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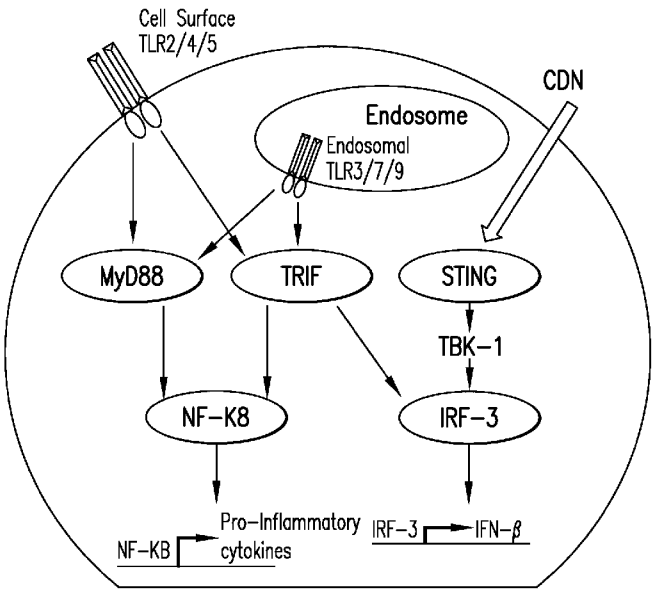

FIG. 1

(57) Abstract: The present invention provides cyclic-di-nucleotide (CDN) compounds that inhibit signaling at a recently discovered cytoplasmic receptor known as STING (Stimulator of Interferon Genes). In particular, the CDNs of the present invention are provided in the form of a composition comprising one or more cyclic purine dinucleotides which inhibit STING-dependent TBK1 activation and the resulting production of type I interferon.

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COMPOSITIONS AND METHODS FOR INHIBITING "STIMULATOR OF INTERFERON GENE"-DEPENDENT SIGNALLING

[0001] The present application claims priority to United States Provisional Application 61/825,009 filed May 18, 2013, and to United States Provisional Application 61/902,125 filed November 8, 2013, each of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] The following discussion of the background of the invention is merely provided to aid the reader in understanding the invention and is not admitted to describe or constitute prior art to the present invention.

[0003] The human immune system may generally be divided into two arms, referred to as "innate immunity" and "adaptive immunity." The innate arm of the immune system is predominantly responsible for an initial inflammatory response via a number of soluble factors, including the complement system and the chemokine/cytokine system; and a number of specialized cell types including mast cells, macrophages, dendritic cells (DCs), and natural killer cells. In contrast, the adaptive immune arm involves a delayed and a longer lasting antibody response together with CD8+ and CD4+ T cell responses that play a critical role in immunological memory against an antigen. A third arm of the immune system may be identified as involving γδ T cells and T cells with limited T cell receptor repertoires such as NKT cells and MAIT cells.

[0004] For an effective immune response to an antigen, antigen presenting cells (APCs) must process and display the antigen in a proper MHC context to a T cell, which then will result in either T cell stimulation of cytotoxic and helper T cells. Following antigen presentation successful interaction of co-stimulatory molecules on both APCs and T cells must occur or activation will be aborted. GM-CSF and IL-12 serve as effective pro-inflammatory molecules in many tumor models. For example, GM-CSF induces myeloid precursor cells to proliferate and differentiate into dendritic cells (DCs) although additional signals are necessary to activate their maturation to effective antigen-presenting cells necessary for activation of T cells. Barriers to effective immune therapies include tolerance to the targeted antigen that can limit induction of cytotoxic CD8 T cells

of appropriate magnitude and function, poor trafficking of the generated T cells to sites of malignant cells, and poor persistence of the induced T cell response.

[0005] DCs that phagocytose tumor-cell debris process the material for major histocompatibility complex (MHC) presentation, upregulate expression of costimulatory molecules, and migrate to regional lymph nodes to stimulate tumor-specific lymphocytes. This pathway results in the proliferation and activation of CD4+ and CD8+ T cells that react to tumor-associated antigens. Indeed, such cells can be detected frequently in the blood, lymphoid tissues, and malignant lesions of patients.

[0006] New insights into the mechanisms underlying immune-evasion, together with combination treatment regimens that potentiate the potency of therapeutic vaccination—either directly or indirectly—through combination with immune checkpoint inhibitors or other therapies, have served as a basis for the development of vaccines that induce effective antitumor immunity. The CDNs cyclic-di-AMP (produced by Listeria monocytogenes) and its analog cyclic-di-GMP (produced by Legionella pneumophila) are recognized by the host cell as a PAMP (Pathogen Associated Molecular Pattern), which bind to the PRR (Pathogen Recognition Receptor) known as STING. STING is an adaptor protein in the cytoplasm of host mammalian cells which activates the TANK binding kinase (TBK1)—IRF3 signaling axis, resulting in the induction of IFN-β and other IRF-3 dependent gene products that strongly activate innate immunity. It is now recognized that STING is a component of the host cytosolic surveillance pathway, that senses infection with intracellular pathogens and in response induces the production of IFN-β, leading to the development of an adaptive protective pathogen-specific immune response consisting of both antigen-specific CD4 and CD8 T cells as well as pathogen-specific antibodies. Examples of cyclic purine dinucleotides are described in some detail in, e.g., U.S. Patent Nos. 7,709458 and 7,592,326; WO2007/054279; and Yan et al., Bioorg. Med. Chem Lett. 18: 5631 (2008), each of which is hereby incorporated by reference.

[0007] There remains a need for improved compositions and methods for immunologic strategies to treating diseases such as cancer that can be refractory to traditional therapeutic approaches.

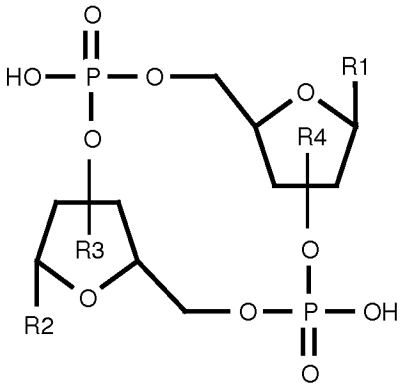
SUMMARY OF THE INVENTION

[0008] It is an object of the present invention to provide combination therapies for the treatment of cancer.

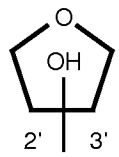
[0009] In a first aspect, the present invention provides compositions comprising:

one or more cyclic purine dinucleotides ("CDNs") which that inhibit STimulator of INTerferon Gene ("STING")-dependent type I interferon production. As described hereinafter, a number of CDNs find use in the present invention. Preferred cyclic purine dinucleotides include, but are not limited to, one or more of c-di-AMP, c-di-GMP, c-di-IMP, c-AMP-GMP, c-AMP-IMP, c-GMP-IMP, and analogs thereof. This list is not meant to be limiting.

[0010] The general structure of a cyclic purine dinucleotide according to the present invention is as follows:



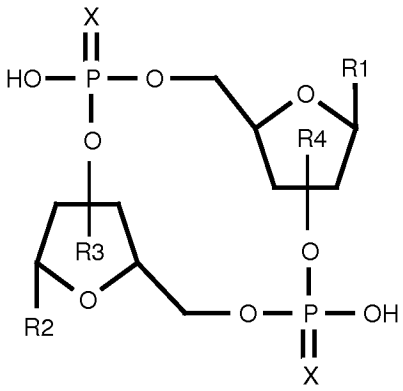
, where each R1 and R2 is a purine, and the structure



is intended to reflect that the phosphate linkage may be to either the 2' or 3'position on the ribose, and the other of the 2' or 3' position which is not participating in the cyclic linkage is an –OH. Thus, the present invention contemplates 2',5',2',5' CDNs, 2',5',3',5' CDNs, and 3',5',3',5' CDNs. BY way of example, c-di-GMP having 3'-5' linkages refers to the molecule indicated above where each of R1 and R2 are guanine, and each phosphate linkage is 3'-to-5'.

[0011] For purposes of the present invention, this general structure is further modified to introduce substituents which confer the ability to inhibit STING-dependent signaling, and

thereby inhibit STING-dependent type I interferon production. By way of example, the present invention provides compositions comprising the following compounds:



, wherein each X is independently O or S, and R3 and R4 are each independently H or an optionally substituted straight chain alkyl of from 1 to 18 carbons and from 0 to 3 heteroatoms, an optionally substituted alkenyl of from 1-9 carbons, an optionally substituted alkynyl of from 1-9 carbons, or an optionally substituted aryl, wherein substitution(s), when present, may be independently selected from the group consisting of C_{1-6} alkyl straight or branched chain, benzyl, halogen, trihalomethyl, C_{1-6} alkoxy, $-NO_2$, $-NH_2$, –OH, =O, –COOR' where R' is H or lower alkyl, $-CH_2OH$, and $-CONH_2$, wherein R3 and R4 are not both H.

[0012] In preferred embodiments, one or both of R3 and R4 are independently an unsubstituted straight chain alkyl of from 1 to 18 carbons, an unsubstituted alkenyl of from 1-9 carbons, an unsubstituted alkynyl of from 1-9 carbons, or an unsubstituted aryl. In certain embodiments, one or both of R3 and R4 are allyl, propargyl, homoallyl, homopropargyl, methyl, ethyl, propyl, isopropyl, isobutyl, cyclopropylmethyl, or benzyl, either substituted or unsubstituted. In certain embodiments, one, but not both, or R3 and R4 provide a prodrug leaving group such as an aliphatic ester which is removed by cellular esterases.

[0013] In certain embodiments, each X is S. In preferred embodiments when each X is S, the compositions comprise one or more substantially pure Sp,Sp, Rp,Rp, Sp,Rp, or Rp,Sp stereoisomers.

[0014] In certain embodiments, each of R1 and R2 are independently selected from the group consisting of adenine, guanine, inosine, and xanthine or analogs thereof. Preferably, each of R1 and R2 are independently adenine or guanine.

[0015] As described hereinafter, a cyclic purine dinucleotide composition according to the present invention can inhibit STING-dependent type I interferon production at least 2-fold, and more preferably 5-fold or 10-fold, or more, as compared to c-di-GMP having 3'-5' linkages.

[0016] The compositions of the present invention may be administered to individuals in need thereof by a variety of parenteral and nonparenteral routes in formulations containing pharmaceutically acceptable carriers, adjuvants and vehicles. Preferred routes are parenteral, and include but, are not limited to, one or more of subcutaneous, intravenous, intramuscular, intraarterial, intradermal, intrathecal and epidural administrations. Particularly preferred is administration by subcutaneous administration. Preferred pharmaceutical compositions are formulated as aqueous, liposomal, or oil-in-water emulsions. Exemplary compositions are described hereinafter.

[0017] In related aspects, the present invention relates to methods of inhibiting or moderating an immune response in an individual, comprising administering a composition according to the present invention to an individual in need thereof. In other related aspects, the present invention relates to methods of inhibiting or moderating type I interferon production in an individual, comprising administering a composition according to the present invention to an individual in need thereof. Examples of autoimmune diseases which may be treated using the compositions of the present invention include, but are not limited to, alopecia areata, autoimmune hemolytic anemia, autoimmune hepatitis, dermatomyositis, diabetes (type 1), autoimmune juvenile idiopathic arthritis, glomerulonephritis, Graves' disease, Guillain-Barré syndrome, idiopathic thrombocytopenic purpura, lupus, myasthenia gravis, some forms of myocarditis, multiple sclerosis, pemphigus/pemphigoid, pernicious anemia, polyarteritis nodosa, polymyositis, primary biliary cirrhosis, psoriasis, rheumatoid arthritis, scleroderma/systemic sclerosis, Sjögren's syndrome, systemic lupus erythematosus, some forms of thyroiditis, some forms of uveitis, vitiligo, and granulomatosis with polyangiitis (Wegener's).

[0018] In other embodiments, the methods described herein can comprise administering to the mammal an effective amount of the substantially pure CDNs of the present invention for the treatment of disorders in which shifting of Th1 to Th2 immunity confers clinical benefit. Cell-mediated immunity (CMI) is associated with TH1 CD4+ T

lymphocytes producing cytokines IL-2, interferon (IFN)-γ and tumor necrosis factor (TNF)-α. In contrast, humoral immunity is associated with TH2 CD4+ T lymphocytes producing IL-4, IL-6 and IL-10. Immune deviation towards TH1 responses typically produces activation of cytotoxic T-cell lymphocytes (CTL), natural killer (NK) cells, macrophages and monocytes. Generally, Th1 responses are more effective against intracellular pathogens (viruses and bacteria that are inside host cells) and tumors, while Th2 responses are more effective against extracellular bacteria, parasites including helminths and toxins. Type I interferons (IFNs-I) are believed to mediate the lethal effects of endotoxemia and sepsis, and so the methods and compositions of the present invention can find use in the treatment of sepsis. In addition, the activation of innate immunity is expected to normalize the T-helper type 1 and 2 (Th1/Th2) immune system balance and to suppress the excessive reaction of Th2 type responses that cause immunoglobulin (Ig) E-dependent allergies and allergic asthma.

BRIEF DESCRIPTION OF THE FIGURES

[0019] Fig. 1 depicts cyclic purine dinucleotide ("CDN")-mediated signaling. A CDN (e.g., c-di-AMP or c-di-GMP) induces production of IFN-β by binding to the cytosolic adaptor protein STING (Stimulator of Interferon Genes), and inducing signaling through the TBK-1/IRF-3 pathway, resulting in both autocrine and paracrine activation of DCs through binding to the IFN receptor and subsequent signaling.

[0020] Fig. 2 depicts a synthesis scheme Synthesis of 2'-O-propargyl-cyclic-A(2',5')pA(3',5')p (2'-O-propargyl-ML-CDA).

[0021] Fig. 3A depicts ^{1}H NMR analytical results for 2'-O-propargyl-ML-CDA (compound 8).

[0022] Fig. 3B depicts ^{31}P NMR analytical results for 2'-O-propargyl-ML-CDA (compound 8).

[0023] Fig. 3C depicts COSY (2.5-6.5ppm – ^{1}H axis) analytical results for 2'-O-propargyl-ML-CDA (compound 8).

[0024] Fig. 3D depicts HMBC (3.5-6.5ppm – ^{1}H axis) analytical results for 2'-O-propargyl-ML-CDA (compound 8).

[0025] Fig. 3E depicts analytical HPLC (2-20% ACN/10 mM TEAA buffer – 20 min) analytical results for 2'-O-propargyl-ML-CDA (compound 8).

[0026] Fig. 4 depicts c-[G(2',5')pG(3',5')p] and dithio ribose O-substitued derivatives.

[0027] Fig. 5 depicts c-[A(2',5')pA(3',5')p] and dithio ribose O-substitued derivatives.

[0028] Fig. 6 depicts c-[G(2',5')pA(3',5')p] and dithio ribose O-substitued derivatives.

[0029] Fig. 7 depicts 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (2'-O-propargyl-ML-CDA) inhibition of STING-dependent activation of type I interferon.

DETAILED DESCRIPTION OF THE INVENTION

[0030] The present invention relates to the use of novel cyclic-di-nucleotide (CDN) compounds that inhibit signaling at a recently discovered cytoplasmic receptor known as STING (Stimulator of Interferon Genes). In particular, the CDNs of the present invention are provided in the form of a composition comprising one or more cyclic purine dinucleotides which inhibit STING-dependent TBK1 activation and the resulting production of type I interferon.

[0031] The CDNs cyclic-di-AMP (produced by Listeria monocytogenes) and its analog cyclic-di-GMP (produced by Legionella pneumophila) are recognized by the host cell as a PAMP (Pathogen Associated Molecular Pattern), which bind to the PRR (Pathogen Recognition Receptor) known as STING. STING is an adaptor protein in the cytoplasm of host mammalian cells which activates the TANK binding kinase (TBK1)—IRF3 signaling axis, resulting in the induction of IFN-γ and other IRF-3 dependent gene products that strongly activate innate immunity. It is now recognized that STING is a component of the host cytosolic surveillance pathway, that senses infection with intracellular pathogens and in response induces the production of IFN, leading to the development of an adaptive protective pathogen-specific immune response consisting of both antigen-specific CD4 and CD8 T cells as well as pathogen-specific antibodies.

[0032] In the case of autoimmune diseases, inhibitors of this pathway can provide a novel therapeutic route which has not been previously exploited.

