

## CRYSTALLINE TRIPEPTIDE EPOXY KETONE PROTEASE INHIBITORS

### Related Applications

This application claims the benefit of priority to U.S. Provisional Application Serial No. 61/162,196, filed March 20, 2009, and U.S. Provisional Application Serial No. 61/180,561, filed May 22, 2009. The specifications of the foregoing applications are hereby incorporated by reference in their entirety.

### Background of the Invention

In eukaryotes, protein degradation is predominately mediated through the ubiquitin pathway in which proteins targeted for destruction are ligated to the 76 amino acid polypeptide ubiquitin. Once targeted, ubiquitinated proteins then serve as substrates for the 26S proteasome, a multicatalytic protease, which cleaves proteins into short peptides through the action of its three major proteolytic activities. While having a general function in intracellular protein turnover, proteasome-mediated degradation also plays a key role in many processes such as major histocompatibility complex (MHC) class I antigen presentation, apoptosis, cell growth regulation, NF- $\kappa$ B activation, antigen processing, and transduction of pro-inflammatory signals.

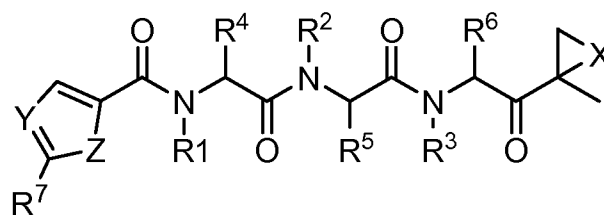
The 20S proteasome is a 700 kDa cylindrical-shaped multicatalytic protease complex comprised of 28 subunits organized into four rings. In yeast and other eukaryotes, 7 different  $\alpha$  subunits form the outer rings and 7 different  $\beta$  subunits comprise the inner rings. The  $\alpha$  subunits serve as binding sites for the 19S (PA700) and 11S (PA28) regulatory complexes, as well as a physical barrier for the inner proteolytic chamber formed by the two  $\beta$  subunit rings. Thus, in vivo, the proteasome is believed to exist as a 26S particle ("the 26S proteasome"). In vivo experiments have shown that inhibition of the 20S form of the proteasome can be readily correlated to inhibition of 26S proteasome. Cleavage of amino-terminal prosequences of  $\beta$  subunits during particle formation expose amino-terminal threonine residues, which serve as the catalytic nucleophiles. The subunits responsible for catalytic activity in proteasomes thus possess an amino terminal nucleophilic residue, and these subunits belong to the family of N-terminal nucleophile (Ntn) hydrolases (where the nucleophilic N-terminal residue is, for example, Cys, Ser, Thr, and other nucleophilic moieties). This family includes, for example, penicillin G acylase (PGA), penicillin V acylase (PVA), glutamine PRPP

amidotransferase (GAT), and bacterial glycosylasparaginase. In addition to the ubiquitously expressed  $\beta$  subunits, higher vertebrates also possess three interferon- $\gamma$ -inducible  $\beta$  subunits (LMP7, LMP2 and MECL1), which replace their normal counterparts,  $\beta_5$ ,  $\beta_1$  and  $\beta_7$  respectively, thus altering the catalytic activities of the proteasome. Through the use of different peptide substrates, three major proteolytic activities have been defined for the eukaryote 20S proteasome: chymotrypsin-like activity (CT-L), which cleaves after large hydrophobic residues; trypsin-like activity (T-L), which cleaves after basic residues; and peptidylglutamyl peptide hydrolyzing activity (PGPH), which cleaves after acidic residues. Two additional less characterized activities have also been ascribed to the proteasome: BrAAP activity, which cleaves after branched-chain amino acids; and SNAAP activity, which cleaves after small neutral amino acids. The major proteasome proteolytic activities appear to be contributed by different catalytic sites, since inhibitors, point mutations in  $\beta$  subunits and the exchange of  $\gamma$  interferon-inducing  $\beta$  subunits alter these activities to various degrees.

Improved compositions and methods for preparing and formulating proteasome inhibitor(s) are needed.

### **Summary of the Invention**

One aspect of the invention relates to crystalline compounds having a structure of Formula (I) or a pharmaceutically acceptable salt thereof,



I

wherein

X is O, NH, or N-alkyl, preferably O;

Y is N, , S, or C(R<sup>8</sup>)<sub>2</sub>, preferably NH;

Z is NH, N-alkyl, O, S or C(R<sup>8</sup>)<sub>2</sub>, preferably S;

R<sup>1</sup>, R<sup>2</sup>, and R<sup>3</sup> are hydrogen;

each of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup> and R<sup>8</sup> is independently selected from hydrogen, C<sub>1-6</sub>alkyl, C<sub>1-6</sub>hydroxyalkyl, C<sub>1-6</sub>alkoxyalkyl, aryl, and C<sub>1-6</sub>aralkyl, each of which is optionally substituted with a group selected from alkyl, amide, amine, carboxylic acid or a pharmaceutically acceptable salt thereof, carboxyl ester, thiol, and thioether, preferably R<sup>4</sup>, R<sup>5</sup> and R<sup>6</sup>, are independently selected from C<sub>1-6</sub>thioether, C<sub>1-6</sub>hydroxyalkyl, and C<sub>1-6</sub>aralkyl and R<sup>7</sup> is C<sub>1-6</sub>alkyl, more preferably, R<sup>4</sup> and R<sup>5</sup> are C<sub>1-6</sub>thioether, and R<sup>7</sup> is C<sub>1-6</sub>alkyl.

### **Brief Description of the Figures**

Figure 1 shows a DSC (differential scanning calorimetry) thermogram of crystalline compound 1.

Figure 2 shows an XRPD (X-ray powder diffraction) pattern of crystalline compound 1.

Figure 3 shows a TG thermogram of crystalline compound 1.

Figure 4 shows modulated thermograms of amorphous compound 1, reversing heat flow (bottom) and non-reversing heat flow (top).

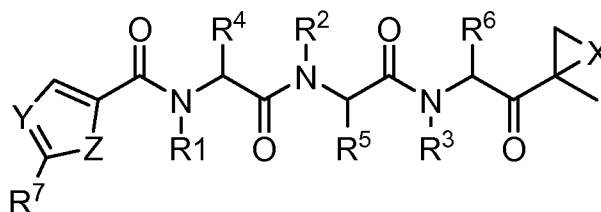
Figure 5 shows a comparison of DSC thermograms of crystalline compound 1 prepared according to Example 2 (middle), Example 3 (top), and Example 4 (bottom).

Figure 6 shows an XRPD pattern of amorphous compound 1 prepared according to Example 1 (bottom), as compared to XRPD patterns of crystalline compound 1 prepared according to Example 2 (top), Example 3 (2<sup>nd</sup> from bottom), and Example 4 (2<sup>nd</sup> from top).

Figure 7 shows a TG thermogram of amorphous compound 1.

### **Detailed Description of the Invention**

In certain embodiments, the invention relates to crystalline compounds having a structure of Formula (I) or a pharmaceutically acceptable salt thereof,



I

wherein

X is O, NH, or N-alkyl, preferably O;

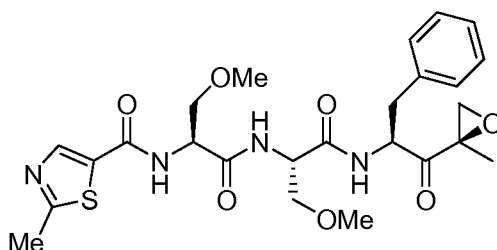
5 Y is NH, N-alkyl, O, S, or C(R<sup>8</sup>)<sub>2</sub>, preferably NH;

Z is NH, N-alkyl, O, S or C(R<sup>8</sup>)<sub>2</sub>, preferably S;

R<sup>1</sup>, R<sup>2</sup>, and R<sup>3</sup> are hydrogen;

each of R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup> and R<sup>8</sup> is independently selected from hydrogen, C<sub>1-6</sub>alkyl, C<sub>1-6</sub>hydroxyalkyl, C<sub>1-6</sub>alkoxyalkyl, aryl, and C<sub>1-6</sub>aralkyl, each of which is optionally substituted with a group selected from alkyl, amide, amine, carboxylic acid or a pharmaceutically acceptable salt thereof, carboxyl ester, thiol, and thioether, preferably R<sup>4</sup>, R<sup>5</sup> and R<sup>6</sup>, are independently selected from C<sub>1-6</sub>thioether, C<sub>1-6</sub>hydroxyalkyl, and C<sub>1-6</sub>aralkyl and R<sup>7</sup> is C<sub>1-6</sub>alkyl, more preferably, R<sup>4</sup> and R<sup>5</sup> are C<sub>1-6</sub>thioether, and each R<sup>7</sup> is C<sub>1-6</sub>alkyl

15 In certain embodiments, the invention relates to a crystalline compound of Formula (II)



(II)

In certain embodiments, the invention relates to a method for the preparation of a crystalline compound of Formula (I) or (II), comprising one or more of: (i) preparing the amorphous compound, e.g., according to U.S. Patent Application No. 11/595,804; (ii) dissolving the amorphous compound in an organic solvent; (iii) bringing the solution to

supersaturation; (iv) isolating the crystals, e.g., by filtering the crystals, by decanting fluid from the crystals, or by any other suitable separation technique; and (v) washing the crystals. In certain embodiments, preparation further comprises inducing crystallization. In certain embodiments, preparation further comprises drying, preferably under reduced pressure, such as under vacuum pressure.

In certain embodiments, the amorphous compound may be dissolved in a solvent selected from acetonitrile, ethyl acetate, heptanes, hexanes, isopropyl acetate, methanol, methylethyl ketone, tetrahydrofuran, toluene, and water, or any combination thereof. In certain embodiments, the amorphous compound of Formula (II) may be dissolved in an organic solvent selected from acetonitrile, heptanes, hexanes, methanol, tetrahydrofuran, and toluene, or any combination thereof. In certain preferred embodiments, the organic solvent is toluene, tetrahydrofuran, or acetonitrile, preferably acetonitrile or toluene.

In certain embodiments, bringing the solution to supersaturation comprises the slow addition of an anti-solvent, such as water, heptanes, hexanes or another polar or non-polar liquid miscible with the organic solvent, allowing the solution to cool (with or without seeding the solution), reducing the volume of the solution, or any combination thereof. In certain embodiments, bringing the solution to supersaturation comprises adding an anti-solvent, cooling the solution to ambient temperature or lower, and reducing the volume of the solution, e.g., by evaporating solvent from the solution. In certain embodiments, allowing the solution to cool may be passive (e.g., allowing the solution to stand at ambient temperature) or active (e.g., cooling the solution in an ice bath or freezer).

In certain embodiments, the method further comprises inducing precipitation or crystallization. In certain embodiments, inducing precipitation or crystallization comprises secondary nucleation, wherein nucleation occurs in the presence of seed crystals or interactions with the environment (crystallizer walls, stirring impellers, sonication, etc.).

In certain embodiments, washing the crystals comprises washing with a liquid selected from anti-solvent, acetonitrile, heptanes, hexanes, methanol, tetrahydrofuran, toluene, water, or a combination thereof. In certain embodiments, the crystals are washed with a combination of anti-solvent and the organic solvent. In certain embodiments, the

anti-solvent is water, while in other embodiments it is an alkane solvent, such as hexane or pentane, or an aromatic hydrocarbon solvent, such as benzene, toluene, or xylene.

In certain embodiments, washing the crystals comprises washing the crystalline compound of Formula (II) with a mix of tetrahydrofuran and an alkane solvent, such as hexanes or heptanes, or with a mix of acetonitrile and water. In certain embodiments, washing the crystals comprises washing the crystalline compound of Formula (II) with toluene. In preferred such embodiments, the toluene is cooled prior to washing.

In certain embodiments, a crystalline compound of Formula (II) is substantially pure. In certain embodiments, the melting point of the crystalline compound of Formula (II) is in the range of about 135 to about 160 °C, about 140 to about 155 °C, about 145 to about 150 °C, or even about 147 to about 149 °C, e.g., about 149 °C.

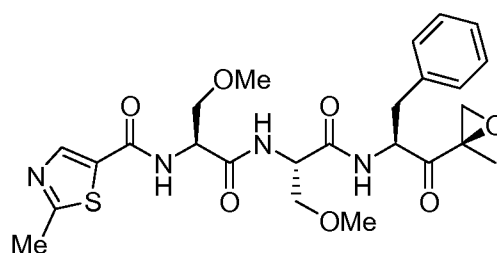
In certain embodiments, the DSC of a crystalline compound of Formula (II) has a sharp endothermic maximum at about 147 °C, e.g., resulting from melting and decomposition of the crystalline form as shown in Figure 1.

