. Therapeutic Compositions

Formulations containing the triptolide derivatives of the invention may take the form of solid, semi-solid, lyophilized powder, or liquid dosage forms, such as tablets, capsules, powders, sustained-release formulations, solutions, suspensions, emulsions, ointments, lotions, or aerosols, preferably in unit dosage forms suitable for simple administration of precise dosages. The compositions typically include a conventional pharmaceutical carrier or excipient and may additionally include other medicinal agents, carriers, or adjuvants.

Preferably, the composition includes about 0.5% to 75% by weight of a compound or compounds of the invention, with the remainder consisting of suitable pharmaceutical excipients. For oral administration, such excipients include pharmaceutical grades of mannitol, lactose, starch, magnesium stearate, sodium saccharine, talcum, cellulose, glucose, gelatin, sucrose, magnesium carbonate, and the like. If desired, the composition may also contain minor amounts of non-toxic auxiliary substances such as wetting agents,

emulsifying agents, or buffers.

The composition may be administered to a subject orally, transdermally or parenterally, *e.g.*, by intravenous, subcutaneous, intraperitoneal, or intramuscular injection. For use in oral liquid preparation, the composition may be prepared as a solution, suspension, emulsion, or syrup, being supplied either in liquid form or a dried form suitable for hydration in water or normal saline. For parenteral administration, an injectable composition for parenteral administration will typically contain the triptolide derivative in a suitable intravenous solution, such as sterile physiological salt solution.

Liquid compositions can be prepared by dissolving or dispersing the triptolide derivative (about 0.5% to about 20%) and optional pharmaceutical adjuvants in a pharmaceutically acceptable carrier, such as, for example, aqueous saline, aqueous dextrose, glycerol, or ethanol, to form a solution or suspension.

The compound may also be administered by inhalation, in the form of aerosol particles, either solid or liquid, preferably of respirable size. Such particles are sufficiently small to pass through the mouth and larynx upon inhalation and into the bronchi and alveoli of the lungs. In general, particles ranging from about 1 to 10 microns in size, and preferably less than about 5 microns in size, are respirable. Liquid compositions for inhalation comprise the active agent dispersed in an aqueous carrier, such as sterile pyrogen free saline solution or sterile pyrogen free water. If desired, the composition may be mixed with a propellant to assist in spraying the composition and forming an aerosol.

Methods for preparing such dosage forms are known or will be apparent to those skilled in the art; for example, see Remington's Pharmaceutical Sciences (20th Ed., Lippincott Williams & Wilkins, 2000). The composition to be administered will contain a quantity of the selected compound in an effective amount for effecting immunosuppression in a subject or apoptosis in a targeted cell.

As described, for example, in Panchagnula *et al.* (2000), the partition coefficient or logP of a pharmaceutical agent can affect its suitability for various routes of administration, including oral bioavailability. The compounds described herein, by virtue of substitution of fluorine for one or more hydroxyl groups, are expected to have higher calculated logP values than the parent compound, triptolide, making them better candidates for oral availability.

IV. Immunomodulating and Antiinflammatory Treatment

The invention thus includes the use of the invention compounds as immunosuppressive agents, *e.g.* as an adjunct to transplant procedures or in treatment of autoimmune disease. The compounds of the invention are effective to inhibit immune responses, such as production of cytokines, in cells or organisms. As shown in Figs. 3-4, a compound of formula **I**, 19-methyl triptolide (designated PG795), and a compound of formula **II**, 18-deoxo-19-dehydro-18-benzoyloxy-19-benzoyl triptolide (designated PG796), inhibited IL-2 production in Jurkat cells (see Example 4) in a dose-dependent manner.

Immunoregulatory abnormalities have been shown to exist in a wide variety of autoimmune and chronic inflammatory diseases, including systemic lupus erythematosis, chronic rheumatoid arthritis, type I and II diabetes mellitus, inflammatory bowel disease, biliary cirrhosis, uveitis, multiple sclerosis and other disorders such as Crohn's disease, ulcerative colitis, bullous pemphigoid, sarcoidosis, psoriasis, ichthyosis, Graves ophthalmopathy and asthma. Although the underlying pathogenesis of each of these conditions may be quite different, they have in common the appearance of a variety of autoantibodies and self-reactive lymphocytes. Such self-reactivity may be due, in part, to a loss of the homeostatic controls under which the normal immune system operates.

Similarly, following a bone-marrow transplant or other transplant of hematopoietic stem cells from a donor tissue source containing mature lymphocytes, the transferred lymphocytes recognize the host tissue antigens as foreign. These cells become activated and mount an attack upon the host (a graft-versus-host response) that can be life-threatening. Moreover, following an organ transplant, the host lymphocytes recognize the foreign tissue antigens of the organ graft and mount cellular and antibody-mediated immune responses (a host-versus-graft response) that lead to graft damage and rejection.

One result of an autoimmune or a rejection reaction is tissue destruction caused by inflammatory cells and the mediators they release. Anti-inflammatory agents such as NSAIDs act principally by blocking the effect or secretion of these mediators but do nothing to modify the immunologic basis of the disease. On the other hand, cytotoxic agents, such as cyclophosphamide, act in such a nonspecific fashion that both the normal and autoimmune responses are shut off. Indeed, patients treated with such nonspecific

immunosuppressive agents are as likely to succumb from infection as they are from their autoimmune disease.

The compositions of the present invention are useful in applications for which triptolide and its prodrugs and other derivatives have proven effective, *e.g.* in immunosuppression therapy, as in treating an autoimmune disease, preventing transplantation rejection, or treating or preventing graft-versus-host disease (GVHD). See, for example, co-owned U.S. Patent No. 6,150,539, which is incorporated herein by reference. Triptolide and the present derivatives are also useful for treatment of other inflammatory conditions, such as traumatic inflammation, and in reducing male fertility.

The compositions are useful for inhibiting rejection of a solid organ transplant, tissue graft, or cellular transplant from an incompatible human donor, thus prolonging survival and function of the transplant, and survival of the recipient. This use would include, but not be limited to, solid organ transplants (such as heart, kidney and liver), tissue grafts (such as skin, intestine, pancreas, gonad, bone, and cartilage), and cellular transplants (such as cells from pancreas, brain and nervous tissue, muscle, skin, bone, cartilage and liver).

The compositions are also useful for inhibiting xenograft (interspecies) rejection; *i.e.* in preventing the rejection of a solid organ transplant, tissue graft, or cellular transplant from a non-human animal, whether natural in constitution or bioengineered (genetically manipulated) to express human genes, RNA, proteins, peptides or other non-native, xenogeneic molecules, or bioengineered to lack expression of the animal's natural genes, RNA, proteins, peptides or other normally expressed molecules. The invention also includes the use of a composition as described above to prolong the survival of such a solid organ transplant, tissue graft, or cellular transplant from a non-human animal.

Also included are methods of treatment of autoimmune diseases or diseases having autoimmune manifestations, such as Addison's disease, autoimmune hemolytic anemia, autoimmune thyroiditis, Crohn's disease, diabetes (Type I), Graves' disease, Guillain-Barre syndrome, systemic lupus erythematosis (SLE), lupus nephritis, multiple sclerosis, myasthenia gravis, psoriasis, primary biliary cirrhosis, rheumatoid arthritis and uveitis, asthma, atherosclerosis, Hashimoto's thyroiditis, allergic encephalomyelitis, glomerulonephritis, and various allergies.