[0033] Definitions

[0034] "Administration" as it is used herein with regard to a human, mammal, mammalian subject, animal, veterinary subject, placebo subject, research subject, experimental subject, cell, tissue, organ, or biological fluid, refers without limitation to contact of an exogenous ligand, reagent, placebo, small molecule, pharmaceutical agent, therapeutic agent, diagnostic agent, or composition to the subject, cell, tissue, organ, or biological fluid, and the like. "Administration" can refer, *e.g.*, to therapeutic, pharmacokinetic, diagnostic, research, placebo, and experimental methods. Treatment of a cell encompasses contact of a reagent to the cell, as well as contact of a reagent to a fluid, where the fluid is in contact with the cell. "Administration" also encompasses in vitro and ex vivo treatments, *e.g.*, of a cell, by a reagent, diagnostic, binding composition, or by another cell. By "administered together" it is not meant to be implied that two or more agents be administered as a single composition. Although administration as a single composition is contemplated by the present invention, such agents may be delivered to a single subject as separate administrations, which may be at the same or different time, and which may be by the same route or different routes of administration.

[0035] An "agonist," as it relates to a ligand and receptor, comprises a molecule, combination of molecules, a complex, or a combination of reagents, that stimulates the receptor. For example, an agonist of granulocyte-macrophage colony stimulating factor (GM-CSF) can encompass GM-CSF, a mutein or derivative of GM-CSF, a peptide mimetic of GM-CSF, a small molecule that mimics the biological function of GM-CSF, or an antibody that stimulates GM-CSF receptor.

[0036] An "antagonist," as it relates to a ligand and receptor, comprises a molecule, combination of molecules, or a complex, that inhibits, counteracts, downregulates, and/or desensitizes the receptor. "Antagonist" encompasses any reagent that inhibits a constitutive activity of the receptor. A constitutive activity is one that is manifest in the absence of a ligand/receptor interaction. "Antagonist" also encompasses any reagent that inhibits or prevents a stimulated (or regulated) activity of a receptor. By way of example, an antagonist of GM-CSF receptor includes, without implying any limitation, an antibody that binds to the ligand (GM-CSF) and prevents it from binding to the receptor, or an antibody that binds to the receptor and prevents the ligand from binding to the receptor, or where the antibody locks the receptor in an inactive conformation.

[0037] By "substantially purified" with regard to CDNs of the invention is meant that a specified species accounts for at least 50%, more often accounts for at least 60%, typically accounts for at least 70%, more typically accounts for at least 75%, most typically accounts for at least 80%, usually accounts for at least 85%, more usually accounts for at least 90%, most usually accounts for at least 95%, and conventionally accounts for at least 98% by weight, or greater, of the CDN activity present in a composition. The weights of water, buffers, salts, detergents, reductants, protease inhibitors, stabilizers (including an added protein such as albumin), and excipients are generally not used in the determination of purity.

[0038] "Specifically" or "selectively" binds, when referring to a ligand/receptor, nucleic acid/complementary nucleic acid, antibody/antigen, or other binding pair (e.g., a cytokine to a cytokine receptor) (each generally referred to herein as a "target biomolecule" or a "target") indicates a binding reaction which is related to the presence of the target in a heterogeneous population of proteins and other biologics. Specific binding can mean, e.g., that the binding compound, nucleic acid ligand, antibody, or binding composition derived from the antigen-binding site of an antibody, of the contemplated method binds to its target with an affinity that is often at least 25% greater, more often at least 50% greater, most often at least 100% (2-fold) greater, normally at least ten times greater, more normally at least 20-times greater, and most normally at least 100-times greater than the affinity with a non-target molecule.

[0039] "Ligand" refers to a small molecule, nucleic acid, peptide, polypeptide, saccharide, polysaccharide, glycan, glycoprotein, glycolipid, or combinations thereof that binds to a target biomolecule. While such ligands may be agonists or antagonists of a receptor, a ligand also encompasses a binding agent that is not an agonist or antagonist, and has no agonist or antagonist properties. Specific binding of a ligand for its cognate target is often expressed in terms of an "Affinity." In preferred embodiments, the ligands of the present invention bind with affinities of between about 10^4 M^{-1} and about 10^8 M^{-1}. Affinity is calculated as $K_d = k_{off}/k_{on}$ (k_{off} is the dissociation rate constant, K_{on} is the association rate constant and K_d is the equilibrium constant).

[0040] Affinity can be determined at equilibrium by measuring the fraction bound (r) of labeled ligand at various concentrations (c). The data are graphed using the Scatchard equation: r/c = K(n-r): where r = moles of bound ligand/mole of receptor at equilibrium; c

= free ligand concentration at equilibrium; K = equilibrium association constant; and n = number of ligand binding sites per receptor molecule. By graphical analysis, r/c is plotted on the Y-axis versus r on the X-axis, thus producing a Scatchard plot. Affinity measurement by Scatchard analysis is well known in the art. *See, e.g.*, van Erp *et al., J. Immunoassay* 12: 425-43, 1991; Nelson and Griswold, *Comput. Methods Programs Biomed.* 27: 65-8, 1988. In an alternative, affinity can be measured by isothermal titration calorimetry (ITC). In a typical ITC experiment, a solution of ligand is titrated into a solution of its cognate target. The heat released upon their interaction (ΔH) is monitored over time. As successive amounts of the ligand are titrated into the ITC cell, the quantity of heat absorbed or released is in direct proportion to the amount of binding. As the system reaches saturation, the heat signal diminishes until only heats of dilution are observed. A binding curve is then obtained from a plot of the heats from each injection against the ratio of ligand and binding partner in the cell. The binding curve is analyzed with the appropriate binding model to determine K_B, n and ΔH. Note that $K_B = 1/K_d$.

[0041] The term "subject" as used herein refers to a human or non-human organism. Thus, the methods and compositions described herein are applicable to both human and veterinary disease. In certain embodiments, subjects are "patients," i.e., living humans that are receiving medical care for a disease or condition. This includes persons with no defined illness who are being investigated for signs of pathology. Preferred are subjects who have an existing diagnosis of a particular cancer which is being targeted by the compositions and methods of the present invention. Preferred cancers for treatment with the compositions described herein include, but are not limited to prostate cancer, renal carcinoma, melanoma, pancreatic cancer, cervical cancer, ovarian cancer, colon cancer, head & neck cancer, lung cancer and breast cancer.

[0042] "Therapeutically effective amount" is defined as an amount of a reagent or pharmaceutical composition that is sufficient to show a patient benefit, i.e., to cause a decrease, prevention, or amelioration of the symptoms of the condition being treated. When the agent or pharmaceutical composition comprises a diagnostic agent, a "diagnostically effective amount" is defined as an amount that is sufficient to produce a signal, image, or other diagnostic parameter. Effective amounts of the pharmaceutical formulation will vary according to factors such as the degree of susceptibility of the individual, the age, gender, and weight of the individual, and idiosyncratic responses of

the individual. "Effective amount" encompasses, without limitation, an amount that can ameliorate, reverse, mitigate, prevent, or diagnose a symptom or sign of a medical condition or disorder or a causative process thereof. Unless dictated otherwise, explicitly or by context, an "effective amount" is not limited to a minimal amount sufficient to ameliorate a condition.

[0043] "Treatment" or "treating" (with respect to a condition or a disease) is an approach for obtaining beneficial or desired results including and preferably clinical results. For purposes of this invention, beneficial or desired results with respect to a disease include, but are not limited to, one or more of the following: preventing a disease, improving a condition associated with a disease, curing a disease, lessening severity of a disease, delaying progression of a disease, alleviating one or more symptoms associated with a disease, increasing the quality of life of one suffering from a disease, and/or prolonging survival. Likewise, for purposes of this invention, beneficial or desired results with respect to a condition include, but are not limited to, one or more of the following: preventing a condition, improving a condition, curing a condition, lessening severity of a condition, delaying progression of a condition, alleviating one or more symptoms associated with a condition, increasing the quality of life of one suffering from a condition, and/or prolonging survival. For instance, in embodiments where the compositions described herein are used for treatment of cancer, the beneficial or desired results include, but are not limited to, one or more of the following: reducing the proliferation of (or destroying) neoplastic or cancerous cells, reducing metastasis of neoplastic cells found in cancers, shrinking the size of a tumor, decreasing symptoms resulting from the cancer, increasing the quality of life of those suffering from the cancer, decreasing the dose of other medications required to treat the disease, delaying the progression of the cancer, and/or prolonging survival of patients having cancer. Depending on the context, "treatment" of a subject can imply that the subject is in need of treatment, e.g., in the situation where the subject comprises a disorder expected to be ameliorated by administration of a reagent.

[0044] The term "antibody" as used herein refers to a peptide or polypeptide derived from, modeled after or substantially encoded by an immunoglobulin gene or immunoglobulin genes, or fragments thereof, capable of specifically binding an antigen or epitope. *See, e.g.* Fundamental Immunology, 3rd Edition, W.E. Paul, ed., Raven Press,

N.Y. (1993); Wilson (1994; J. Immunol. Methods 175:267-273; Yarmush (1992) J. Biochem. Biophys. Methods 25:85-97. The term antibody includes antigen-binding portions, i.e., "antigen binding sites," (e.g., fragments, subsequences, complementarity determining regions (CDRs)) that retain capacity to bind antigen, including (i) a Fab fragment, a monovalent fragment consisting of the VL, VH, CL and CHl domains; (ii) a F(ab')2 fragment, a bivalent fragment comprising two Fab fragments linked by a disulfide bridge at the hinge region; (iii) a Fd fragment consisting of the VH and CHl domains; (iv) a Fv fragment consisting of the VL and VH domains of a single arm of an antibody, (v) a dAb fragment (Ward et al., (1989) Nature 341:544-546), which consists of a VH domain; and (vi) an isolated complementarity determining region (CDR). Single chain antibodies are also included by reference in the term "antibody."

[0045] Cyclic Purine Dinucleotides

[0046] Prokaryotic as well as eukaryotic cells use various small molecules for cell signaling and intra- and intercellular communication. Cyclic nucleotides like cGMP, cAMP, etc. are known to have regulatory and initiating activity in pro- and eukaryotic cells. Unlike eukaryotic cells, prokaryotic cells also use cyclic purine dinucleotides as regulatory molecules. In prokaryotes, the condensation of two GTP molecules is catalyst by the enzyme diguanylate cyclase (DGC) to give c-diGMP, which represents an important regulator in bacteria.

[0047] Recent work suggests that cyclic diGMP or analogs thereof can also stimulate or enhance immune or inflammatory response in a patient or can enhance the immune response to a vaccine by serving as an adjuvant in mammals. Cytosolic detection of pathogen-derived DNA requires signaling through TANK binding kinase 1 (TBK1) and its downstream transcription factor, IFN-regulatory factor 3 (IRF3). A transmembrane protein called STING (stimulator of IFN genes; also known as MITA, ERIS, MPYS and TMEM173) functions as the signaling receptor for these cyclic purine dinucleotides, causing stimulation of the TBK1-IRF3 signalling axis and a STING-dependent type I interferon response. See, e.g., Fig. 1. Burdette et al., Nature 478: 515-18, 2011 demonstrated that STING binds directly to cyclic diguanylate monophosphate, but not to other unrelated nucleotides or nucleic acids.

[0048] Cyclic purine dinucleotides for use as precursors to derive the CDNs of the present invention are described in some detail in, e.g., Gao et al., Cell (2013) 153: doi:

10.1016/j.cell.2013.04.046; U.S. Patent Nos. 7,709458 and 7,592,326; WO2007/054279; and Yan et al., Bioorg. Med. Chem Lett. 18: 5631 (2008), each of which is hereby incorporated by reference. These CDNs may be modified using standard organic chemistry techniques in order to produce the CDNs of the present invention.

[0049] Preferred purines include, but are not limited to, adenine, guanine, inosine, hypoxanthine, xanthine, isoguanine, etc. The CDNs of the present invention are preferably phosphorothioate analogues, and most preferably substantially pure Sp,Sp, Rp,Rp, SpRp, or Rp,Sp stereoisomers thereof.

[0050] As denoted in the structures, each ribose comprises a 2' or 3' hydroxyl which may be substituted. As described hereinafter, the CDNs of the present invention can comprise a substitution at one or both of these 2' or 3' hydroxyls (which is not part of the cyclic linkage) which provide a blocking moiety that is not removed as a prodrug leaving group. Such substitutions include, but are not limited to, O-methyl, O-ethyl, O-propyl, O-isopropyl, O-benzyl, O-methoxyethyl, O-aminoethyl, O-propargyl, O-allyl, etc. This list is not meant to be limiting. The term "prodrug" as used herein refers to a modification of contemplated compounds, wherein the modified compound exhibits less pharmacological activity (as compared to the modified compound) and wherein the modified compound is converted within the body (e.g., in a target cell or target organ) back into the unmodified form through enzymatic or non-enzymatic reactions. In certain embodiments, the hydroxyl on one ribose comprises a prodrug leaving group. Prodrugs can modify the physicochemical, biopharmaceutic, and pharmacokinetic properties of drugs. Traditional prodrugs are classified as drugs that are activated by undergoing transformation in vivo to form the active drug. Reasons for prodrug development are typically poor aqueous solubility, chemical instability, low oral bioavailability, lack of blood brain barrier penetration, and high first pass metabolism associated with the parent drug. Suitable prodrug moieties are described in, for example, "Prodrugs and Targeted Delivery," J. Rautico, Ed., John Wiley & Sons, 2011.

[0051] Preferred cyclic purine dinucleotides are phosphorothioate analogues, referred to herein as "thiophosphates". Phosphorothioates are a variant of normal nucleotides in which one of the nonbridging oxygens is replaced by a sulfur. The sulfurization of the internucleotide bond dramatically reduces the action of endo-and exonucleases, including 5' to 3' and 3' to 5' DNA POL 1 exonuclease, nucleases S1 and P1, RNases, serum

nucleases and snake venom phosphodiesterase. In addition, the potential for crossing the lipid bilayer increases.

[0052] A phosphorothioate linkage in inherently chiral. The skilled artisan will recognize that the phosphates in this structure may each exist in R or S forms. Thus, Rp,Rp, Sp,Sp, Sp,Rp, and Rp,Sp forms are possible.

[0053] As noted above, cyclic purine dinucleotides of the present invention comprise 2'-O- and 3'-O- substituent forms of CDNs, and in particular CDN thiophosphates. Additional stability and bioavailability can be provided by the substitution of the 2'-OH of the ribose moiety. Substituent groups amenable herein include without limitation, halogen, hydroxyl, alkyl, alkenyl, alkynyl, acyl (-C(O)R_{aa}), carboxyl (-C(O)0-R_{aa}), aliphatic groups, alicyclic groups, alkoxy, substituted oxy (-0-R_{aa}), aryl, aralkyl, heterocyclic radical, heteroaryl, heteroarylalkyl, amino (-N(R_{bb})(R_{cc})), imino(=NR_{bb}), amido (-C(O)N(R_{bb})(Rc_C) or -N(R_{bb})C(O)R_{aa}), azido (-N_3), nitro (-N0_2), cyano (-CN), carbamido (-OC(O)N(R_{bb})(R_{cc}) or -N(R_{bb})C(O)OR_{aa}), ureido (-N(R_{bb})C(O)-N(Rbb)(Rcc)), thioureido (-N(R_{bb})C(S)N(R_{bb})(R_{cc})), guanidinyl (-N(R_{bb})C(=NR_{bb})N(R_{bb})(R_{cc})), amidinyl (-C(=NR_{bb})N(R_{bb})(Rc_C) or -N(R_{bb})C(=NR_{bb})(R_{aa})), thiol (-SR_{bb}), sulfinyl (-S(O)R_{bb}), sulfonyl (-S$(O)_2R_b$) and sulfonamidyl (-S$(O)_2$N(R_{bb})(Rc_C) or -N(R_{bb})S$(O)_2R_{bb}$). Wherein each R_{aa}, R_{bb} and R_{cC} is, independently, H, an optionally linked chemical functional group or a further substituent group with a preferred list including without limitation, H, alkyl, alkenyl, alkynyl, aliphatic, alkoxy, acyl, aryl, aralkyl, heteroaryl, alicyclic, heterocyclic and heteroarylalkyl. Selected substituents within the compounds described herein are present to a recursive degree.

[0054] The term "alkyl," as used herein, refers to a saturated straight or branched hydrocarbon radical containing up to twenty four carbon atoms. Examples of alkyl groups include without limitation, methyl, ethyl, propyl, butyl, isopropyl, n-hexyl, octyl, decyl, dodecyl and the like. Alkyl groups typically include from 1 to about 24 carbon atoms, more typically from 1 to about 12 carbon atoms with from 1 to about 6 carbon atoms being more preferred. The term "lower alkyl" as used herein includes from 1 to about 6 carbon atoms. Alkyl groups as used herein may optionally include one or more further substituent groups.

