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(54) Title: METHODS AND COMPOSITIONS FOR THE TREATMENT OF CANCER OR OTHER DISEASES

(57) Abstract: The disclosure relates to methods and compositions for improving immune function and treating diseases, including cancer, infectious diseases and autoimmune diseases. More particularly, the disclosure relates to multi-functional molecules that are capable of being delivered to cells of interest for blocking STAT3 for the treatment of diseases and the improvement of immune function.

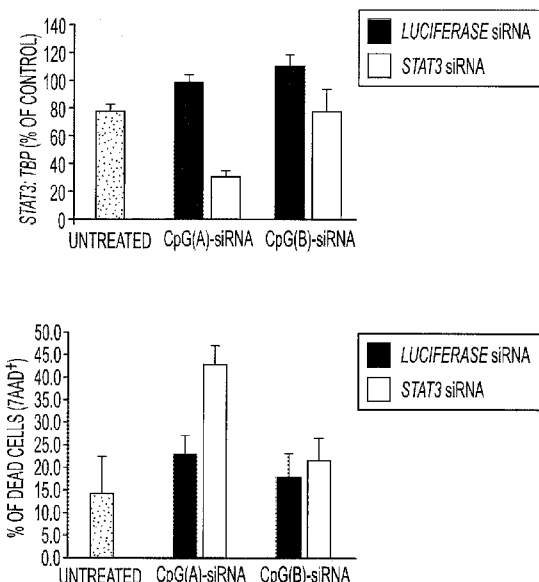


FIG. 2

WO 2012/128785 A1

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METHODS AND COMPOSITIONS FOR THE
TREATMENT OF CANCER OR OTHER DISEASES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to U.S. Provisional Patent Application Serial No. 61/466,086 filed on 22 March 2011.

STATEMENT OF FEDERALLY SPONSORED RESEARCH

[0002] The present invention was made in part with Government support under Grant Numbers R01-89693, R01-100878, R01CA115815, R01CA122976, R01CA115674 and P50CA107399 awarded by the National Institutes of Health/National Cancer Institute, Bethesda, Maryland. The Government has certain rights in this invention.

SEQUENCE SUBMISSION

[0003] The present application is being filed along with a Sequence Listing in electronic format. The Sequence Listing is entitled 1954547PCTSequenceListing.txt, created on 29 August 2011, and is 4 kb in size. The information in the electronic format of the Sequence Listing is part of the present application and is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0004] The present invention relates to methods and compositions for the treatment of diseases, including cancer, infectious diseases and autoimmune diseases. The present invention also relates to methods and compositions for improving immune function. More particularly, the present invention relates to multifunctional molecules that are capable of being delivered to cells of interest for the treatment of diseases and for the improvement in immune function.

[0005] The publications and other materials used herein to illuminate the background of the invention, and in particular, cases to provide additional details respecting the practice, are incorporated by reference, and for convenience are referenced in the following text by author and date and are listed alphabetically by author in the appended bibliography.

[0006] Signal Transducer and Activator of Transcription 3 (Stat3) is constitutively activated at high frequency (50 to 100%) in diverse cancers (Yu and Jove, 2004; Yu et al., 2007; Kortylewski et al., 2005a). Blocking Stat3 in tumor cells induces tumor cell apoptosis, inhibits tumor angiogenesis and abrogates metastasis (Yu and Jove, 2004; Yu et al., 2007; Xie et al., 2004; Xie et al., 2006), and activates antitumor immune responses (Wang et al., 2004;

Kortylewski et al., 2005b). Our recent studies further demonstrate that Stat3 is constitutively activated in tumor-stromal myeloid cells, including Gr1⁺ immature myeloid cells, DCs, macrophages, NK cell, neutrophils. Activated Stat3 inhibits expression of Th-1 type immune responses while promoting tumor accumulation of T regulatory cells and Th17 cells, compromising antitumor effects of immune effector cells, such as NK cells, neutrophils and CD8⁺ T cells (Kortylewski et al., 2005b). Blocking Stat3 in the immune subsets leads to activation of antitumor immunity and immune-mediated tumor growth inhibition and tumor regression (Kortylewski et al., 2005b). Our preliminary data further demonstrate that Stat3 is constitutively activated in CD4⁺CD25⁺/Foxp3⁺ T regulatory cells within the tumor stroma. A requirement of Stat3 for expression of Foxp3, TGFβ and IL-10 – the hallmarks of T regulatory cells – in CD4⁺ T cells has been demonstrated in both animal models and human T cells obtained from clinical trials (Yu et al., 2007). A recent study involving human melanoma cells has also confirmed a critical role of Stat3 in mediating tumor immune evasion/suppression (Sumimoto et al., 2006).

[0007] Stat3 is a point of convergence for numerous tyrosine kinase signaling pathways, which are the most frequently overactive oncogenic pathways in tumor cells of diverse origins (Yu and Jove, 2004). The reason Stat3 is also constitutively-activated in tumor stromal cells is because many of the Stat3 target genes encode secreted molecules whose cognate receptors signal through Stat3 (Yu et al., 2007). For example, Stat3-regulated products such as IL-10, IL-6 and VEGF have their receptors in diverse myeloid cells and T lymphocytes. VEGF and bFGF, both of which also require Stat3 for their expression, activates Stat3 in endothelial cells. Activated Stat3 promotes expression of a wide range of genes critical for tumor cell survival, proliferation, angiogenesis/metastasis and immune suppression. Activated Stat3 also inhibits expression multiple genes that are pro-apoptotic, anti-angiogenic and Th-1 type immunostimulatory, whose upregulation are critical for anti-cancer therapy (Yu and Jove, 2004; Yu et al., 2007; Kortylewski et al., 2005b).

[0008] RNA interference provides compelling opportunities to control gene expression in cells and siRNAs therefore represent a family of new drugs with broad potential for the treatment of diverse human diseases. Several recent studies have demonstrated the feasibility of *in vivo* siRNA delivery, leading to therapeutic effects in mouse models (Song et al., 2005; Hu-Lieskovan et al., 2005; McNamara et al., 2006; Kumar et al., 2007; Poeck et al., 2008) and also in non-human-primates (Li et al., 2005; Zimmermann et al., 2006). Nevertheless, efficient *in vivo* targeted delivery of siRNA into specific cell types, especially those of immune origin,

which are important constituents of the tumor microenvironment and active players in promoting tumor progression, remains to be fully explored before the full potential of therapeutic RNA interference can be realized. One promising approach for targeted delivery of siRNA is the use of aptamers, which are oligonucleotide-based ligands that bind to specific receptors, such as those on tumor cells (McNamara et al., 2006). Recent studies further indicated the ability of specific aptamers to bind and modulate the functions of their cognate targets in T cells, leading to potent antitumor immune responses (McNamara et al., 2008). However, whether these aptamers can mediate siRNA delivery into T cells remains to be determined.

[0009] The immune system can serve as extrinsic tumor suppressor (Bui and Schreiber, 2007; Koebel et al., 2007; Shankaran et al., 2001). However, the microenvironment of established tumors is typically characterized by a paucity of tumor-specific CD8⁺ T cells together with an excess of suppressive regulatory T cells and myeloid-derived suppressor cells (MDSC) that promote tumor immune evasion (Kortylewski et al., 2005b; Yu et al., 2005; Curiel et al., 2004; Ghiringhelli et al., 2005; Melani et al., 2003). Myeloid cells and other immune cells in the tumor microenvironment also produce growth factors and angiogenic/metastatic factors critical for tumor progression (Kujawski et al., 2008). As noted above, Stat3 is an important oncogenic molecule. The orchestration of these processes in the tumor microenvironment is highly dependent on the oncogenic transcription factor, Stat3 (Yu et al., 1995; Bromberg et al., 1999; Yu and Jove, 2004; Darnell, 2002; Yu et al., 2007). In particular, we and others have recently demonstrated a critical role of Stat3 in mediating tumor immune evasion (Wang et al., 2004; Kortylewski et al. 2005b; Yu et al., 2007). Activated Stat3 in myeloid cells inhibits expression of a large number of immunostimulatory molecules related to Th1-type responses, while promoting production of several key immunosuppressive factors (Yu et al., 2007, Kortylewski and Yu, 2008; Kortylewski et al., 2009a) as well as angiogenic factors (Kujawski et al., 2008). In addition, by mediating signaling of certain cytokines and growth factors, notably IL-6, Stat3 activation in myeloid cells activates Stat3 in tumor cells, enhancing tumor cell proliferation and survival (Bollrath et al., 2009; Grivennikov et al., 2009; Lee et al., 2009; Wang et al., 2009).

[0010] It is desired to develop new molecules and methods for the treatment of cancer and other diseases, including new molecules and methods for treatment that involve pathways within cells that modulate the disease, such as the Stat3 pathway.

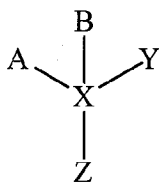
SUMMARY OF THE INVENTION

[0011] The present invention relates to methods and compositions for the treatment of diseases, including cancer, infectious diseases and autoimmune diseases. The present invention also relates to methods and compositions for improving immune function. The present invention relates to blocking Stat3, either through genetic knockout, Stat3 small-molecule inhibitor, or Stat3 siRNA, which drastically improves the immune responses induced by CpG.

[0012] The present invention relates to multifunctional molecules that are capable of being delivered to cells of interest. The multifunctional molecules incorporate an activation element together with a therapeutic element, e.g., a Stat3 blocking element. The multifunctional molecules are capable of being delivered to specific cells of interest including, but not limited to, dendritic cells. These molecules are capable of treating diseases, including cancer, infectious diseases and autoimmune diseases. More particularly, the present invention is related to chimeric molecules consisting of an active oligonucleotide, such as Toll-like receptor (TLR) ligands, and an active agent, such as double stranded RNA, such as siRNA or activating RNA. Such chimeric molecules are taken up and internalized by immune cells and malignant cells, allowing actions of both the TLR ligand and the active agent. More specifically, the present invention relates to specific chimeric molecules that are useful for the treatment of diseases.

[0013] In one aspect, the present invention provides a novel molecule for the delivery of an active agent into cells for the treatment of diseases including, but not limited to cancer, infectious diseases and autoimmune diseases. The novel molecules comprises one or more of a first moiety that directs cell or tissue specific delivery of the novel molecule linked to one or more of a second moiety that is an active agent useful for treating cancer or other diseases. The moieties can be linked together directly or they can be linked together indirectly through a linker. In one embodiment, the novel molecule comprises two moieties as one molecule that is multifunctional. For example, a TLR ligand and an siRNA are made into one molecule for delivery, immune stimulation and blocking immunosuppressive elements, such as Stat3, and/or oncogenic effects, such as caused by Stat3. In another embodiment, the novel molecule comprises multifunctional moieties attached to a linker, such that it can contain a multitude of moieties. In another embodiment, the linker is bifunctional producing a molecule of the structure A-X-B, where X is a linker, one of A and B is a moiety that is capable of delivering the molecule to cells of interest and the other one of A and B is an active agent useful for treating the cancer or other disease. A and/or B may also be subject to further linking. In another embodiment, the linker is multifunctional, producing a molecule having more than two moieties.

In one embodiment, using as an example a quadrifunctional form, such a molecule can have the structure



where X is a linker with four binding sites, one or more of A, B, Y and Z is a moiety that is capable of delivering the molecule to cells of interest and the others are an active agent useful for treating the cancer or other disease. In one embodiment, the active agent is a double stranded RNA molecule that either downregulates gene expression, such as an siRNA molecule, or activates gene expression, such as an activating RNA molecule. In another embodiment, the active agent is a small molecule drug or peptide. In one embodiment, the delivery moiety is a ligand for a toll-like receptor (such as oligonucleotides described herein). In another embodiment, the delivery moiety is another cell-specific ligand (including, but not limited to, aptamers).

[0014] The binding sites on a linker may be specific for each type of moiety to be linked, for example a linker with a structure that has one region capable of likening to an oligonucleotide and another region capable of binding to a peptide. Other variations of structure can be proposed by utilizing structures and linkers that promote branching, circularization or linearization of the molecules, including combinations thereof. Any element of a multimeric molecule, including the linker, may also have additional functional properties such as being a substrate for chemical reactions, including enzyme catalyzed reactions, lability in environmental conditions such as oxygen tension, pH, ionic conditions. In addition, any element of a multimeric molecule, including linkers may also include labels to promote detection – using active or passive detection of electromagnetic emissions (e.g. optical, ultraviolet, infra-red), radioactivity, magnetic resonance or ability to be cleaved or catalyze a reaction. Many means are available to promote this including use of fluorochromes, quantum dots, dyes, inherent physical chemical properties structures such as spectral absorbance or emission characteristics magnetic resonance enhancers, and radioisotopes.

[0015] In a second aspect, the present invention provides a method for the treatment of diseases (including, but not limited to, cancer, infectious diseases, autoimmune diseases, diseases due to excessive angiogenesis and diseases that can benefit from increased angiogenesis) which comprises using the novel molecules of the present invention. The

molecules of the present invention are administered to patients in need of treatment using conventional pharmaceutical practices.

[0016] In a third aspect, the present invention provides active agents that are capable of acting in the Stat3 pathway which, when taken up by the cells of interest, results in the treatment of diseases including, but not limited to, cancer, infectious diseases and autoimmune diseases.