In certain embodiments, the X-ray powder pattern of a crystalline compound of Formula (II) is ( $\theta$ -2 $\theta^\circ$ ): 8.94; 9.39; 9.76; 10.60; 11.09; 12.74; 15.27; 17.74; 18.96; 20.58; 20.88; 21.58; 21.78; 22.25; 22.80; 24.25; 24.66; 26.04; 26.44; 28.32; 28.96; 29.65; 30.22; 30.46; 30.78; 32.17; 33.65; 34.49; 35.08; 35.33; 37.85; 38.48 as shown in Figure 2.

In certain embodiments, the TG thermogram of a crystalline compound of Formula (II) exhibits from 0.0 to 0.3% weight loss in the temperature range of 25 to 125 °C as shown in Figure 3.

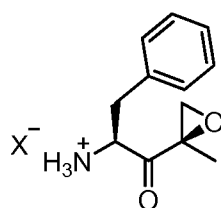
In certain embodiments, a crystalline compound of Formula (II) is not solvated (e.g., the crystal lattice does not comprise molecules of a solvent). In certain alternative embodiments, a crystalline compound of Formula (II) is solvated.

In certain embodiments, the invention relates to a method for the preparation of a crystalline compound of Formula (II),



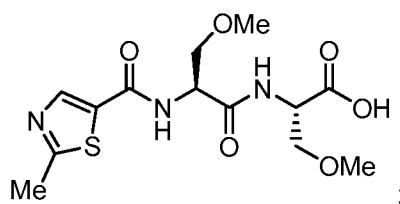
(II)

comprising (i) reacting a compound of Formula (III)



(III)

wherein X is any suitable counterion, with a compound of Formula (IV) in an organic solvent



(IV)

(ii) preparing a solution of a compound of Formula (II) in the organic solvent; (iii) bringing the solution to supersaturation to permit formation of crystals; and (iv) isolating the crystals to provide a crystalline compound of Formula (II), e.g., by filtering the crystals, by decanting, or by any other suitable separation technique.

In certain embodiments a compound of Formula (II) is not purified by chromatography prior to preparation of the solution in the organic solvent.

In certain embodiments, preparation further comprises inducing crystallization. In certain embodiments, preparation further comprises washing the crystals, e.g., with a solvent or non-solvent fluid. In certain embodiments, preparation further comprises drying, preferably under reduced pressure, such as under vacuum pressure.

In certain embodiments, X is a counterion selected from hydrobromide, hydrochloride, sulfate, phosphate, nitrate, acetate, trifluoroacetate, citrate, methanesulfonate, valerate, oleate, palmitate, stearate, laurate, benzoate, lactate, succinate, tosylate, malonate, maleate, fumarate, succinate, tartrate, mesylate, 2-hydroxyethanesulfonate, and the like. (See, for example, Berge et al. (1977) "Pharmaceutical Salts", J. Pharm. Sci. 66: 1-19.) In certain embodiments, X is selected from trifluoroacetate, methanesulfonate, toluenesulfonate, acetate, chloride, and bromide, preferably trifluoroacetate.

In certain embodiments, the organic solvent is selected from acetonitrile, ethyl acetate, heptanes, hexanes, isopropyl acetate, methanol, methylethyl ketone, tetrahydrofuran, toluene, and water, or any combination thereof. In certain embodiments, the amorphous compound of Formula (II) may be dissolved in an organic solvent selected from acetonitrile, heptanes, hexanes, methanol, tetrahydrofuran, and toluene, or any combination thereof. In certain preferred embodiments, the organic solvent is toluene, tetrahydrofuran, or acetonitrile, preferably acetonitrile or toluene.

In certain embodiments, preparation further comprises washing the crystals of Formula (II). In certain embodiments, washing the crystals comprises washing with a liquid selected from anti-solvent, acetonitrile, heptanes, hexanes, methanol, tetrahydrofuran, toluene, water, or a combination thereof. In certain embodiments, the crystals are washed with a combination of anti-solvent and the organic solvent. In certain embodiments, the anti-solvent is water, while in other embodiments it is an alkane solvent, such as hexane or pentane, or an aromatic hydrocarbon solvent, such as benzene, toluene, or xylene.

In certain embodiments, preparation further comprises drying the crystals of both of Formula (II), preferably under reduced pressure, such as under vacuum pressure.

In certain embodiments, the invention relates to a pharmaceutical composition comprising a crystalline compound of Formula (II) and a pharmaceutically acceptable carrier. In certain embodiments, the pharmaceutical composition is selected from tablets, capsules, and injections.

Uses of Crystalline Tripeptide Epoxy Ketones

Orderly protein degradation is crucial to the maintenance of normal cell functions, and the proteasome is integral to the protein degradation process. The proteasome controls the levels of proteins that are important for cell-cycle progression and apoptosis in normal and malignant cells; for example, cyclins, caspases, BCL2 and nF-kB (Kumatori et al., Proc. Natl. Acad. Sci. USA (1990) 87:7071-7075; Almond et al., Leukemia (2002) 16: 433-443). Thus, it is not surprising that inhibiting proteasome activity can translate into therapies to treat various disease states, such as malignant, non-malignant and autoimmune diseases, depending on the cells involved.

Both *in vitro* and *in vivo* models have shown that malignant cells, in general, are susceptible to proteasome inhibition. In fact, proteasome inhibition has already been validated as a therapeutic strategy for the treatment of multiple myeloma. This could be due, in part, to the highly proliferative malignant cell's dependency on the proteasome system to rapidly remove proteins (Rolfe et al., J. Mol. Med. (1997) 75:5-17; Adams, Nature (2004) 4: 349-360). Therefore, certain embodiments of the invention relate to a method of treating a cancer, comprising administering to a subject in need of such treatment an effective amount of a proteasome inhibitor compound disclosed herein. As used herein, the term "cancer" includes, but is not limited to, blood borne and solid tumors. Cancer refers to disease of blood, bone, organs, skin tissue and the vascular system, including, but not limited to, cancers of the bladder, blood, bone, brain, breast, cervix, chest, colon, endometrium, esophagus, eye, head, kidney, liver, lung, lymph nodes, mouth, neck, ovaries, pancreas, prostate, rectum, renal, skin, stomach, testis, throat, and uterus. Specific cancers include, but are not limited to, leukemia (acute lymphocytic leukemia (ALL), acute myelogenous leukemia (AML), chronic lymphocytic leukemia (CLL), chronic myelogenous leukemia (CML), hairy cell leukemia), mature B cell neoplasms (small lymphocytic lymphoma, B cell prolymphocytic leukemia, lymphoplasmacytic lymphoma (such as Waldenström's macroglobulinemia), splenic marginal zone lymphoma, plasma cell myeloma, plasmacytoma, monoclonal immunoglobulin deposition diseases, heavy chain diseases, extranodal marginal zone B cell lymphoma (MALT lymphoma), nodal marginal zone B cell lymphoma (NMZL), follicular lymphoma, mantle cell lymphoma, diffuse B cell lymphoma, mediastinal (thymic) large B cell lymphoma, intravascular large B cell lymphoma, primary effusion

lymphoma and Burkitt lymphoma/leukemia), mature T cell and natural killer (NK) cell neoplasms (T cell prolymphocytic leukemia, T cell large granular lymphocytic leukemia, aggressive NK cell leukemia, adult T cell leukemia/lymphoma, extranodal NK/T cell lymphoma, enteropathy-type T cell lymphoma, hepatosplenic T cell lymphoma, blastic NK cell lymphoma, mycosis fungoides (Sezary syndrome), primary cutaneous anaplastic large cell lymphoma, lymphomatoid papulosis, angioimmunoblastic T cell lymphoma, unspecified peripheral T cell lymphoma and anaplastic large cell lymphoma), Hodgkin's lymphoma (nodular sclerosis, mixed cellularity, lymphocyte-rich, lymphocyte depleted or not depleted, nodular lymphocyte-predominant), myeloma (multiple myeloma, indolent myeloma, smoldering myeloma), chronic myeloproliferative disease, myelodysplastic/myeloproliferative disease, myelodysplastic syndromes, immunodeficiency-associated lymphoproliferative disorders, histiocytic and dendritic cell neoplasms, mastocytosis, chondrosarcoma, Ewing sarcoma, fibrosarcoma, malignant giant cell tumor, myeloma bone disease, osteosarcoma, breast cancer (hormone dependent, hormone independent), gynecological cancers (cervical, endometrial, fallopian tube, gestational trophoblastic disease, ovarian, peritoneal, uterine, vaginal and vulvar), basal cell carcinoma (BCC), squamous cell carcinoma (SCC), malignant melanoma, dermatofibrosarcoma protuberans, Merkel cell carcinoma, Kaposi's sarcoma, astrocytoma, pilocytic astrocytoma, dysembryoplastic neuroepithelial tumor, oligodendrogliomas, ependymoma, glioblastoma multiforme, mixed gliomas, oligoastrocytomas, medulloblastoma, retinoblastoma, neuroblastoma, germinoma, teratoma, malignant mesothelioma (peritoneal mesothelioma, pericardial mesothelioma, pleural mesothelioma), gastro-entero-pancreatic or gastroenteropancreatic neuroendocrine tumor (GEP-NET), carcinoid, pancreatic endocrine tumor (PET), colorectal adenocarcinoma, colorectal carcinoma, aggressive neuroendocrine tumor, leiomyosarcoma, mucinous adenocarcinoma, Signet Ring cell adenocarcinoma, hepatocellular carcinoma, cholangiocarcinoma, hepatoblastoma, hemangioma, hepatic adenoma, focal nodular hyperplasia (nodular regenerative hyperplasia, hamartoma), non-small cell lung carcinoma (NSCLC) (squamous cell lung carcinoma, adenocarcinoma, large cell lung carcinoma), small cell lung carcinoma, thyroid carcinoma, prostate cancer (hormone refractory, androgen independent, androgen dependent, hormone-insensitive), renal cell carcinoma, and soft tissue sarcomas (fibrosarcoma, malignant fibrous histiocytoma, dermatofibrosarcoma, liposarcoma, rhabdomyosarcoma leiomyosarcoma,

hemangiosarcoma, synovial sarcoma, malignant peripheral nerve sheath tumor/neurofibrosarcoma, extraskeletal osteosarcoma).

Many tumors of the haematopoietic and lymphoid tissues are characterized by an increase in cell proliferation, or a particular type of cell. The chronic myeloproliferative diseases (CMPDs) are clonal haematopoietic stem cell disorders characterized by proliferation in the bone marrow of one or more of the myeloid lineages, resulting in increased numbers of granulocytes, red blood cells and/or platelets in the peripheral blood. As such, the use of proteasome inhibitors for the treatment of such diseases is attractive and being examined (Cilloni et al., *Haematologica* (2007) 92: 1124-1229).

CMPD can include chronic myelogenous leukaemia, chronic neutrophilic leukaemia, chronic eosinophilic leukaemia, polycythaemia vera, chronic idiopathic myelofibrosis, essential thrombocythaemia and unclassifiable chronic myeloproliferative disease. An aspect of the invention is the method of treating CMPD comprising administering to a subject in need of such treatment an effective amount of a proteasome inhibitor compound disclosed herein.

Myelodysplastic/myeloproliferative diseases, such as chronic myelomonocytic leukaemia, atypical chronic myeloid leukemia, juvenile myelomonocytic leukaemia and unclassifiable myelodysplastic/myeloproliferative disease, are characterized by hypercellularity of the bone marrow due to proliferation in one or more of the myeloid lineages. Inhibiting the proteasome with a compound or composition as described herein can serve to treat these myelodysplastic/myeloproliferative diseases by providing a subject in need of such treatment an effective amount of the compound or composition.

Myelodysplastic syndromes (MDS) refer to a group of hematopoietic stem cell disorders characterized by dysplasia and ineffective haematopoiesis in one or more of the major myeloid cell lines. Targeting NF- $\kappa$ B with a proteasome inhibitor in these hematologic malignancies induces apoptosis, thereby killing the malignant cell (Braun et al. *Cell Death and Differentiation* (2006) 13:748-758). A further embodiment of the invention is a method to treat MDS comprising administering to a subject in need of such treatment an effective amount of a compound disclosed herein. MDS includes refractory anemia, refractory anemia with ringed sideroblasts, refractory cytopenia with multilineage dysplasia, refractory anemia with excess blasts, unclassifiable

myelodysplastic syndrome and myelodysplastic syndrome associated with isolated del(5q) chromosome abnormality.