[0055] The term "alkenyl," as used herein, refers to a straight or branched hydrocarbon chain radical containing up to twenty four carbon atoms and having at least one carbon-carbon double bond. Examples of alkenyl groups include without limitation, ethenyl, propenyl, butenyl, l-methyl-2-buten-l-yl, dienes such as 1,3 -butadiene and the like. Alkenyl groups typically include from 2 to about 24 carbon atoms, more typically from 2 to about 12 carbon atoms with from 2 to about 6 carbon atoms being more preferred. Alkenyl groups as used herein may optionally include one or more further substituent groups.

[0056] The term "alkynyl," as used herein, refers to a straight or branched hydrocarbon radical containing up to twenty four carbon atoms and having at least one carbon-carbon triple bond. Examples of alkynyl groups include, without limitation, ethynyl, 1-propynyl, 1-butynyl, and the like. Alkynyl groups typically include from 2 to about 24 carbon atoms, more typically from 2 to about 12 carbon atoms with from 2 to about 6 carbon atoms being more preferred. Alkynyl groups as used herein may optionally include one or more further substituent groups.

[0057] The term "acyl," as used herein, refers to a radical formed by removal of a hydroxyl group from an organic acid and has the general Formula -C(O)-X where X is typically aliphatic, alicyclic or aromatic. Examples include aliphatic carbonyls, aromatic carbonyls, aliphatic sulfonyls, aromatic sulfinyls, aliphatic sulfinyls, aromatic phosphates, aliphatic phosphates and the like. Acyl groups as used herein may optionally include further substituent groups.

[0058] The term "alicyclic" refers to a cyclic ring system wherein the ring is aliphatic. The ring system can comprise one or more rings wherein at least one ring is aliphatic. Preferred alicyclics include rings having from about 5 to about 9 carbon atoms in the ring. Alicyclic as used herein may optionally include further substituent groups.

[0059] The term "aliphatic," as used herein, refers to a straight or branched hydrocarbon radical containing up to twenty four carbon atoms wherein the saturation between any two carbon atoms is a single, double or triple bond. An aliphatic group preferably contains from 1 to about 24 carbon atoms, more typically from 1 to about 12 carbon atoms with from 1 to about 6 carbon atoms being more preferred. The straight or branched chain of an aliphatic group may be interrupted with one or more heteroatoms that include nitrogen, oxygen, sulfur and phosphorus. Such aliphatic groups interrupted

by heteroatoms include without limitation, polyalkoxys, such as polyalkylene glycols, polyamines, and polyimines. Aliphatic groups as used herein may optionally include further substituent groups.

[0060] The term "alkoxy," as used herein, refers to a radical formed between an alkyl group and an oxygen atom wherein the oxygen atom is used to attach the alkoxy group to a parent molecule. Examples of alkoxy groups include without limitation, methoxy, ethoxy, propoxy, isopropoxy, n-butoxy, sec-butoxy, tert-butoxy, n-pentoxy, neopentoxy, n-hexoxy and the like. Alkoxy groups as used herein may optionally include further substituent groups.

[0061] The term "aminoalkyl" as used herein, refers to an amino substituted C\-Cn alkyl radical. The alkyl portion of the radical forms a covalent bond with a parent molecule. The amino group can be located at any position and the aminoalkyl group can be substituted with a further substituent group at the alkyl and/or amino portions.

[0062] The terms "aralkyl" and "arylalkyl," as used herein, refer to an aromatic group that is covalently linked to a C\-Cn alkyl radical. The alkyl radical portion of the resulting aralkyl (or arylalkyl) group forms a covalent bond with a parent molecule. Examples include without limitation, benzyl, phenethyl and the like. Aralkyl groups as used herein may optionally include further substituent groups attached to the alkyl, the aryl or both groups that form the radical group.

[0063] The terms "aryl" and "aromatic," as used herein, refer to a mono- or polycyclic carbocyclic ring system radicals having one or more aromatic rings. Examples of aryl groups include without limitation, phenyl, naphthyl, tetrahydronaphthyl, indanyl, idenyl and the like. Preferred aryl ring systems have from about 5 to about 20 carbon atoms in one or more rings. Aryl groups as used herein may optionally include further substituent groups.

[0064] The terms "halo" and "halogen," as used herein, refer to an atom selected from fluorine, chlorine, bromine and iodine.

[0065] The terms "heteroaryl," and "heteroaromatic," as used herein, refer to a radical comprising a mono- or poly-cyclic aromatic ring, ring system or fused ring system wherein at least one of the rings is aromatic and includes one or more heteroatoms. Heteroaryl is also meant to include fused ring systems including systems where one or

more of the fused rings contain no heteroatoms. Heteroaryl groups typically include one ring atom selected from sulfur, nitrogen or oxygen. Examples of heteroaryl groups include without limitation, pyridinyl, pyrazinyl, pyrimidinyl, pyrrolyl, pyrazolyl, imidazolyl, thiazolyl, oxazolyl, isooxazolyl, thiadiazolyl, oxadiazolyl, thiophenyl, furanyl, quinolinyl, isoquinolinyl, benzimidazolyl, benzooxazolyl, quinoxalinyl and the like. Heteroaryl radicals can be attached to a parent molecule directly or through a linking moiety such as an aliphatic group or hetero atom. Heteroaryl groups as used herein may optionally include further substituent groups.

[0066] The term "heteroarylalkyl," as used herein, refers to a heteroaryl group as previously defined that further includes a covalently attached C_1-C_{12} alkyl radical. The alkyl radical portion of the resulting heteroarylalkyl group is capable of forming a covalent bond with a parent molecule. Examples include without limitation, pyridinylmethyl, pyrimidinylethyl, napthyridinylpropyl and the like. Heteroarylalkyl groups as used herein may optionally include further substituent groups on one or both of the heteroaryl or alkyl portions.

[0067] The following terms are defined as follows:

allyl -CH2CH=CH2,

propargyl -CH2C≡CH,

homoallyl -CH2CH2CH=CH2, and

homopropargyl -CH2CH2C≡CH.

[0068] As noted above, preferred cyclic purine dinucleotides also include prodrug forms of CDNs, and in particular CDN thiophosphates. Produrgs can modify the physicochemical, biopharmaceutic, and pharmacokinetic properties of drugs. Traditional prodrugs are classified as drugs that are activated by undergoing transformation in vivo to form the active drug. Reasons for prodrug development are typically poor aqueous solubility, chemical instability, low oral bioavailability, lack of blood brain barrier penetration, and high first pass metabolism associated with the parent drug. Suitable prodrug moieties are described in, for example, “Prodrugs and Targeted Delivery,” J. Rautico, Ed., John Wiley & Sons, 2011.

[0069] The term “substantially pure” as used herein with regard to cyclic purine dinucleotides refers to an Rp,Rp or Rp,Sp form which is at least 75% pure relative to

other possible stereochemistries at the chiral centers indicated in the figure above. By way of example, a "substantially pure Rp,Rp c-di-GMP thiophosphate" would be at least 75% pure with regard to the Rp,Sp and Sp,Sp forms of c-di-GMP thiophosphate. In preferred embodiments, a substantially pure cyclic purine dinucleotide is at least 85% pure, at least 90% pure, at least 95% pure, at least 97% pure, and at least 99% pure. While a substantially pure cyclic purine dinucleotide preparation of the invention is "stereochemically pure," this is not meant to indicate that all CDNs within the preparation having a particular stereochemistry at these chiral centers are otherwise identical. For example, a substantially pure cyclic purine dinucleotide preparation may contain a combination of Rp,Rp c-di-GMP thiophosphate and Rp,Rp c-di-AMP thiophosphate and still be a substantially pure cyclic purine dinucleotide preparation. Such a preparation may also include other components as described hereinafter that are advantageous for patient treatment, provided that all CDNs within the preparation having a particular stereochemistry at these chiral centers.

[0070] The CDN compositions described herein can be administered to a host, either alone or in combination with a pharmaceutically acceptable excipient, in an amount sufficient to modify an appropriate immune response. The immune response can comprise, without limitation, specific immune response, non-specific immune response, both specific and non-specific response, innate response, primary immune response, adaptive immunity, secondary immune response, memory immune response, immune cell activation, immune cell proliferation, immune cell differentiation, and cytokine expression. In certain embodiments, the CDN compositions are administered in conjunction with one or more additional compositions. The CDN compositions may be administered before, after, and/or together with an additional therapeutic or prophylactic composition. Methods for co-administration with an additional therapeutic agent are well known in the art (Hardman, et al. (eds.) (2001) Goodman and Gilman's The Pharmacological Basis of Therapeutics, 10th ed., McGraw-Hill, New York, NY; Poole and Peterson (eds.) (2001) Pharmacotherapeutics for Advanced Practice:A Practical Approach, Lippincott, Williams & Wilkins, Phila., PA; Chabner and Longo (eds.) (2001) Cancer Chemotherapy and Biotherapy, Lippincott, Williams & Wilkins, Phila., PA). In certain embodiments the one or more therapeutics is selected from anti-TNF agents (e.g., etanercept, infliximab), steroids, azathioprine, cyclosporine, methotrexate, abatacept, PDE4 inhibitors (e.g., roflumilast), etc.

[0071] Delivery agents

[0072] Liposomes are vesicles formed from one ("unilamellar") or more ("multilamellar") layers of phospholipid. Because of the amphipathic character of the phospholipid building blocks, liposomes typically comprise a hydrophilic layer presenting a hydrophilic external face and enclosing a hydrophilic core. The versatility of liposomes in the incorporation of hydrophilic/hydrophobic components, their non-toxic nature, biodegradability, biocompatibility, adjuvanticity, induction of cellular immunity, property of sustained release and prompt uptake by macrophages, makes them attractive candidates for the delivery of antigens.

[0073] WO2010/104833, which is incorporated by reference herein in its entirety, describes liposomal preparations which comprise:

a) an aqueous vehicle;

b) liposomes comprising

(i) dimyristoylphosphatidylcholine ("DMPC"),

(ii) dimyristoylphosphatidylglycerol ("DMPG"), dimyristoyltrimethylammonium propane ("DMTAP"), or both DMPG and DMTAP,

and

(iii) at least one sterol derivative; and

c) one or more immunogenic polypeptide(s) or carbohydrate(s) covalently linked to between 1% and 100% of said at least one sterol derivative.

[0074] Such liposomal formulations, referred to herein as VesiVax® (Molecular Express, Inc.), with our without the "immunogenic polypeptide(s) or carbohydrate(s)" referred to above, can contain one or more additional components such as peptidoglycan, lipopeptide, lipopolysaccharide, monophosphoryl lipid A, lipoteichoic acid, resiquimod, imiquimod, flagellin, oligonucleotides containing unmethylated CpG motifs, beta-galactosylceramide, muramyl dipeptide, all-trans retinoic acid, double-stranded viral RNA, heat shock proteins, dioctadecyldimethylammonium bromide, cationic surfactants, toll-like receptor agonists, dimyristoyltrimethylammoniumpropane, and nod-like receptor agonists. Advantageously, these liposomal formulations can be used to deliver one or more cyclic purine dinucleotides in accordance with the present invention.

[0075] Moreover, while the liposomal formulations discussed above employ a" steroid derivative" as an anchor for attaching an immunogenic polypeptide or carbohydrate to a liposome, the steroid may simply be provided as an unconjugated steroid such as cholesterol.

[0076] Suitable methods for preparing liposomes from lipid mixtures are well known in the art. *See, e.g.*, Basu & Basu, Liposome Methods and Protocols (Methods in Molecular Biology), Humana Press, 2002; Gregoriadis, Liposome Technology, 3rd Edition, Informa HealthCare, 2006. Preferred methods include extrusion, homogenization, and sonication methods described therein. An exemplary method for preparing liposomes for use in the present invention, which comprises drying a lipid mixture, followed by hydration in an aqueous vehicle and sonication to form liposomes, is described in WO2010/104833.

[0077] In certain embodiments, the liposomes are provided within a particular average size range. Liposome size can be selected, for example, by extrusion of an aqueous vehicle comprising liposomes through membranes having a preselected pore size and collecting the material flowing through the membrane. In preferred embodiments, the liposomes are selected to be substantially between 50 and 500 nm in diameter, more preferably substantially between 50 and 200 nm in diameter, and most preferably substantially between 50 and 150 nm in diameter. The term "substantially" as used herein in this context means that at least 75%, more preferably 80%, and most preferably at least 90% of the liposomes are within the designated range.

[0078] Other lipid and lipid-like adjuvants which may find use in the present invention include oil-in-water (o/w) emulsions (see, e.g., Muderhwa et al., J. Pharmaceut. Sci. 88: 1332–9, 1999)), VesiVax® TLR (Molecular Express, Inc.), digitonin (see, e.g., U.S. Patent 5,698,432), and glucopyranosyl lipids (see, e.g., United States Patent Application 20100310602).

[0079] Nanoparticles also represent drug delivery systems suitable for most administration routes. Over the years, a variety of natural and synthetic polymers have been explored for the preparation of nanoparticles, of which Poly(lactic acid) (PLA), Poly(glycolic acid) (PGA), and their copolymers (PLGA) have been extensively investigated because of their biocompatibility and biodegradability. Nanoparticles and other nanocarriers act as potential carries for several classes of drugs such as anticancer

agents, antihypertensive agents, immunomodulators, and hormones; and macromolecules such as nucleic acids, proteins, peptides, and antibodies. See, e.g., Crit. Rev. Ther. Drug Carrier Syst. 21:387-422, 2004; Nanomedicine: Nanotechnology, Biology and Medicine 1:22-30, 2005.

[0080] Pharmaceutical Compositions

[0081] The term "pharmaceutical" as used herein refers to a chemical substance intended for use in the cure, treatment, or prevention of disease and which is subject to an approval process by the U.S. Food and Drug Administration (or a non-U.S. equivalent thereof) as a prescription or over-the-counter drug product. Details on techniques for formulation and administration of such compositions may be found in Remington, The Science and Practice of Pharmacy 21st Edition (Mack Publishing Co., Easton, PA) and Nielloud and Marti-Mestres, Pharmaceutical Emulsions and Suspensions: 2nd Edition (Marcel Dekker, Inc, New York).

[0082] For the purposes of this disclosure, the pharmaceutical compositions may be administered by a variety of means including orally, parenterally, by inhalation spray, topically, or rectally in formulations containing pharmaceutically acceptable carriers, adjuvants and vehicles. The term parenteral as used here includes but is not limited to subcutaneous, intravenous, intramuscular, intraarterial, intradermal, intrathecal and epidural injections with a variety of infusion techniques. Intraarterial and intravenous injection as used herein includes administration through catheters. Administration via intracoronary stents and intracoronary reservoirs is also contemplated. The term oral as used herein includes, but is not limited to oral ingestion, or delivery by a sublingual or buccal route. Oral administration includes fluid drinks, energy bars, as well as pill formulations.

[0083] Pharmaceutical compositions may be in any form suitable for the intended method of administration. When used for oral use for example, tablets, troches, lozenges, aqueous or oil suspensions, dispersible powders or granules, emulsions, hard or soft capsules, syrups or elixirs may be prepared. Compositions intended for oral use may be prepared according to any method known to the art for the manufacture of pharmaceutical compositions and such compositions may contain one or more agents including sweetening agents, flavoring agents, coloring agents and preserving agents, in order to provide a palatable preparation. Tablets containing a drug compound in admixture with

non-toxic pharmaceutically acceptable excipient which are suitable for manufacture of tablets are acceptable. These excipients may be, for example, inert diluents, such as calcium or sodium carbonate, lactose, calcium or sodium phosphate; granulating and disintegrating agents, such as maize starch, or alginic acid; binding agents, such as starch, gelatin or acacia; and lubricating agents; such as magnesium stearate, stearic acid or talc. Tablets may be uncoated, or may be coated by known techniques including enteric coating, colonic coating, or microencapsulation to delay disintegration and adsorption in the gastrointestinal tract and/or provide a sustained action over a longer period. For example, a time delay material such as glyceryl monostearate or glyceryl distearate alone or with a wax may be employed.

[0084] Formulations for oral use may be also presented as hard gelatin capsules where the drug compound is mixed with an inert solid diluent, for example calcium phosphate or kaolin, or as soft gelatin capsules wherein the active ingredient is mixed with water or an oil medium, such as peanut oil, liquid paraffin or olive oil.