BRIEF DESCRIPTION OF THE FIGURES

[0017] Figures 1A-1D show that CpG-*STAT3* siRNA approach effectively silences genes in TLR9+ human acute myeloid leukemia (AML) cells, leading to therapeutic antitumor effects in xenotransplanted tumor models in mice. Fig. 1A: NOD/SCID/IL-2R γ null (NSG) mice were injected i.v. with 10⁷ of human MV4-11 leukemia cells. Four weeks later, mice with engrafted AML cells were injected i.v. with the 100 μ g dose of various CpG(A)-siRNAs daily for three days. The percentages of viable bone-marrow resident AML tumor cells after treatment using CpG(A)-*Luciferase* siRNA (top) and CpG(A)-*STAT3* siRNA (bottom) were assessed by FACS using antibodies specific for human CD45 expressed on the surface of MV4-11 cells. *STAT3* gene silencing was assessed in bone marrow-derived AML cells using quantitative real-time PCR (qPCR) (right graph). Fig. 1B: CpG(A)-*STAT3* siRNA *in vivo* treatment leads to *STAT3* gene silencing (left, by qPCR), tumor cell death (middle, by FACS analysis of Annexin V-positive tumor cell suspensions) and reduced growth rate of human myeloma tumors in NSG mice (right). Tumors were treated with daily intratumoral injections of 20 μ g CpG-*STAT3* siRNA starting 4-5 days after injection of 10⁷ of tumor cells (at the average tumor size 10 mm). Blocking of *STAT3* in MonoMac6 cells (Fig. 1C) and *BCL-XL* in MV4-11 AML cells (Fig. 1D) *in vivo* inhibits growth of xenotransplanted tumors in NSG mice. The target gene silencing (left graphs in Fig. 1C, 1D), tumor cell death (middle graph in Fig. 1D) and tumor growth kinetics (right panels) were assessed as described above. Statistically significant differences between CpG-*STAT3* or *BCL-XL* siRNA- and CpG-*Luc* RNA-treated groups (from two-way ANOVA test) are indicated by asterisks as described in the legend for Fig. 3. Shown are the representative results from one of two independent experiments (Fig. 1B) or from single experiments (Figs. 1A, 1C, 1D) using 5-6 mice per each experimental group; means \pm s.e.m.

[0018] Figure 2 shows the efficacy of *in vivo* target gene silencing by CpG-*STAT3* siRNA depends on the CpG ODN sequence. Fig. 2 top: NOD/SCID/IL-2R γ null (NSG) mice were injected *s.c.* with 5x10⁶ of human MV4-11 leukemia cells. Tumors were treated with two daily intratumoral injections of 20 μ g various CpG-siRNAs as indicated, including CpG-*Luciferase*

siRNA and CpG-*STAT3* siRNA in two versions, conjugated to class A (D19 ODN) or class B (7909) CpG ODN. The *STAT3* gene silencing was assessed by quantitative real-time PCR (Fig. 2 top), while tumor cell death was measured by FACS analysis using Annexin V staining of tumor cell suspensions (Fig. 2 bottom). Shown are the representative results from a single experiments using 5-6 mice per each experimental group; means \pm s.e.m.

[0019] Figure 3 shows that the class A ODN-based CpG(D19)-*STAT3* siRNA conjugates induce production of proinflammatory protein mediators without stimulating expression of potentially tumor promoting IL-6, IL-8 or IL-10, which are co-activated by two other CpG-siRNA types. Human PBMCs were incubated for 24 h in the presence of class A - CpG(D19)-*STAT3* siRNA, class B - CpG(7909)-*STAT3* siRNA or class C - CpG(2429)-*STAT3* siRNA conjugates in concentrations as indicated. Supernatants from cultured PBMCs were analyzed for the production of pro-inflammatory and anti-inflammatory protein mediators using Cytokine Bead Arrays on Luminex platform. Shown are representative results from one of two independent experiment performed in triplicates; ND – not detectable.

[0020] Figure 4 shows that the CpG(D19)-*STAT3* siRNA does not induce exacerbated type I interferon response, in contrast to unconjugated D19 class A oligodeoxynucleotides. Human PBMCs were incubated for 24 h in the presence of *STAT3* siRNA, CpG(A)-D19, CpG(B)-7909 alone or as CpG-*STAT3* siRNA conjugates in concentrations as indicated. Supernatants from cultured PBMCs were analyzed for the IFN α production using Cytokine Bead Array on Luminex platform. Shown are representative results from one of two independent experiment performed in triplicates; ND – not detectable.

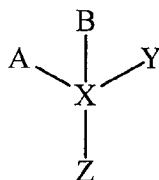
DETAILED DESCRIPTION OF THE INVENTION

[0021] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which the invention belongs.

[0022] The present invention relates to methods and compositions for the treatment of diseases. More particularly, the present invention relates to multifunctional molecules that are capable of being delivered to cells of interest for the treatment of diseases including, but not limited to, cancer, infectious diseases and autoimmune diseases. More specifically, the present invention relates to specific chimeric molecules that are useful for the treatment of diseases.

[0023] In one aspect, the present invention provides a novel molecule for the delivery of an active agent into cells for the treatment of cancer and other diseases including, but not limited to infectious diseases and autoimmune diseases. The novel molecules comprises one or more of a

first moiety that directs cell or tissue specific delivery of the novel molecule linked to one or more of a second moiety that is an active agent useful for treating cancer or other diseases. The moieties can be linked together directly or they can be linked together indirectly through a linker. In one embodiment, the novel molecule comprises two moieties as one molecule that is multifunctional. For example, a TLR ligand and an siRNA are made into one molecule for delivery, immune stimulation and blocking immunosuppressive elements, such as Stat3, and/or oncogenic effects, such as caused by Stat3. In another embodiment, the novel molecule comprises moieties attached to a linker that is multifunctional, such that it can contain a multitude of moieties. In another embodiment, the linker is bifunctional producing a molecule of the structure A-X-B, where X is a linker, one of A and B is a moiety that is capable of delivering the molecule to cells of interest and the other one of A and B is an active agent useful for treating the cancer or other disease. In another embodiment the linker is a modification of, or structure present on, either moiety A or B, or both, that results in a binding between the two elements. The binding maybe covalent or non-covalent bonds. In another embodiment, the linker is multifunctional, for example, quadrifunctional, producing a molecule having more than two moieties. In one embodiment, such a molecule can have the structure



where X is the linker, one or more of A, B, Y and Z is a moiety that is capable of delivering the molecule to cells of interest and the others are an active agent useful for treating the cancer or other disease. The linker may have any number of other moieties attached to it, and the examples of having two or four moieties, and their lack of any secondary extension, for example a modification of Y, is merely for illustration purposes and not intended to be limiting.

[0024] In one embodiment, the active agent is a double stranded RNA molecule that either downregulates gene expression, such as a siRNA molecule, or activates gene expression, such as an activating RNA molecule. In another embodiment, the active agent is a small molecule drug or peptide. In one embodiment, the delivery moiety is a ligand for a toll-like receptor (such as oligonucleotides described herein). In another embodiment, the delivery moiety is another cell-specific ligand (such as aptamers).

[0025] In a second aspect, the present invention provides a method for the treatment of diseases which comprises using the novel molecules of the present invention. Diseases which

can be treated in accordance with the present invention include cancer, infectious diseases, autoimmune diseases, diseases due to excessive angiogenesis and diseases that can benefit from increased angiogenesis. Cancers which can be treated with the molecules of the present invention include, but are not limited to, melanoma, skin cancer, precancerous skin lesions, breast cancer, prostate cancer, lung cancer, glioma, pancreatic cancer, head and neck cancer, multiple myeloma, leukemias, lymphomas. Examples of infectious diseases include, but are not limited to, HIV, HPV infection and hepatitis. Examples of autoimmune diseases include, but are not limited to, psoriasis, multiple sclerosis (MS) and inflammatory bowel disease (IBD). Examples of diseases due to excessive angiogenesis include, but are not limited to, cancer, diabetic retinopathy and Kaposi's Sarcoma. Examples of diseases that can benefit from increased angiogenesis include, but are not limited to, diseases needing wound repair (healing). The molecules of the present invention are administered to patients in need of treatment using conventional pharmaceutical practices.

[0026] In a third aspect, the present invention provides active agents that are capable of acting in the Stat3 pathway which, when taken up by the cells of interest, results in the treatment diseases including, but not limited to cancer, infectious diseases and autoimmune diseases.

[0027] The molecules of the present invention have several advantages that result from the characteristics of the molecules. These advantages include:

[0028] (a) ease of use and cost effectiveness primarily because of a reduction in the need to use transfection reagents;

[0029] (b) simplicity primarily because of the ability to make the molecules by chemical synthesis using standard synthesizers;

[0030] (c) versatility primarily because the molecules of the present invention can be easily adapted for various gene targets and modified be further modified for small molecule drug or peptide delivery with the use of appropriate chemical linkers; and

[0031] (d) flexibility primarily because a similar design can be adapted for different cell types capable of ODN or ORN uptake.

[0032] An "oligonucleotide" or "oligo" shall mean multiple nucleotides (i.e. molecules comprising a sugar (e.g. ribose or deoxyribose) linked to a phosphate group and to an exchangeable organic base, which is either a substituted pyrimidine (e.g. cytosine (C), thymine (T) or uracil (U)) or a substituted purine (e.g. adenine (A) or guanine (G)). The term "oligonucleotide" as used herein refers to both oligoribonucleotides (ORNs) and oligodeoxyribonucleotides (ODNs). The term "oligonucleotide" shall also include

oligonucleosides (i.e. an oligonucleotide minus the phosphate) and any other organic base containing polymer. Oligonucleotides can be obtained from existing nucleic acid sources (e.g. genomic or cDNA), but are preferably synthetic (e.g. produced by oligonucleotide synthesis).

[0033] A "stabilized oligonucleotide" shall mean an oligonucleotide that is relatively resistant to *in vivo* degradation (e.g. via an *exo-* or *endo-*nuclease). Preferred stabilized oligonucleotides of the instant invention have a modified phosphate backbone. Especially preferred oligonucleotides have a phosphorothioate modified phosphate backbone (i.e. at least one of the phosphate oxygens is replaced by sulfur). Other stabilized oligonucleotides include: nonionic DNA analogs, such as alkyl- and aryl- phosphonates (in which the charged phosphonate oxygen is replaced by an alkyl or aryl group), phosphodiester and alkylphosphotriesters, in which the charged oxygen moiety is alkylated. Oligonucleotides which contain a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini have also been shown to be substantially resistant to nuclease degradation.

[0034] A "CpG containing oligonucleotide," "CpG ODN" or "CpG ORN" refers to an oligonucleotide, which contains a cytosine/guanine dinucleotide sequence. Preferred CpG oligonucleotides are between 2 to 100 base pairs in size and contain a consensus mitogenic CpG motif represented by the formula:



wherein C and G are unmethylated, X₁, X₂, X₃ and X₄ are nucleotides and a GCG trinucleotide sequence is not present at or near the 5' and 3' ends. Examples of CpG ODNs are described in U.S. Patent Nos. 6,194,388 and 6,207,646, each incorporated herein by reference. Preferably the CpG oligonucleotides range between 8 and 40 base pairs in size. In addition, the CpG oligonucleotides are preferably stabilized oligonucleotides, particularly preferred are phosphorothioate stabilized oligonucleotides. The CpG ODNs or CpG ORNs can be synthesized as an oligonucleotide. Alternatively, CpG ODNs or CpG ORNs can be produced on a large scale in plasmids.

[0035] An "aptamer" refers to a nucleic acid molecule that is capable of binding to a particular molecule of interest with high affinity and specificity (Tuerk and Gold, 1990; Ellington and Szostak, 1990). The binding of a ligand to an aptamer, which is typically RNA, changes the conformation of the aptamer and the nucleic acid within which the aptamer is located. The conformation change inhibits translation of an mRNA in which the aptamer is located, for example, or otherwise interferes with the normal activity of the nucleic acid. Aptamers may also be composed of DNA or may comprise non-natural nucleotides and

nucleotide analogs. An aptamer will most typically have been obtained by *in vitro* selection for binding of a target molecule. However, *in vivo* selection of an aptamer is also possible. An aptamer will typically be between about 10 and about 300 nucleotides in length. More commonly, an aptamer will be between about 30 and about 100 nucleotides in length. See, e.g., U.S. Patent No. 6,949,379, incorporated herein by reference. Examples of aptamers that are useful for the present invention include, but are not limited to, PSMA aptamer (McNamara et al., 2006), CTLA4 aptamer (Santulli-Marotto et al., 2003) and 4-1BB aptamer (McNamara et al., 2007).

[0036] As used herein, the terms "Toll-like receptor" or "TLR" refer to any member of a family of at least ten highly conserved mammalian pattern recognition receptor proteins (TLR1-TLR10) which recognize pathogen-associated molecular patterns (PAMPs) and act as key signaling elements in innate immunity. TLR polypeptides share a characteristic structure that includes an extracellular (extracytoplasmic) domain that has leucine-rich repeats, a transmembrane domain, and an intracellular (cytoplasmic) domain that is involved in TLR signaling. TLRs include, but are not limited, to human TLRs. TLRs include, but are not limited to TLR9, TLR8 and TLR3.

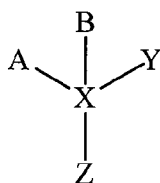
[0037] As used herein, the terms "TLR ligand" or "ligand for a TLR" refer to a molecule, that interacts, directly or indirectly, with a TLR through a TLR domain and is capable of being internalized by cells. In one embodiment a TLR ligand is a natural ligand, i.e., a TLR ligand that is found in nature. In one embodiment a TLR ligand refers to a molecule other than a natural ligand of a TLR, e.g., a molecule prepared by human activity, such as a CpG containing oligonucleotide.

[0038] In accordance with the present invention, target cells for ODN- or ORN-mediated delivery include any cell that is capable of internalizing a TLR ligand. Such cells include (a) cells of the myeloid lineage including dendritic cells, macrophages and monocytes, (b) cells of the lymphoid lineage including B cells and T cells, (c) endothelial cells and (d) malignant cells being derivatives of the previously mentioned cells, e.g., multiple myeloma, B cell lymphoma and T cell lymphoma. The malignant cells can also be any cells that possess the capacity of uptaking and/or internalizing a TLR ligand.

[0039] In accordance with the present invention, novel molecules are provided by an active moiety for delivering an active agent to a cell of interest for the treatment of diseases as disclosed herein. The novel molecules comprises one or more of a first moiety that directs cell or tissue specific delivery of the novel molecule linked to one or more of a second moiety that is

an active agent useful for treating cancer or other diseases. The moieties can be linked together directly or they can be linked together indirectly through a linker. In one embodiment, the novel molecule comprises two moieties as one molecule that is multifunctional. For example, a TLR ligand and an siRNA are made into one molecule for delivery, immune stimulation and blocking immunosuppressive elements, such as Stat3, and/or oncogenic effects, such as caused by Stat3. In another embodiment, the novel molecule comprises moieties attached to a linker that is multifunctional, such that it can contain a multitude of moieties. The linkage of the first and second moieties can be provided through diverse structures and/or chemistry. The linkage can also be designed to allow for one first moiety to be linked to multiple second moieties. The linkage can be designed to allow for linkage of a first moiety to small molecule drugs or peptides.