Mastocytosis is a proliferation of mast cells and their subsequent accumulation in one or more organ systems. Mastocytosis includes, but is not limited to, cutaneous mastocytosis, indolent systemic mastocytosis (ISM), systemic mastocytosis with associated clonal haematological non-mast-cell-lineage disease (SM-AHNMD), aggressive systemic mastocytosis (ASM), mast cell leukemia (MCL), mast cell sarcoma (MCS) and extracutaneous mastocytoma. Another embodiment of the invention is a method to treat mastocytosis, comprising administering an effective amount of a compound or composition disclosed herein to a subject diagnosed with mastocytosis.

The proteasome regulates NF- $\kappa$ B, which in turn regulates genes involved in the immune and inflammatory response. For example, NF- $\kappa$ B is required for the expression of the immunoglobulin light chain  $\kappa$  gene, the IL-2 receptor  $\alpha$ -chain gene, the class I major histocompatibility complex gene, and a number of cytokine genes encoding, for example, IL-2, IL-6, granulocyte colony-stimulating factor, and IFN- $\beta$  (Palombella et al., *Cell* (1994) 78:773-785). Thus, in certain embodiments, the invention relates to methods of affecting the level of expression of IL-2, MHC-I, IL-6, TNF $\alpha$ , IFN- $\beta$  or any of the other previously-mentioned proteins, each method comprising administering to a subject an effective amount of a proteasome inhibitor compound or composition disclosed herein.

In certain embodiments, the invention includes a method of treating an autoimmune disease in a mammal comprising administering a therapeutically effective amount of a compound or composition described herein. An "autoimmune disease" herein is a disease or disorder arising from and directed against an individual's own tissues. Examples of autoimmune diseases or disorders include, but are not limited to, inflammatory responses such as inflammatory skin diseases including psoriasis and dermatitis (e.g., atopic dermatitis); systemic scleroderma and sclerosis; responses associated with inflammatory bowel disease (such as Crohn's disease and ulcerative colitis); respiratory distress syndrome (including adult respiratory distress syndrome; ARDS); dermatitis; meningitis; encephalitis; uveitis; colitis; glomerulonephritis; allergic conditions such as eczema and asthma and other conditions involving infiltration of T cells and chronic inflammatory responses; atherosclerosis; leukocyte adhesion deficiency; rheumatoid arthritis; systemic lupus erythematosus (SLE); diabetes mellitus (e.g., Type I diabetes mellitus or insulin

dependent diabetes mellitus); multiple sclerosis; Reynaud's syndrome; autoimmune thyroiditis; allergic encephalomyelitis; Sjogren's syndrome; juvenile onset diabetes; and immune responses associated with acute and delayed hypersensitivity mediated by cytokines and T-lymphocytes typically found in tuberculosis, sarcoidosis, polymyositis, granulomatosis and vasculitis; pernicious anemia (Addison's disease); diseases involving leukocyte diapedesis; central nervous system (CNS) inflammatory disorder; multiple organ injury syndrome; hemolytic anemia (including, but not limited to cryoglobulinemia or Coombs positive anemia); myasthenia gravis; antigen-antibody complex mediated diseases; anti-glomerular basement membrane disease; antiphospholipid syndrome; allergic neuritis; Graves' disease; Lambert-Eaton myasthenic syndrome; pemphigoid bullous; pemphigus; autoimmune polyendocrinopathies; Reiter's disease; stiff-man syndrome; Beheet disease; giant cell arteritis; immune complex nephritis; IgA nephropathy; IgM polyneuropathies; immune thrombocytopenic purpura (ITP) or autoimmune thrombocytopenia.

The immune system screens for autologous cells that are virally infected, have undergone oncogenic transformation, or present unfamiliar peptides on their surface. Intracellular proteolysis generates small peptides for presentation to T-lymphocytes to induce MHC class I-mediated immune responses. Thus, in certain embodiments, the invention relates to a method of using the compound as an immunomodulatory agent for inhibiting or altering antigen presentation in a cell, comprising exposing the cell (or administering to a subject) to a compound described herein. Specific embodiments include a method of treating graft or transplant-related diseases, such as graft-versus-host disease or host versus-graft disease in a mammal, comprising administering a therapeutically effective amount of a compound described herein. The term "graft" as used herein refers to biological material derived from a donor for transplantation into a recipient. Grafts include such diverse material as, for example, isolated cells such as islet cells; tissue such as the amniotic membrane of a newborn, bone marrow, hematopoietic precursor cells, and ocular tissue, such as corneal tissue; and organs such as skin, heart, liver, spleen, pancreas, thyroid lobe, lung, kidney, tubular organs (e.g., intestine, blood vessels, or esophagus). The tubular organs can be used to replace damaged portions of esophagus, blood vessels, or bile duct. The skin grafts can be used not only for burns, but also as a dressing to damaged intestine or to close certain defects such as diaphragmatic hernia. The graft is derived from any mammalian source, including human, whether from

cadavers or living donors. In some cases, the donor and recipient is the same mammal. Preferably the graft is bone marrow or an organ such as heart and the donor of the graft and the host are matched for HLA class II antigens.

Histiocytic and dendritic cell neoplasms are derived from phagocytes and accessory cells, which have major roles in the processing and presentation of antigens to lymphocytes. Depleting the proteasome content in dendritic cells has been shown to alter their antigen-induced responses (Chapatte et al. Cancer Res. (2006) 66:5461-5468). Thus, another embodiment of the invention comprises administering an effective amount of a compound or composition disclosed herein to a subject with histiocytic or dendritic cell neoplasm. Histiocytic and dendritic cell neoplasms include histiocytic sarcoma, Langerhans cell histiocytosis, Langerhans cell sarcoma, interdigitating dendritic cell sarcoma/tumor, follicular dendritic cell sarcoma/tumor and non-specified dendritic cell sarcoma.

Inhibition of the proteasome has been shown to be beneficial to treat diseases whereby a cell type is proliferating and immune disorders; thus, an embodiment of the invention includes the treatment of lymphoproliferative diseases (LPD) associated with primary immune disorders (PID) comprising administering an effective amount of the disclosed compound to a subject in need thereof. The most common clinical settings of immunodeficiency associated with an increased incidence of lymphoproliferative disorders, including B-cell and T-cell neoplasms and lymphomas, are primary immunodeficiency syndromes and other primary immune disorders, infection with the human immunodeficiency virus (HIV), iatrogenic immunosuppression in patients who have received solid organ or bone marrow allografts, and iatrogenic immunosuppression associated with methotrexate treatment. Other PIDs commonly associated with LPDs, but not limited to, are ataxia telangiectasia (AT), Wiskott-Aldrich syndrome (WAS), common variable immunodeficiency (CVID), severe combined immunodeficiency (SCID), X-linked lymphoproliferative disorder (XLP), Nijmegen breakage syndrome (NBS), hyper-IgM syndrome, and autoimmune lymphoproliferative syndrome (ALPS).

Additional embodiments of the invention relate to methods for affecting the proteasome-dependent regulation of oncoproteins and methods of treating or inhibiting cancer growth, each method comprising exposing a cell (*in vivo*, e.g., in a subject, or *in vitro*) to the proteasome inhibitor composition disclosed herein. HPV-16 and HPV-18-

derived E6 proteins stimulate ATP-and ubiquitin-dependent conjugation and degradation of p53 in crude reticulocyte lysates. The recessive oncogene p53 has been shown to accumulate at the nonpermissive temperature in a cell line with a mutated thermolabile E1. Elevated levels of p53 may lead to apoptosis. Examples of proto-oncoproteins degraded by the ubiquitin system include c-Mos, c-Fos, and c-Jun. In certain embodiments, the invention relates to a method for treating p53-related apoptosis, comprising administering to a subject an effective amount of a proteasome inhibitor composition disclosed herein.

Another aspect of the invention relates to the use of proteasome inhibitor compositions disclosed herein for the treatment of neurodegenerative diseases and conditions, including, but not limited to, stroke, ischemic damage to the nervous system, neural trauma (e.g., percussive brain damage, spinal cord injury, and traumatic damage to the nervous system), multiple sclerosis and other immune-mediated neuropathies (e.g., Guillain-Barre syndrome and its variants, acute motor axonal neuropathy, acute inflammatory demyelinating polyneuropathy, and Fisher Syndrome), HIV/AIDS dementia complex, axonopathy, diabetic neuropathy, Parkinson's disease, Huntington's disease, multiple sclerosis, bacterial, parasitic, fungal, and viral meningitis, encephalitis, vascular dementia, multi-infarct dementia, Lewy body dementia, frontal lobe dementia such as Pick's disease, subcortical dementias (such as Huntington or progressive supranuclear palsy), focal cortical atrophy syndromes (such as primary aphasia), metabolic-toxic dementias (such as chronic hypothyroidism or B12 deficiency), and dementias caused by infections (such as syphilis or chronic meningitis).

Alzheimer's disease is characterized by extracellular deposits of  $\beta$ -amyloid protein ( $\beta$ -AP) in senile plaques and cerebral vessels.  $\beta$ -AP is a peptide fragment of 39 to 42 amino acids derived from an amyloid protein precursor (APP). At least three isoforms of APP are known (695, 751, and 770 amino acids). Alternative splicing of mRNA generates the isoforms; normal processing affects a portion of the  $\beta$ -AP sequence, thereby preventing the generation of  $\beta$ -AP. It is believed that abnormal protein processing by the proteasome contributes to the abundance of  $\beta$ -AP in the Alzheimer brain. The APP-processing enzyme in rats contains about ten different subunits (22 kDa-32 kDa). The 25 kDa subunit has an N-terminal sequence of X-Gln-Asn-Pro-Met-X-Thr-Gly-Thr-Ser, which is identical to the  $\beta$ -subunit of human macropain (Kojima, S. et al., *Fed. Eur.*

*Biochem. Soc.*, (1992) 304:57-60). The APP-processing enzyme cleaves at the Gln<sup>15</sup>--Lys<sup>16</sup> bond; in the presence of calcium ion, the enzyme also cleaves at the Met<sup>1</sup>--Asp<sup>1</sup> bond and the Asp<sup>1</sup>--Ala<sup>2</sup> bond to release the extracellular domain of  $\beta$ -AP.

One aspect of the invention, therefore, relates to a method of treating Alzheimer's disease, comprising administering to a subject an effective amount of a proteasome inhibitor compound or composition disclosed herein. Such treatment includes reducing the rate of  $\beta$ -AP processing, reducing the rate of  $\beta$ -AP plaque formation, reducing the rate of  $\beta$ -AP generation, and reducing the clinical signs of Alzheimer's disease.

Fibrosis is the excessive and persistent formation of fibrous connective tissue resulting from the hyperproliferative growth of fibroblasts and is associated with activation of the TGF- $\beta$  signaling pathway. Fibrosis involves extensive deposition of extracellular matrix and can occur within virtually any tissue or across several different tissues. Normally, the level of intracellular signaling protein (Smad) that activates transcription of target genes upon TGF- $\beta$  stimulation is regulated by proteasome activity (Xu et al., 2000). However, accelerated degradation of the TGF- $\beta$  signaling components has been observed in fibrotic conditions, such as cystic fibrosis, injection fibrosis, endomyocardial fibrosis, idiopathic pulmonary fibrosis, myelofibrosis, retroperitoneal fibrosis, progressive massive fibrosis, nephrogenic systemic fibrosis. Other conditions that are often associated with fibrosis include cirrhosis, diffuse parenchymal lung disease, post-vasectomy pain syndrome, tuberculosis, sickle-cell anemia and rheumatoid arthritis. An embodiment of the invention is the method of treating a fibrotic or fibrotic-associated condition comprising administering an effective amount of the composition described herein to a subject in need of such treatment.

The treatment of burn victims is often hampered by fibrosis. Thus, in certain embodiments, the invention relates to the topical or systemic administration of a subject inhibitor to treat burns. Wound closure following surgery is often associated with disfiguring scars, which may be prevented by inhibition of fibrosis. Thus, in certain embodiments, the invention relates to a method for the prevention or reduction of scarring.