Further uses may include the treatment and prophylaxis of inflammatory and

hyperproliferative skin diseases and cutaneous manifestations of immunologically mediated illnesses, such as psoriasis, atopic dermatitis, pemphigus, urticaria, cutaneous eosinophilias, acne, and alopecia areata; various eye diseases such as conjunctivitis, uveitis, keratitis, and sarcoidosis; inflammation of mucous and blood vessels such as gastric ulcers, vascular damage caused by ischemic diseases and thrombosis, ischemic bowel diseases, inflammatory bowel diseases, and necrotizing enterocolitis; intestinal inflammations/allergies such as Coeliac diseases and ulcerative colitis; renal diseases such as interstitial nephritis, Good-pasture's syndrome, hemolytic-uremic syndrome and diabetic nephropathy; hematopoietic diseases such as idiopathic thrombocytopenia purpura and autoimmune hemolytic anemia; skin diseases such as dermatomyositis and cutaneous T cell lymphoma; circulatory diseases such as arteriosclerosis and atherosclerosis; renal diseases such as ischemic acute renal insufficiency and chronic renal insufficiency; and Behcet's disease.

The compositions and method of the invention are also useful for the treatment of inflammatory conditions such as asthma, both intrinsic and extrinsic manifestations, for example, bronchial asthma, allergic asthma, intrinsic asthma, extrinsic asthma and dust asthma, particularly chronic or inveterate asthma (for example, late asthma and airway hyperresponsiveness). The composition and method may also be used for treatment of other inflammatory conditions, including traumatic inflammation, inflammation in Lyme disease, chronic bronchitis (chronic infective lung disease), chronic sinusitis, sepsis associated acute respiratory distress syndrome, and pulmonary sarcoidosis. For treatment of respiratory conditions such as asthma, the composition is preferably administered via inhalation, but any conventional route of administration may be useful.

In treating an autoimmune condition, the patient is given the composition on a periodic basis, *e.g.*, 1-2 times per week, at a dosage level sufficient to reduce symptoms and improve patient comfort. For treating rheumatoid arthritis, in particular, the composition may be administered by intravenous injection or by direct injection into the affected joint. The patient may be treated at repeated intervals of at least 24 hours, over a several week period following the onset of symptoms of the disease in the patient. The dose that is administered is preferably in the range of 1-25 mg/kg patient body weight per day, with lower amounts being preferred for parenteral administration, and higher amounts being preferred for oral administration. Optimum dosages can be determined by

routine experimentation according to methods known in the art.

For therapy in transplantation rejection, the method is intended particularly for the treatment of rejection of heart, kidney, liver, cellular, and bone marrow transplants, and may also be used in the treatment of GVHD. The treatment is typically initiated perioperatively, either soon before or soon after the surgical transplantation procedure, and is continued on a daily dosing regimen, for a period of at least several weeks, for treatment of acute transplantation rejection. During the treatment period, the patient may be tested periodically for immunosuppression level, *e.g.*, by a mixed lymphocyte reaction involving allogeneic lymphocytes, or by taking a biopsy of the transplanted tissue.

In addition, the composition may be administered chronically to prevent graft rejection, or in treating acute episodes of late graft rejection. As above, the dose administered is preferably 1-25 mg/kg patient body weight per day, with lower amounts being preferred for parenteral administration, and higher amounts for oral administration. The dose may be increased or decreased appropriately, depending on the response of the patient, and over the period of treatment, the ability of the patient to resist infection.

In treatment or prevention of graft-versus-host disease, resulting from transplantation into a recipient of matched or mismatched bone marrow, spleen cells, fetal tissue, cord blood, or mobilized or otherwise harvested stem cells, the dose is preferably in the range 0.25-2 mg/kg body weight/day, preferably 0.5-1 mg/kg/day, given orally or parenterally.

Also within the scope of the invention is a combination therapy comprising a compound of formula I and one or more conventional immunosuppressive agents. These immunosuppressant agents within the scope of this invention include, but are not limited to, Imurek® (azathioprine sodium), brequinar sodium, Spanidin™ (gusperimus trihydrochloride, also known as deoxyspergualin), mizoribine (also known as bredinin), Cellcept® (mycophenolate mofetil), Neoral® (Cyclosporin A; also marketed as a different formulation under the trademark Sandimmune®), Prograf™ (tacrolimus, also known as FK-506), Rapimmune® (sirolimus, also known as rapamycin), leflunomide (also known as HWA-486), Zenapax®, glucocortcoids, such as prednisolone and its derivatives, antibodies such as orthoclone (OKT3), and antithymyocyte globulins, such as thymoglobulins. The compounds are useful as potentiators when administered concurrently with another immunosuppressive drug for immunosuppressive treatments as discussed above. A conventional immunosuppressant drug, such as those above, may

thus be administered in an amount substantially less (*e.g.* 20% to 50% of the standard dose) than when the compound is administered alone. Alternatively, the invention compound and immunosuppressive drug are administered in amounts such that the resultant immunosuppression is greater than what would be expected or obtained from the sum of the effects obtained with the drug and invention compound used alone. Typically, the immunosuppressive drug and potentiator are administered at regular intervals over a time period of at least 2 weeks.

The compositions of the invention may also be administered in combination with a conventional anti-inflammatory drug (or drugs), where the drug or amount of drug administered is, by itself, ineffective to induce the appropriate suppression or inhibition of inflammation.

Immunosuppressive activity of compounds *in vivo* can be evaluated by the use of established animal models known in the art. Such assays may be used to evaluate the relative effectiveness of immunosuppressive compounds and to estimate appropriate dosages for immunosuppressive treatment. These assays include, for example, a well-characterized rat model system for allografts, described by Ono and Lindsey (1969), in which a transplanted heart is attached to the abdominal great vessels of an allogeneic recipient animal, and the viability of the transplanted heart is gauged by the heart's ability to beat in the recipient animal. A xenograft model, in which the recipient animals are of a different species, is described by Wang (1991) and Murase (1993). A model for evaluating effectiveness against GVHD involves injection of normal F1 mice with parental spleen cells; the mice develop a GVHD syndrome characterized by splenomegaly and immunosuppression (Korngold, 1978; Gleichmann, 1984). Single cell suspensions are prepared from individual spleens, and microwell cultures are established in the presence and absence of concanavalin A to assess the extent of mitogenic responsiveness.

V. Anticancer Treatment

As shown in Figs. 1-2, a compound of formula **I**, 19-methyl triptolide (designated PG795), and a compound of formula **II**, 18-deoxo-19-dehydro-18-benzoyloxy-19-benzoyl triptolide (designated PG796), were each cytotoxic to Jurkat cells (see Example 2) in a dose-dependent manner. The invention thus includes the use of the invention compounds as cytotoxic agents, particularly to treat cancers. As used herein, "cancer"

refers to all types of cancer or neoplasm or malignant tumors found in mammals especially humans, including leukemias, sarcomas, carcinomas and melanoma.