[0040] In one embodiment, the molecule may have the structure A-X-B. In another embodiment, the molecule may have the structure



where X is a linker between the A and B moieties or between the A, B, Y and Z moieties. In one embodiment, we can make 2 or (n)- element chains, stars, branches (or mixtures thereof) etc and defining the chemistry and valency of the linker(s). Valency can be substrate specific to control polymerization. In one embodiment, X may be multifunctional reactive molecule having, e.g., NNP, where N is a nucleic acid binding sites and P is a peptide binding site. The linker may be derivatized, e.g., with FITC, such that the X moiety itself is also functional. In this embodiment, X may be derivatized with a fluorochrome or similar molecule, or may be derivatized with a chemotherapeutic agent.

[0041] In one embodiment, A, B, etc., i.e., any moiety attached to the linker, can be small molecules, peptides, polypeptides, proteins, antibodies and fragments thereof, other molecules such as lectins, DNA, RNA, ds RNA ds DNA, RNA/DNA hybrids (and modifications thereto), locked nucleic acids, RNA with 5' triphosphates, antibodies, antibody fragments, antigens or antigen fragments.

[0042] In one embodiment, the function of A, B, etc., i.e., any moiety attached to the linker, can be selected to include from delivery (including approaches to target to cells, tissues, organs), improved pharmacokinetic properties, cytotoxic, cytostatic, apoptotic, gene modulating

(including upregulation, e.g., activating RNA, or downregulation, e.g., siRNA), pro-inflammatory, anti-inflammatory, antigenic, immunogenic pro-coagulant, anti-coagulant properties, pro-drug elements and combinations thereof. In another embodiment, each of these moieties can be modified as known in current state of art to improve their desired properties. These (A, B or desired modifications) can also be selected for via screening, evolution or combinatorial approaches as is well known to the skilled artisan.

[0043] In one embodiment, moieties that can be used for delivery include CpG ODNs, CpG ORNs, polyG (Peng et al., 2005), poly(I:C) (Alexopoulou et al., 2001) (such as ligands for toll-like receptors (TLRs)) and aptamers. The TLR ligands are useful for delivering the molecules of the present invention to cells that are capable of internalizing TLR ligands. Aptamers are useful for delivering the molecules of the present invention to cells which specifically bind the aptamers.

[0044] In one embodiment, some elements or moieties may be themselves bifunctional or derivatized to be bifunctional or have improved function (e.g., adding a 5' triphosphate on a CpG may be an enhanced stimulator of intracellular and/or extracellular signaling).

[0045] The present invention also provides for linkers and/or methods for providing the molecules of the present invention. In one embodiment, a molecule of the present invention is prepared by linking a first moiety, e.g. a CpG ODN, CpG ORN, oligonucleotides or aptamer, to a second moiety, e.g., a dsRNA, using multiple units of the C3 spacer as the linker (Dela et al., 1987). A method for preparing such a molecule in which the first moiety is a CpG ODN is shown in the Examples.

[0046] In an embodiment in which the first moiety is an ODN, ORN, oligonucleotides or aptamer and the second moiety is a dsRNA, a molecule of the present invention can be prepared by providing a dsRNA in which one of the strands has an overhang and the first moiety has a complementary overhang. The overhang can be spaced from the first moiety and the dsRNA by using linkers comprising multiple units of the C3 spacer. After annealing, both components are connected creating a desired construct. By controlling the length of the overhang and its makeup we can control the strength and the specificity of the attachment. The preferred component of the overhang are: 2'-O-methyl RNA (2'-OMe), 2'-Fluoro RNA (2'-F) or Locked Nucleic Acids (LNAs) or PNA. Extremely high melting temperatures of an LNA/LNA duplex allow for the use of much shorter overhangs. 2'-Fluoro RNA (2'-F) were reported to have lower toxicity than 2'-O-methyl RNA (2'-OMe). Since the cost of LNA is still 10-15 times higher than 2'-Fluoro RNA (2'-F) the latter seems to be the optimal choice for overhang component. Use of

all of the above increases the resistance of the oligonucleotide to cellular nucleases. See, for example, Kurreck et al. (2002), Braasch et al. (2002) and Braasch et al. (2003). The other exemplary sugar modifications include, for example, a 2'-O-methoxyethyl nucleotide, a 2'-O-NMA, a 2'-DMAEOE, a 2'-AP, 2'-hydroxy, or a 2'-ara-fluoro or extended nucleic acid (ENA), hexose nucleic acid (HNA), or cyclohexene nucleic acid (CeNA). The use of overhangs for the construction allows for: (i) use of smaller molecules, (ii) higher purity at lower cost, (iii) lower cost of final product and (iv) flexibility (construction of product on demand; possibility of matching of one component with multiple components). The use of a universal overhangs allows for the interchangeability of the components.

[0047] The use of branching or bridging compounds allows for the synthesis of a component carrying two or more overhangs. Such branching or bridging compounds allows for the attachment of multiple first moiety components, e.g., CpG ODN, to the second moiety component, e.g., dsRNA, and/or for the attachment of multiple second moiety components to the multiple first moiety components. The use of molecules having in multiple overhangs allows for the assembly of complementary constructs consisting of two or more aptamers. Constructs of this kind would be used in the dimerization experiments. The use of molecules having multiple overhangs allows for the assembly of complementary constructs consisting of an aptamer and two or more siRNA duplexes.

[0048] Covalent constructs can also be prepared to form the molecules of the present invention. In this embodiment, the first and second moieties have reactive groups. A covalent bond is created during the chemical reaction between the reactive groups. Examples of such pairs of the reactive groups are as follows.

[0049] (A) carboxyl group and amino group. The attachment to be achieved by creating a covalent bond between the carboxyl group on one component and the amino group at the other component; it is possible to use a carbodimide to create the covalent bond.

[0050] (B) azide and acetylene groups. These groups combine readily with each other--when held in close proximity--to form triazoles. Click chemistry is the use of chemical building blocks with "built-in high-energy content to drive a spontaneous and irreversible linkage reaction with appropriate complementary sites in other blocks," Use of the azide-acetylene reaction represents "true progress" because of its high selectivity.

[0051] (C) vinyl sulfones and sulfhydryl group, vinyl sulfones and terminal phosphothioesters, vinyl sulfones and amino group. Vinyl sulfones and substituted divinyl

sulfones readily react with sulfhydryl group (SH) in pH 5-7, with and terminal phosphothioesters in pH7, and with primary and secondary amines at higher pH.

[0052] Conjugation of two biopolymers with the use of click chemistry (as described above) can also be used to create the molecules of the present invention. Reaction of dsRNA component having multiple reactive groups with the excess of the CPG or aptamer component leads to the products consisting of multiple dsRNAs attached to the single CPG or aptamer component. Reaction of first moiety having multiple reactive groups with the excess of the small molecule drug leads to the products consisting of multiple drug molecules attached to a single CpG or aptamer component. Drugs may be attached to the constructs through the hydrolysable-digestible linker, such as a short peptide hydrolysable by esterase, to facilitate its release upon delivery to the target.

[0053] In one aspect, the active agents of the present invention are double stranded RNA molecules. These double stranded RNA molecules may be useful for downregulating gene expression, such as siRNA molecules. Alternatively, the double stranded RNA molecules may be useful for upregulating gene transcription, such as activating RNA molecules.

[0054] The siRNA molecule may have different forms, including a single strand, a paired double strand (dsRNA) or a hairpin (shRNA) and can be produced, for example, either synthetically or by expression in cells. In one embodiment, DNA sequences for encoding the sense and antisense strands of the siRNA molecule to be expressed directly in mammalian cells can be produced by methods known in the art, including but not limited to, methods described in U.S. published application Nos. 2004/0171118 A1, 2005/0244858 A1 and 2005/0277610 A1, each incorporated herein by reference. The siRNA molecules are coupled to carrier molecules, such as CpG oligonucleotides, various TLR-ligands (such as polyG or poly(I:C) or RNA aptamers, using the techniques known in the art or described herein.

[0055] In one aspect, DNA sequences encoding a sense strand and an antisense strand of a siRNA specific for a target sequence of a gene are introduced into mammalian cells for expression. To target more than one sequence in the gene (such as different promoter region sequences and/or coding region sequences), separate siRNA-encoding DNA sequences specific to each targeted gene sequence can be introduced simultaneously into the cell. In accordance with another embodiment, mammalian cells may be exposed to multiple siRNAs that target multiple sequences in the gene.

[0056] The siRNA molecules generally contain about 19 to about 30 base pairs, and may be designed to cause methylation of the targeted gene sequence. In one embodiment, the siRNA

molecules contain about 19-23 base pairs, and preferably about 21 base pairs. In another embodiment, the siRNA molecules contain about 24-28 base pairs, and preferably about 26 base pairs. In a further embodiment, the dsRNA has an asymmetric structure, with the sense strand having a 25-base pair length, and the antisense strand having a 27-base pair length with a 2 base 3'-overhang. See, for example, U.S. published application Nos. 2005/0244858 A1, 2005/0277610 A1 and 2007/0265220 A1, each incorporated herein by reference. In another embodiment, this dsRNA having an asymmetric structure further contains 2 deoxynucleotides at the 3' end of the sense strand in place of two of the ribonucleotides. Individual siRNA molecules also may be in the form of single strands, as well as paired double strands ("sense" and "antisense") and may include secondary structure such as a hairpin loop. Individual siRNA molecules could also be delivered as precursor molecules, which are subsequently altered to give rise to active molecules. Examples of siRNA molecules in the form of single strands include a single stranded anti-sense siRNA against a non-transcribed region of a DNA sequence (e.g. a promoter region).

[0057] The sense and antisense strands anneal under biological conditions, such as the conditions found in the cytoplasm of a cell. In addition, a region of one of the sequences, particularly of the antisense strand, of the dsRNA has a sequence length of at least 19 nucleotides, wherein these nucleotides are adjacent to the 3' end of antisense strand and are sufficiently complementary to a nucleotide sequence of the RNA produced from the target gene.

[0058] The RNAi molecule, may also have one or more of the following additional properties: (a) the antisense strand has a right shift from the typical 21mer and (b) the strands may not be completely complementary, i.e., the strands may contain simple mismatch pairings. A "typical" 21mer siRNA is designed using conventional techniques, such as described above. This 21mer is then used to design a right shift to include 1-7 additional nucleotides on the 5' end of the 21mer. The sequence of these additional nucleotides may have any sequence. Although the added ribonucleotides may be complementary to the target gene sequence, full complementarity between the target sequence and the siRNA is not required. That is, the resultant siRNA is sufficiently complementary with the target sequence. The first and second oligonucleotides are not required to be completely complementary. They only need to be substantially complementary to anneal under biological conditions and to provide a substrate for Dicer that produces a siRNA sufficiently complementary to the target sequence. In one embodiment, the dsRNA has an asymmetric structure, with the antisense strand having a 25-base pair length, and the sense strand having a 27-base pair length with a 2 base 3'-overhang. In

another embodiment, this dsRNA having an asymmetric structure further contains 2 deoxynucleotides at the 3' end of the antisense strand.

[0059] Suitable dsRNA compositions that contain two separate oligonucleotides can be linked by a third structure. The third structure will not block Dicer activity on the dsRNA and will not interfere with the directed destruction of the RNA transcribed from the target gene. In one embodiment, the third structure may be a chemical linking group. Many suitable chemical linking groups are known in the art and can be used. Alternatively, the third structure may be an oligonucleotide that links the two oligonucleotides of the dsRNA in a manner such that a hairpin structure is produced upon annealing of the two oligonucleotides making up the dsRNA composition. The hairpin structure will not block Dicer activity on the dsRNA and will not interfere with the directed destruction of the RNA transcribed from the target gene.

[0060] The sense and antisense sequences may be attached by a loop sequence. The loop sequence may comprise any sequence or length that allows expression of a functional siRNA expression cassette in accordance with the invention. In a preferred embodiment, the loop sequence contains higher amounts of uridines and guanines than other nucleotide bases. The preferred length of the loop sequence is about 4 to about 9 nucleotide bases, and most preferably about 8 or 9 nucleotide bases.

[0061] In another embodiment of the present invention, the dsRNA, i.e., the RNAi molecule, has several properties which enhances its processing by Dicer. According to this embodiment, the dsRNA has a length sufficient such that it is processed by Dicer to produce an siRNA and at least one of the following properties: (i) the dsRNA is asymmetric, e.g., has a 3' overhang on the sense strand and (ii) the dsRNA has a modified 3' end on the antisense strand to direct orientation of Dicer binding and processing of the dsRNA to an active siRNA. According to this embodiment, the longest strand in the dsRNA comprises 24-30 nucleotides. In one embodiment, the sense strand comprises 24-30 nucleotides and the antisense strand comprises 22-28 nucleotides. Thus, the resulting dsRNA has an overhang on the 3' end of the sense strand. The overhang is 1-3 nucleotides, such as 2 nucleotides. The antisense strand may also have a 5' phosphate.

[0062] Modifications can be included in the dsRNA, i.e., the RNAi molecule, so long as the modification does not prevent the dsRNA composition from serving as a substrate for Dicer. In one embodiment, one or more modifications are made that enhance Dicer processing of the dsRNA. In a second embodiment, one or more modifications are made that result in more effective RNAi generation. In a third embodiment, one or more modifications are made that

support a greater RNAi effect. In a fourth embodiment, one or more modifications are made that result in greater potency per each dsRNA molecule to be delivered to the cell. Modifications can be incorporated in the 3'-terminal region, the 5'-terminal region, in both the 3'-terminal and 5'-terminal region or in some instances in various positions within the sequence. With the restrictions noted above in mind any number and combination of modifications can be incorporated into the dsRNA. Where multiple modifications are present, they may be the same or different. Modifications to bases, sugar moieties, the phosphate backbone, and their combinations are contemplated. Either 5'-terminus can be phosphorylated.