Overproduction of lipopolysaccharide (LPS)-induced cytokines such as TNF $\alpha$  is considered to be central to the processes associated with septic shock. Furthermore, it is generally accepted that the first step in the activation of cells by LPS is the binding of

LPS to specific membrane receptors. The  $\alpha$ - and  $\beta$ -subunits of the 20S proteasome complex have been identified as LPS-binding proteins, suggesting that the LPS-induced signal transduction may be an important therapeutic target in the treatment or prevention of sepsis (Qureshi, N. et al., *J. Immun.* (2003) 171: 1515-1525). Therefore, in certain  
5       embodiments, the proteasome inhibitor composition may be used for the inhibition of TNF $\alpha$  to prevent and/or treat septic shock.

Ischemia and reperfusion injury results in hypoxia, a condition in which there is a deficiency of oxygen reaching the tissues of the body. This condition causes increased degradation of I $\kappa$ -B $\alpha$ , thereby resulting in the activation of NF- $\kappa$ B (Koong et al., 1994).  
10       It has been demonstrated that the severity of injury resulting in hypoxia can be reduced with the administration of a proteasome inhibitor (Gao et al., 2000; Bao et al., 2001; Pye et al., 2003). Therefore, certain embodiments of the invention relate to a method of treating an ischemic condition or reperfusion injury comprising administering to a subject  
15       in need of such treatment an effective amount of the proteasome inhibitor compound disclosed herein. Examples of such conditions or injuries include, but are not limited to, acute coronary syndrome (vulnerable plaques), arterial occlusive disease (cardiac, cerebral, peripheral arterial and vascular occlusions), atherosclerosis (coronary sclerosis, coronary artery disease), infarctions, heart failure, pancreatitis, myocardial hypertrophy, stenosis, and restenosis.

NF- $\kappa$ B also binds specifically to the HIV-enhancer/promoter. When compared to the Nef of mac239, the HIV regulatory protein Nef of pbj14 differs by two amino acids in the region which controls protein kinase binding. It is believed that the protein kinase signals the phosphorylation of I $\kappa$ B, triggering I $\kappa$ B degradation through the ubiquitin-proteasome pathway. After degradation, NF- $\kappa$ B is released into the nucleus, thus  
20       enhancing the transcription of HIV (Cohen, J., *Science*, (1995) 267:960). In certain  
25       embodiments, the invention relates to a method for inhibiting or reducing HIV infection in a subject, or a method for decreasing the level of viral gene expression, each method comprising administering to the subject an effective amount of a proteasome inhibitor compound or composition disclosed herein.

30       Viral infections contribute to the pathology of many diseases. Heart conditions such as ongoing myocarditis and dilated cardiomyopathy have been linked to the coxsackievirus B3. In a comparative whole-genome microarray analyses of infected

mouse hearts, specific proteasome subunits were uniformly up-regulated in hearts of mice which developed chronic myocarditis (Szalay et al, Am J Pathol 168:1542-52, 2006). Some viruses utilize the ubiquitin-proteasome system in the viral entry step where the virus is released from the endosome into the cytosol. The mouse hepatitis virus (MHV) belongs to the *Coronaviridae* family, which also includes the severe acute respiratory syndrome (SARS) coronavirus. Yu and Lai (J Virol 79:644-648, 2005) demonstrated that treatment of cells infected with MHV with a proteasome inhibitor resulted in a decrease in viral replication, correlating with reduced viral titer as compared to that of untreated cells. The human hepatitis B virus (HBV), a member of the *Hepadnaviridae* virus family, likewise requires virally encoded envelop proteins to propagate. Inhibiting the proteasome degradation pathway causes a significant reduction in the amount of secreted envelope proteins (Simsek et al, J Virol 79:12914-12920, 2005). In addition to HBV, other hepatitis viruses (A, C, D and E) may also utilize the ubiquitin-proteasome degradation pathway for secretion, morphogenesis and pathogenesis. Accordingly, in certain embodiments, the invention relates to a method for treating viral infection, such as SARS or hepatitis A, B, C, D and E, comprising contacting a cell with (or administering to a subject) an effective amount of a compound or composition disclosed herein.

In certain embodiments, the disclosed compositions may be useful for the treatment of a parasitic infection, such as infections caused by protozoan parasites. The proteasome of these parasites is considered to be involved primarily in cell differentiation and replication activities (Paugam et al., Trends Parasitol. 2003, 19(2): 55-59). Furthermore, entamoeba species have been shown to lose encystation capacity when exposed to proteasome inhibitors (Gonzales, et al., Arch. Med. Res. 1997, 28, Spec No: 139-140). In certain such embodiments, the administrative protocols for the proteasome inhibitor compositions are useful for the treatment of parasitic infections in humans caused by a protozoan parasite selected from *Plasmodium* spp. (including *P. falciparum*, *P. vivax*, *P. malariae*, and *P. ovale*, which cause malaria), *Trypanosoma* spp. (including *T. cruzi*, which causes Chagas' disease, and *T. brucei* which causes African sleeping sickness), *Leishmania* spp. (including *L. amazonensis*, *L. donovani*, *L. infantum*, *L. mexicana*, etc.), *Pneumocystis carinii* (a protozoan known to cause pneumonia in AIDS and other immunosuppressed patients), *Toxoplasma gondii*, *Entamoeba histolytica*, *Entamoeba invadens*, and *Giardia lamblia*. In certain embodiments, the disclosed proteasome inhibitor compositions are useful for the treatment of parasitic infections in

animals and livestock caused by a protozoan parasite selected from *Plasmodium hermani*, *Cryptosporidium* sps., *Echinococcus granulosus*, *Eimeria tenella*, *Sarcocystis neurona*, and *Neurospora crassa*. Other compounds that act as proteasome inhibitors in the treatment of parasitic diseases are described in WO 98/10779, which is incorporated  
5 herein in its entirety.

In certain embodiments, the proteasome inhibitor compositions inhibit proteasome activity in a parasite without recovery in red blood cells and white blood cells. In certain such embodiments, the long half-life of blood cells may provide prolonged protection with regard to therapy against recurring exposures to parasites. In certain embodiments,  
10 the proteasome inhibitor compositions may provide prolonged protection with regard to chemoprophylaxis against future infection.

Prokaryotes have an equivalent to the eukaryote 20S proteasome particle. Although the subunit composition of the prokaryote 20S particle is simpler than that of eukaryotes, it has the ability to hydrolyze peptide bonds in a similar manner. For  
15 example, the nucleophilic attack on the peptide bond occurs through the threonine residue on the N-terminus of the  $\beta$ -subunits. Thus, an embodiment of this invention relates to a method of treating prokaryotic infections, comprising administering to a subject an effective amount of a proteasome inhibitor compound or composition disclosed herein. Prokaryotic infections may include diseases caused by either mycobacteria (such as  
20 tuberculosis, leprosy or Buruli ulcer) or archaeobacteria.

It has also been demonstrated that inhibitors that bind to the 20S proteasome stimulate bone formation in bone organ cultures. Furthermore, when such inhibitors have been administered systemically to mice, certain proteasome inhibitors increased bone volume and bone formation rates over 70% (Garrett, I. R. et al., *J. Clin. Invest.* (2003)  
25 111: 1771-1782), therefore suggesting that the ubiquitin-proteasome machinery regulates osteoblast differentiation and bone formation. Therefore, a disclosed proteasome inhibitor compound or composition may be useful in the treatment and/or prevention of diseases associated with bone loss, such as osteoporosis.

Thus, in certain embodiments, the invention relates to a method for treating a  
30 disease or condition selected from cancer, autoimmune disease, graft or transplant-related condition, neurodegenerative disease, fibrotic-associated condition, ischemic-related

conditions, infection (viral, parasitic or prokaryotic) and diseases associated with bone loss, comprising administering a compound or composition as disclosed herein.

#### Administration of Crystalline Tripeptide Epoxy Ketones

5           Compounds prepared as described herein can be administered in various forms, depending on the disorder to be treated and the age, condition, and body weight of the patient, as is well known in the art. For example, where the compounds are to be administered orally, they may be formulated as tablets, capsules, granules, powders, or syrups; or for parenteral administration, they may be formulated as injections  
10 (intravenous, intramuscular, or subcutaneous), drop infusion preparations, or suppositories. For application by the ophthalmic mucous membrane route, they may be formulated as eye drops or eye ointments. These formulations can be prepared by conventional means, and if desired, the active ingredient may be mixed with any conventional additive or excipient, such as a binder, a disintegrating agent, a lubricant, a  
15 corrigent, a solubilizing agent, a suspension aid, an emulsifying agent, a coating agent, a cyclodextrin, and/or a buffer. Although the dosage will vary depending on the symptoms, age and body weight of the patient, the nature and severity of the disorder to be treated or prevented, the route of administration and the form of the drug, in general, a daily dosage of from 0.01 to 2000 mg of the compound is recommended for an adult human patient,  
20 and this may be administered in a single dose or in divided doses. The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will generally be that amount of the compound which produces a therapeutic effect.

          The precise time of administration and/or amount of the composition that will yield the most effective results in terms of efficacy of treatment in a given patient will  
25 depend upon the activity, pharmacokinetics, and bioavailability of a particular compound, physiological condition of the patient (including age, sex, disease type and stage, general physical condition, responsiveness to a given dosage, and type of medication), route of administration, etc. However, the above guidelines can be used as the basis for fine-tuning the treatment, e.g., determining the optimum time and/or amount of administration,  
30 which will require no more than routine experimentation consisting of monitoring the subject and adjusting the dosage and/or timing.

The phrase “pharmaceutically acceptable” is employed herein to refer to those ligands, materials, compositions, and/or dosage forms which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and animals without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio.

The phrase “pharmaceutically acceptable carrier” as used herein means a pharmaceutically acceptable material, composition, or vehicle, such as a liquid or solid filler, diluent, excipient, solvent or encapsulating material. Each carrier must be “acceptable” in the sense of being compatible with the other ingredients of the formulation and not injurious to the patient. Some examples of materials which can serve as pharmaceutically acceptable carriers include: (1) sugars, such as lactose, glucose, and sucrose; (2) starches, such as corn starch, potato starch, and substituted or unsubstituted  $\beta$ -cyclodextrin; (3) cellulose, and its derivatives, such as sodium carboxymethyl cellulose, ethyl cellulose, and cellulose acetate; (4) powdered tragacanth; (5) malt; (6) gelatin; (7) talc; (8) excipients, such as cocoa butter and suppository waxes; (9) oils, such as peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil, and soybean oil; (10) glycols, such as propylene glycol; (11) polyols, such as glycerin, sorbitol, mannitol, and polyethylene glycol; (12) esters, such as ethyl oleate and ethyl laurate; (13) agar; (14) buffering agents, such as magnesium hydroxide and aluminum hydroxide; (15) alginic acid; (16) pyrogen-free water; (17) isotonic saline; (18) Ringer’s solution; (19) ethyl alcohol; (20) phosphate buffer solutions; and (21) other non-toxic compatible substances employed in pharmaceutical formulations. In certain embodiments, pharmaceutical compositions of the present invention are non-pyrogenic, i.e., do not induce significant temperature elevations when administered to a patient.

The term “pharmaceutically acceptable salt” refers to the relatively non-toxic, inorganic and organic acid addition salts of the inhibitor(s). These salts can be prepared in situ during the final isolation and purification of the inhibitor(s), or by separately reacting a purified inhibitor(s) in its free base form with a suitable organic or inorganic acid, and isolating the salt thus formed. Representative salts include the hydrobromide, hydrochloride, sulfate, bisulfate, phosphate, nitrate, acetate, valerate, oleate, palmitate, stearate, laurate, benzoate, lactate, phosphate, tosylate, citrate, maleate, fumarate, succinate, tartrate, naphthylate, mesylate, glucoheptonate, lactobionate, laurylsulphonate

salts, and amino acid salts, and the like. (See, for example, Berge et al. (1977) "Pharmaceutical Salts", J. Pharm. Sci. 66: 1-19.)