The term "leukemia" refers broadly to progressive, malignant diseases of the blood-forming organs and is generally characterized by a distorted proliferation and development of leukocytes and their precursors in the blood and bone marrow. The term "sarcoma" generally refers to a tumor which is made up of a substance like the embryonic connective tissue and is generally composed of closely packed cells embedded in a fibrillar or homogeneous substance. The term "melanoma" is taken to mean a tumor arising from the melanocytic system of the skin and other organs. The term "carcinoma" refers to a malignant new growth made up of epithelial cells tending to infiltrate the surrounding tissues and give rise to metastases.

Included, for example, are cancers involving cells derived from reproductive tissue (such as Sertoli cells, germ cells, developing or more mature spermatogonia, spermatids or spermatocytes and nurse cells, germ cells and other cells of the ovary), the lymphoid or immune systems (such as Hodgkin's disease and non-Hodgkin's lymphomas), the hematopoietic system, and epithelium (such as skin, including malignant melanoma, and gastrointestinal tract), solid organs, the nervous system, *e.g.* glioma (see Y.X. Zhou *et al.*, 2002), and musculo-skeletal tissue. The compounds may be used for treatment of various cancer cell types, including, but not limited to, brain, including medulloblastoma, head and neck, breast, colon, small cell lung, large cell lung, thyroid, testicle, bladder, prostate, liver, kidney, pancreatic, esophogeal, stomach, ovarian, cervical or lymphoma tumors. Treatment of breast, colon, lung, and prostate tumors is particularly contemplated.

The compositions may be administered to a patient afflicted with cancer and/or leukemia by any conventional route of administration, as discussed above. The method is useful to slow the growth of tumors, prevent tumor growth, induce partial regression of tumors, and induce complete regression of tumors, to the point of complete disappearance. The method is also useful in preventing the outgrowth of metastases derived from solid tumors.

The compositions of the invention may be administered as sole therapy or with other supportive or therapeutic treatments not designed to have anti-cancer effects in the subject. The method also includes administering the invention compositions in combination with one or more conventional anti-cancer drugs or biologic protein agents,

where the amount of drug(s) or agent(s) is, by itself, ineffective to induce the appropriate suppression of cancer growth, in an amount effective to have the desired anti-cancer effects in the subject. Such anti-cancer drugs include actinomycin D, camptothecin, carboplatin, cisplatin, cyclophosphamide, cytosine arabinoside, daunorubicin, doxorubicin, etoposide, fludarabine, 5-fluorouracil, hydroxyurea, gemcitabine, irinotecan, methotrexate, mitomycin C, mitoxantrone, paclitaxel, taxotere, teniposide, topotecan, vinblastine, vincristine, vindesine, and vinorelbine. Anti-cancer biologic protein agents include tumor necrosis factor (TNF), TNF-related apoptosis inducing ligand (TRAIL), other TNF-related or TRAIL-related ligands and factors, interferon, interleukin-2, other interleukins, other cytokines, chemokines, and factors, antibodies to tumor-related molecules or receptors (such as anti-HER2 antibody), and agents that react with or bind to these agents (such as members of the TNF super family of receptors, other receptors, receptor antagonists, and antibodies with specificity for these agents).

Antitumor activity *in vivo* of a particular composition can be evaluated by the use of established animal models, as described, for example, in Fidler *et al.*, U.S. Patent No. 6,620,843. Clinical doses and regimens are determined in accordance with methods known to clinicians, based on factors such as severity of disease and overall condition of the patient.

VI. Other Indications

The compounds of the present invention may also be used in the treatment of certain CNS diseases. Glutamate fulfills numerous physiological functions, including an important role in the pathophysiology of various neurological and psychiatric diseases. Glutamate excitotoxicity and neurotoxicity have been implicated in hypoxia, ischemia and trauma, as well as in chronic neurodegenerative or neurometabolic diseases, Alzheimer's dementia, Huntington's disease and Parkinson's disease. In view of the reported neuroprotective effects of triptolide, particularly protection from glutamate-induced cell death (Q. He *et al.*, 2003; X. Wang *et al.*, 2003), compounds of the invention are envisioned to antagonize the neurotoxic action of glutamates and thus may be a novel therapy for such diseases.

Recent evidence from MS patients in relapse suggests an altered glutamate homeostasis in the brain. Neurotoxic events occurring in MS patients can be responsible

for oligodendrocyte and neuronal cell death. Antagonizing glutamate receptor-mediated excitotoxicity by treatment with compounds of this invention may have therapeutic implications in MS patients. Other CNS diseases such as Guillain-Barre syndrome, Meniere's disease, polyneuritis, multiple neuritis, mononeuritis and radiculopathy may also be treated with the compounds of the present invention.

The compounds of the present invention may also be used in the treatment of certain lung diseases. Idiopathic pulmonary fibrosis (PF) is a progressive interstitial lung disease with no known etiology. PF is characterized by excessive deposition of intracellular matrix and collagen in the lung interstitium and gradual replacement of the alveoli by scar tissue as a result of inflammation and fibrosis. As the disease progresses, the increase in scar tissue interferes with the ability to transfer oxygen from the lungs to the bloodstream. A 14-succinimide ester of triptolide has been reported to block bleomycin-induced PF (G. Krishna *et al.*, 2001). Accordingly, the compounds of the present invention may be useful for treatment of PF. Treatment of other respiratory diseases, such as sarcoidosis, fibroid lung, and idiopathic interstitial pneumonia is also considered.

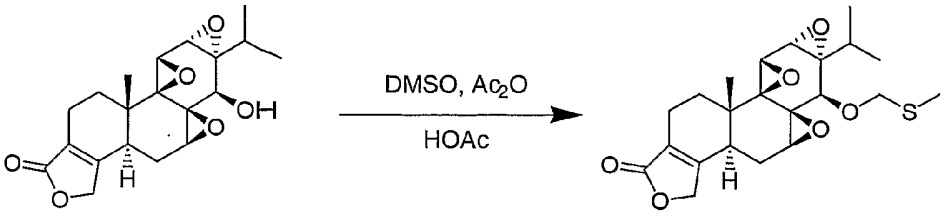
Other diseases involving the lung and envisioned to be treatable by compounds of this invention include Severe Acute Respiratory Syndrome (SARS) and acute respiratory distress syndrome (ARDS). In particular, with respect to SARS, the reduction of virus content (SARS-CoV) before the peak of the disease process and the usefulness of corticosteroid treatment, as noted below, suggest that the development of the most severe, life-threatening effects of SARS may result from the exaggerated response of the body to the infection (immune hyperactivity) rather than effects of the virus itself. (See also copending and co-owned US provisional application S.N. 60/483,335, which is incorporated herein by reference.) Corticosteroid treatment has been used in SARS patients to suppress the massive release of cytokines that may characterize the immune hyperactive phase, in the hope that it will stop the progression of pulmonary disease in the next phase. Corticosteroid treatment has produced good clinical results in reduction of some of the major symptoms of SARS. However, there are several treatment-related side effects, and there is a clear need for more selective immunosuppressive and/or antiinflammatory agents.

EXAMPLES

The following examples are intended to illustrate but not in any way limit the invention.