[0063] In another embodiment, the antisense strand is modified for Dicer processing by suitable modifiers located at the 3' end of the antisense strand, i.e., the dsRNA is designed to direct orientation of Dicer binding and processing. Suitable modifiers include nucleotides such as deoxyribonucleotides, dideoxyribonucleotides, acyclonucleotides and the like and sterically hindered molecules, such as fluorescent molecules and the like. Acyclonucleotides substitute a 2-hydroxyethoxymethyl group for the 2'-deoxyribofuranosyl sugar normally present in dNMPs. Other nucleotide modifiers could include 3'-deoxyadenosine (cordycepin), 3'-azido-3'-deoxythymidine (AZT), 2',3'-dideoxyinosine (ddI), 2',3'-dideoxy-3'-thiacytidine (3TC), 2',3'-didehydro-2',3'-dideoxythymidine (d4T) and the monophosphate nucleotides of 3'-azido-3'-deoxythymidine (AZT), 2',3'-dideoxy-3'-thiacytidine (3TC) and 2',3'-didehydro-2',3'-dideoxythymidine (d4T). In one embodiment, deoxynucleotides are used as the modifiers. When nucleotide modifiers are utilized, 1-3 nucleotide modifiers, or 2 nucleotide modifiers are substituted for the ribonucleotides on the 3' end of the antisense strand. When sterically hindered molecules are utilized, they are attached to the ribonucleotide at the 3' end of the antisense strand. Thus, the length of the strand does not change with the incorporation of the modifiers. In another embodiment, the invention contemplates substituting two DNA bases in the dsRNA to direct the orientation of Dicer processing. In a further invention, two terminal DNA bases are located on the 3' end of the antisense strand in place of two ribonucleotides forming a blunt end of the duplex on the 5' end of the sense strand and the 3' end of the antisense strand, and a two-nucleotide RNA overhang is located on the 3'-end of the sense strand. This is an asymmetric composition with DNA on the blunt end and RNA bases on the overhanging end.

[0064] Examples of modifications contemplated for the phosphate backbone include phosphonates, including methylphosphonate, phosphorothioate, and phosphotriester modifications such as alkylphosphotriesters, and the like. Examples of modifications

contemplated for the sugar moiety include 2'-alkyl pyrimidine, such as 2'-O-methyl, 2'-fluoro, amino, and deoxy modifications and the like (see, e.g., Amarzguoui et al., 2003). Examples of modifications contemplated for the base groups include abasic sugars, 2-O-alkyl modified pyrimidines, 4-thiouracil, 5-bromouracil, 5-iodouracil, and 5-(3-aminoallyl)-uracil and the like. Locked nucleic acids, or LNA's, could also be incorporated. Many other modifications are known and can be used so long as the above criteria are satisfied. Examples of modifications are also disclosed in U.S. Patent Nos. 5,684,143, 5,858,988, 6,291,438 and 7,307,069 and in U.S. published patent application No. 2004/0203145 A1, each incorporated herein by reference. Other modifications are disclosed in Herdewijn (2000), Eckstein (2000), Rusckowski et al. (2000), Stein et al. (2001) and Vorobjev et al. (2001), each incorporated herein by reference.

[0065] Additionally, the siRNA structure can be optimized to ensure that the oligonucleotide segment generated from Dicer's cleavage will be the portion of the oligonucleotide that is most effective in inhibiting gene expression. For example, in one embodiment of the invention a 27-bp oligonucleotide of the dsRNA structure is synthesized wherein the anticipated 21 to 22-bp segment that will inhibit gene expression is located on the 3'-end of the antisense strand. The remaining bases located on the 5'-end of the antisense strand will be cleaved by Dicer and will be discarded. This cleaved portion can be homologous (i.e., based on the sequence of the target sequence) or non-homologous and added to extend the nucleic acid strand.

[0066] Activating RNA molecules are similar in design as siRNA molecules. However, they can also be shorter than siRNA molecules. Thus, activating RNA molecules may be 12-30 nucleotides in length, although a length of 18-30 nucleotides is preferred. Activating RNA molecules are targeted to the promoter region of the gene of interest and are designed to induce transcriptional activation. In one embodiment, the region within the promoter of the gene is selected from a partially single-stranded structure, a non-B-DNA structure, an AT-rich sequence, a cruciform loop, a G-quadruplex, a nuclease hypersensitive elements (NHE), and a region located between nucleotides -100 to +25 relative to a transcription start site of the gene. See, for example, Li et al. (2006), Kuwabara et al. (2005), Janowski et al. (2007) and U.S. published application No. 2007/0111963, each incorporated herein by reference. A broad spectrum of chemical modifications can be made to duplex RNA, without negatively impacting the ability of the dsRNA to selectively increase synthesis of the target transcript. These chemical modifications included those described above for siRNA molecules as well as those described in U.S. published application No. 2007/0111963.

[0067] RNA for the siRNA or activating RNA component of the present invention may be produced enzymatically or by partial/total organic synthesis, and modified ribonucleotides can be introduced by *in vitro* enzymatic or organic synthesis. In one embodiment, each strand is prepared chemically. Methods of synthesizing RNA molecules are known in the art, in particular, the chemical synthesis methods as described in Verma and Eckstein (1998).

[0068] In another aspect, the active agents of the present invention are small molecule drugs or peptides. Examples of small molecule drugs include, but are not limited to, Stat3 inhibitors (such as those commercially available from Calbiochem), Imatinib (Bcr-Abl), Sunitib (VEGF receptor), Sorefenib (Raf) and DASATINIB (Src). Examples of peptides include, but are not limited to, Stat3 peptidomimetics, p53 peptidomimetics and Farnesyl Transferase inhibitors.

[0069] The present invention further provides active agents that are capable of acting in the Stat3 signaling pathway or affecting genes regulated by Stat3. These active agents, when taken up by the cells of interest, result in the treatment of cancer or other diseases. In one embodiment, the active agent is an siRNA molecule directed against Stat3 and results in the down regulation of Stat3. In another embodiment, the active agent is an siRNA molecule directed against SOCS3 which is an inhibitor of Stat3. In a further embodiment, the active agent is an activating RNA for tumor suppressor genes.

[0070] In addition, the present invention provides a method for treating diseases. The molecules of the present invention are administered to patients in need of treatment using conventional pharmaceutical practices. Suitable pharmaceutical practices are described in *Remington: The Science and Practice of Pharmacy*, 21st Ed., University of Sciences in Philadelphia, Ed., Philadelphia, 2005. In one embodiment, the present invention provides for the delivery of dsRNA, such as siRNA or activating RNA, for the treatment of cancer. In another embodiment, the present invention provides for the delivery of dsRNA for the treatment of infectious diseases. In a further embodiment, the present invention provides the delivery of dsRNA for the treatment of autoimmune diseases. The dsRNA can be specifically delivered to cells as described herein.

[0071] The present invention can also be used to deliver DNA or RNA that encode antigens to cells, e.g., DCs to stimulate an immune response, e.g., vaccine or immunomodulator. Suitable antigens could be tumor or infectious agents, including but not limited to, virus, fungus, bacteria, rickettsia, amoeba.

[0072] Thus, the present invention relates to the use of multifunctional molecules to modulate cancer and the immune system. The present invention relates delivery of RNA

(siRNA and/or activating RNA) by TLR ligands as single molecule *in vivo*. The present invention is illustrated herein by a covalently linked siRNA and CpG molecule. In particular, we show the (mouse) CpG motif coupled to a 27mer siRNA against Stat-3. Other TLR ligands, including but not limited to polyI:C, polyG LPS, and peptidoglycan can also be linked to siRNAs for various target genes.

[0073] Stat3 is a ‘master switch’– in both cancer and tumor cells and tumor-associated immune cells – that controls tumor survival, angiogenesis/metastasis and immune evasion. The challenge is to turn Stat3 off in the desired cells in cancer in patients. The present invention describes the development of optimal Stat3 siRNAs (Dicer) with antitumor effects *in vivo*, and shows that Stat3siRNA linked to CpG oligonucleotide efficiently enters dendritic cells. Targeting Stat3 drastically improves CpG-based cancer. The utility of the present invention has been demonstrated herein using melanoma as the model. However, it is understood that the present invention is not limited to melanoma but is equally applicable to all types of cancer.

[0074] Many promising immunotherapeutic approaches are in clinical trials for melanoma patients. However, these approaches face a major challenge: tumor-induced immune suppression. Since Stat3 is a key mediator of tumor-induced immunosuppression in melanoma, we reasoned that targeting Stat3 – although not perfect with current drugs – will significantly improve the tumor immunologic microenvironment and thus enhance various immunotherapeutic approaches. As demonstrated herein, targeting Stat3 dramatically improves CpG ODN-based melanoma immunotherapy. We show that inhibiting Stat3 in myeloid cells, in conjunction with local CpG treatment, can eliminate large (1.5 cm in diameter) established B16 melanomas. We also demonstrate that targeting Stat3 systemically with a small-molecule Stat3 inhibitor not only dramatically improve the antitumor effects at primary tumor sites receiving CpG injection but also leads to concomitant antitumor effects on distal tumors without CpG treatment. In addition to the potent antitumor effects, our results indicate that blocking Stat3 in tumor-stromal immune cells activates Stat1 and NF- κ B, leading to Th-1 immune responses of diverse immune subsets that are fundamental for numerous cancer immunotherapies. Consistent with the idea that targeting Stat3 can improve immunotherapeutic efficacies are the findings by Kirkwood and colleagues (Kirkwood et al., 1999), who demonstrated that high dose IFN α -based immunotherapy response inversely correlates with Stat3 activity in melanoma patients.

[0075] In another aspect, the present invention provides for a pharmaceutical composition comprising of molecules of the present invention, i.e., the molecules that contain a cell specific delivery moiety and one or more additional active agents. The cell specific delivery moiety and

the additional active agent(s) may be directly linked together or they may be indirectly linked together through the use of a linker. As described herein, the active agent may be an siRNA, an activating RNA, a small molecule drug or a peptide. These molecules can be suitably formulated and introduced into the environment of the cell by any means that allows for a sufficient portion of the sample to enter the cell to induce gene silencing, if it is to occur. Many formulations for dsRNA are known in the art and can be used for delivery of the molecules of the present invention to mammalian cells so long as active agent gains entry to the target cells so that it can act. See, e.g., U.S. published patent application Nos. 2004/0203145 A1 and 2005/0054598 A1, each incorporated herein by reference. For example, siRNA can be formulated in buffer solutions such as phosphate buffered saline solutions, liposomes, micellar structures, and capsids. Formulations of siRNA with cationic lipids can be used to facilitate transfection of the dsRNA into cells. For example, cationic lipids, such as lipofectin (U.S. Patent No. 5,705,188, incorporated herein by reference), cationic glycerol derivatives, and polycationic molecules, such as polylysine (published PCT International Application WO 97/30731, incorporated herein by reference), can be used. Suitable lipids include Oligofectamine, Lipofectamine (Life Technologies), NC388 (Ribozyme Pharmaceuticals, Inc., Boulder, CO), or FuGene 6 (Roche) all of which can be used according to the manufacturer's instructions.

[0076] It can be appreciated that the method of introducing the molecules of the present invention into the environment of the cell will depend on the type of cell and the make up of its environment. For example, when the cells are found within a liquid, one preferable formulation is with a lipid formulation such as in lipofectamine and the molecules of the present invention can be added directly to the liquid environment of the cells. Lipid formulations can also be administered to animals such as by intravenous, intramuscular, or intraperitoneal injection, or orally or by inhalation or other methods as are known in the art. When the formulation is suitable for administration into animals such as mammals and more specifically humans, the formulation is also pharmaceutically acceptable. Pharmaceutically acceptable formulations for administering oligonucleotides are known and can be used. In some instances, it may be preferable to formulate molecules of the present invention in a buffer or saline solution and directly inject the formulated dsRNA into cells, as in studies with oocytes. The direct injection of dsRNA duplexes may also be done. For suitable methods of introducing siRNA see U.S. published patent application No. 2004/0203145 A1, incorporated herein by reference.

[0077] Suitable amounts of molecules of the present invention must be introduced and these amounts can be empirically determined using standard methods. Typically, effective concentrations of individual dsRNA species in the environment of a cell will be about 50 nanomolar or less 10 nanomolar or less, or compositions in which concentrations of about 1 nanomolar or less can be used. In other embodiment, methods utilize a concentration of about 200 picomolar or less and even a concentration of about 50 picomolar or less can be used in many circumstances. Typically, effective doses of small molecule drugs or peptides can be lower than previously used in view of the cell specific delivery provided by the present invention.

[0078] The method can be carried out by addition of the compositions containing the molecules of the present invention to any extracellular matrix in which cells can live provided that the composition is formulated so that a sufficient amount of the active agent can enter the cell to exert its effect. For example, the method is amenable for use with cells present in a liquid such as a liquid culture or cell growth media, in tissue explants, or in whole organisms, including animals, such as mammals and especially humans.

[0079] Expression of a target gene can be determined by any suitable method now known in the art or that is later developed. It can be appreciated that the method used to measure the expression of a target gene will depend upon the nature of the target gene. For example, when the target gene encodes a protein the term "expression" can refer to a protein or transcript derived from the gene. In such instances the expression of a target gene can be determined by measuring the amount of mRNA corresponding to the target gene or by measuring the amount of that protein. Protein can be measured in protein assays such as by staining or immunoblotting or, if the protein catalyzes a reaction that can be measured, by measuring reaction rates. All such methods are known in the art and can be used. Where the gene product is an RNA species expression can be measured by determining the amount of RNA corresponding to the gene product. The measurements can be made on cells, cell extracts, tissues, tissue extracts or any other suitable source material.

[0080] The determination of whether the expression of a target gene has been reduced can be by any suitable method that can reliably detect changes in gene expression. Typically, the determination is made by introducing into the environment of a cell undigested siRNA such that at least a portion of that siRNA enters the cytoplasm and then measuring the expression of the target gene. The same measurement is made on identical untreated cells and the results obtained from each measurement are compared. Similarly the determination can be made by introducing

into the environment of a cell undigested activating RNA such that at least a portion of that activating RNA enters the cytoplasm and then measuring the expression of the target gene.

[0081] The molecules of the present invention can be formulated as a pharmaceutical composition which comprises a pharmacologically effective amount of the molecules and pharmaceutically acceptable carrier. A pharmacologically or therapeutically effective amount refers to that amount of a molecule of the present invention effective to produce the intended pharmacological, therapeutic or preventive result. The phrases "pharmacologically effective amount" and "therapeutically effective amount" or simply "effective amount" refer to that amount of a dsRNA, small molecule drug or peptide effective to produce the intended pharmacological, therapeutic or preventive result. For example, if a given clinical treatment is considered effective when there is at least a 20% reduction in a measurable parameter associated with a disease or disorder, a therapeutically effective amount of a drug for the treatment of that disease or disorder is the amount necessary to effect at least a 20% reduction in that parameter.