In other cases, the inhibitors useful in the methods of the present invention may contain one or more acidic functional groups and, thus, are capable of forming pharmaceutically acceptable salts with pharmaceutically acceptable bases. The term "pharmaceutically acceptable salts" in these instances refers to the relatively non-toxic inorganic and organic base addition salts of an inhibitor(s). These salts can likewise be prepared in situ during the final isolation and purification of the inhibitor(s), or by separately reacting the purified inhibitor(s) in its free acid form with a suitable base, such as the hydroxide, carbonate, or bicarbonate of a pharmaceutically acceptable metal cation, with ammonia, or with a pharmaceutically acceptable organic primary, secondary, or tertiary amine. Representative alkali or alkaline earth salts include the lithium, sodium, potassium, calcium, magnesium, and aluminum salts, and the like. Representative organic amines useful for the formation of base addition salts include ethylamine, diethylamine, ethylenediamine, ethanolamine, diethanolamine, piperazine, and the like (see, for example, Berge et al., supra).

Wetting agents, emulsifiers, and lubricants, such as sodium lauryl sulfate and magnesium stearate, as well as coloring agents, release agents, coating agents, sweetening, flavoring, and perfuming agents, preservatives and antioxidants can also be present in the compositions.

Examples of pharmaceutically acceptable antioxidants include: (1) water soluble antioxidants, such as ascorbic acid, cysteine hydrochloride, sodium bisulfate, sodium metabisulfite, sodium sulfite, and the like; (2) oil-soluble antioxidants, such as ascorbyl palmitate, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), lecithin, propyl gallate, alpha-tocopherol, and the like; and (3) metal chelating agents, such as citric acid, ethylenediamine tetraacetic acid (EDTA), sorbitol, tartaric acid, phosphoric acid, and the like.

Formulations suitable for oral administration may be in the form of capsules, cachets, pills, tablets, lozenges (using a flavored basis, usually sucrose and acacia or tragacanth), powders, granules, or as a solution or a suspension in an aqueous or non-aqueous liquid, or as an oil-in-water or water-in-oil liquid emulsion, or as an elixir or syrup, or as pastilles (using an inert matrix, such as gelatin and glycerin, or sucrose and

acacia) and/or as mouthwashes, and the like, each containing a predetermined amount of an inhibitor(s) as an active ingredient. A composition may also be administered as a bolus, electuary, or paste.

In solid dosage forms for oral administration (capsules, tablets, pills, dragees, powders, granules, and the like), the active ingredient may be mixed with one or more pharmaceutically acceptable carriers, such as sodium citrate or dicalcium phosphate, and/or any of the following: (1) fillers or extenders, such as starches, cyclodextrins, lactose, sucrose, glucose, mannitol, and/or silicic acid; (2) binders, such as, for example, carboxymethylcellulose, alginates, gelatin, polyvinyl pyrrolidone, sucrose, and/or acacia; (3) humectants, such as glycerol; (4) disintegrating agents, such as agar-agar, calcium carbonate, potato or tapioca starch, alginic acid, certain silicates, and sodium carbonate; (5) solution retarding agents, such as paraffin; (6) absorption accelerators, such as quaternary ammonium compounds; (7) wetting agents, such as, for example, acetyl alcohol and glycerol monostearate; (8) absorbents, such as kaolin and bentonite clay; (9) lubricants, such as talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate, and mixtures thereof; and (10) coloring agents. In the case of capsules, tablets, and pills, the pharmaceutical compositions may also comprise buffering agents. Solid compositions of a similar type may also be employed as fillers in soft and hard-filled gelatin capsules using such excipients as lactose or milk sugars, as well as high molecular weight polyethylene glycols, and the like. In certain embodiments the crystalline tripeptide epoxyketone is administered to a mammal as a capsule. In another embodiment, the crystalline tripeptide epoxyketone is a compound of formula (I). In a more preferred embodiment, the crystalline tripeptide epoxyketone is a compound of formula (II).

A tablet may be made by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared using binder (for example, gelatin or hydroxypropylmethyl cellulose), lubricant, inert diluent, preservative, disintegrant (for example, sodium starch glycolate or cross-linked sodium carboxymethyl cellulose), surface-active or dispersing agent. Molded tablets may be made by molding in a suitable machine a mixture of the powdered inhibitor(s) moistened with an inert liquid diluent.

Tablets, and other solid dosage forms, such as dragees, capsules, pills, and granules, may optionally be scored or prepared with coatings and shells, such as enteric coatings and other coatings well known in the pharmaceutical-formulating art. They may also be formulated so as to provide slow or controlled release of the active ingredient therein using, for example, hydroxypropylmethyl cellulose in varying proportions to provide the desired release profile, other polymer matrices, liposomes, and/or microspheres. They may be sterilized by, for example, filtration through a bacteria-retaining filter, or by incorporating sterilizing agents in the form of sterile solid compositions which can be dissolved in sterile water, or some other sterile injectable medium immediately before use. These compositions may also optionally contain opacifying agents and may be of a composition that they release the active ingredient(s) only, or preferentially, in a certain portion of the gastrointestinal tract, optionally, in a delayed manner. Examples of embedding compositions which can be used include polymeric substances and waxes. The active ingredient can also be in micro-encapsulated form, if appropriate, with one or more of the above-described excipients.

Liquid dosage forms for oral administration include pharmaceutically acceptable emulsions, microemulsions, solutions, suspensions, syrups, and elixirs. In addition to the active ingredient, the liquid dosage forms may contain inert diluents commonly used in the art, such as, for example, water or other solvents, solubilizing agents, and emulsifiers such as ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, oils (in particular, cottonseed, groundnut, corn, germ, olive, castor, and sesame oils), glycerol, tetrahydrofuryl alcohol, polyethylene glycols, and fatty acid esters of sorbitan, and mixtures thereof.

Besides inert diluents, the oral compositions can also include adjuvants such as wetting agents, emulsifying and suspending agents, sweetening, flavoring, coloring, perfuming, and preservative agents.

Suspensions, in addition to the active inhibitor(s) may contain suspending agents as, for example, ethoxylated isostearyl alcohols, polyoxyethylene sorbitol and sorbitan esters, microcrystalline cellulose, aluminum metahydroxide, bentonite, agar-agar and tragacanth, and mixtures thereof.

Formulations for rectal or vaginal administration may be presented as a suppository, which may be prepared by mixing one or more inhibitor(s) with one or more

suitable nonirritating excipients or carriers comprising, for example, cocoa butter, polyethylene glycol, a suppository wax or a salicylate, which is solid at room temperature, but liquid at body temperature and, therefore, will melt in the rectum or vaginal cavity and release the active agent.

5           Formulations which are suitable for vaginal administration also include pessaries, tampons, creams, gels, pastes, foams, or spray formulations containing such carriers as are known in the art to be appropriate.

          Dosage forms for the topical or transdermal administration of an inhibitor(s) include powders, sprays, ointments, pastes, creams, lotions, gels, solutions, patches, and  
10           inhalants. The active component may be mixed under sterile conditions with a pharmaceutically acceptable carrier, and with any preservatives, buffers, or propellants which may be required.

          The ointments, pastes, creams, and gels may contain, in addition to inhibitor(s), excipients, such as animal and vegetable fats, oils, waxes, paraffins, starch, tragacanth,  
15           cellulose derivatives, polyethylene glycols, silicones, bentonites, silicic acid, talc, and zinc oxide, or mixtures thereof.

          Powders and sprays can contain, in addition to an inhibitor(s), excipients such as lactose, talc, silicic acid, aluminum hydroxide, calcium silicates, and polyamide powder, or mixtures of these substances. Sprays can additionally contain customary propellants,  
20           such as chlorofluorohydrocarbons and volatile unsubstituted hydrocarbons, such as butane and propane.

          The inhibitor(s) can be alternatively administered by aerosol. This is accomplished by preparing an aqueous aerosol, liposomal preparation, or solid particles containing the composition. A nonaqueous (e.g., fluorocarbon propellant) suspension  
25           could be used. Sonic nebulizers are preferred because they minimize exposing the agent to shear, which can result in degradation of the compound.

          Ordinarily, an aqueous aerosol is made by formulating an aqueous solution or suspension of the agent together with conventional pharmaceutically acceptable carriers and stabilizers. The carriers and stabilizers vary with the requirements of the particular  
30           composition, but typically include nonionic surfactants (Tweens, Pluronics, sorbitan esters, lecithin, Cremophors), pharmaceutically acceptable co-solvents such as

polyethylene glycol, innocuous proteins like serum albumin, oleic acid, amino acids such as glycine, buffers, salts, sugars, or sugar alcohols. Aerosols generally are prepared from isotonic solutions.

Transdermal patches have the added advantage of providing controlled delivery of an inhibitor(s) to the body. Such dosage forms can be made by dissolving or dispersing the agent in the proper medium. Absorption enhancers can also be used to increase the flux of the inhibitor(s) across the skin. The rate of such flux can be controlled by either providing a rate controlling membrane or dispersing the inhibitor(s) in a polymer matrix or gel.

Pharmaceutical compositions of this invention suitable for parenteral administration comprise one or more inhibitors(s) in combination with one or more pharmaceutically acceptable sterile aqueous or nonaqueous solutions, dispersions, suspensions or emulsions, or sterile powders which may be reconstituted into sterile injectable solutions or dispersions just prior to use, which may contain antioxidants, buffers, bacteriostats, solutes which render the formulation isotonic with the blood of the intended recipient or suspending or thickening agents.

Examples of suitable aqueous and nonaqueous carriers which may be employed in the pharmaceutical compositions of the invention include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), and suitable mixtures thereof, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials, such as lecithin, by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants.

These compositions may also contain adjuvants such as preservatives, wetting agents, emulsifying agents, and dispersing agents. Prevention of the action of microorganisms may be ensured by the inclusion of various antibacterial and antifungal agents, for example, paraben, chlorobutanol, phenol sorbic acid, and the like. It may also be desirable to include tonicity-adjusting agents, such as sugars, sodium chloride, and the like into the compositions. In addition, prolonged absorption of the injectable pharmaceutical form may be brought about by the inclusion of agents which delay absorption such as aluminum monostearate and gelatin.

In some cases, in order to prolong the effect of a drug, it is desirable to slow the absorption of the drug from subcutaneous or intramuscular injection. For example, delayed absorption of a parenterally administered drug form is accomplished by dissolving or suspending the drug in an oil vehicle.

5           Injectable depot forms are made by forming microcapsule matrices of inhibitor(s) in biodegradable polymers such as polylactide-polyglycolide. Depending on the ratio of drug to polymer, and the nature of the particular polymer employed, the rate of drug release can be controlled. Examples of other biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations are also prepared  
10 by entrapping the drug in liposomes or microemulsions which are compatible with body tissue.

The preparations of agents may be given orally, parenterally, topically, or rectally. They are, of course, given by forms suitable for each administration route. For example, they are administered in tablets or capsule form, by injection, inhalation, eye lotion,  
15 ointment, suppository, infusion; topically by lotion or ointment; and rectally by suppositories. Oral administration is preferred.

The phrases "parenteral administration" and "administered parenterally" as used herein means modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravenous, intramuscular,  
20 intraarterial, intrathecal, intracapsular, intraorbital, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal and intrasternal injection, and infusion.

The phrases "systemic administration," "administered systemically," "peripheral administration" and "administered peripherally" as used herein mean the administration  
25 of a ligand, drug, or other material other than directly into the central nervous system, such that it enters the patient's system and thus, is subject to metabolism and other like processes, for example, subcutaneous administration.

These inhibitors(s) may be administered to humans and other animals for therapy by any suitable route of administration, including orally, nasally, as by, for example, a  
30 spray, rectally, intravaginally, parenterally, intracisternally, and topically, as by powders, ointments or drops, including buccally and sublingually.

Regardless of the route of administration selected, the inhibitor(s), which may be used in a suitable hydrated form, and/or the pharmaceutical compositions of the present invention, are formulated into pharmaceutically acceptable dosage forms by conventional methods known to those of skill in the art.

5 Actual dosage levels of the active ingredients in the pharmaceutical compositions of this invention may be varied so as to obtain an amount of the active ingredient which is effective to achieve the desired therapeutic response for a particular patient, composition, and mode of administration, without being toxic to the patient.

10 The concentration of a disclosed compound in a pharmaceutically acceptable mixture will vary depending on several factors, including the dosage of the compound to be administered, the pharmacokinetic characteristics of the compound(s) employed, and the route of administration. In general, the compositions of this invention may be provided in an aqueous solution containing about 0.1-10% w/v of a compound disclosed herein, among other substances, for parenteral administration. Typical dose ranges are  
15 from about 0.01 to about 50 mg/kg of body weight per day, given in 1-4 divided doses. Each divided dose may contain the same or different compounds of the invention. The dosage will be an effective amount depending on several factors including the overall health of a patient, and the formulation and route of administration of the selected compound(s).