Example 1. Preparation of 19-Methyl Triptolide (PG795)

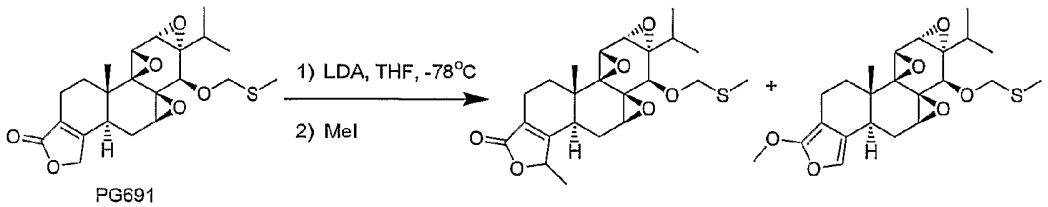
A. Protection of 14-hydroxyl group



PG691

To a solution of triptolide (designated PG490) (0.56 g, 1.6 mmol) in DMSO (8.5 mL, 0.12 mol) was added acetic acid (28 mL, .49 mol) and acetic anhydride (5.6 mL, 59 mol). The clear colorless solution was stirred at room temperature for five days. The reaction mixture was poured into 200 mL of water and neutralized with solid sodium bicarbonate, added in portions. The mixture was extracted with ethyl acetate (3 x 150 mL), and the extract was dried over anhydrous sodium sulfate. Concentration under reduced pressure gave the crude product as an oil. Silica gel column chromatography purification (3:2 hexanes/ethyl acetate) gave the 14-(methylthio)methoxy derivative (designated PG691) (0.45 g, 69%) as a white foam. ^{1}H NMR ($CDCl_3$) δ 0.83 (d, J = 6.8 Hz, 3H), 1.01 (d, J = 6.8 Hz, 3H), 1.10 (s, 3H), 1.20 (m, 1H), 1.61 (m, 1H), 1.92 (dd, J = 14.7, 13.4 Hz, 1H), 2.19 (s, 3H), 2.10-2.42 (m, 4H), 2.70 (m, 1H), 3.24 (d, J = 5.5 Hz, 1H), 3.51 (d, J = 3.1 Hz, 1H), 3.68 (s, 1H), 3.79 (d, J = 3.1 Hz, 1H), 4.68 (m, 2H), 4.95 (d, J = 11.8 Hz, 1H), 5.09 (d, J = 11.8 Hz, 1H)

B. Methylation



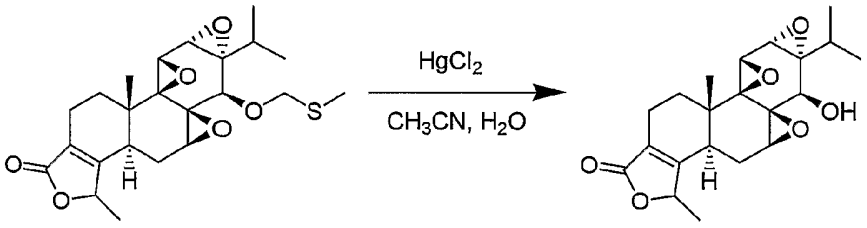
PG691

To a solution of PG691 (0.22g, 0.52 mmol) in anhydrous THF (10 mL) was added a solution of LDA in heptane/THF/ethyl benzene (0.30 mL of 2.0 M solution, 0.60 mmol) dropwise at -78°C. The resulting solution was stirred at this temperature for 15 min, followed by the dropwise addition of methyl iodide (50 μL, 0.80 mmol). The reaction

mixture was stirred at -78°C for 2 h, then allowed to come to room temperature overnight.

The reaction mixture was neutralized with 1N HCl, and the biphasic solution was extracted with EtOAc (10 mL x 3). The EtOAc solution was washed with 5% aqueous sodium thiosulfate (10 mL x 2) and dried over anhydrous sodium sulfate. Concentration under reduce pressure gave an oil. Column purification (silica gel, 3:2 hexanes/ethyl acetate) gave two products, methylthiomethyl protected 19-methyltriptolide (45.9 mg, 20%), ^{1}H NMR ($CDCl_3$) δ 0.84 (d, J = 6.9 Hz, 3H), 1.03 (d, J = 6.9 Hz, 3H), 1.10 (s, 3H), 1.16 (m, 1H), 1.44 (d, J = 6.6 Hz, 3H), 1.59 (m, 1H), 1.92 (t, J = 14.0 Hz, 1H), 2.19 (s, 3H), 2.10-2.42 (m, 4H), 2.62 (m, 1H), 3.25 (d, J = 5.5 Hz, 1H), 3.31 (d, J = 3.1 Hz, 1H), 3.69 (s, 1H), 3.79 (d, J = 3.2 Hz, 1H), 4.89 (m, 1H), 4.95 (d, J = 11.8 Hz, 1H), 5.09 (d, J = 11.8 Hz, 1H), and methylthiomethyl protected 18-methoxyfuranotriptolide (33.1 mg, 15%), ^{1}H NMR ($CDCl_3$) δ 0.84 (d, J = 6.9 Hz, 3H), 1.01 (s, 3H), 1.02 (d, J = 6.9 Hz, 3H), 1.30 (s, 3H), 1.37 (m, 2H), 1.69 (m, 2H), 1.95 (dd, J = 15.0, 12.6 Hz, 1H), 2.10 (m, 1H), 2.19 (s, 3H), 2.27-2.47 (m, 2H), 3.19 (d, J = 5.3 Hz, 1H), 3.54 (d, J = 3.3 Hz, 1H), 3.67 (s, 1H), 3.93 (d, J = 3.3 Hz, 1H), 4.94 (d, J = 11.9 Hz, 1H), 5.08 (d, J = 11.9 Hz, 1H), 6.44 (d, J = 2.0 Hz, 1H).

C. Deprotection



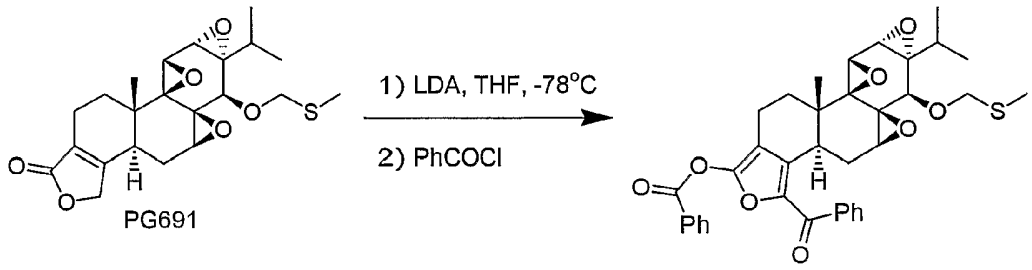
PG795

To a solution of methylthiomethyl protected 19-methyltriptolide, prepared as described above (45.9 mg, 0.106 mmol), in 1.5 mL acetonitrile/water (4:1) was added mercuric chloride (0.285 g, 1.05 mmol) in one portion. The resulting solution was stirred at room temperature overnight. The white solid which precipitated from the solution was removed by filtration through Celite® and rinsed with ethyl acetate. The EtOAc solution was washed twice with 5% aqueous NH_4OAc. The organic phase was dried (Na_2SO_4) and concentrated under reduced pressure to give the crude product. Purification by column chromatography (silica gel, 1:1 hexanes/ethyl acetate) gave the pure product (39.5 mg, 99%). ^{1}H NMR ($CDCl_3$) δ 0.88 (d, J = 6.8 Hz, 3H), 1.01 (d, J = 6.8 Hz, 3H),

1.11 (s, 3H), 1.16 (dt, J = 11.5, 2.0 Hz, 1H), 1.43 (d, J = 6.6 Hz, 3H), 1.54 (ddd, J = 12.4, 6.4, 1.3 Hz, 1H), 1.92 (dd, J = 14.9, 13.4 Hz, 1H), 2.10-2.36 (m, 4H), 2.62 (m, 1H), 2.74 (d, J = 10.8 Hz, 1H), 3.38 (d, J = 5.5 Hz, 1H), 3.42 (d, J = 10.8 Hz, 1H), 3.53 (dd, J = 3.1, 0.9 Hz, 1H), 3.90 (d, J = 3.1 Hz, 1H), 4.88 (m, 1H); IR (CH_2Cl_2) 1754, 1047 cm^{-1}.