[0082] The phrase "pharmaceutically acceptable carrier" refers to a carrier for the administration of a therapeutic agent. Exemplary carriers include saline, buffered saline, dextrose, water, glycerol, ethanol, and combinations thereof. For drugs administered orally, pharmaceutically acceptable carriers include, but are not limited to pharmaceutically acceptable excipients such as inert diluents, disintegrating agents, binding agents, lubricating agents, sweetening agents, flavoring agents, coloring agents and preservatives. Suitable inert diluents include sodium and calcium carbonate, sodium and calcium phosphate, and lactose, while corn starch and alginic acid are suitable disintegrating agents. Binding agents may include starch and gelatin, while the lubricating agent, if present, will generally be magnesium stearate, stearic acid or talc. If desired, the tablets may be coated with a material such as glyceryl monostearate or glyceryl distearate, to delay absorption in the gastrointestinal tract. The pharmaceutically acceptable carrier of the disclosed dsRNA composition may be micellar structures, such as a liposomes, capsids, capsoids, polymeric nanocapsules, or polymeric microcapsules.

[0083] Polymeric nanocapsules or microcapsules facilitate transport and release of the encapsulated or bound dsRNA into the cell. They include polymeric and monomeric materials, especially including polybutylcyanoacrylate. A summary of materials and fabrication methods has been published (see Kreuter, 1991). The polymeric materials which are formed from monomeric and/or oligomeric precursors in the polymerization/nanoparticle generation step, are per se known from the prior art, as are the molecular weights and molecular weight distribution

of the polymeric material which a person skilled in the field of manufacturing nanoparticles may suitably select in accordance with the usual skill.

[0084] Suitably formulated pharmaceutical compositions of this invention can be administered by any means known in the art such as by parenteral routes, including intravenous, intramuscular, intraperitoneal, subcutaneous, transdermal, airway (aerosol), rectal, vaginal and topical (including buccal and sublingual) administration. In some embodiments, the pharmaceutical compositions are administered by intravenous or intraparenteral infusion or injection.

[0085] In general a suitable dosage unit of active agent moiety of the molecules of the present invention will be in the range of 0.001 to 0.25 milligrams per kilogram body weight of the recipient per day, or in the range of 0.01 to 20 micrograms per kilogram body weight per day, or in the range of 0.01 to 10 micrograms per kilogram body weight per day, or in the range of 0.10 to 5 micrograms per kilogram body weight per day, or in the range of 0.1 to 2.5 micrograms per kilogram body weight per day. Pharmaceutical composition comprising the siRNA can be administered once daily. However, the therapeutic agent may also be dosed in dosage units containing two, three, four, five, six or more sub-doses administered at appropriate intervals throughout the day. In that case, the active agent, e.g., dsRNA, contained in each sub-dose must be correspondingly smaller in order to achieve the total daily dosage unit. The dosage unit can also be compounded for a single dose over several days, e.g., using a conventional sustained release formulation which provides sustained and consistent release of the active agent, e.g., dsRNA, over a several day period. Sustained release formulations are well known in the art. In this embodiment, the dosage unit contains a corresponding multiple of the daily dose. Regardless of the formulation, the pharmaceutical composition must contain active agent, e.g., dsRNA, in a quantity sufficient to inhibit expression of the target gene in the animal or human being treated. The composition can be compounded in such a way that the sum of the multiple units of active agent together contain a sufficient dose.

[0086] Data can be obtained from cell culture assays and animal studies to formulate a suitable dosage range for humans. The dosage of compositions of the invention lies within a range of circulating concentrations that include the ED₅₀ (as determined by known methods) with little or no toxicity. The dosage may vary within this range depending upon the dosage form employed and the route of administration utilized. For any compound used in the method of the invention, the therapeutically effective dose can be estimated initially from cell culture assays. A dose may be formulated in animal models to achieve a circulating plasma

concentration range of the compound that includes the IC₅₀ (i.e., the concentration of the test compound which achieves a half-maximal inhibition of symptoms) as determined in cell culture. Such information can be used to more accurately determine useful doses in humans. Levels of dsRNA in plasma may be measured by standard methods, for example, by high performance liquid chromatography.

[0087] In a further aspect, the present invention relates to a method for TGS in a mammalian, including human, cell. The method comprises introducing the siRNA containing molecules of the present invention into the appropriate cell. The term “introducing” encompasses a variety of methods of introducing the siRNA containing molecules into a cell, either *in vitro* or *in vivo*, such as described above.

[0088] In a further aspect, the present invention relates to a method for gene activation in a mammalian cell, including human cell. The method comprises introducing the activating RNA containing molecules of the present invention into the appropriate cell. The term “introducing” encompasses a variety of methods of introducing the siRNA containing molecules into a cell, either *in vitro* or *in vivo*, such as described above.

[0089] In a further aspect, the present invention relates to a method for treating a disease or physiological disorder or condition in a mammal, including a human. The method comprises introducing the small molecule drug or peptide containing molecules of the present invention into the appropriate cell. The term “introducing” encompasses a variety of methods of introducing the siRNA containing molecules into a cell, either *in vitro* or *in vivo*, such as described above.

[0090] TLR ligands, such as CpG, are known to stimulate innate immunity. The present invention illustrates that blocking Stat3, either genetically, or pharmacologically, results in drastically improved immune responses and antitumor effects.

[0091] A major challenge facing siRNA-based therapies is efficient uptake of siRNA by desired cells *in vivo*. The present studies demonstrate that a TLR ligand, e.g., a moiety consisting of oligonucleotides that can activate immune responses against cancer and infectious diseases when it is linked to siRNA, is able to mediate siRNA uptake and internalization by desired immune cells. They include myeloid cells, such as macrophages and dendritic cells, in cultured cells, and in animals through either intratumoral or intravenous injections of the chimeric constructs. This uptake occurs in the absence of any transfection agents. The DNA-RNA chimeric constructs can be processed by Dicer and is associated with Dicer in living cells. *In vivo* delivery of the chimeric constructs results in gene silencing in DCs and macrophages,

including those reside in tumors and the tumor draining lymph nodes. Similar construct involving TLR ligand and siRNA can also be uptaken by human monocytes, leading to gene silencing.

[0092] In addition to macrophages, dendritic cells and monocytes, the present studies show that the CpG-siRNA chimeric constructs can be efficiently taken up by both human and mouse B cell malignant cells (B cell lymphoma and multiple myeloma).

[0093] Stat3 is a potent oncogenic transcriptional factor that is continuously activated in diverse human cancer (Yu and Jove, 2004). Activated Stat3 not only promotes tumor cell survival, proliferation and angiogenesis (Yu and Jove, 2004), it also mediates tumor immune suppression through its activation in both tumor cells and in immune cells in the tumor microenvironment (Wang et al., 2004; Kortylewski et al., 2005b; Yu et al., 2007). Effective targeting of Stat3 in tumor cells has been shown to induce tumor cell apoptosis, inhibit tumor cell proliferation, angiogenesis/metastasis (Yu and Jove, 2004). Inhibiting Stat3 in both tumor cells and/or immune cells also elicits multi-component antitumor immune responses (Wang et al., 2004; Kortylewski et al., 2005b). Although CpG is a potent immune stimulator, its effects in tumor-bearing hosts are dampened by the tumor microenvironment, which is, at least in part, mediated by Stat3 activation. Interestingly, CpG, like several other pathogen-associated immune stimulators, such as LPS, is an activator of Stat3 (through activating IL-10, which in turn activates Stat3), and Stat3 serves as feedback mechanism to limit their immunostimulatory effects (Benkhart et al., 2000; Samarasinghe et al., 2006). These findings suggest that triggering toll-like receptor through its ligand while blocking Stat3 should negate the inhibitory effects associated with CpG, thereby generating potent immune responses and improving CpG treatment for both cancer and infectious diseases. Our data generated with CpG treatment in conjunction with genetic knockout of Stat3 in myeloid cells prove this point. These data illustrate that blocking Stat3, by any means, are highly desirable for enhancing the efficacies of TLR ligand-based therapies. See U.S. Patent Application Publication No. 2008/02144356, PCT International Publication No. WO 2008/094254, and U.S. Patent Application Serial No. 12,879,199 filed 10 September 2010, each incorporated herein in its entirety for all that it discloses.

[0094] As an example of the TLR ligand-siRNA chimeric construct, siRNA against Stat3 (SEQ ID NO:3 for sense strand; SEQ ID NO:2 for antisense strand) is linked to toll-like receptor 9 ligand, CpG oligonucleotide (ODN) (SEQ ID NO:1). Optimal sequences of both human and mouse Stat3 siRNA have been selected, followed by linkage to CpG single stranded ODN, and

other toll-like receptor ligands. The construct can be processed by Dicer, and is associated with Dicer in living cells, and causes gene silencing. The chimeric constructs, when delivered in vivo in tumor bearing mice, are efficiently uptaken and internalized by targeted cells, such as macrophages and dendritic cells. These immune cells are able to traffic from tumor to tumor training lymph nodes, where they can interact with T cells. *In vivo* gene silencing is also detected in dendritic cells and macrophages in tumor draining lymph nodes. The immune modulation induced by the toll-like receptor 9 ligand-Stat3 siRNA leads to potent antitumor effects on well established B16 melanoma. Both local intratumoral injection and systemic intravenous injection routes are tested, demonstrating the usefulness of the ODN-siRNAs as therapeutic agents. CpG alone, Stat3siRNA alone, or CpG-linked to a scrambled siRNA are not able to induce significant antitumor effects, testifying the superior efficacies of linking two active moieties: TLR9 ligand and Stat3 siRNA. Tumor bearing mice treated with the CpG-Stat3siRNA constructs display activation of dendritic cells, increased CD8+ T cells, NK cells and reduced number of T regulatory cells in the tumor and/or tumor draining lymph nodes. Treating tumor-bearing mice with CpG-Stat3siRNA also increases tumor infiltrating tumor antigen-specific CD8+ T cells. See U.S. Patent Application Publication No. 2008/02144356, PCT International Publication No. WO 2008/094254, and U.S. Patent Application Serial No. 12,879,199 filed 10 September 2010.

[0095] Similarly, TLR ligand-siRNA chimeric constructs can also be taken up by human monocytes, leading to gene silencing. See U.S. Patent Application Publication No. 2008/02144356, PCT International Publication No. WO 2008/094254, and U.S. Patent Application Serial No. 12,879,199 filed 10 September 2010.

[0096] We have further shown that the CpG-Stat3siRNA is easily uptaken by both murine and human B malignant cells, including both lymphoma and multiple myeloma cells, many of which also express TLR (Bourke et al., 2003; Reid et al., 2005; Jahrsdorfer et al., 2005). We show that uptake and internalization of the CpG-Stat3siRNA leads to gene silencing of Stat3, which is accompanied by increased cell cycle arrest of the myeloma cells relative to those treated with CpG-scrambled siRNA in cell culture. Furthermore, in vivo treatment with the CpG-Stat3siRNA construct leads to significant growth inhibition of well-established murine myeloma tumors. Tumor growth inhibition due to CpG-Stat3siRNA in vivo treatment is associated with upregulation of co-stimulatory molecules on tumor-infiltrating dendritic cells. See U.S. Patent Application Publication No. 2008/02144356, PCT International Publication No. WO 2008/094254, and U.S. Patent Application Serial No. 12,879,199 filed 10 September 2010

[0097] The DNA (or RNA)-RNA constructs are synthesized chemically without involvement of enzymes. The success of CpG-Stat3siRNA chimeric molecule for inducing immune responses and antitumor effects, through blocking Stat3 in immune cells and/or in tumor cells, demonstrates a novel general approach: using TLR ligand oligonucleotides, which include CpG, polyI:C (TLR3 ligand), polyG (TLR8 ligand), to deliver short RNA, which include both siRNA and activating RNA, to desired cells in vitro and in vivo, to stimulate innate immunity, to negate undesired effects and/or elicit desired effects through siRNA and/or activating RNA.

[0098] As a result, creating chimeric molecule consisting of TLR ligand and siRNA and/or activating RNA, has great versatility and can be easily adapted for various gene targets. It also has flexibility: similar design can be adapted for different cell types capable of ODN/ORN uptake and internalization. Using a linker, modification of such approach to include multiple active moieties, such as multiple siRNA, with TLR ligand as a single agent for treating cancer and infectious disease is feasible. This approach can also be modified to enable small molecule drug delivery.

[0099] More specifically, the present invention relates to specific chimeric molecules that are useful for the treatment of diseases. Thus, in one aspect, the present invention provides a standard conjugate for use in preclinical and phase I studies. In accordance with this aspect, the chimeric molecule comprises the components:

A. Human STAT3 SS siRNA (sense strand; underlined are deoxyribonucleotides):

5' GGAAGCUGCAGAAAGAUACGACUGA 3' (SEQ ID NO:4);

B. Human CpG(D19)-STAT3 AS siRNA (antisense strand; asterisks indicate phosphorothioated sites, X indicates single C3 carbon chain linker/propanediol linker):

5' G*GTGCATCGATGCAGG*G*G*G*G-XXXXX-UCAGUCGUAUCUUUCUGCA GCUUCCGU 3' (SEQ ID NO:5-XXXXX-SEQ ID NO:6).

[0100] In a second aspect, the present invention provides a chimeric molecule that is prepared to include modification sites for the sense strand sequence to produce a conjugate with increased serum stability. In accordance with this aspect, the modified sense strand comprises:

A. Human STAT3 SS siRNA (sense strand; underlined are deoxyribonucleotides; bold are chemically modified for increased nuclease resistance, e.g. 2'F-, 2'OMe-, LNA, nucleotides or other modifications described herein):

5' GGAAGCUGCAGAAAGAUACGACUGA 3' (SEQ ID NO:7).

In one embodiment, this sense strand is combined with the human CpG(D19)-STAT3 AS siRNA described above.