## 20 Definitions

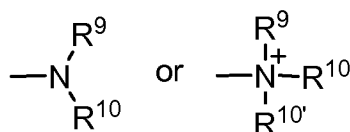
The term “C<sub>x-y</sub>alkyl” refers to substituted or unsubstituted saturated hydrocarbon groups, including straight-chain alkyl and branched-chain alkyl groups that contain from x to y carbons in the chain, including haloalkyl groups such as trifluoromethyl and 2,2,2-trifluoroethyl, etc. C<sub>0</sub>alkyl indicates a hydrogen where the group is in a terminal position,  
25 a bond if internal. The terms “C<sub>2-y</sub>alkenyl” and “C<sub>2-y</sub>alkynyl” refer to substituted or unsubstituted unsaturated aliphatic groups analogous in length and possible substitution to the alkyls described above, but that contain at least one double or triple bond respectively.

The term “alkoxy” refers to an alkyl group having an oxygen attached thereto. Representative alkoxy groups include methoxy, ethoxy, propoxy, tert-butoxy and the like.  
30 An “ether” is two hydrocarbons covalently linked by an oxygen. Accordingly, the substituent of an alkyl that renders that alkyl an ether is or resembles an alkoxy.

The term “C<sub>1-6</sub>alkoxyalkyl” refers to a C<sub>1-6</sub>alkyl group substituted with an alkoxy group, thereby forming an ether.

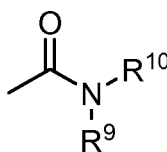
The term “C<sub>1-6</sub>aralkyl”, as used herein, refers to a C<sub>1-6</sub>alkyl group substituted with an aryl group.

- 5           The terms “amine” and “amino” are art-recognized and refer to both unsubstituted and substituted amines and salts thereof, e.g., a moiety that can be represented by the general formulae:



- 10           wherein R<sup>9</sup>, R<sup>10</sup> and R<sup>10'</sup> each independently represent a hydrogen, an alkyl, an alkenyl, -(CH<sub>2</sub>)<sub>m</sub>-R<sup>8</sup>, or R<sup>9</sup> and R<sup>10</sup> taken together with the N atom to which they are attached complete a heterocycle having from 4 to 8 atoms in the ring structure; R<sup>8</sup> represents an aryl, a cycloalkyl, a cycloalkenyl, a heterocyclyl or a polycyclyl; and m is zero or an integer from 1 to 8. In preferred embodiments, only one of R<sup>9</sup> or R<sup>10</sup> can be a carbonyl, e.g., R<sup>9</sup>, R<sup>10</sup>, and the nitrogen together do not form an imide. In even more preferred
- 15           embodiments, R<sup>9</sup> and R<sup>10</sup> (and optionally R<sup>10'</sup>) each independently represent a hydrogen, an alkyl, an alkenyl, or -(CH<sub>2</sub>)<sub>m</sub>-R<sup>8</sup>. In certain embodiments, the amino group is basic, meaning the protonated form has a pK<sub>a</sub> ≥ 7.00.

The terms “amide” and “amido” are art-recognized as an amino-substituted carbonyl and includes a moiety that can be represented by the general formula:



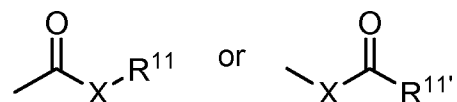
- 20           wherein R<sup>9</sup>, R<sup>10</sup> are as defined above. Preferred embodiments of the amide will not include imides which may be unstable.

- 25           The term “aryl” as used herein includes 5-, 6-, and 7-membered substituted or unsubstituted single-ring aromatic groups in which each atom of the ring is carbon. The term “aryl” also includes polycyclic ring systems having two or more cyclic rings in which two or more carbons are common to two adjoining rings wherein at least one of the rings is aromatic, e.g., the other cyclic rings can be cycloalkyls, cycloalkenyls,

cycloalkynyls, aryls, heteroaryls, and/or heterocyclyls. Aryl groups include benzene, naphthalene, phenanthrene, phenol, aniline, and the like.

The terms “carbocycle” and “carbocyclyl”, as used herein, refer to a non-aromatic substituted or unsubstituted ring in which each atom of the ring is carbon. The terms “carbocycle” and “carbocyclyl” also include polycyclic ring systems having two or more cyclic rings in which two or more carbons are common to two adjoining rings wherein at least one of the rings is carbocyclic, e.g., the other cyclic rings can be cycloalkyls, cycloalkenyls, cycloalkynyls, aryls, heteroaryls, and/or heterocyclyls.

The term “carbonyl” is art-recognized and includes such moieties as can be represented by the general formula:



wherein X is a bond or represents an oxygen or a sulfur, and  $\text{R}^{11}$  represents a hydrogen, an alkyl, an alkenyl,  $-(\text{CH}_2)_m\text{---}\text{R}^8$  or a pharmaceutically acceptable salt,  $\text{R}^{11'}$  represents a hydrogen, an alkyl, an alkenyl or  $-(\text{CH}_2)_m\text{---}\text{R}^8$ , where m and  $\text{R}^8$  are as defined above.

Where X is an oxygen and  $\text{R}^{11}$  or  $\text{R}^{11'}$  is not hydrogen, the formula represents an “ester”. Where X is an oxygen, and  $\text{R}^{11}$  is a hydrogen, the formula represents a “carboxylic acid”.

The terms “heteroaryl” includes substituted or unsubstituted aromatic 5- to 7-membered ring structures, more preferably 5- to 6-membered rings, whose ring structures include one to four heteroatoms. The term “heteroaryl” also includes polycyclic ring systems having two or more cyclic rings in which two or more carbons are common to two adjoining rings wherein at least one of the rings is heteroaromatic, e.g., the other cyclic rings can be cycloalkyls, cycloalkenyls, cycloalkynyls, aryls, heteroaryls, and/or heterocyclyls. Heteroaryl groups include, for example, pyrrole, furan, thiophene, imidazole, isoxazole, oxazole, thiazole, triazole, pyrazole, pyridine, pyrazine, pyridazine and pyrimidine, and the like.

The term “heteroatom” as used herein means an atom of any element other than carbon or hydrogen. Preferred heteroatoms are nitrogen, oxygen, phosphorus, and sulfur.

The terms “heterocyclyl” or “heterocyclic group” refer to substituted or unsubstituted non-aromatic 3- to 10-membered ring structures, more preferably 3- to 7-membered rings, whose ring structures include one to four heteroatoms. The term terms

“heterocyclyl” or “heterocyclic group” also include polycyclic ring systems having two or more cyclic rings in which two or more carbons are common to two adjoining rings wherein at least one of the rings is heterocyclic, e.g., the other cyclic rings can be cycloalkyls, cycloalkenyls, cycloalkynyls, aryls, heteroaryls, and/or heterocyclyls.

5 Heterocyclyl groups include, for example, tetrahydrofuran, piperidine, piperazine, pyrrolidine, morpholine, lactones, lactams, and the like..

The term “C<sub>1-6</sub>heterocycloalkyl”, as used herein, refers to a C<sub>1-6</sub>alkyl group substituted with a heterocyclyl group.

10 The term “C<sub>1-6</sub>hydroxyalkyl” refers to a C<sub>1-6</sub>alkyl group substituted with a hydroxy group.

As used herein, the term “inhibitor” is meant to describe a compound that blocks or reduces an activity of an enzyme (for example, inhibition of proteolytic cleavage of standard fluorogenic peptide substrates such as suc-LLVY-AMC, Box-LLR-AMC and Z-LLE-AMC, inhibition of various catalytic activities of the 20S proteasome). An inhibitor  
15 can act with competitive, uncompetitive, or noncompetitive inhibition. An inhibitor can bind reversibly or irreversibly, and therefore the term includes compounds that are suicide substrates of an enzyme. An inhibitor can modify one or more sites on or near the active site of the enzyme, or it can cause a conformational change elsewhere on the enzyme.

As used herein, the term “orally bioavailable” is meant to describe a compound  
20 administered to a mouse at 40 mg/kg or less, 20 mg/kg or less, or even 10 mg/kg or less, wherein one hour after oral administration such a compound shows at least about 50%, at least about 75% or even at least about 90% inhibition of proteasome CT-L activity in the blood.

As used herein, the term “peptide” includes not only standard amide linkage with  
25 standard  $\alpha$ -substituents, but commonly utilized peptidomimetics, other modified linkages, non-naturally occurring side chains, and side chain modifications, as detailed below.

The terms “polycyclyl” or “polycyclic” refer to two or more rings (e.g., cycloalkyls, cycloalkenyls, cycloalkynyls, aryls, heteroaryls, and/or heterocyclyls) in which two or more carbons are common to two adjoining rings, e.g., the rings are “fused  
30 rings”. Each of the rings of the polycycle can be substituted or unsubstituted.

The term “proteasome” as used herein is meant to include immuno- and constitutive proteasomes.

The term “substantially pure” as used herein, refers to a crystalline polymorph that is greater than 90% pure, meaning that contains less than 10% of any other compound, including the corresponding amorphous compound. Preferably, the crystalline polymorph is greater than 95% pure, or even greater than 98% pure.

The term “preventing” is art-recognized, and when used in relation to a condition, such as a local recurrence (e.g., pain), a disease such as cancer, a syndrome complex such as heart failure or any other medical condition, is well understood in the art, and includes administration of a composition which reduces the frequency of, or delays the onset of, symptoms of a medical condition in a subject relative to a subject which does not receive the composition. Thus, prevention of cancer includes, for example, reducing the number of detectable cancerous growths in a population of patients receiving a prophylactic treatment relative to an untreated control population, and/or delaying the appearance of detectable cancerous growths in a treated population versus an untreated control population, e.g., by a statistically and/or clinically significant amount. Prevention of an infection includes, for example, reducing the number of diagnoses of the infection in a treated population versus an untreated control population, and/or delaying the onset of symptoms of the infection in a treated population versus an untreated control population. Prevention of pain includes, for example, reducing the magnitude of, or alternatively delaying, pain sensations experienced by subjects in a treated population versus an untreated control population.

The term “prodrug” encompasses compounds that, under physiological conditions, are converted into therapeutically active agents. A common method for making a prodrug is to include selected moieties that are hydrolyzed under physiological conditions to reveal the desired molecule. In other embodiments, the prodrug is converted by an enzymatic activity of the host animal.

The term “prophylactic or therapeutic” treatment is art-recognized and includes administration to the host of one or more of the subject compositions. If it is administered prior to clinical manifestation of the unwanted condition (e.g., disease or other unwanted state of the host animal) then the treatment is prophylactic, (i.e., it protects the host against developing the unwanted condition), whereas if it is administered after

manifestation of the unwanted condition, the treatment is therapeutic, (i.e., it is intended to diminish, ameliorate, or stabilize the existing unwanted condition or side effects thereof).

The term “proteasome” as used herein is meant to include immuno- and constitutive proteasomes.