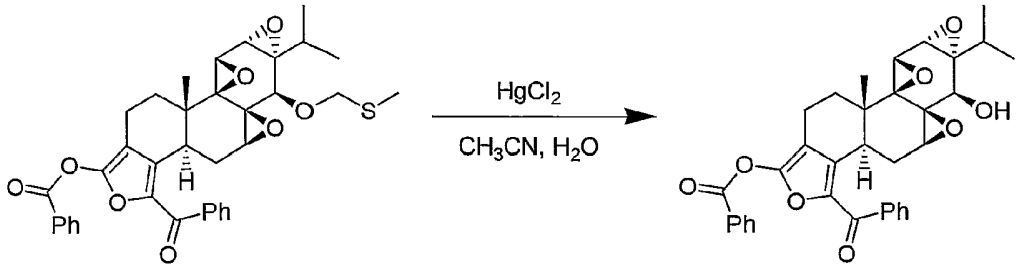
Example 2. Preparation of 18-deoxo-19-dehydro-18-benzoyloxy-19-benzoyl triptolide (PG796)

A. Acylation



To a solution of PG691, prepared as described above (73.1 mg, 0.174 mmol), in anhydrous THF (5 mL) was added a solution of LDA in heptane/THF/ethyl benzene (0.17 mL of 2.0 M solution, 0.34 mmol) dropwise at -78 °C. The resulting solution was stirred at this temperature for 15 min, followed by the dropwise addition of neat benzoyl chloride (100 µL, 0.86 mmol). The reaction was stirred at -78 °C for 2 h. The reaction was quenched with water and the mixture was extracted with ethyl acetate (25 mL x 3). The combined organic solution was dried over anhydrous over anhydrous sodium sulfate. Concentration under reduce pressure gave an oil. Column purification (silica gel, 3:2 hexanes/ethyl acetate) gave the 14-protected product (51.2 mg, 47%). ^{1}H NMR ($CDCl_3$) δ 0.78 (d, J = 6.8 Hz, 3H), 0.91 (d, J = 6.8 Hz, 3H), 1.13 (s, 3H), 1.17 (m, 1H), 1.58 (m, 1H), 1.86 (m, 1H), 2.13 (s, 3H), 2.17-2.39 (m, 3H), 2.45 (d, J = 6.0 Hz, 1H), 2.58-2.76 (m, 2H), 3.21 (s, 1H), 3.39 (d, J = 3.1 Hz, 1H), 3.70 (d, J = 3.1 Hz, 1H), 4.85 (d, J = 11.87 Hz, 1H), 4.95 (d, J = 11.8 Hz, 1H), 7.34-7.48 (m, 3H), 7.56-7.65 (m, 2H), 7.65-7.71 (m, 1H), 7.71-7.78 (m, 2H), 8.21-8.29 (m, 2H).

B. Deprotection



To a solution of the 14-methylthiomethyl protected product, prepared as described above (51.2 mg, 0.0814 mmol), in 1.5 mL acetonitrile/water (4:1) was added mercuric chloride (0.22 g, 0.81 mmol) in one portion. The resulting solution was stirred at room temperature overnight. The white solid which precipitated from the solution was removed by filtration through Celite® and rinsed with ethyl acetate. The EtOAc solution was washed twice with 5% aqueous NH_4OAc. The organic phase was dried (Na_2SO_4) and concentrated under reduced pressure to give the crude product. Purification by column chromatography provided the pure product (32.8 mg, 71%). ^1H NMR ($CDCl_3$) δ 0.82 (d, J = 6.9 Hz, 3H), 0.92 (d, J = 6.9 Hz, 3H), 1.15 (s, 3H), 1.17 (m, 1H), 1.54 (m, 1H), 1.88 (m, 1H), 2.18 (septet, J = 6.9 Hz), 2.30-2.40 (m, 2H), 2.53 (d, J = 10.4 Hz, 1H), 2.56 (d, J = 7.1 Hz, 1H), 2.61 (m, 1H), 2.72 (ddd, J = 15.0, 6.4, 4.2 Hz, 2H), 2.98 (d, J = 10.2 Hz, 1H), 3.40 (d, J = 3.0 Hz, 1H), 3.81 (d, J = 3.0 Hz, 1H), 7.35-7.47 (m, 3H), 7.54-7.63 (m, 2H), 7.63-7.71 (m, 1H), 7.71-7.78 (m, 2H), 8.21-8.28 (m, 2H); IR (CH_2Cl_2) 1768, 1751, 1236, 1123 cm^{-1}.

Example 3. Cytotoxicity (MTT) Assay

Test compounds were dissolved in DMSO at a concentration of 20 mM. Further dilutions were done in RPMI1640 medium (GIBCO, Rockville, MD) supplemented with 10% Fetal Calf Serum (HyClone Laboratories, Logan, UT).

Cytotoxicity of the compounds was determined in a standard MTT assay using Cell Proliferation Kit I (#1 465 007, Roche Diagnostics, Mannheim, Germany). Briefly, human T cell lymphoma (Jurkat) cells (4 x 10^5 per well) were cultured for 24h, in 96-well tissue culture plates, in the presence of serial three-fold dilutions of test compounds or medium containing the same concentration of DMSO as in the test samples at each dilution point. The cultures were then supplemented with 10 µl/well MTT reagent for 4h

and then with 0.1 ml/well solubilizing reagent for an additional 16h. Optical density at 570 nm (OD_{570}) was measured on a ThermoScan microplate reader (Molecular Devices, Menlo Park, CA).

The data is presented as OD_{570} values versus concentration of the compounds. The results for 19-methyl triptolide (PG795), compared with triptolide (PG490) and a medium control, are given in Fig. 1. The results for PG796, compared with triptolide 14-succinate (PG490-88) and a medium control, are given in Fig. 2. In this case, data is provided for both compounds incubated in human serum and in mouse serum, and for PG796 without incubation.