[0101] In a third aspect, the present invention provides an alternative three-component conjugate with complementary “sticky ends” instead of fixed propanediol linker between CpG and siRNA moieties (to simplify synthesis). In accordance with this aspect, the chimeric molecule comprises the components:

A. Human STAT3 SS siRNA-overhang (sense strand; X indicates single C3 carbon chain linker/propanediol linker; bold are chemically modified 2’F- or 2’OMe-nucleotides or other modifications as described herein):

5’ GGAAGCUGCAGAAAGAUACGACUGA-XXXXX-ACGUGGCCGACUUC
CU 3’ (SEQ ID NO:8 XXXXX SEQ ID NO:9);

B. Human CpG(D19)-overhang (asterisks indicate phosphorothioated sites; X indicates single C3 carbon chain linker/propanediol linker; bold are chemically modified 2’F- or 2’OMe-nucleotides or other modifications as described herein):

5’ G*GTGCATCGATGCAGG*G*G*G*G-XXXXX-AGGAAGUCGGCCACGU 3’
(SEQ ID NO:5 XXXXX SEQ ID NO:10);

C. Human STAT3 AS siRNA (antisense strand):

5’ UCAGUCGUAUCUUUCUGCAGCUUCCGU 3’ (SEQ ID NO:6).

[0102] The practice of the present invention employs, unless otherwise indicated, conventional techniques of chemistry, molecular biology, microbiology, recombinant DNA, genetics, immunology, cell biology, cell culture and transgenic biology, which are within the skill of the art. See, e.g., Maniatis *et al.*, 1982, *Molecular Cloning* (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); Sambrook *et al.*, 1989, *Molecular Cloning*, 2nd Ed. (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); Sambrook and Russell, 2001, *Molecular Cloning*, 3rd Ed. (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); Ausubel *et al.*, 1992), *Current Protocols in Molecular Biology* (John Wiley & Sons, including periodic updates); Glover, 1985, *DNA Cloning* (IRL Press, Oxford); Russell, 1984, *Molecular biology of plants: a laboratory course manual* (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.); Anand, *Techniques for the Analysis of Complex Genomes*, (Academic Press, New York, 1992); Guthrie and Fink, *Guide to Yeast Genetics and Molecular Biology* (Academic Press, New York, 1991); Harlow and Lane, 1988, *Antibodies*, (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York); *Nucleic Acid Hybridization* (B. D.

Hames & S. J. Higgins eds. 1984); *Transcription And Translation* (B. D. Hames & S. J. Higgins eds. 1984); *Culture Of Animal Cells* (R. I. Freshney, Alan R. Liss, Inc., 1987); *Immobilized Cells And Enzymes* (IRL Press, 1986); B. Perbal, *A Practical Guide To Molecular Cloning* (1984); the treatise, *Methods In Enzymology* (Academic Press, Inc., N.Y.); *Methods In Enzymology*, Vols. 154 and 155 (Wu et al. eds.), *Immunochemical Methods In Cell And Molecular Biology* (Mayer and Walker, eds., Academic Press, London, 1987); *Handbook Of Experimental Immunology*, Volumes I-IV (D. M. Weir and C. C. Blackwell, eds., 1986); Riott, *Essential Immunology*, 6th Edition, Blackwell Scientific Publications, Oxford, 1988; Fire et al., *RNA Interference Technology: From Basic Science to Drug Development*, Cambridge University Press, Cambridge, 2005; Schepers, *RNA Interference in Practice*, Wiley-VCH, 2005; Engelke, *RNA Interference (RNAi): The Nuts & Bolts of siRNA Technology*, DNA Press, 2003; Gott, *RNA Interference, Editing, and Modification: Methods and Protocols (Methods in Molecular Biology)*, Human Press, Totowa, NJ, 2004; Sohail, *Gene Silencing by RNA Interference: Technology and Application*, CRC, 2004.

EXAMPLES

[0103] The present invention is described by reference to the following Examples, which are offered by way of illustration and are not intended to limit the invention in any manner. Standard techniques well known in the art or the techniques specifically described below were utilized. These examples summarize the results of the examples described in U.S. Patent Application Publication No. 2008/02144356, PCT International Publication No. WO 2008/094254, and U.S. Patent Application Serial No. 12,879,199 filed 10 September 2010. Full details of the methodology and experimental results and data are set forth in these patent publications and patent application.

EXAMPLE 1

Stat3 Ablation in Hematopoietic Cells Drastically Improves TLR9 Triggering-Induced Antitumor Effects

[0104] To provide proof-of-principle evidence that targeting Stat3 can markedly enhance CpG-ODN-based immunotherapy, we induced Stat3 allele truncation in the hematopoietic cells of adult mice using the Mx1-Cre-loxP system as described previously (Kuhn et al., 1995). We employed PCR-based genotyping assay to confirm the truncation of loxP-flanked Stat3 alleles induced by repeated injections of poly(I:C) in hematopoietic cells in Mx1-Cre expressing mice.

To avoid any interference from poly(I:C) treatment, subcutaneous B16(F10) tumor challenge was performed five days after last poly(I:C) administration. Established B16 tumors (day 10 post 10^6 tumor cell challenge, >10 mm diameter) were treated with a single peritumoral injection of 5 μ g CpG1668-oligonucleotide. Although CpG-ODN treatment did not show significant antitumor activity in control mice (Stat3+/+) with heavy tumor load, the same treatment resulted in eradication of large B16 tumors (some of them reaching 1.5 cm in diameter) in mice lacking intact alleles within 3 days after injection. Similarly, whereas CpG-ODN injection showed only weak inhibition of tumor growth in mice with smaller initial B16 tumors (4-6 mm diameter), peritumoral treatment of with CpG-ODN in mice with truncated Stat3 alleles in the hematopoietic cells resulted in regression of rapidly growing B16 tumors and prevented their reoccurrence over the period of at least 3 weeks. In contrast, treatment with control GpC oligonucleotide lacking CpG motif recognized by TLR9 did not significantly inhibit tumor progression.

[0105] To assess whether the dramatically increased antitumor effects contributed by Stat3 inhibition in the hematopoietic cells was mediated by T cells, we used CD8 and CD4 antibodies to deplete T cells. The enhanced antitumor immunity due to Stat3 allele truncation in hematopoietic cells was abrogated in mice depleted of CD4 and CD8 T cells. However, lack of both lymphocyte populations did not prevent the initial robust tumor regression, strongly suggesting the involvement of innate immunity in eliminating the established tumors. Indeed, NK cell depletion experiments indicated a partial role of NK cells for the observed antitumor effect.

EXAMPLE 2

Ablating Stat3 in Hematopoietic Cells Further Activates DCs Primed by CpG

[0106] We next assessed if Stat3 inhibition affects CpG-induced DC activation in tumor-bearing mice. Flow cytometric analysis of CD11c+ DCs isolated from tumor-draining lymph nodes of mice with truncated Stat3 in hematopoietic cells showed enhanced DCs activation as measured by increased expression of major histocompatibility complex (MHC) class II, CD86, CD80 and CD40 molecules two days after peritumoral injection of CpG-ODN but not control GpC-ODN. We further assessed the expression of several immunostimulatory cytokines like IL-12 (p35 and p40 subunits), RANTES and IL-6 in DCs freshly isolated from tumor microenvironment following local treatment with CpG-ODN. CpG-ODN induced high levels of

all tested proinflammatory mediators in Stat3-deficient but not in wild-type DCs within 18 hrs after treatment.

[0107] To evaluate the effect of Stat3 blocking on CpG-induced effector lymphocyte activity, we analyzed CD8 T cells within tumor-draining lymph nodes of Stat3-positive and Stat3-negative mice after CpG-ODN treatment. CD8⁺ lymphocytes in tumor-draining lymph nodes of Stat3-ablated mice showed very high levels of CD69 immediate early activation marker, shortly after peritumoral injection of CpG-ODN. Moreover, 10 days after CpG-treatment Stat3-deficient mice had increased ability to mount tumor antigen-specific responses. The number of IFN- γ -secreting T cells was strongly enhanced by CpG-treatment in the tumor-draining lymph nodes of Stat3^{-/-} mice, as indicated by ELISPOT assay following *ex vivo* exposure to B16 tumor-specific p15E antigen.

EXAMPLE 3

Targeting Stat3 in Myeloid Cells (Dendritic Cells and Macrophages) by a Chimeric ssDNA-siRNA Construct

[0108] Our results provide proof-of-principle evidence that blocking Stat3 signaling in the hematopoietic cells removes a key negative regulator of DC activation, thereby drastically improving TLR-9-mediated DC activation and antitumor immunity. However, previous studies indicated that prolonged, and effective blockade of Stat3 signaling through gene ablation/truncation in the whole hematopoietic compartment can lead to autoimmunity (Alonzi et al., 2004; Kobayashi et al., 2003; Welte et al., 2003). In order to minimize the side-effects of Stat3 blocking and yet achieve Stat3 inhibition-mediated enhancement of antitumor immunity induced by TLR triggering, it would be ideal to specifically and efficiently block Stat3 in antigen presenting cells while simultaneously activating TLR9 pathway. To achieve this goal, we tested the possibility to generate an ssDNA-dsRNA chimeric construct that contains both CpG and Stat3 siRNA. The 20 bp long single-stranded CpG1668 ODN sequence was fused to a double-stranded 25/27-mer Stat3siRNA. The selection of optimized 25/27 Stat3siRNA (both human and mouse) is based on the report that Dicer-processed siRNA has enhanced silencing effects of target genes (Kim et al., 2005). *In vitro* cleavage assay confirmed that the chimeric CpG-Stat3 siRNA construct is processed by recombinant Dicer enzyme, just like the 25/27-mer Stat3 siRNA without CpG.

[0109] To test cell specific uptake of chimeric ssDNA-dsRNA oligonucleotide constructs, freshly isolated splenocytes from wild-type C57BL/6 mice were incubated overnight with the

fluorescein-labeled CpG-Stat3-siRNA construct. Such incubation in the absence of any transfection agents resulted in dose-dependent uptake of the DNA-RNA chimeric construct by splenic DCs and macrophages but not granulocytes or T cells. Under the same conditions the uptake of fluorescently-labeled naked Stat3-siRNA was insignificant. Further analysis of CpG-Stat3-siRNA uptake by confocal microscopy indicated rapid internalization of the chimeric construct with kinetics similar to the one previously reported for the CpG-ODN alone (Latz et al., 2004). In stable DC cell line (DC2.4), the CpG-Stat3-siRNA can be detectable as early as 15 min, with high uptake after 1 h of incubation. At this time point CpG-Stat3-siRNA construct was found to colocalize with TLR9 within perinuclear endocytic vesicles. Previous studies indicated that binding of the Dicer nuclease to the siRNA oligonucleotide is required for its further processing into shorter 21-mer fragments before interacting with RISC complex, which is responsible for the final gene silencing effect (Chendrimada et al., 2005; Haase et al., 2005). We observed transient colocalization of the CpG-Stat3-siRNA with Dicer within 2 h after adding the oligonucleotide chimeric construct to cultured DCs. The association between the CpG-Stat3-siRNA and Dicer became weaker by 4 h and undetectable after 24 h. These data suggest a sequential mode of CpG-Stat3-siRNA construct action, which starts with the uptake into cytoplasmic endocytic vesicles, followed by binding to TLR9 and subsequent interaction with Dicer. Quantitative real-time PCR analysis of the Stat3 mRNA expression in cultured primary DCs and in DC2.4 cells indicated a dose-dependent downregulation of the Stat3 expression after 24 h incubation with CpG-Stat3-siRNA, while the CpG-scrambled-RNA control had negligible effect. These results indicate that chimeric CpG-siRNA molecules are efficiently internalized by TLR9-positive cells, undergo processing by Dicer and induce gene silencing. Of note, we observed that CpG treatment itself can upregulate Stat3 activity and also gene expression.

EXAMPLE 4

In vivo Characterization of the Chimeric CpG-siRNA

[0110] To evaluate the feasibility of using chimeric CpG-siRNA *in vivo*, we estimated first the uptake of the CpG-Stat3 siRNA in tumor-bearing mice. C57BL/6 mice with B16 tumors (6-10 mm in diameter) were injected peritumorally with FITC-labeled CpG-Stat3 siRNA at 0.78 nmol (20 µg)/injection. We detected large numbers of FITC-positive CD11b⁺ myeloid cells in tumor-draining nodes but not in collateral lymph nodes, 6 h after injection. More sensitive detection by two-photon microscopy confirmed the presence of FITC-positive cells in tumor-draining lymph node as early as 1 h after injecting the labeled construct. Further studies have

shown that repeated peritumoral and to lesser extent intravenous injections of 0.78 nmole CpG-Stat3-siRNA, but not CpG-scrambled-RNA, silence Stat3 expression in DCs and/or macrophages within tumor-draining lymph nodes.

EXAMPLE 5

Antitumor Effects of the CpG-Stat3 siRNA Chimeric Construct

[0111] Both macrophages and DCs in the tumor microenvironment are known to promote immune tolerance. We next assessed if the CpG-Stat3-siRNA chimeric constructs would negate immunosuppressive effects imposed by the tumor-microenvironment and at the same time allow effective antitumor immunity induced by TLR9 triggering. Local treatment with CpG-Stat3-siRNA oligonucleotides inhibited growth of subcutaneously growing B16 melanoma. In contrast, treatment with CpG-ODN alone or the CpG-scrambled-RNA construct had relatively weak antitumor effects. The ability of CpG-Stat3-siRNA to inhibit metastatic tumor growth was further demonstrated in the model of established B16 lung metastasis. We assessed the effect of 2-week systemic treatment with CpG-Stat3-siRNA, using relatively small amount of the oligonucleotide (1 mg/kg). Systemic injection of 0.78 nmole CpG-Stat3-siRNA led to significant reduction in the number of lung metastasis with lesser effect of CpG-scrambled-RNA and CpG-ODN alone, which is accompanied by upregulation of MHC class II, CD80 and CD40 molecules on tumor infiltrating DCs.

[0112] The ratio of effector to negative regulatory T cells within tumor microenvironment is considered an important indicator of the effect of adaptive immune responses against tumor. We investigated the numbers of tumor infiltrating T cell populations in subcutaneously growing B16 tumors treated locally for 2 weeks with CpG-Stat3-siRNA, CpG-scrambled-RNA control or left untreated. We observed an increase in the infiltration of CD8⁺ T cells in the tumor stroma from 5 to more than 20%, and an increase in tumor antigen, TRP2, positive CD8⁺ T cells in the tumor. In addition to CD8⁺ T cells, the numbers of tumor-infiltrating NK cells and neutrophils are higher in mice treated with CpG-Stat3-siRNA. Concomitant with an increase in tumor infiltrating CD8⁺, NK and neutrophils that are important killing tumor cells, the percentage of CD4⁺/FoxP3⁺ T reg cells within all CD4⁺ T cells dropped from approximately 60 to 25% after repeated peritumoral injections of CpG-Stat3-siRNA.