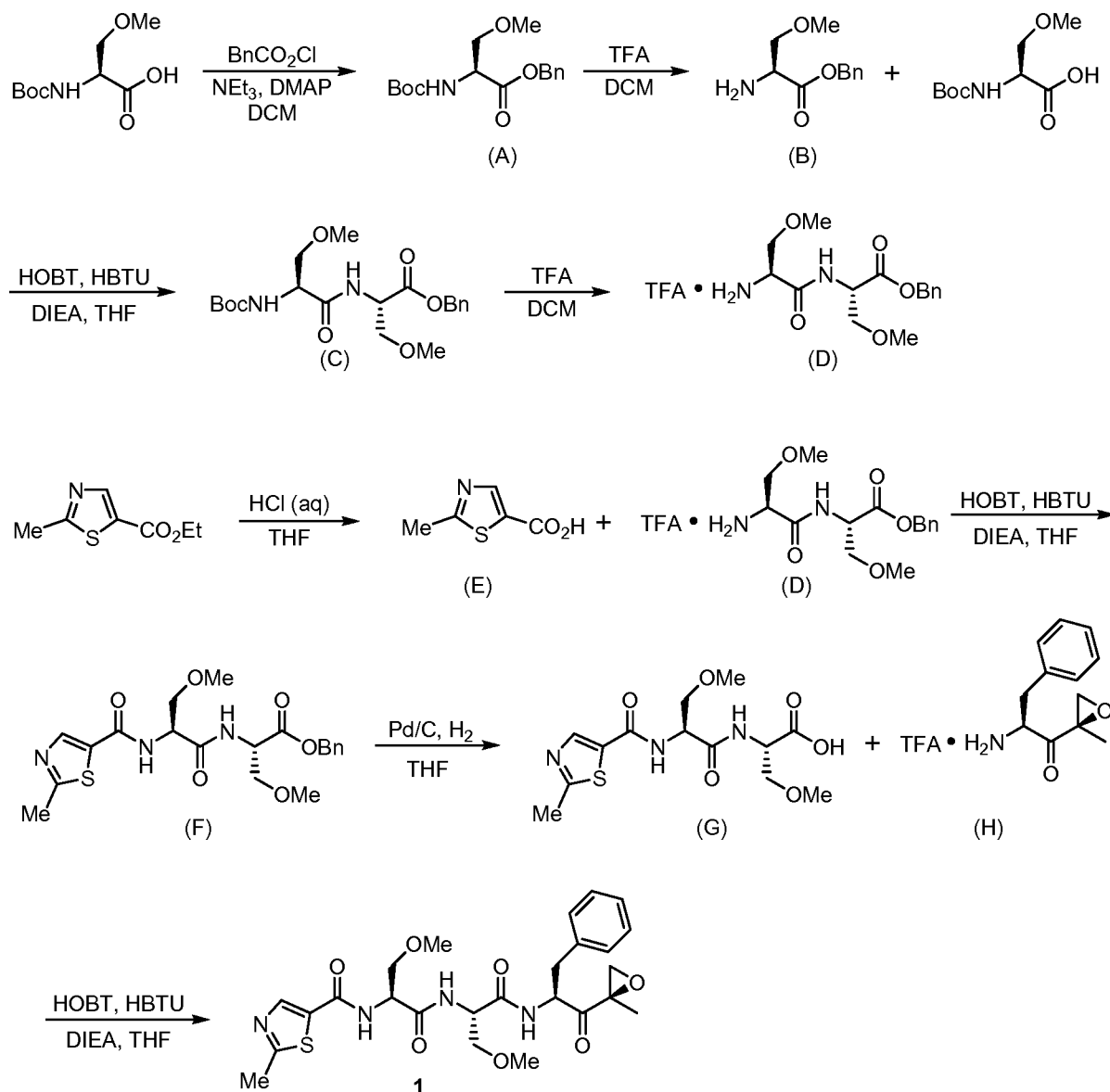
The term “substituted” refers to moieties having substituents replacing a hydrogen on one or more carbons of the backbone. It will be understood that “substitution” or “substituted with” includes the implicit proviso that such substitution is in accordance with permitted valence of the substituted atom and the substituent, and that the substitution results in a stable compound, e.g., which does not spontaneously undergo transformation such as by rearrangement, cyclization, elimination, etc. As used herein, the term “substituted” is contemplated to include all permissible substituents of organic compounds. In a broad aspect, the permissible substituents include acyclic and cyclic, branched and unbranched, carbocyclic and heterocyclic, aromatic and non-aromatic substituents of organic compounds. The permissible substituents can be one or more and the same or different for appropriate organic compounds. For purposes of this invention, the heteroatoms such as nitrogen may have hydrogen substituents and/or any permissible substituents of organic compounds described herein which satisfy the valences of the heteroatoms. Substituents can include, for example, a halogen, a hydroxyl, a carbonyl (such as a carboxyl, an alkoxycarbonyl, a formyl, or an acyl), a thiocarbonyl (such as a thioester, a thioacetate, or a thioformate), an alkoxyl, a phosphoryl, a phosphate, a phosphonate, a phosphinate, an amino, an amido, an amidine, an imine, a cyano, a nitro, an azido, a sulfhydryl, an alkylthio, a sulfate, a sulfonate, a sulfamoyl, a sulfonamido, a sulfonyl, a heterocyclyl, an aralkyl, or an aromatic or heteroaromatic moiety. It will be understood by those skilled in the art that the moieties substituted on the hydrocarbon chain can themselves be substituted, if appropriate.

A “therapeutically effective amount” of a compound with respect to the subject method of treatment, refers to an amount of the compound(s) in a preparation which, when administered as part of a desired dosage regimen (to a mammal, preferably a human) alleviates a symptom, ameliorates a condition, or slows the onset of disease conditions according to clinically acceptable standards for the disorder or condition to be

treated or the cosmetic purpose, e.g., at a reasonable benefit/risk ratio applicable to any medical treatment.

5 The term “thioether” refers to an alkyl group, as defined above, having a sulfur moiety attached thereto. In preferred embodiments, the “thioether” is represented by -S-alkyl. Representative thioether groups include methylthio, ethylthio, and the like.

As used herein, the term “treating” or “treatment” includes reversing, reducing, or arresting the symptoms, clinical signs, and underlying pathology of a condition in manner to improve or stabilize a subject's condition.

**Exemplification***Example 1**Synthesis of Compound 1*

5

*Synthesis of (A)*

To a 0 °C solution of *N*-Boc serine(methyl ether) (43.8 g, 200 mmol), triethylamine (26.5 g, 260 mmol) and 4-(dimethylamino)pyridine in dichloromethane (1.2 L) was added a solution of benzyl chloroformate (41 g, 240 mmol) in dichloromethane (250 mL) over 30 minutes. The resulting mixture was stirred at the same temperature for another 3 hours. Saturated aqueous sodium bicarbonate (200 mL) was added and organic

10

layer was separated, the residual mixture was extracted with dichloromethane (2 x 400 mL). The combined organic layers were washed with saturated aqueous sodium bicarbonate (200 mL) and brine (200 mL), dried over sodium sulfate and filtered through Celite-545. The solvents were removed under reduced pressure and residue was purified by flash chromatography (silica gel, hexane and ethyl acetate). Compound (A) (54 g) was isolated and characterized by LC/MS (LRMS(MH)  $m/z$ : 310.16).

*Synthesis of (B)*

To a 0 °C solution of Compound (A) (54 g) in dichloromethane (200 mL) was added trifluoroacetic acid (200 mL) over 10 minutes, and the resulting mixture was stirred at the same temperature for another 3 hours. The solvents were removed under reduced pressure and the residue was placed under high vacuum overnight giving the TFA salt of Compound (B), which was characterized by LC/MS (LRMS (MH)  $m/z$ : 210.11).

*Synthesis of (C)*

To a 0 °C solution of Compound (B) (43.8 g, 200 mmol), *N*-Boc serine(methyl ether) (36.7 g, 167 mmol), HOBt (27 g, 200 mmol) and HBTU (71.4 g, 200 mmol) in tetrahydrofuran (1.2 L) was added a solution of *N,N*-diethylisopropylamine (75 g, 600 mmol) in tetrahydrofuran (250 mL) over 10 minutes, and the pH of the resulting mixture was ~8. The mixture was stirred at room temperature for another 5 hours. Most of the solvent were removed under reduced pressure at room temperature and diluted with saturated aqueous sodium bicarbonate (400 mL). Then it was extracted with ethyl acetate (3 x 400 mL), washed with sodium bicarbonate (100 mL) and brine (100 mL). The combined organic layers were dried over sodium sulfate and filtered through Celite-545. The solvents were removed under reduced pressure and residue was purified by flash chromatography (silica gel, hexane and ethyl acetate). Compound (C) (65 g) was isolated and characterized by LC/MS (LRMS (MH)  $m/z$ : 411.21).

*Synthesis of (D)*

To a 0 °C solution of Compound (C) (18 g) in dichloromethane (100 mL) was added trifluoroacetic acid (80 mL) over 5 minutes, and the resulting mixture was stirred at the same temperature for another 3 hours. The solvents were removed under reduced pressure and the residue was placed under high vacuum overnight giving the TFA salt of intermediate (D), which was characterized by LC/MS (LRMS (MH)  $m/z$ : 311.15).

*Synthesis of (E)*

To a 0 °C solution of ethyl 2-methyl-thiazole-5-carboxylate (15 g, 88 mmol) in tetrahydrofuran (50 mL) was added aqueous sodium hydroxide solution (5 N, 50 mL) over 10 minutes, and the resulting solution was stirred at room temperature for another 2 hours. It was then acidified with hydrochloric acid (2 N) to pH=1 and extracted with tetrahydrofuran (3 x 100 mL). The combined organic layers were washed with brine (30 mL) and dried over sodium sulfate. Most of the solvents were removed under reduced pressure and the residue was lyophilized to afford Compound (E) (14 g).

*Synthesis of (F)*

To a 0 °C solution of Compound (D) (41 mmol) and 2-methyl-thiazole-5-carboxylic acid (E) (6.0 g, 42 mmol), HOBT (7.9 g, 50 mmol) and HBTU (18.0 g, 50 mmol) in tetrahydrofuran (800 mL) was added a solution of N,N-diethylisopropylamine (~50 g) in tetrahydrofuran (200 mL) over 5 minutes until its pH reached approximately 8.5. The resulting mixture was stirred at same temperature overnight. It was then quenched with saturated aqueous sodium bicarbonate solution (200 mL), and most of the solvents were removed under reduced pressure. The residual mixture was extracted with ethyl acetate (3 x 400 mL). The combined organic layers were washed with saturated aqueous sodium bicarbonate (200 mL) and brine (100 mL), dried over sodium sulfate and filtered through Celite-545. The solvents were removed under reduced pressure and residue was purified by flash chromatography (silica gel, ethyl acetate with 2% methanol). Compound (F) (17.1 g) was isolated and characterized by LC/MS (LRMS (MH)  $m/z$ : 436.15).

*Synthesis of (G)*

To a solution of Compound (F) (17.1 g, 95 mmol) in methanol (300 mL) was added 10% Pd/C (3 g). The resulting mixture was allowed to stir under 1 atmosphere of hydrogen for 48 hours. The mixture was filtered through Celite 545 and the filter cake was washed with methanol (~200 mL). The organic layers were concentrated under reduced pressure and placed under high vacuum to yield Compound (G), which was characterized by LC/MS (LRMS (MH)  $m/z$ : 346.1).

*Synthesis of (H)*

N-Boc phenylalanine-ketoepoxide (140 mg, 0.46 mmol) was diluted with DCM (2 mL) and cooled to 0 °C. To this solution was added trifluoroacetic acid (6 mL). The cooling bath was removed and the reaction stirred for 1 hour at which time TLC showed complete consumption of starting material. The resulting solution was concentrated under reduced pressure and placed under high vacuum to yield TFA salt of Compound (H).

*Synthesis of Compound 1*

To a 0 °C solution of aforementioned Compounds (H) (131 mg, 0.38 mmol) and (J) (0.46 mmol), HOBT (75 mg, 0.48 mmol) and HBTU (171 mg, 0.48 mmol) in tetrahydrofuran (20 mL) and *N,N*-dimethylformamide (10 mL) was added *N,N*-diethylisopropylamine (1 mL) dropwise. The mixture was stirred at the same temperature for another 5 hours. It was then quenched with saturated aqueous sodium bicarbonate solution (20 mL), and most of the solvents were removed under reduced pressure. The residual mixture was then extracted with ethyl acetate (3 x 40 mL). The combined organic layers were washed with saturated aqueous sodium bicarbonate (20 mL) and brine (10 mL), dried over sodium sulfate and filtered through Celite-545. The solvents were removed under reduced pressure and residue was purified by HPLC (0.02 M aqueous ammonium acetate and acetonitrile (66/34) to afford Compound 1 (92 mg), which was lyophilized and characterized by LC/MS (LRMS (MH) *m/z*: 533.2).

*Example 2*

Amorphous Compound 1 (50 mg) was dissolved in acetonitrile (1 mL), then deionized water (2 mL) was added, and the solution brought to supersaturation by slowly evaporating off 1 mL over about 1-2 weeks. The resulting crystals were filtered, washed with 1 mL 1:2 acetonitrile-water, and dried under vacuum for 12 hours to provide a crystalline polymorph of Compound 1 (25 mg) with a melting point of 148 °C. The characteristic DSC curve of the sample is shown in Figure 1 as recorded on a TA Instruments Differential Scanning Calorimeter 2920 at a heating rate of 10 °C/minute.