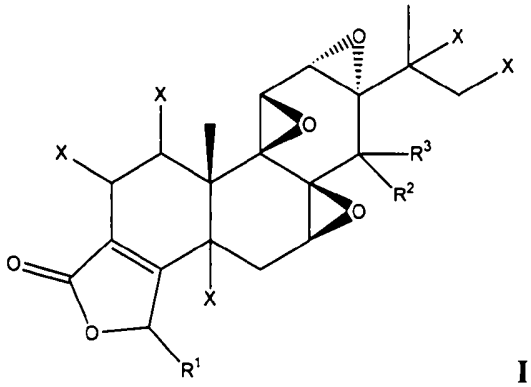
Example 4: IL-2 Production Assay

Test samples were diluted to 1 mM in complete tissue culture medium. Aliquots were placed in microculture plates that had been coated with anti-CD3 antibody (used to stimulate the production of IL-2 by Jurkat cells), and serial dilutions were prepared so that the final concentration would encompass the range of 0.001 to 10,000 nM in log increments. Cells from an exponentially expanding culture of Jurkat human T cell line (#TIB-152 obtained from American Type Culture Collection, Manassas, VA) were harvested, washed once by centrifugation, re-suspended in complete tissue culture medium, and diluted to a concentration of 2×10^6 cells/ml. A volume of 50 µl of Jurkat cells (1×10^5 cells) was added to wells containing 100 µl of the diluted compounds, 50 µl of PMA (10 ng/ml) was added to each well, and the plates were incubated at 37°C in a 5% CO_2 incubator. After 24 hours, the plates were centrifuged to pellet the cells, 150 µl of supernatant was removed from each well, and the samples were stored at -20 °C. The stored supernatants were analyzed for human IL-2 concentration using the Luminex 100 (Luminex Corporation, Austin, TX), Luminex microspheres coupled with anti-IL-2 capture antibody, and fluorochrome-coupled anti-IL-2 detection antibody. The data were expressed as pg/ml of IL-2.

The data were plotted as the concentration of compound versus IL-2 concentration. The results for 19-methyl triptolide (PG795), compared with triptolide (PG490) and a medium control, are given in Fig. 3. The results for PG796, compared with triptolide 14-succinate (PG490-88) and a medium control, are given in Fig. 4. In this case, data is provided for both compounds incubated in human serum and in mouse serum, and for PG796 without incubation.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A compound having the structure **I**:



I

where

R^1 is alkyl, alkenyl, alkynyl, arylalkyl, aryl, arylacyl, or $C(OH)R^4R^5$,

wherein arylacyl is -C(O)R and R is aryl;

wherein R^4 and R^5 are independently hydrogen, alkyl, cycloalkyl, alkenyl, or cycloalkenyl, any of which, excepting hydrogen, may be substituted with alkoxy, hydroxy, acyloxy, or aryl, wherein each said alkyl, alkenyl, alkynyl, alkoxy, and acyloxy includes at most four carbon atoms, each said cycloalkyl and cycloalkenyl includes at most six carbon atoms, and each said aryl is monocyclic and non-heterocyclic;

CR^2R^3 is CHOH or C=O; and

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

2. The compound of claim 1, wherein CR^2R^3 is CHOH.

3. The compound of claim 2, wherein CR^2R^3 is CHOH (β-hydroxy).

4. The compound according to any one of claims 1-3, wherein each X is hydrogen.

5. The compound according to any one of claims 1-4, wherein R^1 is alkyl, alkenyl or $C(OH)R^4R^5$.

6. The compound of claim 5, wherein R^4 and R^5 are independently hydrogen, alkyl or alkenyl.

7. The compound according to any one of claims 1-4, wherein R^1 is alkyl or hydroxyalkyl.

8. The compound of claim 7, wherein R^1 is C_1-C_3 alkyl or hydroxyalkyl.

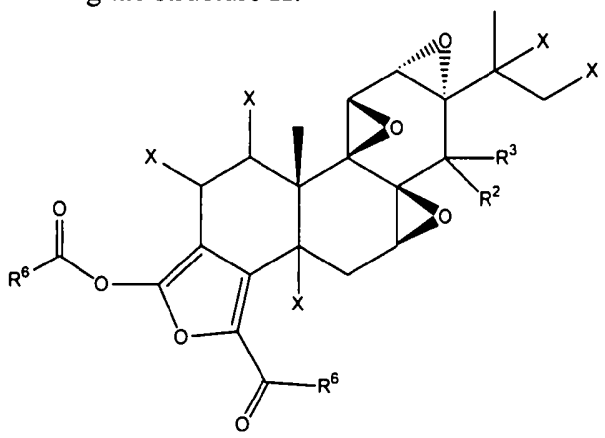
9. The compound of claim 8, wherein R^1 is methyl.

10. The compound according to any one of claims 1-4, wherein R^1 is arylacyl.

11. The compound of claim 10, wherein R^1 is benzoyl ($C(O)C_6H_5$).

12. The compound of claim 4, wherein R^1 is benzoyl.

13. A compound having the structure **II**:



II

where

each R^6 is independently selected from alkyl, alkenyl, alkynyl, or aryl;

wherein each said alkyl, alkenyl, and alkynyl includes at most four carbon atoms, and each said aryl is monocyclic and non-heterocyclic;

CR^2R^3 is CHOH or C=O;

at most one of the groups X is hydroxyl, and the remaining groups X are hydrogen.

14. The compound of claim 13, wherein CR^2R^3 is CHOH.

15. The compound of claim 14, wherein CR^2R^3 is CHOH (β-hydroxy).

16. The compound according to any one of claims 13-15, wherein each X is hydrogen.

17. The compound according to any one of claims 13-16, wherein each R^6 is aryl.

18. The compound of claim 17, wherein each R^6 is phenyl.

19. A method of effecting immunosuppression, comprising administering to a subject in need of such treatment, in a pharmaceutically acceptable vehicle, an effective amount of a compound according to any one of claims 1-18.

20. A method of inducing apoptosis in a cell, comprising contacting said cell with an effective amount of a compound according to any one of claims 1-18.

21. Use of a compound according to any one of claims 1-18, in a pharmaceutically acceptable vehicle, for effecting immunosuppression in a subject, by administering an effective amount of said compound to said subject.

22. Use of a compound according to any one of claims 1-18 for inducing apoptosis in a cell, by contacting said cell with an effective amount of said compound.

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23. A compound according to claim 1 or claim 14, substantially as hereinbefore described.