[0085] Pharmaceutical compositions may be formulated as aqueous suspensions in admixture with excipients suitable for the manufacture of aqueous-suspensions. Such excipients include a suspending agent, such as sodium carboxymethylcellulose, methylcellulose, hydroxypropyl methylcellulose, sodium alginate, polyvinylpyrrolidone, gum tragacanth and gum acacia, and dispersing or wetting agents such as a naturally occurring phosphatide (e.g., lecithin), a condensation product of an alkylene oxide with a fatty acid (e.g., polyoxyethylene stearate), a condensation product of ethylene oxide with a long chain aliphatic alcohol (e.g., heptadecaethyleneoxycetanol), a condensation product of ethylene oxide with a partial ester derived from a fatty acid and a hexitol anhydride (e.g., polyoxyethylene sorbitan monooleate). The aqueous suspension may also contain one or more preservatives such as ethyl or n-propyl p-hydroxy-benzoate, one or more coloring agents, one or more flavoring agents and one or more sweetening agents, such as sucrose or saccharin.

[0086] Oil suspensions may be formulated by suspending the active ingredient in a vegetable oil, such as arachis oil, olive oil, sesame oil or coconut oil, or a mineral oil such as liquid paraffin. The oral suspensions may contain a thickening agent, such as beeswax, hard paraffin or cetyl alcohol. Sweetening agents, such as those set forth above, and

flavoring agents may be added to provide a palatable oral preparation. These compositions may be preserved by the addition of an antioxidant such as ascorbic acid.

[0087] Dispersible powders and granules of the disclosure suitable for preparation of an aqueous suspension by the addition of water provide the active ingredient in admixture with a dispersing or wetting agent, a suspending agent, and one or more preservatives. Suitable dispersing or wetting agents and suspending agents are exemplified by those disclosed above. Additional excipients, for example sweetening, flavoring and coloring agents, may also be present.

[0088] The pharmaceutical compositions of the disclosure may also be in the form of oil-in-water emulsions. The oily phase may be a vegetable oil, such as olive oil or arachis oil, a mineral oil, such as liquid paraffin, or a mixture of these. Suitable emulsifying agents include naturally-occurring gums, such as gum acacia and gum tragacanth, naturally occurring phosphatides, such as soybean lecithin, esters or partial esters derived from fatty acids and hexitol anhydrides, such as sorbitan monooleate, and condensation products of these partial esters with ethylene oxide, such as polyoxyethylene sorbitan monooleate. The emulsion may also contain sweetening and flavoring agents.

[0089] Syrups and elixirs may be formulated with sweetening agents, such as glycerol, sorbitol or sucrose. Such formulations may also contain a demulcent, a preservative, a flavoring or a coloring agent.

[0090] The pharmaceutical compositions of the disclosure may be in the form of a sterile injectable preparation, such as a sterile injectable aqueous or oleaginous suspension. This suspension may be formulated according to the known art using those suitable dispersing or wetting agents and suspending agents which have been mentioned above. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally acceptable diluent or solvent such as a solution in 1,3-butane-diol or prepared as a lyophilized powder. Among the acceptable vehicles and solvents that may be employed are water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile fixed oils may conventionally be employed as a solvent or suspending medium. For this purpose any bland fixed oil may be employed including synthetic mono- or diglycerides. In addition, fatty acids such as oleic acid may likewise be used in the preparation of injectables.

[0091] The amount of active ingredient that may be combined with the carrier material to produce a single dosage form will vary depending upon the host treated and the particular mode of administration. For example, a time-release formulation intended for oral administration to humans may contain approximately 20 to 500 mg of active material compounded with an appropriate and convenient amount of carrier material which may vary from about 5 to about 95% of the total compositions. It is preferred that the pharmaceutical composition be prepared which provides easily measurable amounts for administration. Typically, an effective amount to be administered systemically is about 0.1 mg/kg to about 100 mg/kg and depends upon a number of factors including, for example, the age and weight of the subject (e.g., a mammal such as a human), the precise condition requiring treatment and its severity, the route of administration, and will ultimately be at the discretion of the attendant physician or veterinarian. It will be understood, however, that the specific dose level for any particular patient will depend on a variety of factors including the activity of the specific compound employed, the age, body weight, general health, sex and diet of the individual being treated; the time and route of administration; the rate of excretion; other drugs which have previously been administered; and the severity of the particular condition undergoing therapy, as is well understood by those skilled in the art.

[0092] As noted above, formulations of the disclosure suitable for oral administration may be presented as discrete units such as capsules, cachets or tablets each containing a predetermined amount of the active ingredient, as a powder or granules; as a solution or a suspension in an aqueous or non-aqueous liquid, or as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion. The pharmaceutical compositions may also be administered as a bolus, electuary or paste.

[0093] A tablet may be made by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a suitable machine the active ingredient in a free flowing form such as a powder or granules, optionally mixed with a binder (e.g., povidone, gelatin, hydroxypropyl ethyl cellulose), lubricant, inert diluent, preservative, disintegrant (e.g., sodium starch glycolate, cross-linked povidone, cross-linked sodium carboxymethyl cellulose) surface active or dispersing agent. Molded tablets may be made in a suitable machine using a mixture of the powdered compound moistened with an inert liquid diluent. The tablets

may optionally be coated or scored and may be formulated so as to provide slow or controlled release of the active ingredient therein using, for example, hydroxypropyl methylcellulose in varying proportions to provide the desired release profile. Tablets may optionally be provided with an enteric or colonic coating to provide release in parts of the gut other than the stomach. This is particularly advantageous with the compounds of formula 1 when such compounds are susceptible to acid hydrolysis.

[0094] Formulations suitable for topical administration in the mouth include lozenges comprising the active ingredient in a flavored base, usually sucrose and acacia or tragacanth; pastilles comprising the active ingredient in an inert base such as gelatin and glycerin, or sucrose and acacia; and mouthwashes comprising the active ingredient in a suitable liquid carrier.

[0095] Formulations for rectal administration may be presented as a suppository with a suitable base comprising for example cocoa butter or a salicylate.

[0096] Formulations suitable for vaginal administration may be presented as pessaries, tampons, creams, gels, pastes, foams or spray formulations containing in addition to the active ingredient such carriers as are known in the art to be appropriate.

[0097] Formulations suitable for parenteral administration include aqueous and non-aqueous isotonic sterile injection solutions which may contain antioxidants, buffers, bacteriostats and solutes which render the formulation isotonic with the blood of the intended recipient; and aqueous and non-aqueous sterile suspensions which may include suspending agents and thickening agents. The formulations may be presented in unit-dose or multi-dose sealed containers, for example, ampoules and vials, and may be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid carrier, for example water for injections, immediately prior to use. Injection solutions and suspensions may be prepared from sterile powders, granules and tablets of the kind previously described.

[0098] As used herein, pharmaceutically acceptable salts include, but are not limited to: acetate, pyridine, ammonium, piperazine, diethylamine, nicotinamide, formic, urea, sodium, potassium, calcium, magnesium, zinc, lithium, cinnamic, methylamino, methanesulfonic, picric, tartaric, triethylamino, dimethylamino, and

tris(hydoxymethyl)aminomethane. Additional pharmaceutically acceptable salts are known to those skilled in the art.

[0099] An effective amount for a particular patient may vary depending on factors such as the condition being treated, the overall health of the patient, the route and dose of administration and the severity of side effects. Guidance for methods of treatment and diagnosis is available (see, e.g., Maynard, et al. (1996) A Handbook of SOPs for Good Clinical Practice, Interpharm Press, Boca Raton, FL; Dent (2001) Good Laboratory and Good Clinical Practice, Urch Publ., London, UK).

[00100] An effective amount may be given in one dose, but is not restricted to one dose. Thus, the administration can be two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty, or more, administrations of pharmaceutical composition. Where there is more than one administration of a pharmaceutical composition in the present methods, the administrations can be spaced by time intervals of one minute, two minutes, three, four, five, six, seven, eight, nine, ten, or more minutes, by intervals of about one hour, two hours, three, four, five, six, seven, eight, nine, ten, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 hours, and so on. In the context of hours, the term "about" means plus or minus any time interval within 30 minutes. The administrations can also be spaced by time intervals of one day, two days, three days, four days, five days, six days, seven days, eight days, nine days, ten days, 11 days, 12 days, 13 days, 14 days, 15 days, 16 days, 17 days, 18 days, 19 days, 20 days, 21 days, and combinations thereof. The invention is not limited to dosing intervals that are spaced equally in time, but encompass doses at non-equal intervals.

[00101] A dosing schedule of, for example, once/week, twice/week, three times/week, four times/week, five times/week, six times/week, seven times/week, once every two weeks, once every three weeks, once every four weeks, once every five weeks, and the like, is available for the invention. The dosing schedules encompass dosing for a total period of time of, for example, one week, two weeks, three weeks, four weeks, five weeks, six weeks, two months, three months, four months, five months, six months, seven months, eight months, nine months, ten months, eleven months, and twelve months.

[00102] Provided are cycles of the above dosing schedules. The cycle can be repeated about, e.g., every seven days; every 14 days; every 21 days; every 28 days; every 35 days;

42 days; every 49 days; every 56 days; every 63 days; every 70 days; and the like. An interval of non dosing can occur between a cycle, where the interval can be about, e.g., seven days; 14 days; 21 days; 28 days; 35 days; 42 days; 49 days; 56 days; 63 days; 70 days; and the like. In this context, the term "about" means plus or minus one day, plus or minus two days, plus or minus three days, plus or minus four days, plus or minus five days, plus or minus six days, or plus or minus seven days.

[00103] Methods for co-administration with an additional therapeutic agent are well known in the art (Hardman, et al. (eds.) (2001) Goodman and Gilman's The Pharmacological Basis of Therapeutics, 10th ed., McGraw-Hill, New York, NY; Poole and Peterson (eds.) (2001) Pharmacotherapeutics for Advanced Practice:A Practical Approach, Lippincott, Williams & Wilkins, Phila., PA; Chabner and Longo (eds.) (2001) Cancer Chemotherapy and Biotherapy, Lippincott, Williams & Wilkins, Phila., PA).

[00104] As noted, the compositions of the present invention are preferably formulated as pharmaceutical compositions for parenteral or enteral delivery. A typical pharmaceutical composition for administration to an animal comprises a pharmaceutically acceptable vehicle such as aqueous solutions, non-toxic excipients, including salts, preservatives, buffers and the like. See, e.g., Remington's Pharmaceutical Sciences, 15th Ed., Easton ed. , Mack Publishing Co., pp 1405-1412 and 1461- 1487 (1975); The National Formulary XIV, 14th Ed., American Pharmaceutical Association, Washington, DC (1975) . Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oil and injectable organic esters such as ethyloleate. Aqueous carriers include water, alcoholic/aqueous solutions, saline solutions, parenteral vehicles such as sodium chloride, Ringer's dextrose, *etc.* Intravenous vehicles include fluid and nutrient replenishers. Preservatives include antimicrobial agents, anti-oxidants, chelating agents and inert gases. The pH and exact concentration of the various components the pharmaceutical composition are adjusted according to routine skills in the art.

EXAMPLES

[00105] The following examples serve to illustrate the present invention. These examples are in no way intended to limit the scope of the invention.

[00106] Example 1. General Methods

[00107] Anhydrous solvents and reagents suitable for solution phase oligonucleotide synthesis were purchased and handled under dry argon or nitrogen using anhydrous technique. Amidite coupling reactions and cyclizations were carried out in anhydrous acetonitrile or pyridine under dry argon or nitrogen. The starting materials for all reactions in dry pyridine were dried by concentration (three times) from pyridine. Preparative silica gel flash chromatography was carried out using Fluka 60A high-purity grade or Merck Grade 9385 silica using gradients of methanol in dichloromethane. Analytical HPLC was carried out on a Varian ProStar 210 HPLC system with a ProStar 330 photodiode array detector monitoring at 254nm using a either a Varian Microsorb 10 micron C18 250x4.6mm or a Varian 3micronC18 100x4.6mm column and gradients of 10 mM TEAA and acetonitrile. Preparative HPLC was carried out on a Shimadzu preparative LC20-AP HPLC system, equipped with a SPD-20A UV/Vis detector monitoring at 254nm on a Varian Microsorb 60-8 C-18 41.6 x 250 mm column using gradients of 10 mM TEAA and acetonitrile at a flow rate of 50 ml/min. Solid phase extractions using C-18 Sep-Pak (Waters) were carried out at loadings of 3% (wt/wt). LC/MS (ESI/APCI) was obtained on a single quadrapole Shimadzu 2010EV instrument with PDA, MS, and ELSD detection using a Shimadzu LC20D analytical HPLC. High resolution FT-ICR mass spec was obtained from both WM Keck Foundation Biotechnology Resource Laboratory at Yale University in New Haven, CT, and the QB3/Chemistry Mass Spect Lab at UC Berkeley.

[00108] ^{1}H, ^{31}P, ^{1}H-^{1}H COSY (2D NMR correlation spectroscopy), ^{1}H-^{31}P HMBC (heteronuclear multiple-bond correlation spectroscopy) spectra were acquired in d6-DMSO with10 uL D_2O (16 hr delay after D_2O addition) at 45 °C on a Varian INOVA-500 NMR spectrometer operating at 500 MHz for 1H and 202 MHz for 31P. The resulting FIDs were transferred to a PC and processed using NUTS NMR processing software from Acorn NMR Inc. The chemical shifts were referenced to the DMSO solvent, 2.50 ppm for 1H. Per IUPAC recommendations for referencing of NMR spectra1, the 31P chemical shifts were referenced using the "unified scale" to the absolute 1H frequency of 0 ppm. Some of the 1H and 31P spectra were acquired on a JEOL ECX-400 NMR spectrometer operating at 400 MHz for 1H and 162 MHz for 31P. The gradient COSY spectra were acquired at 45.0°C on a Varian INOVA-500 NMR spectrometer operating at 500 MHz for 1H and 202 MHz for 31P. The resulting FIDs were transferred to a PC and processed using NUTS NMR processing software from Acorn NMR Inc. The chemical

shifts were referenced to the DMSO solvent, 2.50 ppm for 1H. Per IUPAC recommendations for referencing of NMR spectra1, the 31P chemical shifts were referenced using the "unified scale" to the absolute 1H frequency of 0 ppm. The gradient COSY spectrum was acquired in absolute value mode using 2048 data points in the direct dimension and 256 time points in the indirect dimension. Both dimensions were apodized using sinebell squared functions. The indirect dimension was zero filled to give a final matrix size of 2048x2048 points and a resolution of 3.91 Hz/data point in both dimensions.

[00109] Assignment of regiochemistry at phosphodiester linkage: 1H-1H COSY in combination with ^{1}H-^{31}P HMBC experiments were used to provide direct evidence that the regiochemistry of the phosphodiester linkages are 2', 5'-3', 5' (see for example Fig. 3C and 3D).

[00110] Abbreviations and Acronyms. Guanine = G. isobutyryl guanine = G^{ib}. 4,4-dimethoxytrityl = DMT. $OCH_2CH_2CH_3$ = CEO. *tert*-butyldimethylsilyl = TBS. adenine = A. benzoyl adenine = A^{Bz}, 2'-O-myristoyl- cyclic-[G(2',5')pG(3',5')p] = C14-ML-CDG = **10** (TEA salt). All CDN products were ≥ 95% pure as indicated by C18 reverse phase HPLC analysis using UV detection at 254 nm (see Fig. 2E for purity of structure **8**).

[00111] Example 2. Synthesis of 2'-O-propargyl-cyclic-A(2',5')pA(3',5')p (2'-O-propargyl-ML-CDA, structure **8**), Fig. 2).

[00112] 1) Preparation of **3**.

[00113] To a solution of 1.7 g (1.72 mmol) N^6-benzoyl-5'-O-(4,4'-dimethoxytrityl)-3'-O-*tert*-butyldimethylsilyl-2'-O-[(2-cyanoethyl)-N,N-diisopropylaminophinyl]adenosine (**1**) in 7.5ml acetonitrile was added 0.054 ml (3 mmole) water and 0.35g (1.8 mmole) pyridinium trifluoroacetate. After 5 minutes stirring at room temperature 7.5 ml *tert*-butylamine was added and the reaction stirred for 15 minutes at room temperature. The solvents were removed under reduced pressure to give **2** as a foam which was then co-evaporated with acetonitrile (3x15 ml), then dissolved in 18 ml dichloromethane. To this solution was added water (0.27 ml, 15 mmole) and 18 ml of 6% (v/v) dichloroacetic acid (13.2 mmole) in dichloromethane. After 10 minutes at room temperature the reaction was quenched by the addition of pyridine (2.1 ml, 26 mmole), and concentrated to an oil

which was dried by three co-evaporations with 12 ml anhydrous acetonitrile, the last time leaving **3** in a volume of ~4 ml.