*Example 3*

Amorphous Compound 1 (611 mg) was dissolved in tetrahydrofuran (5 mL), followed by addition of hexanes (5 mL) and the solution was seeded with crystalline polymorph Compound 1 as prepared in Example 2, and the solution brought to

supersaturation by slowly evaporating off 5 mL over about 17 hours. The resulting crystals were filtered, washed with 1 mL 1:1 tetrahydrofuran-hexanes, and dried under vacuum for 12 hours to provide a crystalline polymorph of Compound 1 (150 mg) with a melting point of 147 °C.

5     *Example 4*

Amorphous Compound 1 (176 mg) was dissolved in tetrahydrofuran (5 mL), then toluene (25 mL) was added. The solution was seeded with crystalline polymorph Compound 1 as prepared in Example 2, and the solution was brought to supersaturation by slowly evaporating off 20 mL over about 2 days. The resulting crystals were filtered,  
10     washed with 15 mL toluene, and dried under vacuum for 12 hours to provide a crystalline polymorph of Compound 1 (88 mg) with a melting point of 149 °C.

*Example 5*

Amorphous Compound 1 (312 mg) was dissolved in toluene (50 mL), heated to about 100 °C to complete dissolution, then hexanes (50 mL) were added and the solution  
15     was seeded with crystalline polymorph Compound 1 as prepared in Example 2, and the solution brought to supersaturation by slowly evaporating off 60 mL over about 2 days. The resulting crystals were filtered, washed with 10 mL toluene, and dried under vacuum for 12 hours to provide a crystalline polymorph of Compound 1 (156 mg) with a melting point of 149 °C.

20     *Example 6*

Amorphous Compound 1 (1.4 g) was dissolved in toluene (25 mL), heated to about 50 °C to complete dissolution, then brought to supersaturation by cooling to 22 °C and allowing the compound to crystallize for 12 hours. The resulting crystals were filtered, washed with 5 mL hexanes, and dried under vacuum for 12 hours to provide a  
25     crystalline polymorph of Compound 1 (0.94 g) with a melting point of 149 °C.

*Example 7*

*Synthesis of Compound 1*

*Synthesis of (H)*

N-Boc phenylalanine-ketoepoxide (1.0 equivalent) was dissolved in DCM (3 L/kg  
30     of N-Boc phenylalanine-ketoepoxide) in a 3-neck round bottom flask under inert

atmosphere and the solution was cooled in ice bath. Then, TFA (5.0 equivalents) was added at a rate to maintain the internal temperature below 10 °C. The reaction mixture was then warmed to approximately 20 °C and stirred for 1 to 3 hours. MTBE (3.6 L/kg of N-Boc phenylalanine-ketoepoxide) was then added to the reaction mixture while  
5 maintaining mixture temperature below 25 °C. Heptane (26.4 L/kg of N-Boc phenylalanine-ketoepoxide) was then added the reaction was cooled to between -5 and 0 °C for 2 to 3 hours to allow crystallization of Compound (H). The white solid was filtered and rinsed with heptane (3 L/kg of N-Boc phenylalanine-ketoepoxide). The white solid was then under vacuum for 12 hours at 22 °C. Yield obtained was 86%, with HPLC  
10 purity 99.4%.

#### *Synthesis of Compound 1*

Compound (H) (1.2 equivalents), Compound (G) (1.0 equivalent), HBTU (1.2 equivalents), HOBT (1.2 equivalents) and N-methyl pyrrolidinone (8 L/kg of Compound (G)) were added to a dry flask under inert atmosphere, and the mixture was stirred at 23  
15 °C to complete dissolution. The reaction was then cooled to between -5 and 0 °C, and diisopropylethylamine (2.1 equivalents) was added over 15 minutes, while maintaining an internal reaction temperature of less than 0 °C. The reaction mixture was stirred at 0 °C for 12 hours.

Crude Compound 1 was precipitated by pouring the reaction mixture onto 8%  
20 sodium bicarbonate (40 L/kg of Compound (G)) and the suspension of crude Compound 1 was stirred for 12 hours at 20 to 25 °C, followed by stirring at 0 to 5 °C for 1 hour. The white solid was filtered and rinsed with water (5 L/kg of Compound (G)). The white solid was then reslurried in water (15 L/kg) for 3 hours at 20 to 25 °C, filtered and rinsed with water (5 L/kg of Compound (G)) and isopropyl acetate (2 x 2 L/kg of Compound  
25 (G)). The white solid was dried under vacuum at 45 °C to constant weight. Yield of crude Compound 1 was 65%, with HPLC purity of 97.2%.

Crude Compound 1 was completely dissolved in isopropyl acetate (20 L/kg of crude Compound 1) by stirring and heating at 85 °C. The solution was then hot filtered to remove any particulate mater and the solution was re-heated to 85 °C to provide clear  
30 solution. The clear solution was allowed to cool at 10 °C per hour to 65 °C before adding seed crystals. The solution was allowed to cool at 10 °C per hour to 20 °C, when substantial crystallization of Compound 1 occurred. The suspension was stirred at 20 °C

for 6 hours, followed by stirring at 0 to 5 °C for a minimum of 2 hours and filtration and rinsing with isopropyl acetate (1 L/kg of crude Compound 1). The purified Compound 1 was dried under vacuum at 45 °C for a minimum of 24 hours to constant weight. Yield of Compound 1 was 87%, with HPLC purity 97.2%.

5     *Example 8*

*Synthesis of Compound 1*

Compound (H) (1.1 equivalents), Compound (G) (1.0 equivalent), HBTU (1.5 equivalents), HOBT (1.5 equivalents) and DMF (8 L/kg of Compound (G)) were added to a dry flask under inert atmosphere, and the mixture was stirred at 23 °C to complete  
10     dissolution. The reaction was then cooled to between -5 and 0 °C, and diisopropylethylamine (2.1 equivalents) was added over 15 minutes, while maintaining an internal reaction temperature of less than 0 °C. The reaction mixture was then stirred at 0 °C for 3 hours.

The reaction mixture was quenched by addition of pre-chilled saturated sodium  
15     bicarbonate (94 L/kg of Compound (G)), while maintaining internal temperature of less than 10 °C. The content was then transferred to a separatory funnel. The mixture was extracted with ethyl acetate (24 L/kg of Compound (G)), and the organic layer was washed with saturated sodium bicarbonate (12 L/kg of Compound (G)) and with saturated sodium chloride (12 L/kg of Compound (G)).

20     The organic layer was concentrated under reduced pressure with a bath temperature of less than 30 °C to 15 L/kg of Compound (G), followed by co-distillation with isopropyl acetate (2 x 24 L/kg of PR-022). Final volume was adjusted to 82 L/kg of Compound (G) with isopropyl acetate before heating to 60 °C to obtain a clear solution. The clear solution mixture was allowed to cool to 50 °C before adding seed crystals. The  
25     solution was allowed to cool to 20 °C, when substantial crystallization of Compound 1 had occurred. The suspension was stirred at 0 °C for 12 hours before filtration and rinsing with isopropyl acetate (2 L/kg of Compound 1). Compound 1 was dried under vacuum at 20 °C for 12 hours to constant weight. Yield of Compound 1 was 48%, with HPLC purity of 97.4%.

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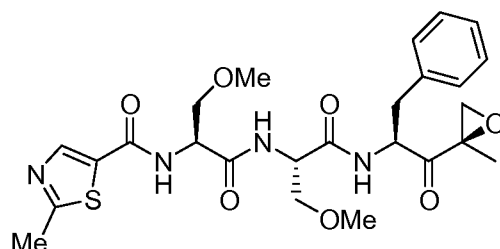
**Equivalents**

Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, numerous equivalents to the compounds and methods of use thereof described herein. Such equivalents are considered to be within the scope of this invention and are covered by the following claims.

All of the above-cited references and publications are hereby incorporated by reference.

**We Claim:**

1. A method for preparing a crystalline compound of Formula (II)



(II)

- 5 comprising (i) preparing a solution of a compound of Formula (II) in an organic solvent;  
(ii) bringing the solution to supersaturation to cause formation of crystals; and (iii)  
isolating the crystals.
2. A method of claim 1, wherein the organic solvent is selected from  
acetonitrile, ethyl acetate, heptanes, hexanes, isopropyl acetate, methanol, methylethyl  
10 ketone, tetrahydrofuran, toluene and water, or any combination thereof.
3. A method of claim 2, wherein the organic solvent is selected from  
acetonitrile, heptanes, hexanes, methanol, tetrahydrofuran, and toluene.
4. A method of claim 3, wherein the organic solvent is selected from  
hexanes, tetrahydrofuran and toluene.
- 15 5. A method of any one of claims 1 to 4, wherein bringing the solution to  
supersaturation comprises addition of an anti-solvent, allowing the solution to cool,  
reducing the volume of the solution, or any combination thereof.
6. A method of claim 5, wherein bringing the solution to supersaturation  
comprises adding an anti-solvent, cooling the solution to ambient temperature, and  
20 reducing the volume of the solution.
7. A method of claim 5, wherein the anti-solvent is added slowly.

8. A method of claim 5, wherein the anti-solvent is selected from hexanes, toluene and water.

9. A method of claim 5, wherein the volume reduction is performed by evaporation.

5 10. A method of any one of claims 1 to 9, further comprising seeding the solution.

11. A method of claim 10, further comprising washing the crystals.

12. A method of claim 11, wherein the washing comprises washing with a liquid selected from anti-solvent, acetonitrile, heptanes, hexanes, methanol,  
10 tetrahydrofuran, toluene, water, or a combination thereof.

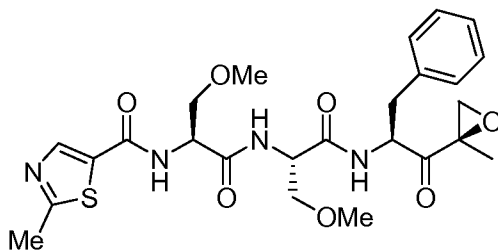
13. A method of claim 12, wherein washing comprises washing with a combination of an anti-solvent and the organic solvent.

14. A method of claim 13, wherein the anti-solvent is hexanes or heptanes.

15 15. A method of any one of claims 1 to 14, wherein isolating the crystals comprises filtering the crystals.

16. A method of any one of claims 1 to 15, further comprising drying the crystals under reduced pressure.

17. A crystalline compound having a structure of Formula (II)



(II)

18. A crystalline compound of claim 17, having a DSC thermogram substantially as shown in Figure 1.

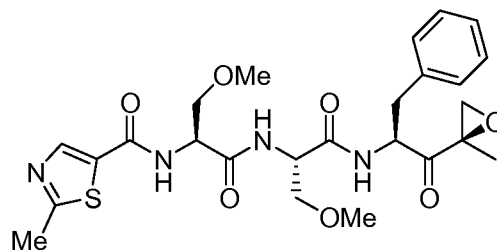
19. A crystalline compound of claim 17, having a melting point of about 140 to about 155 °C.

20. A crystalline compound of claim 19, having a melting point of about 145 to about 150 °C.

21. A crystalline compound of claim 17, having an XRPD pattern substantially as shown in Figure 2.

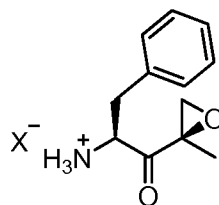
22. A crystalline compound of claim 17 having 2θ values 8.94; 9.39; 9.76; 10.60; 11.09; 12.74; 15.27; 17.74; 18.96; 20.58; 20.88; 21.58; 21.78; 22.25; 22.80; 24.25; 24.66; 26.04; 26.44; 28.32; 28.96; 29.65; 30.22; 30.46; 30.78; 32.17; 33.65; 34.49; 35.08; 35.33; 37.85; 38.48.

23. A method for the preparation of a crystalline compound of Formula (II),



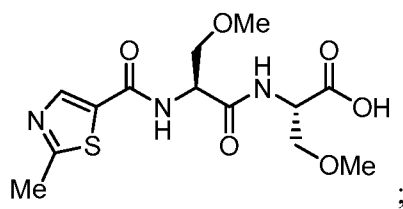
(II)

comprising (i) reacting a compound of Formula (III)



(III)

wherein X is any suitable counterion, with a compound of Formula (IV) in a second organic solvent



(IV)

- (ii) preparing a solution of a compound of Formula (II) in the second organic solvent; (iii) bringing the solution to supersaturation to permit formation of crystals; and (iv) isolating the crystals to provide a crystalline compound of Formula (II).

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