24. A method according to claim 19 or claim 20, substantially as hereinbefore described.

25. A use according to claim 21 or claim 22, substantially as hereinbefore described.

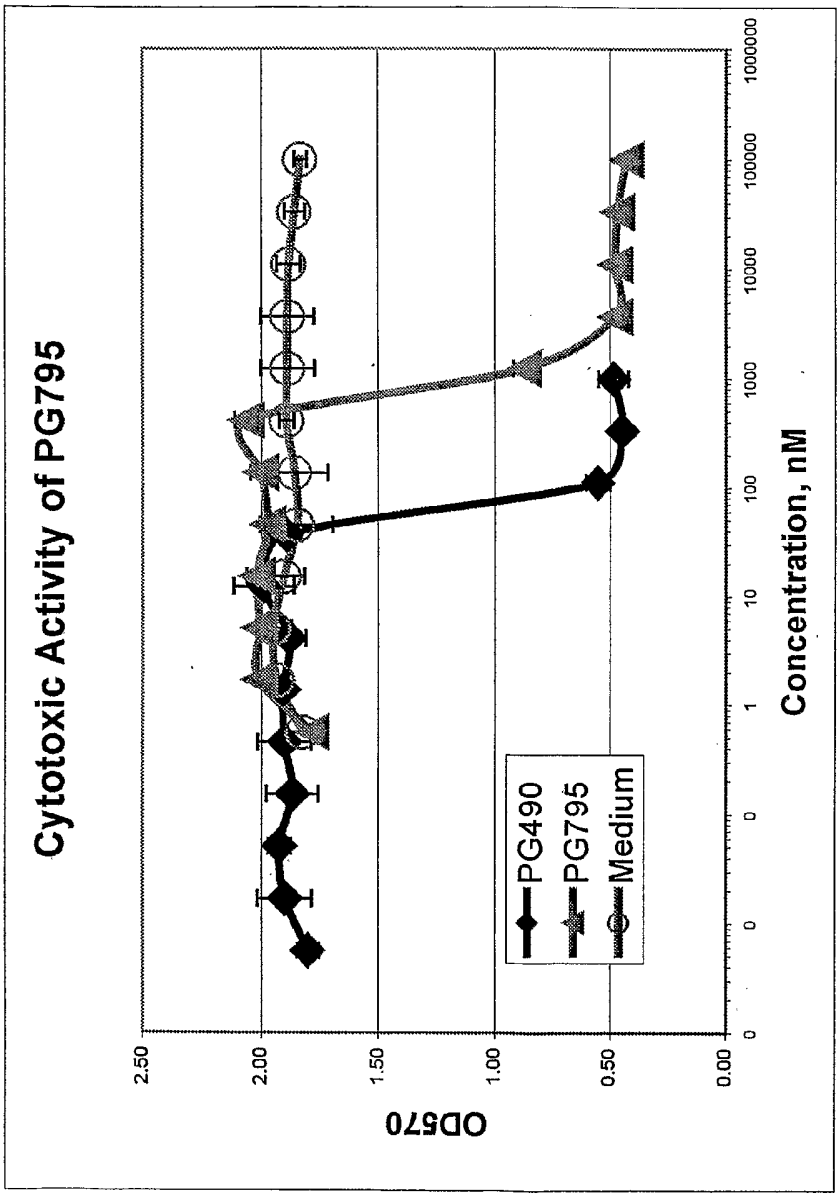
Cytotoxic Activity of PG795
OD570
2.50
2.00
1.50
1.00
0.50
0.00
0
0
0
1
10
100
1000
10000
100000
1000000
Concentration, nM
PG490
PG795
Medium

Fig. 1

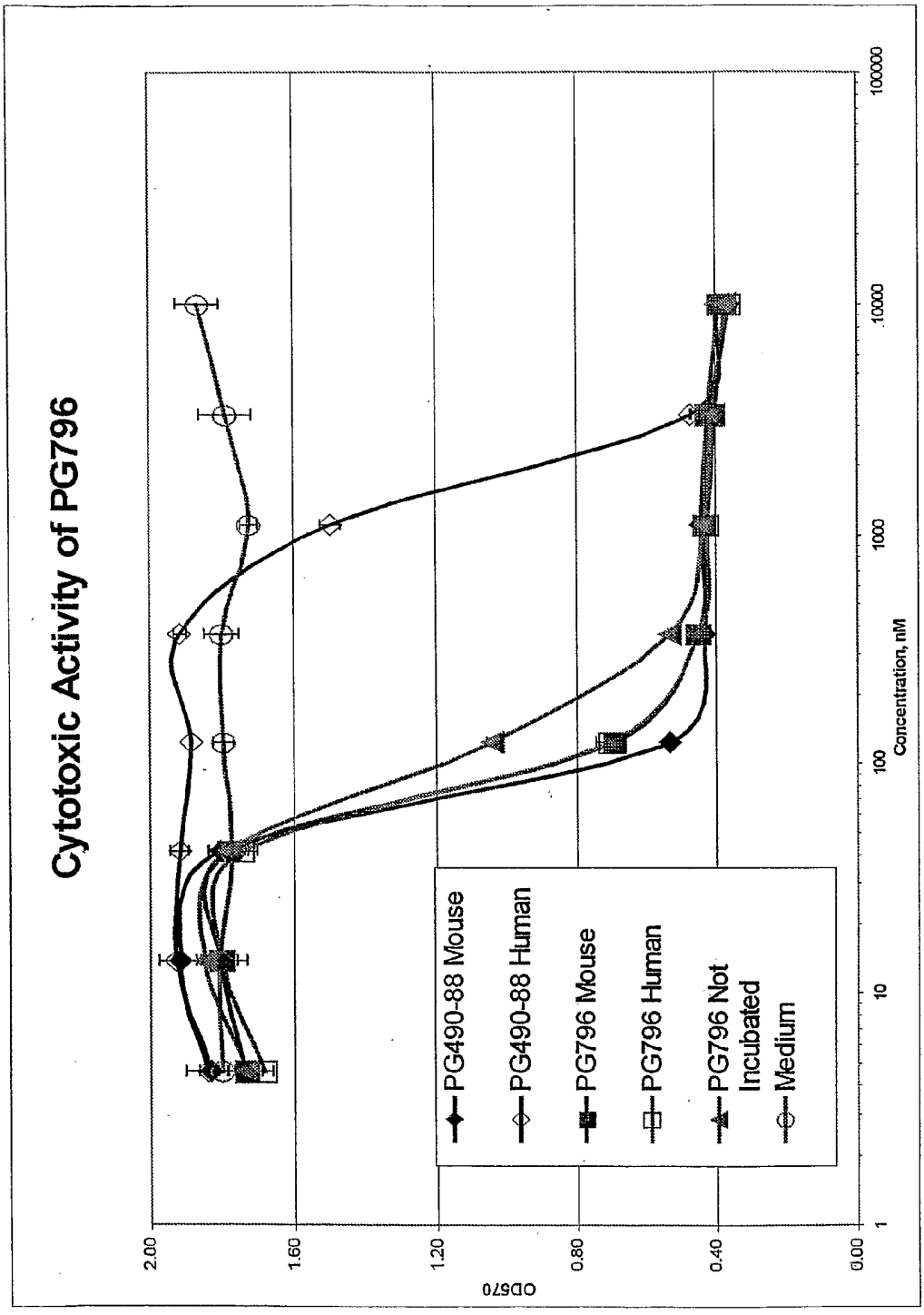
Cytotoxic Activity of PG796
OD570
2.00
1.60
1.20
0.80
0.40
0.00
1
10
100
1000
10000
100000
Concentration, nM
PG490-88 Mouse
PG490-88 Human
PG796 Mouse
PG796 Human
PG796 Not Incubated
Medium