[00114] 2) Preparation of a dry solution of **4**.

[00115] N^6-benzoyl-5'-O-(4,4'-dimethoxytrityl)-2'-O-propargyl-3'-O-[(2-cyanoethyl)-N,N-diisopropylaminophinyl]adenosine (**4**, 2 g, 2.2 mmole) was dissolved in 25 ml anhydrous acetonitrile and dried by three co-evaporations with 25 ml anhydrous acetonitrile, the last time leaving ~6 ml. Ten 3Å molecular sieves were added and the dried solution stored under argon until use.

[00116] 3) Preparation of 2',5'-linear dimer **5**.

[00117] Azeo dried **4** (2 g, 2.2 mmole) in ~6 ml acetonitrile was added via syringe to a solution of **3** (1.72 mmole) in ~4 ml of anhydrous acetonitrile. After 5 minutes stirring at room temperature, 0.82 ml (4.5 mmole) of 5.5M tert-butyl hydroperoxide in decane was added and the reaction stirred for 30 minutes at room temperature. The reaction was cooled in an ice bath, and 0.38g $NaHSO_3$ in 0.75ml water was added and stirred at room temperature for 5 minutes. The reaction was concentrated and the residual oil dissolved in 24 ml dichloromethane. Water (0.27 ml, 15 mmole) and 24 ml of 6% (v/v) dichloroacetic acid (17.4 mmole) in dichloromethane was added, and the reaction stirred for 10 minutes at room temperature. 15 ml pyridine was added to quench the dichloroacetic acid, which was then concentrated down to ~4ml.

[00118] 4) Cyclization and oxidation of **5** to give the fully-protected-propargyl-cyclic-dinucleotide **6**.

[00119] **5** was dissolved in 45 ml dry pyridine which was concentrated down to a volume of approximately 30 ml. 2-chloro-5,5-dimethyl-1,3,2-dioxaphosphorinane-2-oxide (DMOCP, 1 g, 5.2 mmole) was then added and the reaction stirred for 10 minutes at room temperature. 1 ml water was added immediately followed by addition of I_2 (0.5 g, 2 mmole), and the reaction stirred for 5 minutes at room temperature. The reaction mix was then poured into 210 ml water containing 0.3 g $NaHSO_3$ and stirred for 5 minutes at room temperature. 6g $NaHCO_3$ was slowly added and stirred for 5 minutes at room temperature, then poured into a separatory funnel and extracted with 250 ml 1:1 ethyl acetate:diethyl ether. The aqueous layer was extracted again with 60 ml 1:1 ethyl acetate:diethyl ether. The organic layers were combined and concentrated under reduced

pressure to yield approximately 5.6 g of an oil containing fully-protected-propargyl cyclic dinucleotide **6.**

[00120] 6) Deprotection of the fully-protected-propargyl cyclic dinucleotide **6** to crude **7.**

[00121] 5.6 g of crude **6** was transferred to a thick-walled glass pressure tube. 30 ml methanol and 30 ml concentrated aqueous ammonia was added and the tube was heated with stirring in an oil bath at 55°C for 4 h, at which time analytical HPLC showed deprotection was complete. The reaction mixture was cooled to near ambient temperature, sparged with a stream of argon gas for 30 minutes, and then transferred to a large round bottom flask. Most of the volatiles were removed under reduced pressure to give a residue of 4.7g, which was triturated against 20ml 1:1 (v/v) dichloromethane: hexane. Any remaining solvent was removed under reduced pressure to give 4.5g of a solid containing **7**.

[00122] 7) Preparative HPLC purification of crude **7** to give pure **7**.

[00123] The crude solid containing **7** was taken up in 25ml of CH_3CN/water (1:1). After 0.45 micron PTFE filtration, 4-5ml sample portions were applied to a C-18 Dynamax column (40x250mm). Elution was performed with a gradient of acetonitrile and 10 mM aqueous triethylammonium acetate (20% to 50% CH_3CN over 20 minutes at 50 ml/min flow). Fractions from the preparative HPLC runs containing pure **7** were pooled, evaporated to remove most of the CH_3CN and water and coevaporated several times with CH_3CN to give 55mg of pure **7**.

[00124] 8) Deprotection of the TBS group of **7** with triethylamine trihydrofluoride, neutralization with TEAB, solid phase extraction with a C-l8 Sep-Pak and lyophilization to give pure **8** as the bis-triethylammonium salt.

[00125] To 55 mg of **7** was added 1.0 ml of neat triethylamine trihydrofluoride. The mixture was stirred at room temperature for approximately 3 h. The mixture was then transferred to an oil bath at 50°C for an additional 2 hours, at which time analytical HPLC confirmed completion of the reaction. The sample was neutralized by dropwise addition into 5 ml of chilled, stirred 1M triethylammonium bicarbonate. Approximately 1-2 ml TEA was added dropwise to the stirred, chilled solution until pH paper showed neutral/slightly basic (~pH8) conditions were achieved. The neutralized solution was

desalted on a Waters C-18 Sep-Pak and the product eluted with CH_3CN/10 mM aqueous triethylammonium acetate (15:85). The CH_3CN was evaporated under reduced pressure and the solution was frozen and lyophilized. An additional round of lyophilization from water gave 9 mg (13μmole) of 2'-O-propargyl-ML-CDA (**8**) as the bis-triethylammonium salt. ^{1}H NMR (500 MHz, 45 °C, DMSO-D_6 + 15μL D_2O) δ 8.68 (s, 1H), 8.31 (s, 1H), 8.15 (s, 1H), 8.14 (s, 1H), 6.10 (d, *J* = 8.0, 1H), 5.99 (d, *J* = 6.0, 1H), 5.06-5.04 (m, 1H), 4.98-4.94 (m, 1H), 4.53 (qt, J = 16.0, 2.5, 2H), 4.39 (d, *J* = 4.0, 1H), 4.27-4.26 (m, 1H), 4.14-4.13 (m, 1H), 4.05-3.90 (m, 3H) , 3.74 (d, J = 12.0, 1H) , 3.21 (t, J = 2.5, 1H) , 3.03 (q, *J* = 7.0, 12H), 1.14 (t, J = 7.5, 19H); ^{31}P NMR (200 MHz, 45 °C, DMSO-D_6 + 15μL D_2O) δ -1.48, -1.82 (Fig. 3A-3D); HRMS (FT-ICR) m/z: $[M-H]^-$ calcd for $C_{23}H_{25}N_{10}O_{12}P_2$ 695.1134; found 695.1118.

[00126] Figs. 4-6 depict alternative compounds which may be made by analogous methods to those described herein.

[00127] Example 3. Inhibition of STING-dependent responses

[00128] To evaluate if the antagonist 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) can inhibit STING-dependent induction of type I interferon induction by Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA) in human cells, $4x10^5$ THP1-Blue™ ISG cells (a human monocyte cell line transfected with an IRF-inducible secreted embryonic alkaline phosphatase reporter gene (Invivogen) which express alkaline phosphatase under the control of a promoter comprised of five IFN-stimulated response elements) were incubated with 50 μM of Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA), 10 μM or 50 μM of the antagonist 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA), both 50 μM Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA) and 10 μM or 50 μM 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA), or 50 μM Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA) after a 30 min pre-incubation with 10 μM 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA). After 30 minutes, cells were washed and plated in 96-well dish in RPMI media containing 10% FBS, and incubated at 37°C with 5% CO_2. Cell culture supernatants from each sample were collected after 16 hr incubation, and 20 μL of the cell culture supernatants was added to 180 μL QUANTI-Blue reagent (Invivogen) and incubated for 5 minutes to evaluate type I interferon protein levels. Readings at Absorbance 655 nm were measured with a Versa Max kinetic spectrophotometer (Molecular Diagnostics).

[00129] As shown in Fig. 7A, addition of 10 μM or 50 μM of the antagonist 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) with 50 μM Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA) significantly inhibited the induction of type I IFN by Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA) in a dose-dependent manner. Figure 7B shows that pre-incubation with 10 μM 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) inhibits induction of type I interferon by the subsequent addition of 50 μM Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA). It is known that cyclic di-nucleotides such as Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA) induce type I IFN signaling via STING. Therefore, the reduction in Rp, Rp dithio cyclic [A(2',5')pA(3',5')p] (ML RR-CDA)-induced type I IFN production by 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) demonstrates that 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) is an antagonist of human STING.

[00130] Structural studies of apo and cyclic di-nucleotide-bound forms of STING have shown that STING forms a symmetrical v-shaped dimer in the free and bound states with the cyclic di-nucleotide bound in a pocket formed by the dimer interface (*Gao P., et al., (2013). Cell 154, 748-762 and reviewed in Burdette and Vance, (2013) Nature Immunology 14, 19-26*). STING undergoes a large conformational switch upon ligand binding from a more "open" conformation in the apo form to a "closed" conformation with a four-stranded antiparallel β sheet lid forming over the ligand-binding.

[00131] The results shown here demonstrate that 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) can bind in the same binding pocket formed by the interface of two STING dimers. Binding of 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) within the pocket would prevent the binding of an activating cyclic di-nucleotide. The propargyl group on 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) extending from the antagonist molecule residing in the STING binding pocket sterically blocks formation of the antiparallel β sheet lid over the ligand-binding pocket, thereby preventing STING from transitioning to the signaling competent conformation. Collectively these results indicate that 2'-O-propargyl-cyclic-[A(2',5')pA(3',5')p] (ML-propargyl-CDA) is capable of inhibiting the activity of human STING.

[00132] One skilled in the art readily appreciates that the present invention is well adapted to carry out the objects and obtain the ends and advantages mentioned, as well as those inherent therein. The examples provided herein are representative of preferred embodiments, are exemplary, and are not intended as limitations on the scope of the invention.

[00133] It is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of embodiments in addition to those described and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein, as well as the abstract, are for the purpose of description and should not be regarded as limiting.

[00134] As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other structures, methods and systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present invention.

[00135] While the invention has been described and exemplified in sufficient detail for those skilled in this art to make and use it, various alternatives, modifications, and improvements should be apparent without departing from the spirit and scope of the invention. The examples provided herein are representative of preferred embodiments, are exemplary, and are not intended as limitations on the scope of the invention. Modifications therein and other uses will occur to those skilled in the art. These modifications are encompassed within the spirit of the invention and are defined by the scope of the claims.

[00136] It will be readily apparent to a person skilled in the art that varying substitutions and modifications may be made to the invention disclosed herein without departing from the scope and spirit of the invention.

[00137] All patents and publications mentioned in the specification are indicative of the levels of those of ordinary skill in the art to which the invention pertains. All patents

and publications are herein incorporated by reference to the same extent as if each individual publication was specifically and individually indicated to be incorporated by reference.

[00138] The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations which is not specifically disclosed herein. Thus, for example, in each instance herein any of the terms "comprising", "consisting essentially of" and "consisting of" may be replaced with either of the other two terms. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the appended claims.

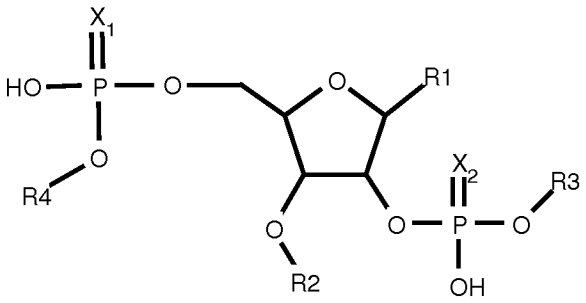
[00139] Other embodiments are set forth within the following claims.

We claim:

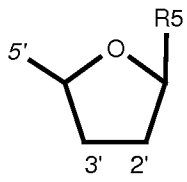
1. A composition comprising:

one or more cyclic purine dinucleotides that inhibit STING-dependent type I Interferon production.

2. A composition according to claim 1, wherein the cyclic purine dinucleotides present in the composition have the structure:



(a)



covalently linked to (b), wherein

R3 is a covalent bond to the 5' carbon of (b),

R4 is a covalent bond to the 2' or 3' carbon of (b),

R1 is a purine linked through its N9 nitrogen to the ribose ring of (a),

R5 is a purine linked through its N9 nitrogen to the ribose ring of (b),

Each of X_1 and X_2 are independently O or S,

R2 is H or an optionally substituted straight chain alkyl of from 1 to 18 carbons and from 0 to 3 heteroatoms, an optionally substituted alkenyl of from 1-9 carbons, an optionally substituted alkynyl of from 1-9 carbons, or an optionally substituted aryl, wherein substitution(s), when present, may be independently selected from the group consisting of

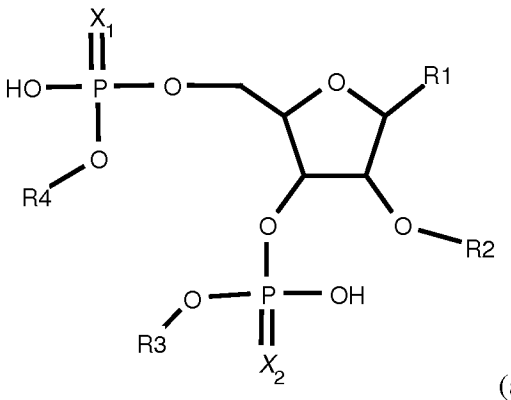
C_{1-6} alkyl straight or branched chain, benzyl, halogen, trihalomethyl, C_{1-6} alkoxy, $-NO_2$, $-NH_2$, –OH, =O, –COOR' where R' is H or lower alkyl, $-CH_2OH$, and $-CONH_2$,

the 2' or 3' carbon of (b) which is not in a covalent bond with (a) is –O–R6, wherein R6 is H or an optionally substituted straight chain alkyl of from 1 to 18 carbons and from 0 to 3 heteroatoms, an optionally substituted alkenyl of from 1-9 carbons, an optionally substituted alkynyl of from 1-9 carbons, or an optionally substituted aryl, wherein substitution(s), when present, may be independently selected from the group consisting of C_{1-6} alkyl straight or branched chain, benzyl, halogen, trihalomethyl, C_{1-6} alkoxy, $-NO_2$, $-NH_2$, –OH, =O, –COOR' where R' is H or lower alkyl, $-CH_2OH$, and $-CONH_2$, and

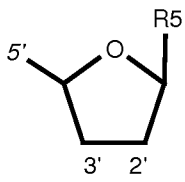
wherein R2 and R6 are not both H,

or prodrugs or pharmaceutically acceptable salts thereof.

3. A composition according to claim 1, wherein the cyclic purine dinucleotides present in the composition have the structure:



(a)



covalently linked to (b), wherein

R3 is a covalent bond to the 5' carbon of (b),

R4 is a covalent bond to the 3' carbon of (b),

R1 is a purine linked through its N9 nitrogen to the ribose ring of (a),

R5 is a purine linked through its N9 nitrogen to the ribose ring of (b),

Each of X_1 and X_2 are independently O or S,

R2 is H or an optionally substituted straight chain alkyl of from 1 to 18 carbons and from 0 to 3 heteroatoms, an optionally substituted alkenyl of from 1-9 carbons, an optionally substituted alkynyl of from 1-9 carbons, or an optionally substituted aryl, wherein substitution(s), when present, may be independently selected from the group consisting of C_{1-6} alkyl straight or branched chain, benzyl, halogen, trihalomethyl, C_{1-6} alkoxy, $-NO_2$, $-NH_2$, –OH, =O, –COOR' where R' is H or lower alkyl, $-CH_2OH$, and $-CONH_2$,

the 2' carbon of (b) is –O–R6, wherein R6 is H or an optionally substituted straight chain alkyl of from 1 to 18 carbons and from 0 to 3 heteroatoms, an optionally substituted alkenyl of from 1-9 carbons, an optionally substituted alkynyl of from 1-9 carbons, or an optionally substituted aryl, wherein substitution(s), when present, may be independently selected from the group consisting of C_{1-6} alkyl straight or branched chain, benzyl, halogen, trihalomethyl, C_{1-6} alkoxy, $-NO_2$, $-NH_2$, –OH, =O, –COOR' where R' is H or lower alkyl, $-CH_2OH$, and $-CONH_2$, and

wherein R2 and R6 are not both H,

or prodrugs or pharmaceutically acceptable salts thereof.

4. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 are independently an unsubstituted straight chain alkyl of from 1 to 18 carbons, an unsubstituted alkenyl of from 1-9 carbons, an unsubstituted alkynyl of from 1-9 carbons, or an unsubstituted aryl, and most preferably selected from the group consisting of selected from the group consisting of allyl, propargyl, homoallyl, homopropargyl, methyl, ethyl, propyl, isopropyl, isobutyl, cyclopropylmethyl, and benzyl.

5. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 are allyl.

6. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 comprise a propargyl.

7. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 are methyl.

8. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 are ethyl.

9. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 are propyl.

10. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one or both of R2 and R6 are benzyl.

11. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-4, wherein one of R2 or R6 is selected from the group consisting of allyl, propargyl, homoallyl, homopropargyl, methyl, ethyl, propyl, isopropyl, isobutyl, cyclopropylmethyl, and benzyl, and the other of R2 or R6 comprises a prodrug leaving group.

12. A substantially pure cyclic purine dinucleotide composition according to claim 11, wherein the prodrug leaving group is a moiety removed by cellular esterases.

13. A substantially pure cyclic purine dinucleotide composition according to claim 12, wherein the prodrug leaving group is a C6 to C18 fatty acid ester.

14. A substantially pure cyclic purine dinucleotide composition according to one of claims 1- 13, wherein X_1 and X_2 are both S.

15. A substantially pure cyclic purine dinucleotide composition according to claim 14, wherein the cyclic purine dinucleotides present in the composition comprise one or more substantially pure Sp,Sp, Rp,Rp, SpRp, or Rp,Sp stereoisomers.

16. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-15, wherein R1 and R5 are independently selected from the group consisting of adenine, guanine, inosine, and xanthine.

17. A substantially pure cyclic purine dinucleotide composition according to claim 16, wherein one or both of R1 and R5 are adenine.

18. A substantially pure cyclic purine dinucleotide composition according to claim 16, wherein one or both of R1 and R5 are guanine.

19. A substantially pure cyclic purine dinucleotide composition according to claim 16, wherein R1 is adenine and R5 is guanine

20. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-19, wherein the composition inhibits STING-dependent type I Interferon production at least 2-fold, and more preferably 5-fold or 10-fold, as compared to c-di-GMP having 3'-5' linkages.

21. A substantially pure cyclic purine dinucleotide composition according to one of claims 1-20, wherein the cyclic purine dinucleotide is formulated with a delivery vehicle which enhances cellular uptake and/or stability of the cyclic purine dinucleotide.

22. A substantially pure cyclic purine dinucleotide composition according to claim 21, wherein the delivery vehicle comprises one or more agents selected from the group consisting of lipids, interbilayer crosslinked multilamellar vesicles, biodegradeable poly(D,L-lactic-co-glycolic acid) [PLGA]-based or poly anhydride-based nanoparticles or microparticles, and nanoporous particle-supported lipid bilayers.

23. A method of inhibiting an immune response in an individual, comprising:

administering a composition according to one of claims 1-22 to the individual.

24. A method of inhibiting STING-dependent type I Interferon production in an individual, comprising:

administering a composition according to one of claims 1-22 to the individual in an amount sufficient to inhibit STING-dependent type I Interferon production.

25. A method according to claim 24, wherein the administration is parenteral.

26. A method according to claim 25, wherein the administration is subcutaneous, intramuscular, or intradermal.

27. A method according to one of claims 24-26, wherein X_1 and X_2 of the cyclic purine dinucleotides present in the composition are both S.

28. A method according to claim 27, wherein the cyclic purine dinucleotides present in the composition comprise one or more substantially pure Sp,Sp, Rp,Rp, SpRp, or Rp,Sp stereoisomers.

29. A method according to claim 28, wherein the cyclic purine dinucleotides present in the composition comprise a substantially pure Rp,Rp stereoisomer.

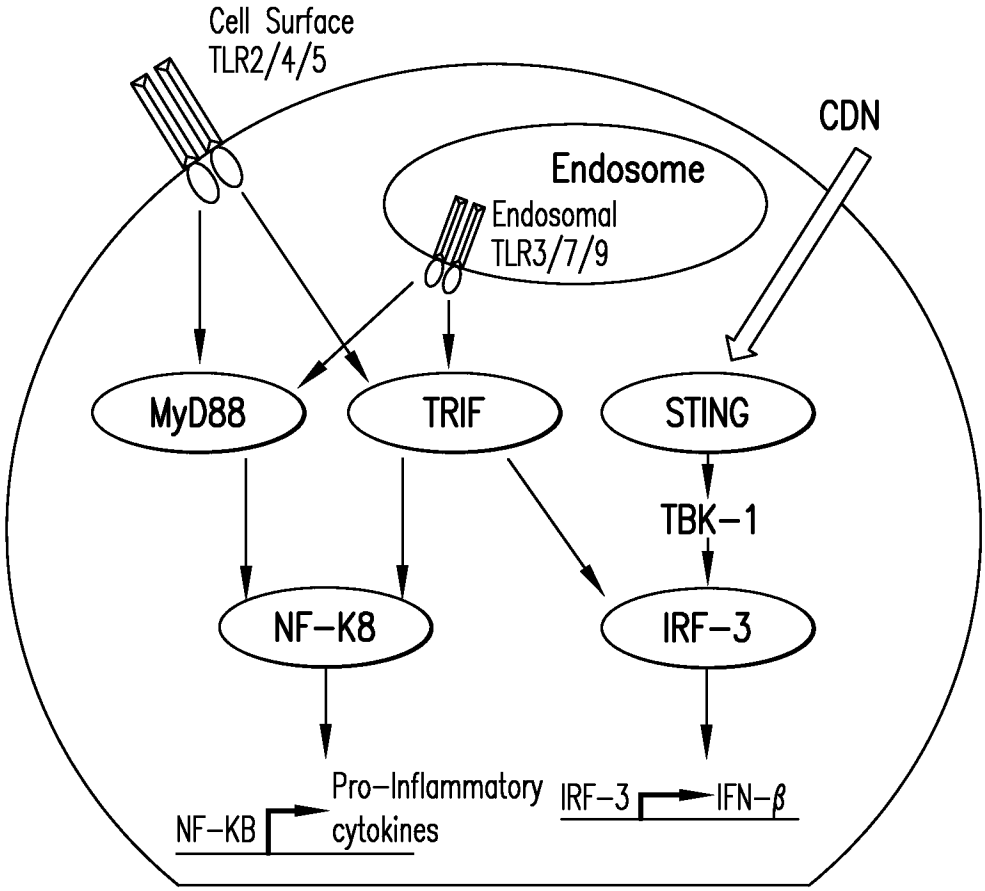

Cell Surface
TLR2/4/5
CDN
Endosome
Endosomal
TLR3/7/9
MyD88
TRIF
STING
TBK-1
NF-K8
IRF-3
Pro-Inflammatory
cytokines
NF-KB
IRF-3
IFN-β

FIG. 1

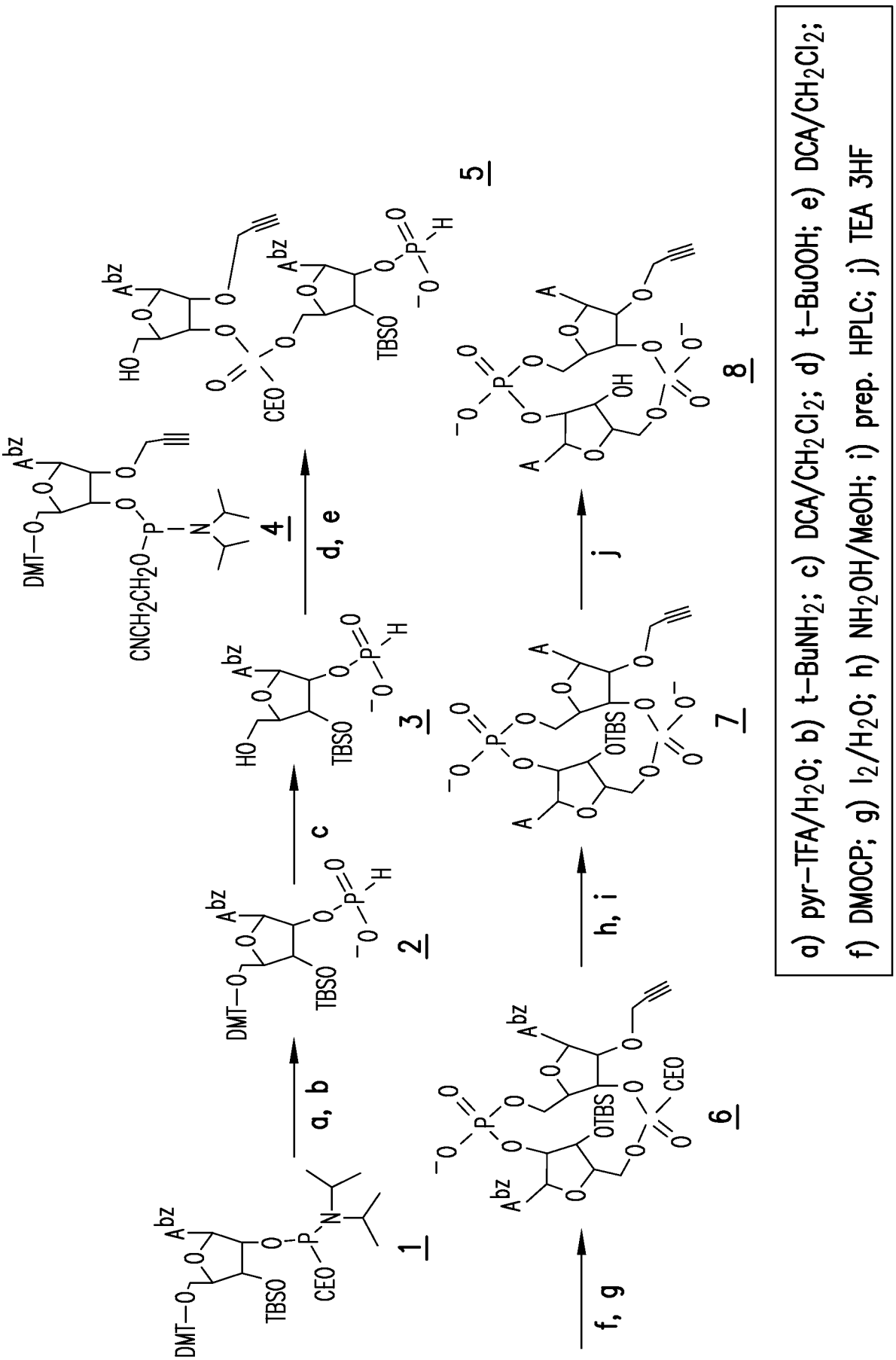

a) pyr–TFA/H2O; b) t–BuNH2; c) DCA/CH2Cl2; d) t–BuOOH; e) DCA/CH2Cl2;
f) DMOCP; g) I2/H2O; h) NH2OH/MeOH; i) prep. HPLC; j) TEA 3HF

FIG.2

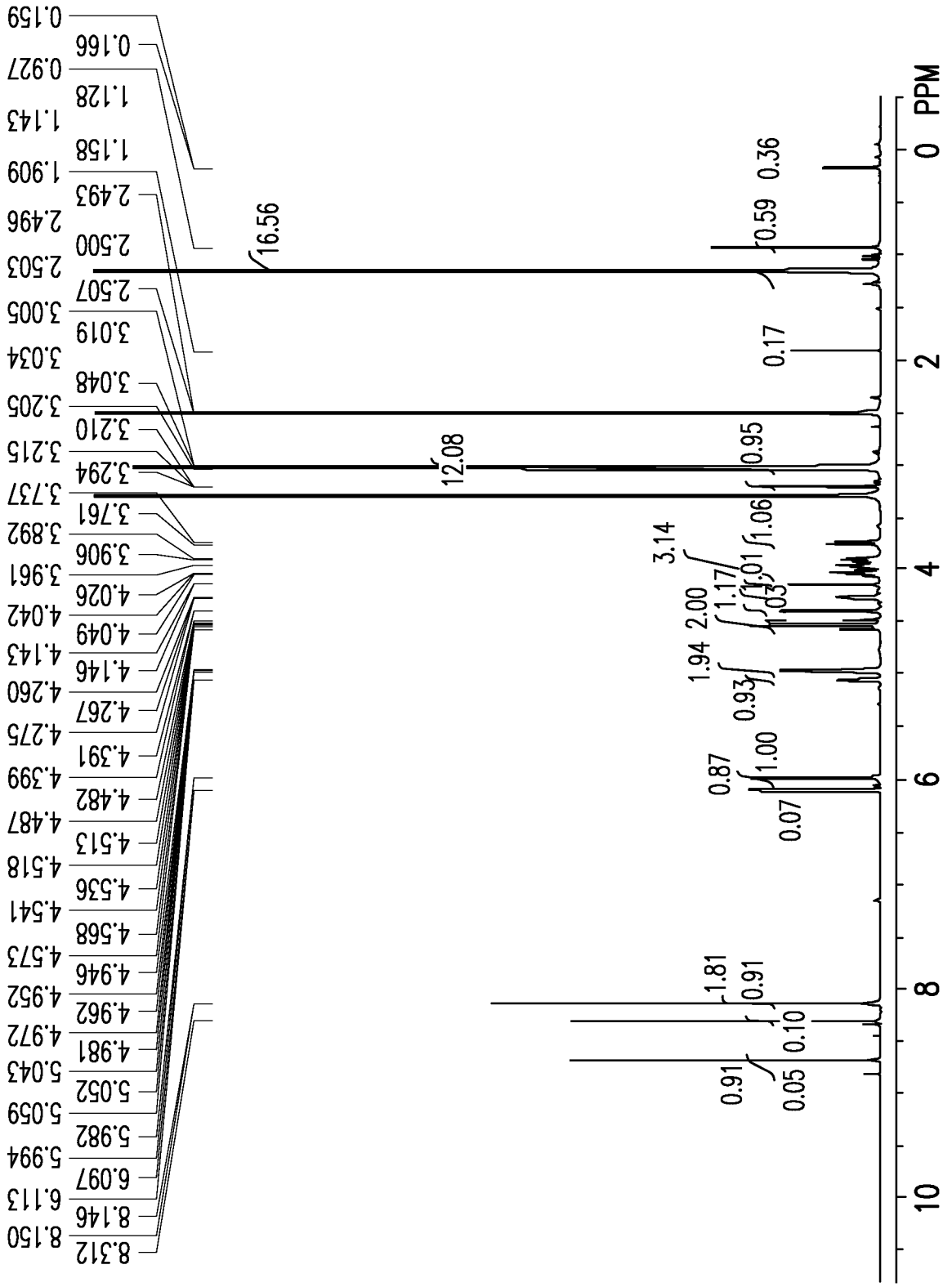

0.159
0.166
0.927
1.128
1.143
1.158
1.909
2.493
2.496
2.500
2.503
2.507
3.005
3.019
3.034
3.048
3.205
3.210
3.215
3.294
3.737
3.761
3.892
3.906
3.961
4.026
4.042
4.049
4.143
4.146
4.260
4.267
4.275
4.391
4.399
4.482
4.487
4.513
4.518
4.536
4.541
4.568
4.573
4.946
4.952
4.962
4.972
4.981
5.043
5.052
5.059
5.982
5.994
6.097
6.113
8.146
8.150
8.312
16.56
12.08
0.36
0.59
0.17
0.95
1.06
3.14
1.01
1.17
1.03
2.00
1.94
0.93
1.00
0.87
0.07
1.81
0.91
0.10
0.91
0.05
PPM
0
2
4
6
8
10