EXAMPLE 6

Silencing STAT3 in Human Monocyte-Derived DCs to Prevent Immunosuppression

[0113] The expression of TLR9 as well as the ability to take up CpG-based oligonucleotides is reportedly restricted to relatively rare population of plasmacytoid DCs in humans. However, moderate levels of TLR9 expression have recently been found also in more common monocyte-derived DCs (MoDCs) isolated or expanded from peripheral blood mononuclear cells (PBMCs). We created an analogue chimeric oligonucleotide by fusion of CpG(D19) sequence optimized for activation of human TLR9-positive cells with the STAT3-specific siRNA selected for the highest silencing effect in human cells. Next, we incubated fluorescein-labeled CpG(D19)-STAT3-siRNA with human PBMCs to determine the level and specificity of oligonucleotide uptake. Flow cytometric analysis revealed the internalization of fusion oligonucleotide by CD14⁺ monocytes but not by other PBMCs including CD3⁺ lymphocytes. Similarly to the mouse DCs, CpG(D19)-STAT3-siRNA uptake is detectable after short incubation time. Chimeric oligonucleotide internalization is dose dependent within the range of 20 to 500 nM, with maximal near 100% uptake at the highest concentration after 24 h. Under these conditions, CpG(D19)-STAT3-siRNA reduced STAT3 expression by almost 75% comparing to CpG-scrambled-RNA control as measured by real-time PCR analysis.

EXAMPLE 7

Targeting Stat3 in Malignant B Cells by CpG-Stat3 siRNA

[0114] Not only Stat3 is activated in immune cells in the tumor microenvironment, promoting tumor immunosuppression, Stat3 is constitutively activated in tumor cells of diverse origin (Yu and Jove, 2004; Yu et al., 2007). Stat3 activity intrinsic to the tumor cells upregulate a large range of genes critical for tumor growth, survival, angiogenesis/metastasis and immunosuppression. It is therefore highly desirable for any Stat3 inhibitor to be able to block Stat3 in the tumor cells. Because many malignant cells of B cell origin, including multiple myeloma and B cell lymphoma express TLR9 (Bourke et al., 2003, Reid et al., 2005; Jahrsdorfer et al., 2005), we test the possibility that CpG-Stat3siRNA can be internalized by these tumor cells, leading to gene silencing and tumor growth inhibition. To directly test these possibilities, we incubated several human B lymphoma cell lines with CpG-Stat3siRNA for uptake and internalization. The data shows that CpG-STAT3 siRNA allows for siRNA delivery into various types of human B lymphoma cells, in a dose-dependent manner. We then assess the uptake and the effects of CpG-Stat3siRNA in a mouse myeloma model. The results indicate that mouse

myeloma cells, MCP11, internalize FITC-labeled CpG-Stat3 siRNA in a dose-dependent manner, as shown by flow cytometry after 24 h incubation. Furthermore, CpG-Stat3siRNA can lead to Stat3 silencing in MPC 11 cells treated with 100 nM CpG-Stat3 siRNA for 24 h, as measured by real-time PCR. Importantly, MCP11 cells treated with CpG-Stat3siRNA leads to accumulation in the G₂M phase of cell cycle as measured by flow cytometry after propidium iodide staining.

[0115] We next determined whether targeting Stat3 by CpG-Stat3 siRNA causes antitumor effects against MPC11 multiple myeloma. Mice bearing large MCP11 tumors (10-13mm in diameter) are injected intratumorally with 0.78 nmole of CpG-siStat3 or CpG-scrRNA and two more times every second day. MPC11 tumor is very aggressive, but *in vivo* treatment with CpG-Stat3siRNA results in significant tumor growth inhibition. Analysis of the tumor samples indicate that CpG-Stat3siRNA increases tumor cell apoptosis. An increased percentage of DCs in tumor-draining lymph-nodes after CpG-Stat3 siRNA treatment is also detected. Moreover, there is an increase in CD40 and CD86 expression in tumor-draining lymph node DCs, suggesting that CpG-Stat3siRNA treatment can lead to activation of DCs in the tumor milieu. These results demonstrate that CpG-siRNA approach can target tumor cells of B cell origin, leading to antitumor effects through direct effects on the tumor cells.

EXAMPLE 8

TLR Agonist-*Stat3* siRNA Conjugates: Cell-Specific Gene Silencing and Enhanced Antitumor Immune Responses

[0116] Efficient delivery of siRNA to specific cell populations *in vivo* is important to its successful therapeutic application. A novel siRNA-based approach – synthetically linking siRNA to an oligonucleotide TLR9 agonist – that targets and silences genes in TLR9⁺ myeloid cells and B cells, both of which are key components of the tumor microenvironment is described. Because Stat3 in tumor-associated immune cells suppresses antitumor immune responses and hinders TLR9 signaling, we tested CpG-Stat3siRNA conjugates for anti-tumor effects. When injected locally at the tumor site or systemically through an intravenous route, the CpG-Stat3siRNA conjugates access tumor-associated dendritic cells, macrophages and B cells, inhibit *Stat3* expression, leading to activation of diverse tumor-associated immune cells, and ultimately potent anti-tumor immune responses. The findings described herein demonstrate the potential of TLR agonist-siRNA conjugates for targeted gene silencing coupled with TLR stimulation and immune activation in the tumor microenvironment.

[0117] Because Stat3 also restrains TLR-mediated Th1 immune responses (Kortylewski et al., 2005b; Kortylewski et al., 2009b; Yu et al., 2007), we reasoned that simultaneously silencing *Stat3* by siRNA and triggering TLRs by their agonists could effectively shift the tumor microenvironment from pro-carcinogenic to anti-carcinogenic, potentially resulting in systemic tumor-specific immunity that could further inhibit tumor metastases. A recent study using polymer-mediated *in vivo* transfection of 5'-triphosphate-*Bcl2* siRNA has demonstrated the power of simultaneously inducing antitumor immunity and silencing an oncogenic gene (Poeck et al., 2008).

[0118] In this study, we explored a strategy of linking siRNAs to synthetic oligonucleotide agonists for endosomal TLRs, which include TLR3, TLR7, TLR8 and TLR9 (Iwasaki and Medzhitov, 2004; Kanzler et al., 2007; Barchet et al., 2008), for targeted delivery of siRNA into the endosomal compartment of immune cells, such as myeloid cells and B cells, together with TLR-dependent activation of antitumor immune responses. The endosomal location of the oligonucleotide-binding TLRs, such as TLR9, might be advantageous in facilitating ultimate uptake of the siRNA component to the cytosol of targeted cells for more efficient gene silencing in cells selectively expressing the cognate TLR. In order to model this concept, we chose TLR9-specific oligodeoxynucleotides containing an unmethylated CpG-motif (CpG ODN), because they are already in clinical testing (Krieg, 2008). Additionally, CpG ODN are efficiently internalized by various antigen-presenting cells, such as dendritic cells, macrophages and B cells, and their binding to TLR9 can initiate a cascade of innate and adaptive immune responses (Klimman et al., 2004; Barchet et al., 2008; Krieg, 2008). These immune cells are also critical components of the tumor microenvironment that actively promote oncogenesis (Kujawski et al., 2008; Yu et al., 2007; Kortylewski et al., 2008; Bollrath et al., 2009; Grivennikov et al., 2009). By linking the single-stranded CpG ODN with double-stranded siRNA, we have created a single synthetic molecule capable of delivering siRNA into myeloid and B cells, silencing an immune checkpoint and/or oncogenic gene, and activating TLR, leading to therapeutic antitumor immune responses.

EXAMPLE 9

Construction And *In Vitro* Characterization of the CpG-*Stat3* siRNA Conjugate Molecule

[0119] Synthesis of the antisense strand of the siRNA (27mer) was followed by CpG1668 ODN synthesis (Klinman et al., 19996; Krieg et al., 1995), producing a single stranded

oligonucleotide connected through a carbon chain linker. The sense strand sequence of the *Stat3* siRNA (25mer) is also shown. A 25/27mer form of siRNA was chosen over the conventional 21mer duplex to allow uncoupling of the siRNA from the CpG sequence by the Dicer enzyme once inside the cell. The asymmetric 25/27mer siRNA was optimized for specific processing by Dicer and was more potent in silencing of target genes (Kim et al., 2005; Rose et al., 2005). We first evaluated whether attaching siRNA to CpG ODN through the linker would interfere with TLR9 activation. Adding either CpG1688 alone or CpG-*Stat3* siRNA conjugate to cultured DC2.4 dendritic cells resulted in a similar increase in expression of co-stimulatory CD40 and CD80 molecules, suggesting that CpG-*Stat3* siRNA retains its capacity to activate TLR9. In addition, we verified that the immunostimulatory properties of CpG-siRNA conjugates do not differ from the effect of CpG alone as measured by production of inflammatory cytokines in primary cells and NF- κ B/AP1 activation in a stable macrophage cell line designed for such test. To assess whether the conjugation of siRNA with CpG moiety would still allow Dicer processing, we compared *in vitro* Dicer activity on CpG-*Stat3* siRNA substrate versus 25/27mer *Stat3* siRNA alone. The CpG-*Stat3* siRNA and *Stat3* siRNA were incubated with 1U of recombinant Dicer for 1h at 37°C and then visualized on polyacrylamide gel through SYBRGold staining. Both the CpG-*Stat3* siRNA and *Stat3* siRNA were processed to 21mer siRNA by recombinant Dicer. Finally, to determine whether the CpG-*Stat3* siRNA retains gene silencing function, the chimeric molecule was transfected into cells using Lipofectamine transfection reagent. Results from this experiment indicated that linking CpG ODN to siRNA did not interfere with *Stat3* gene silencing. Both CpG-*Stat3* siRNA and *Stat3* siRNA alone reduced the total protein levels of Stat3 by 55% and 49%, respectively, as measured by densitometry.

EXAMPLE 10

Cell Specific Uptake and Gene Silencing Effects by the CpG-siRNA Conjugate Molecules

[0120] To determine the specificity and efficiency of CpG-siRNA uptake, freshly prepared mouse splenocytes were incubated for 3 h with two concentrations of CpG-linked *Stat3* siRNA or an unconjugated *Stat3* siRNA, in the absence of any transfection reagent(s). Both the CpG-*Stat3* siRNA and unconjugated *Stat3* siRNA were labeled with fluorescein. Fluorescein-positive DCs, macrophages, B cells, granulocytes and T cells were assessed by FACS analysis. Results from the flow cytometric analyses indicated that the chimeric CpG-*Stat3* siRNA was efficiently taken up by both plasmacytoid (CD11c⁺B220⁺) and conventional (CD11c⁺B220⁻) splenic DCs,

macrophages (F4/80⁺Gr1⁻) and B cells (B220⁺CD11c⁻), whereas uptake by splenic granulocytes (Gr1⁺F4/80⁻) or T cells (CD3⁺) was minimal. This uptake pattern reflects the known distribution of TLR9 expression in murine leukocyte subsets (Hemmi et al., 2000; Iwasaki and Medzhitov, 2004). CD11c⁺ DCs were confirmed to express TLR9, as shown by intracellular staining of TLR9 in fixed splenocytes by flow cytometry. Unconjugated *Stat3* siRNA was not efficiently incorporated into DCs even after 24 h incubation, demonstrating that linkage to the TLR9 ligand facilitates siRNA uptake.

[0121] We further evaluated CpG-*Stat3* siRNA-FITC uptake by DC 2.4 mouse dendritic cells. FACS analyses and fluorescent microscopy indicated that without transfection reagents, the CpG-*Stat3* siRNA-FITC was internalized by DC 2.4 cells, with kinetics similar to that CpG-ODN alone and reported previously (Latz et al., 2004). By 60 min, greater than 80% DC 2.4 cells were positive for uptake of the conjugate, which was confirmed by confocal microscopic analysis. The uptake of the CpG-*Stat3* siRNA-FITC was dose dependent, observable at the concentration of 100 nM and reaching maximum at 500 nM.

[0122] Confocal microscopy analyses further showed that at one hour after incubation, the CpG-*Stat3* siRNA colocalized with TLR9 within perinuclear endocytic vesicles. This colocalization diminished at 2 and 4 h after CpG-siRNA treatment. Previous studies have demonstrated that binding of the Dicer nuclease to the siRNA oligonucleotide is required for further siRNA processing to shorter 21mer fragments that can mediate RISC complex-dependent mRNA degradation (Chendrimada et al., 2005). We observed transient colocalization of the CpG-*Stat3* siRNA with Dicer within 2 h after adding the oligonucleotide to cultured dendritic cells. The colocalization of CpG-*Stat3*-siRNA and Dicer became weaker by 4 h and undetectable after 24 h.

[0123] To determine gene silencing effects of the CpG-*Stat3* siRNA, DC2.4 cells were incubated with CpG-*Stat3* siRNA, CpG-scrambled RNA or GpC-conjugated *Stat3* siRNA. Quantitative real-time PCR analysis of the *Stat3* mRNA expression in DC2.4 cells indicated a dose-dependent downregulation of *Stat3* expression by CpG-*Stat3* siRNA, compared to CpG-scrambled RNA. Maximum effect on *Stat3* silencing (ca. 80% reduction) was observed at relatively high 1 μ M concentration of CpG-*Stat3* siRNA in serum-containing cell culture medium. GpC-conjugated *Stat3* siRNA, which binds but does not activate TLR9 (Latz et al. 2004), failed to silence *Stat3*, suggesting a possible requirement of TLR9 activation for the CpG-siRNA to be further processed. Further experiments demonstrated that in *TLR9*^{-/-} myeloid cells and DCs, while cellular uptake of CpG-*Stat3* siRNA was normal, the gene silencing effect

of CpG-siRNA was completely impaired. We further confirmed the gene silencing effects using electrophoretic mobility shift assays (EMSA) to detect Stat3 DNA-binding activity in DC2.4 cells, which was induced by IL-10 stimulation. Note that, as indicated above, stimulation using CpG itself also resulted in Stat3 activation, which serves as a negative feedback mechanism (Kortylewski et al., 2009b; Samarasinghe et al., 2006), thereby complicating the EMSA analysis for detection of *Stat3* silencing. None-the-less, the higher concentrations of CpG-*Stat3* siRNA diminished Stat3 DNA binding activity relative to the conjugate scrambled RNA controls.