Fig. 2

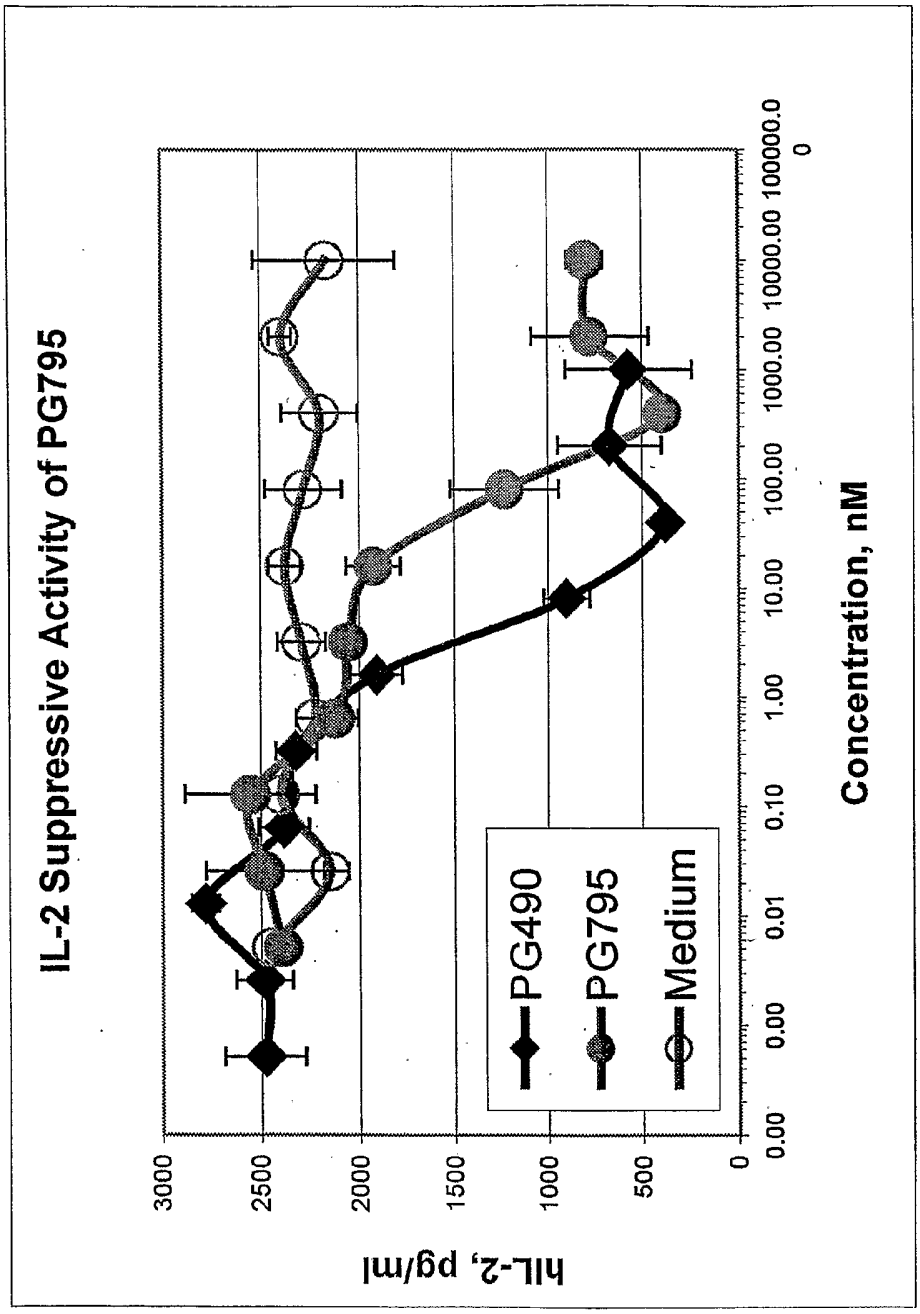
IL-2 Suppressive Activity of PG795
hIL-2, pg/ml
3000
2500
2000
1500
1000
500
0
0.00
0.00
0.01
0.10
1.00
10.00
100.00
1000.00
10000.00
100000.0
0
Concentration, nM
PG490
PG795
Medium

Fig. 3

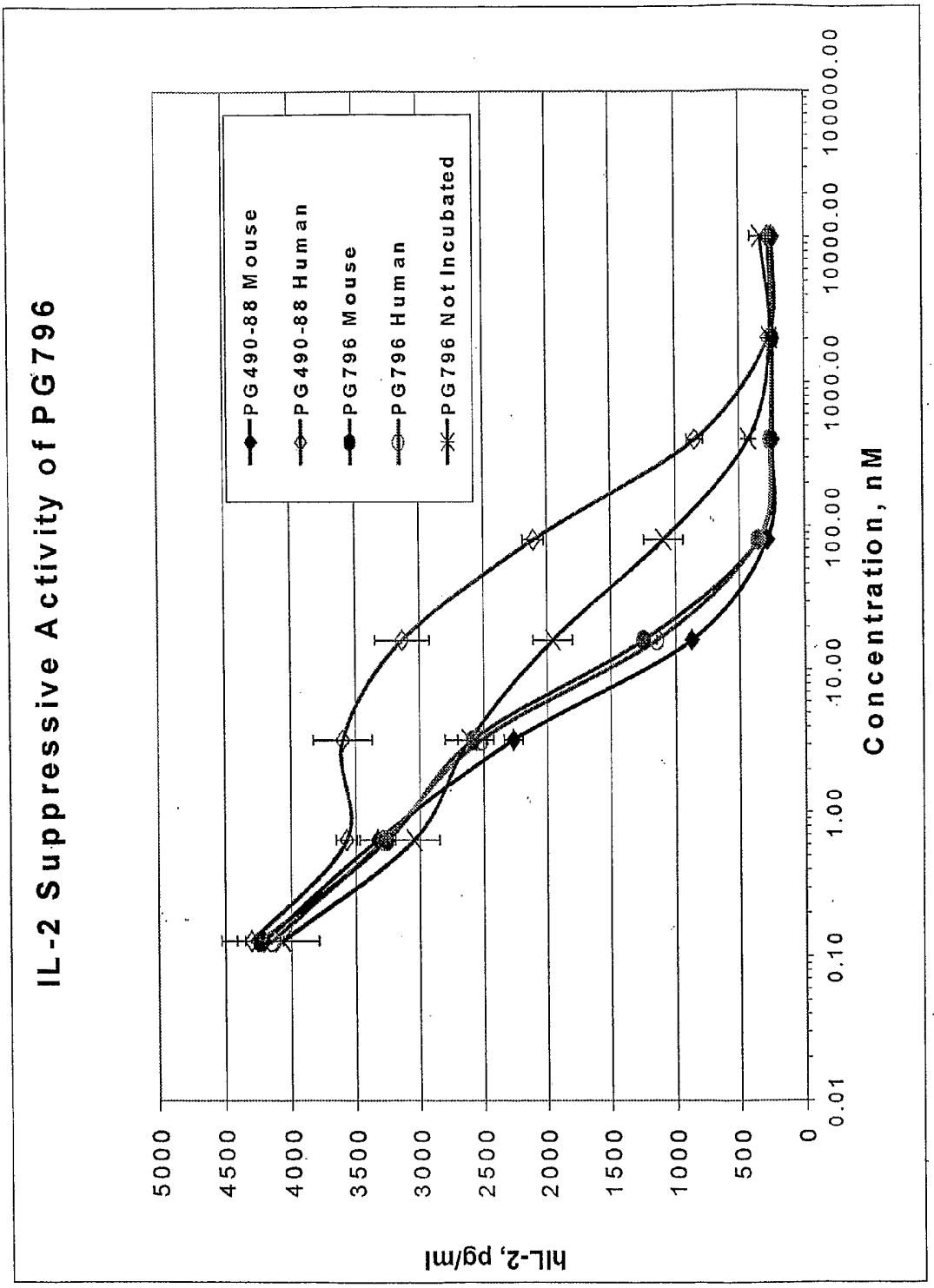
IL-2 Suppressive Activity of PG796
PG490-88 Mouse
PG490-88 Human
PG796 Mouse
PG796 Human
PG796 Not Incubated
hIL-2, pg/ml
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0.01
0.10
1.00
10.00
100.00
1000.00
10000.00
100000.00
Concentration, nM

Fig. 4