FIG.3A

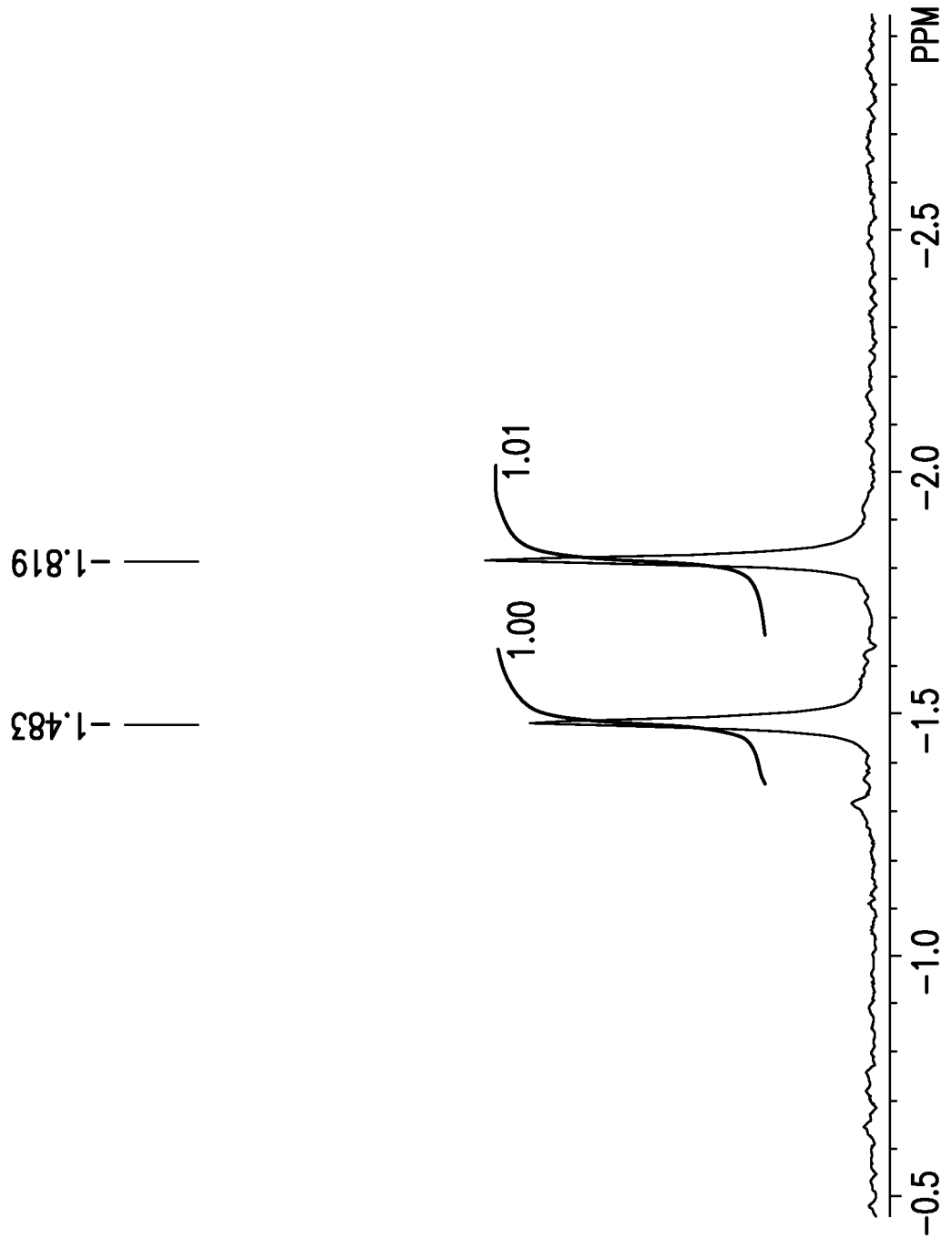


FIG.3B

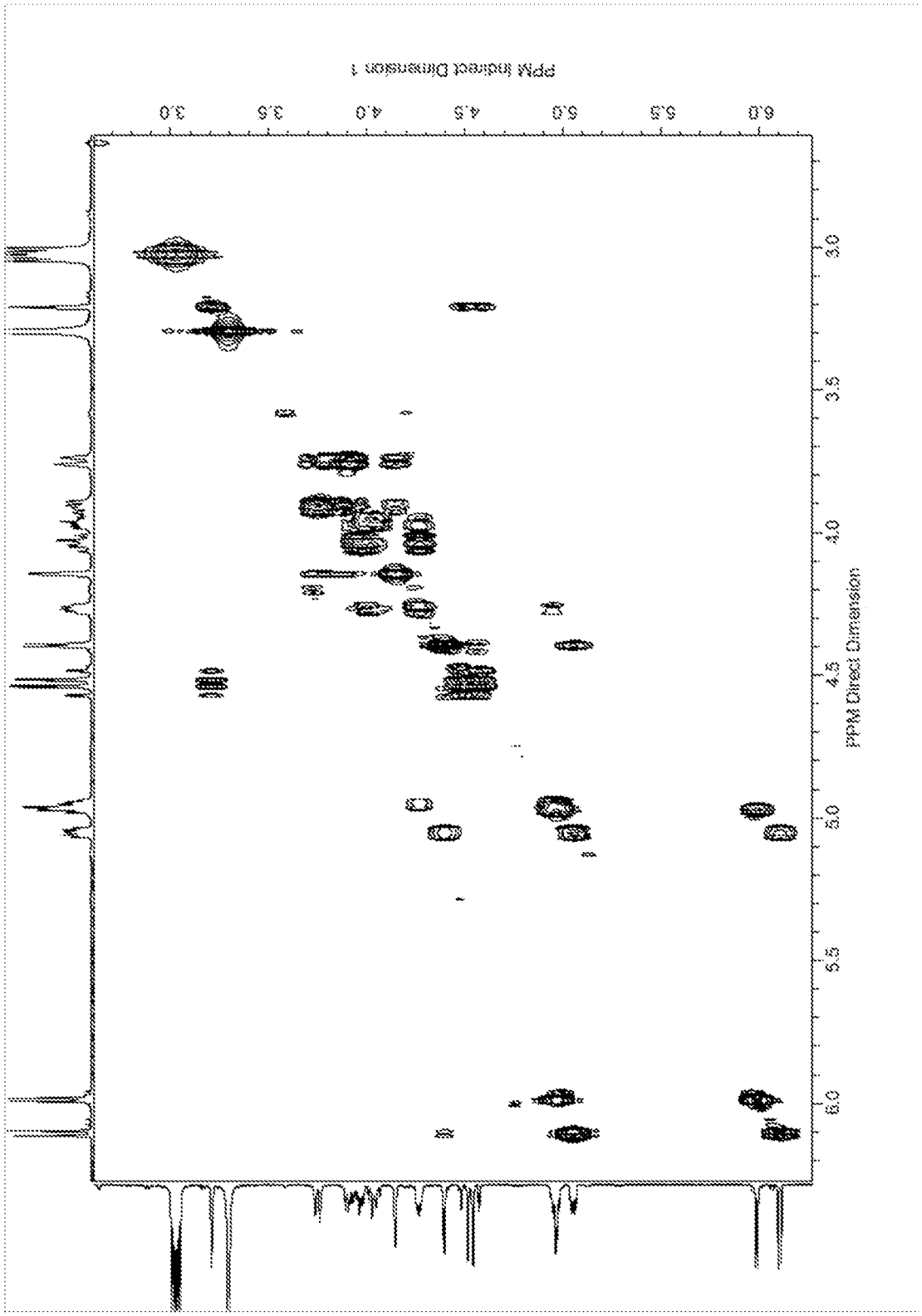

PPM Indirect Dimension 1
6.0
5.5
5.0
4.5
4.0
3.5
3.0
PPM Direct Dimension
3.0
3.5
4.0
4.5
5.0
5.5
6.0

FIG. 3C

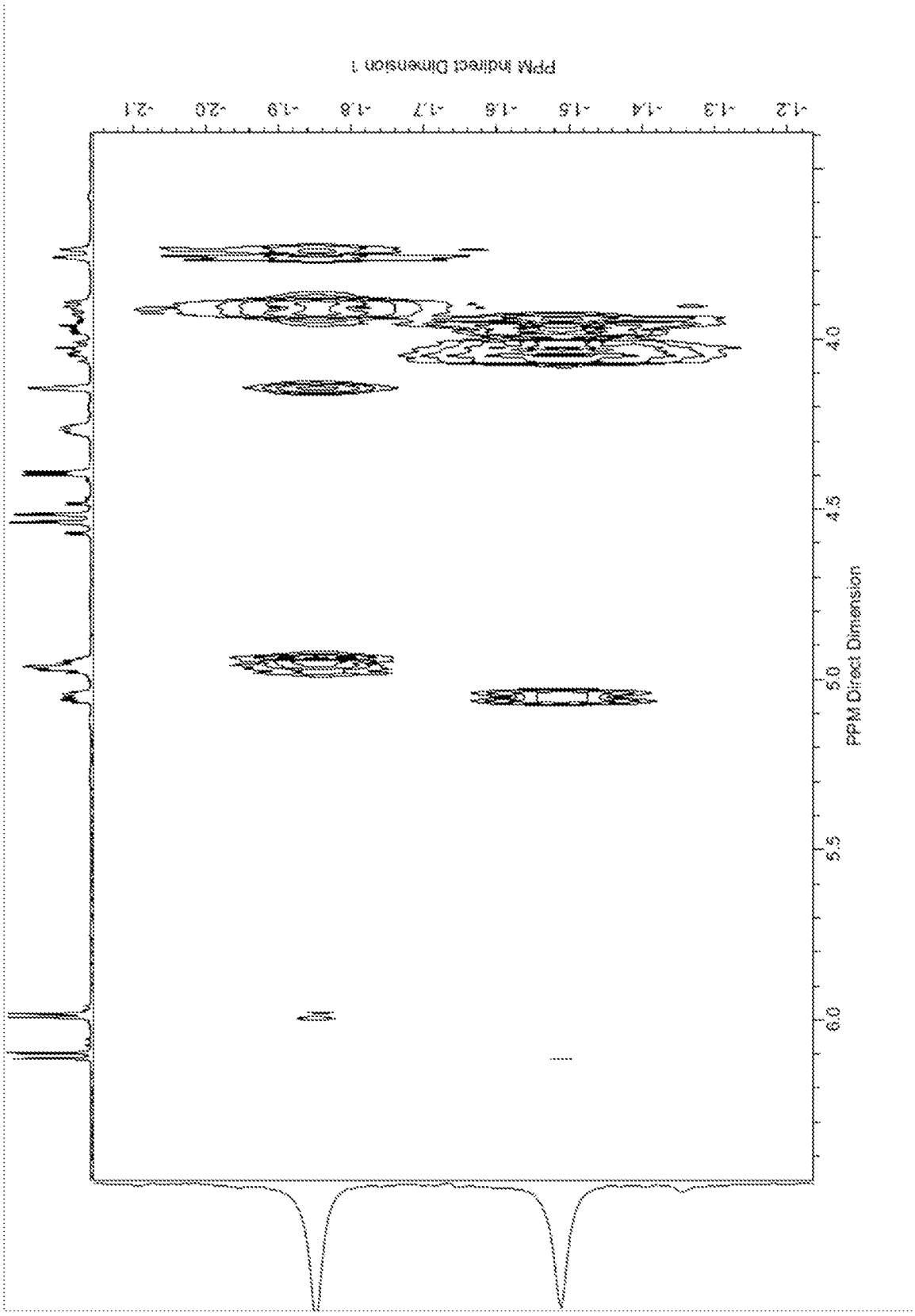

PPM Indirect Dimension 1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
4.0
4.5
5.0
5.5
6.0
PPM Direct Dimension

FIG. 3D

FIG. 3E

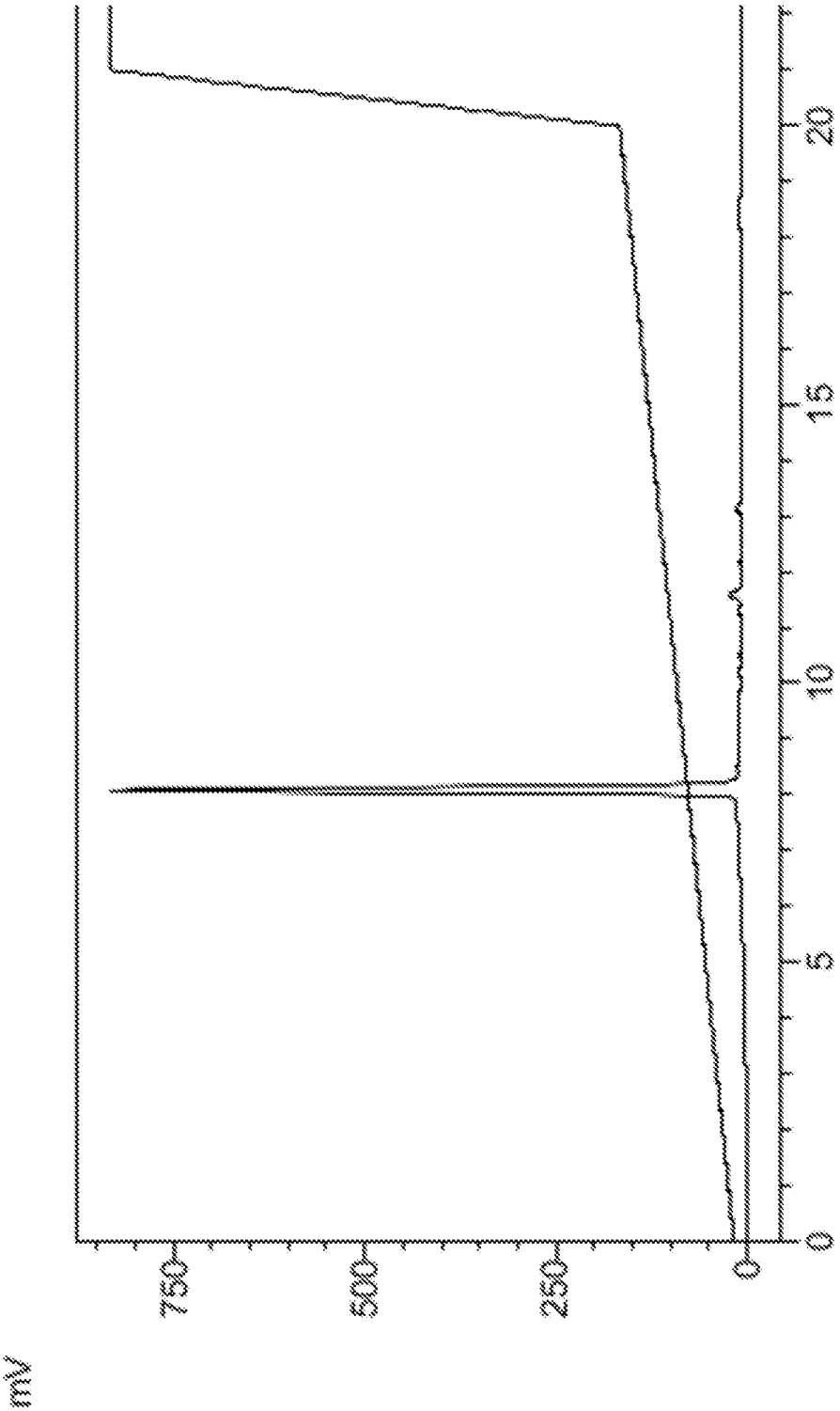


FIG.4

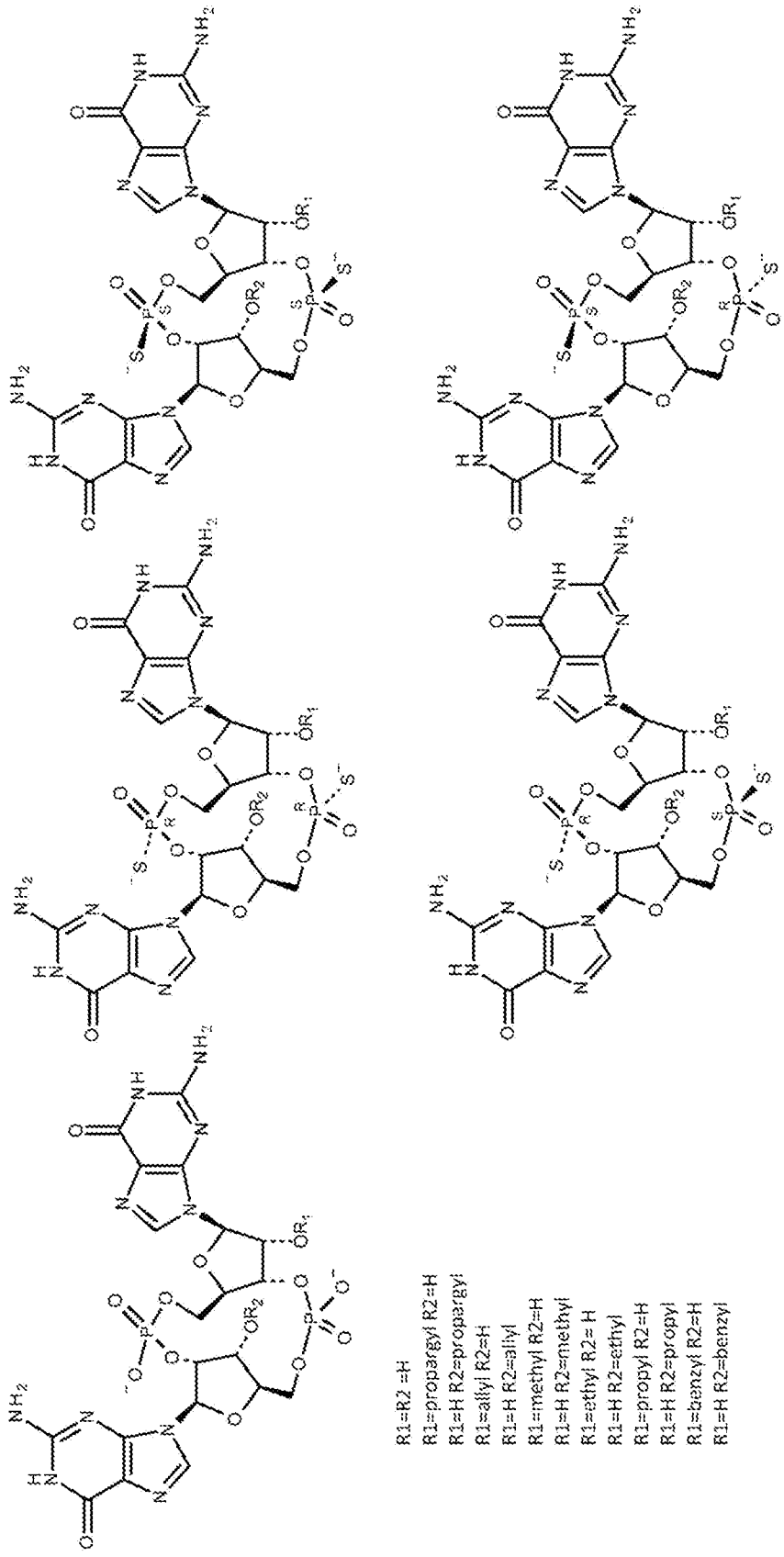

R1=R2 =H
R1=propargyl R2=H
R1=H R2=propargyl
R1=allyl R2=H
R1=H R2=allyl
R1=methyl R2=H
R1=H R2=methyl
R1=ethyl R2= H
R1=H R2=ethyl
R1=propyl R2=H
R1=H R2=propyl
R1=benzyl R2=H
R1=H R2=benzyl

FIG. 5

X=O

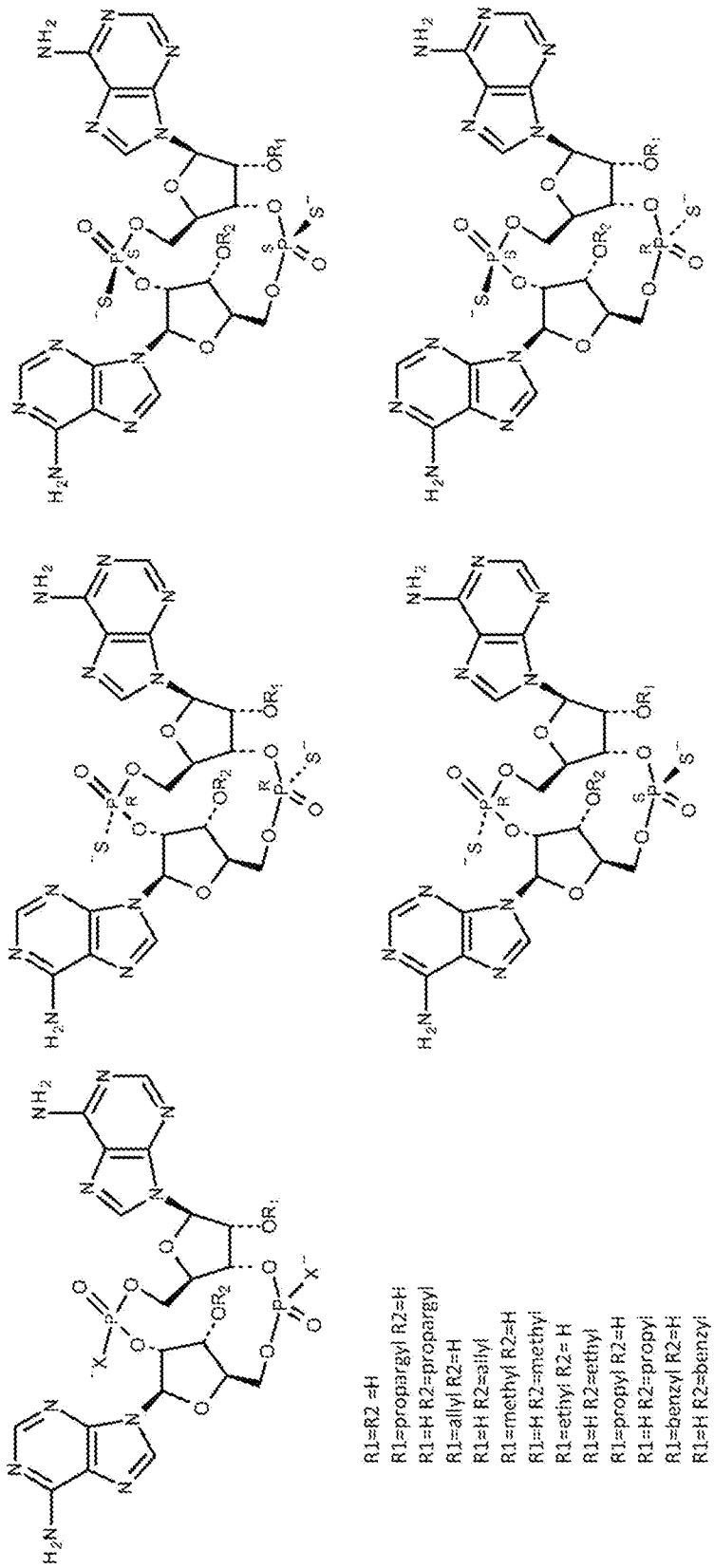

R1=R2 =H
R1=propargyl R2=H
R1=H R2=propargyl
R1=allyl R2=H
R1=H R2=allyl
R1=methyl R2=H
R1=H R2=methyl
R1=ethyl R2= H
R1=H R2=ethyl
R1=propyl R2=H
R1=H R2=propyl
R1=benzyl R2=H
R1=H R2=benzyl

FIG. 6

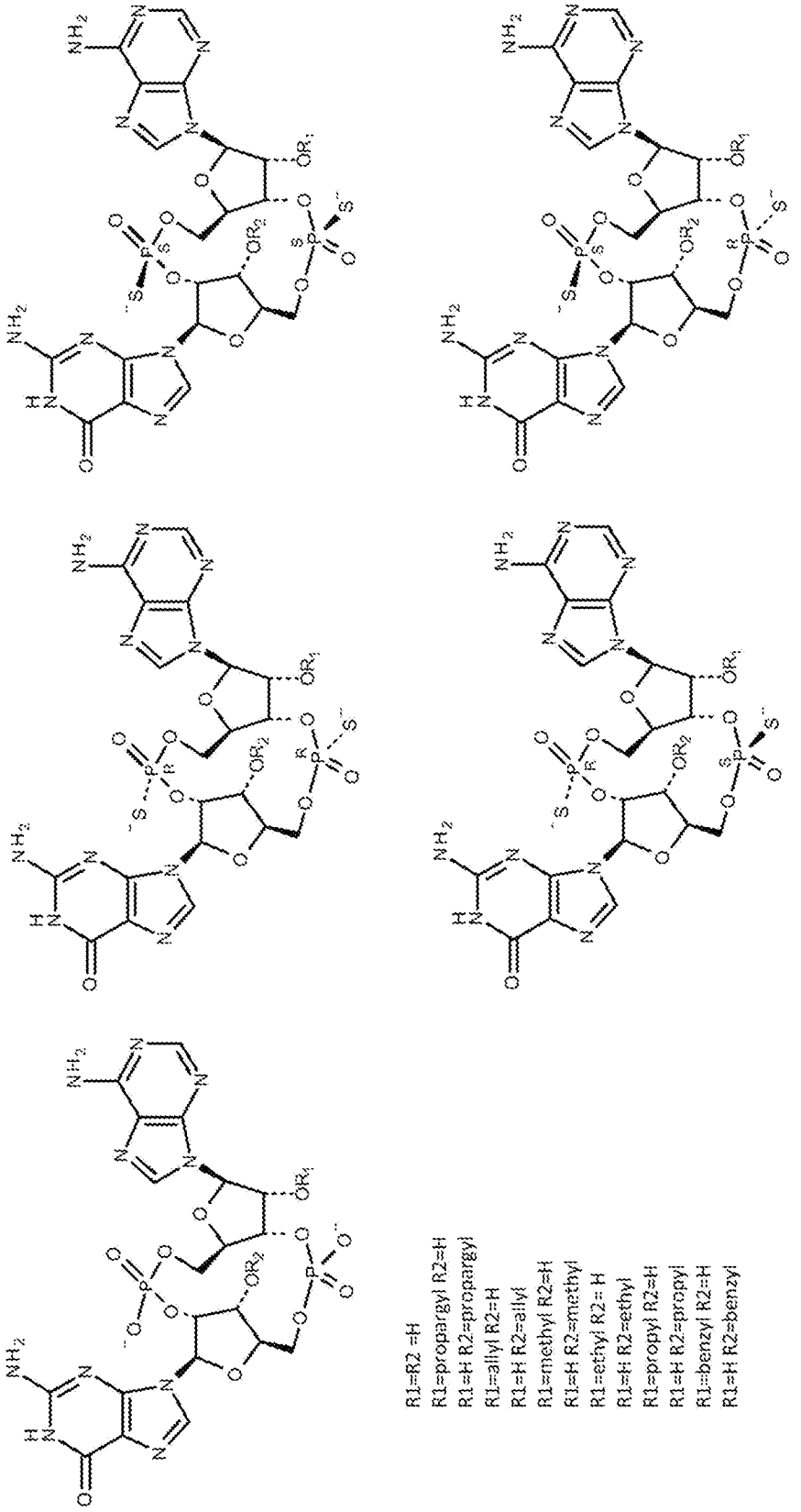
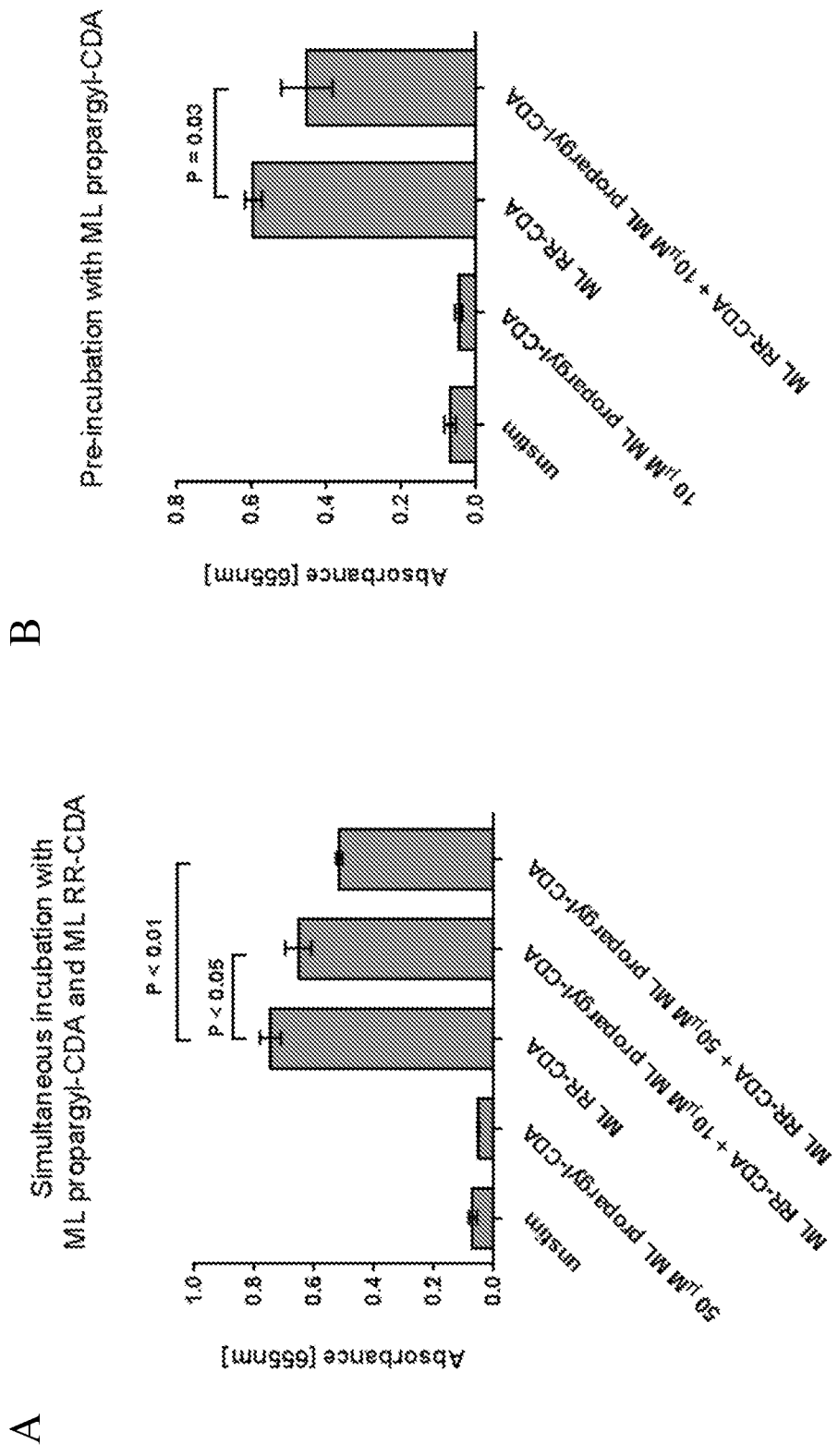

R1=R2 =H
R1=propargyl R2=H
R1=H R2=propargyl
R1=allyl R2=H
R1=H R2=allyl
R1=methyl R2=H
R1=H R2=methyl
R1=ethyl R2= H
R1=H R2=ethyl
R1=propyl R2=H
R1=H R2=propyl
R1=benzyl R2=H
R1=H R2=benzyl

FIG. 7


A
Simultaneous incubation with
ML propargyl-CDA and ML RR-CDA
Absorbance [655nm]
1.0
0.8
0.6
0.4
0.2
0.0
P < 0.01
P < 0.05
unstim
50 μM ML propargyl-CDA
ML RR-CDA
ML RR-CDA + 10 μM ML propargyl-CDA
ML RR-CDA + 50 μM ML propargyl-CDA
B
Pre-incubation with ML propargyl-CDA
Absorbance [655nm]
0.8
0.6
0.4
0.2
0.0
P = 0.03
unstim
10 μM ML propargyl-CDA
ML RR-CDA
ML RR-CDA + 10 μM ML propargyl-CDA

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 14/38526

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A01N 43/04 (2014.01)
CPC - C07H 19/16, A61K 31/70
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
CPC -C07H 19/16, A61K 31/70

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - C07H 19/16; A61K 31/70 (see search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, PubWest, ProQuest Dialog, Google Scholar, Google
Search Terms: STimulator of INTerferon Gene, STING, C-di-AMP, c-di-GMP, c-di-IMP, c-AMP-GMP, c-AMP-IMP, c-GMP-IMP, cyclic, purine di-nucleotides

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y -- A	US 2012/0164107 A1 (Portnoy et al.) 28 June 2012 (28.06.2012) para [0010], [0039], Fig. 3c	1 ------- 2-4
Y -- A	Burdette et al. STING is a direct innate immune sensor of cyclic di-GMP. Nature, 27 October 2011 (27.10.2011), Volume: 478, Pages: 515-518, abstract	1 -------- 2-4
X/E	US 2014/0205653 A1 (Dubensky, JR. et al.) 24 July 2014 (24.07.2014) abstract	1-3
X/P	WO 2013/185052 A1 (Dubensky, et al.) 12 December 2013 (12.12.2013) abstarct	1-3
A	US 2008/0286296 A1 (Ebensen et al.) 20 November 2008 (20.11.2008) entire document especially para [00037]-[0046]	1-4

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 August 2014 (26.08.2014)	19 SEP 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 14/38526

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 5-29
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.