[0124] To demonstrate the generality of this approach to gene silencing, we used another system to verify the gene silencing effects of the CpG-siRNA constructs. Mouse A20 B cell lymphoma cells, which are TLR9-positive, could internalize CpG-siRNA. A chimeric conjugate linking a Dicer substrate siRNA specific for firefly luciferase (*Luc*) conjugated to the 20 deoxyribonucleotides CpG1668 ODN (CpG-*Luc* siRNA) inhibited luciferase overexpression in A20-Luc cells, which was determined by measuring luciferase activity.

EXAMPLE 11

Antitumor Effects of the CpG-*Stat3*siRNA Conjugate Molecule

[0125] To evaluate the feasibility of using the CpG-siRNA conjugates *in vivo* for therapeutic purposes, we focused on potential immunologically mediated anti-tumor effects of the CpG-*Stat3* siRNA conjugates. The initial biodistribution experiments in naive tumor-free mice confirmed that CpG-*Stat3* siRNA is specifically internalized by resident macrophages in different tissues as well as DCs and B cells in lymph nodes. Next, we estimated the uptake of the CpG-*Stat3* siRNA by macrophages and dendritic cells in tumor-bearing mice. C57BL/6 mice with aggressive poorly immunogenic B16 tumors (6-10 mm in diameter) were injected peritumorally with FITC-labeled CpG-*Stat3* siRNA at 0.78 nmol (20 µg)/injection. As shown by immunofluorescent staining and FACS analysis, numerous myeloid cells accumulated at the site of CpG-*Stat3* siRNA injection already 1 h later. Furthermore, *in vivo* intravital two-photon microscopy indicated the presence of FITC-positive cells in tumor-draining lymph node, as early as 1 h after injection of the labeled construct, but not in the contralateral lymph nodes. Additionally, high resolution imaging by intravital two-photon microscopy revealed not only an increased number of FITC-positive cells in tumor draining lymph nodes, but also an accumulation of FITC-labeled CpG-*Stat3* siRNAs in perinuclear endocytic vesicles, which was also observed in cultured dendritic cells.

[0126] We next evaluated the gene silencing and antitumor effects of CpG-*Stat3* siRNAs *in vivo*. Peritumoral injections of the CpG-*Stat3* siRNA resulted in relatively effective gene silencing in dendritic cells, macrophages and B cells accumulated in tumor draining lymph nodes, compared to control CpG-*Luc* siRNA, as measured by quantitative real-time PCR. *Stat3* inactivation in CD11c⁺ dendritic cells isolated from tumor draining lymph nodes was confirmed at protein level. Furthermore, quantitative real-time PCR and Western blotting indicate *Stat3* silencing in the total tumor draining lymph nodes as well. We also used CpG-*Luc* siRNA conjugate to confirm that CpG-siRNA conjugates are able to reduce protein expression specifically within myeloid cells *in vivo*. Mice over-expressing firefly luciferase under control of the β -actin promoter (Cao et al., 2004) were challenged with tumor cells, followed by repeated peritumoral injections of CpG-*Luc* siRNA. Results from these experiments indicated effective inhibition of luciferase activity in CD11b⁺ myeloid cells but not in CD4⁺ lymphocytes within tumor-draining lymph nodes.

[0127] Both dendritic cells and macrophages in the tumor microenvironment are known to promote immune tolerance (Dhodapkar et al., 2008; Vicari et al., 2002; Zou et al. 2005). Our previous work demonstrated that *Stat3* is constitutively-activated in myeloid cells in the tumor milieu and that genetic ablation of *Stat3* in the myeloid compartment elicits potent antitumor immunity (Kortylewski et al., 2005b). Furthermore, both CpG and LPS treatment activates *Stat3* (Samarasinghe et al., 2006; Kortylewski et al., 2009b; Benkhart et al., 2000), which acts as a negative feedback mechanism to constrain Th1 immune responses. Therefore, we assessed whether the CpG-*Stat3*-siRNA conjugates could reverse the immunosuppressive effects imposed by the tumor-microenvironment and at the same time allow effective antitumor immunity induced by TLR9 triggering. Local treatment with CpG-*Stat3* siRNA oligonucleotides inhibited growth of subcutaneously growing B16 melanoma (3-5 mm in diameter at the initial treatment). In contrast, treatment with unconjugated CpG-ODN plus *Stat3* siRNA, or CpG-scrambled RNA construct, or GpC-*Stat3* siRNA had significantly less antitumor effects. This finding was confirmed by using two additional CpG-*Stat3* siRNA conjugates containing alternative *Stat3* siRNA sequences (data not shown). To confirm that the antitumor effects induced by CpG-*Stat3* siRNA were mainly mediated by immune cells, we performed *in vivo* experiments with antibody-mediated depletion of CD8/CD4 T cells and NK cells. The results show that in the absence of CD8⁺ and CD4⁺ immune cell populations (including possibly also the cross priming CD11c⁺CD8⁺ DCs), the effects of CpG-*Stat3* siRNA treatment were partially reduced and

comparable to the moderate antitumor effect of the control CpG-*Luc* siRNA, and lack of NK cells abrogated therapeutic effect of CpG-*Stat3* siRNA.

[0128] We confirmed that local treatment with CpG-*Stat3* siRNA can reduce growth of other tumors independently of their genetic background. CpG-*Stat3* siRNA oligonucleotides inhibited growth of both a poorly immunogenic variant of K1735 melanoma, C4 (Xie et al., 2004), and CT26 colon carcinomas in C3H and BALB/c mice, respectively. Furthermore, CpG-*Stat3* siRNA treatment of the carcinoembryonic antigen (CEA) transgenic C57BL/6 mice bearing MC38 colon carcinomas expressing CEA led to tumor regression. To assess *in vivo* effects of the CpG-*Stat3* siRNA on tumor cells, we stained B16 tumor tissues with fluorescent antibody specific to activated caspase-3. Data from these analysis showed that B16 tumors received CpG-*Stat3* siRNA had undergone more extensive apoptosis relative to the other three treatment groups.

[0129] We further investigated the possibility that intravenous injections of CpG-*Stat3* siRNA can lead to gene silencing and antitumor effects. Intravenous injection of CpG-*Stat3* siRNA (0.78 nmol) reduced *Stat3* expression in dendritic cells within tumor-draining lymph nodes relative to CpG-scrambled RNA. We also tested the ability of systemic delivery of CpG-*Stat3* siRNA to inhibit metastatic tumor growth in an established B16 lung metastasis model. Mice with disseminated B16 tumor cells were treated systemically with CpG-*Stat3* siRNA thrice weekly for two weeks. Relatively small amounts of the oligonucleotide (< 1 mg/kg) were used for the systemic injection, which led to significant reduction in the number of lung metastasis. A significantly lower antitumor effect due to CpG-scrambled RNA and CpG ODN alone was also observed. Thus, maximal antitumor effects required conjugation of the CpG TLR9 ligand with a functional *Stat3* siRNA.

EXAMPLE 12

Modulation of the Tumor Immunologic Milieu by the CpG-*Stat3* siRNA Conjugate Molecule

[0130] To further assess the role of immune modulation in the observed antitumor effects mediated by CpG-*Stat3* siRNA conjugate treatment, we analyzed changes in Th1 cytokine/chemokines and co-stimulatory molecule expression by dendritic cells in the tumor draining lymph nodes. Lack of *Stat3* in DCs has been shown to upregulate expression of Th1 cytokines/chemokines (Kortylewski et al., 2005b; Kortylewski et al., 2009a; Takeda et al., 1999; Welte et al., 2003), which can be greatly amplified by CpG treatment (Kortylewski et al.,

2009b);). The results show that local tumor site injection of the CpG-*Stat3* siRNA resulted in upregulation of several Th1 cytokines and chemokines, which were shown to be upregulated by *Stat3* ablation (Kortylewski et al., 2005b; Kortylewski et al., 2009a; Takeda et al., 1999; Welte et al., 2003). It has also been documented that dendritic cells with low expression levels of co-stimulatory molecules mediate immune tolerance (Dhodapkar et al., 2001), which is one of the proposed mechanisms for tumor immune evasion induced by *Stat3* activation in tumor-associated dendritic cells (Kortylewski et al., 2005b). We therefore analyzed expression of co-stimulatory molecules by dendritic cells enriched from tumor draining lymph nodes. Results from these analyses indicated that CpG-*Stat3* siRNA reduced the number of the dendritic cells with low expression of co-stimulatory molecules, including MHC class II, CD80 and CD40, which was accompanied by a modest increase in expression of these co-stimulatory molecules. *Stat3* ablation in myeloid cells followed by local treatment has been shown to induce potent antitumor innate immune responses that involve neutrophils (Kortylewski et al., 2005b). We therefore assessed whether CpG-*Stat3* siRNA conjugate treatment could lead to neutrophil-associated tumor cell apoptosis. Co-staining B16 tumor tissue sections with antibodies specific to activated caspase-3 and neutrophils revealed that CpG-*Stat3* siRNA treatment-induced massive tumor cell apoptosis (activated caspase 3-positive) was associated with an increase in tumor-infiltrating neutrophils.

[0131] The ratio of effector to regulatory T cells within the tumor microenvironment is considered to correlate well with the effect of adaptive immune responses on tumor progression and metastasis (Bui et al., 2006). We investigated the numbers of tumor infiltrating T cell populations in subcutaneously growing B16 tumors treated locally for 2 weeks with CpG-*Stat3* siRNA, CpG-scrambled RNA control or treated with PBS only. We found that although CpG-*Stat3* siRNA treatment did not induce significant changes in overall CD4⁺ T cell numbers within the tumors, as shown by flow cytometric analysis, the percentage of CD4⁺/FoxP3⁺ Treg cells within all CD4⁺ T cells dropped from approximately 60% to 25% after peritumoral injections of CpG-*Stat3* siRNA. We observed an increase in the infiltration of total CD8⁺ T cells in the tumor stroma from 5% to almost 20%, although CpG-scrambled RNA control treatment also led to some recruitment of CD8⁺ T cells, as shown by flow cytometric analysis. These effects probably result from TLR9-mediated immunostimulation of tumor-infiltrating APCs. At the same time, we cannot rule out antitumor effects contributed by non-specific immunostimulation by double-stranded RNA. Fluorescent immunostaining of frozen tumor tissues with anti-CD8 antibody confirmed data generated by flow cytometric analysis that CpG-*Stat3* siRNA treatment caused

increased CD8⁺ T cell infiltration in tumors. Activation of tumor antigen-specific CD8⁺ T cells is believed to be critical for immune-mediated antitumor effects. We therefore examined the ability of CpG-*Stat3* siRNA treatment to generate CD8⁺ T cells specific for the B16 tumor antigen, TRP2. ELISPOT assays to determine IFN γ production by T cells isolated from tumor draining lymph nodes in response to recall stimulation with TRP2 peptide indicated that *in vivo* CpG-*Stat3* siRNA administration indeed induced antigen-specific CD8⁺ T cells.

[0132] Additional results show that for different siRNA *Stat3* sequences. These results (i) show the validation of CpG-siRNA approach for cancer immunotherapy by using additional siRNAs with different sequences; (ii) show that TLR9 is not necessary for uptake but is required for silencing effect of CpG-*Stat3* siRNA by myeloid cells and (iii) show that the CpG-siRNA approach effectively silences genes in TLR9⁺ human tumor cells leading to therapeutic antitumor effects in animals.

[0133] We have developed a new strategy for targeted siRNA delivery together with immune activation by covalently linking TLR oligonucleotide agonists to siRNAs. These conjugates encompass three activities in a single molecule: targeting to immune cells, which include DCs, macrophages, and B cells, TLR activation and immune checkpoint silencing. In addition to TLR9, several other intracellular TLRs, such as TLR3, TLR7 and TLR8 also recognize nucleic acids, suggesting a broad application of this approach using various ligands for these TLRs to deliver various siRNAs into different immune cells. TLRs are important for stimulating dendritic cell maturation, antigen uptake and presentation, leading to CTL activation and CD4⁺ T helper cell differentiation. Therefore, TLR agonist-siRNA approaches can further stimulate desired immune responses for treating diseases such as cancer and infections. Although it has been established that binding to TLR9 is necessary for CpG-mediated immune activation, it remains to be fully explored how CpG ODN enter cells (Latz et al., 2004). Our results indicated that cellular uptake of both CpG ODN and the CpG-siRNA constructs can occur in the absence of TLR9. However, TLR9 is required for CpG-siRNA mediated gene silencing. While the exact underlying mechanism(s) remains to be determined, it is possible that triggering TLR9 could effect either endosomal release of CpG-siRNA into the cytoplasm, or/and its intracellular processing.

[0134] Although TLR9 is expressed in different types of mouse dendritic cells, its expression is more selective in humans. While the highest levels of constitutive TLR9 expression is

observed on human plasmacytoid DCs and B cells, it is also expressed at lower levels on human monocytes and macrophages (Iwasaki and Medzhitov, 2004). These immune cells can serve as antigen-presenting cells and induce innate, adaptive or humoral immunity (Kanzler et al., 2007; Krieg, 2008; Marshner et al., 2005; Klinman et al., 2008). Furthermore, it has been demonstrated recently that adding triphosphate to the 5' of siRNA can greatly potentiate the antitumor effects of siRNA by stimulating antitumor immune responses, likely through intracellular RNA sensors such as RIG-I or MDA-5 (Poeck et al., 2008). It is therefore conceivable to incorporate triphosphate to the CpG-siRNA to further amplify antitumor immunity. In addition, a critical role of tumor stromal macrophages and B cells in promoting tumor development has been well documented (Pollard, 2004; Sica and Bronte, 2007; Tan and Coussens, 2007). Importantly, Stat3 and several other molecules produced by the tumor myeloid population, and possibly tumor-associated B cells, are critical for tumor immunosuppression (Yu et al., 2007), and Stat3 activity in the myeloid compartment (possibly B cells as well) promotes Stat3 activity in tumor cells and endothelial cells in the tumor, enhancing tumor cell growth/survival (Kujawski et al., 2008; Bollrath et al., 2009; Grivennikov et al., 2009; Lee et al., 2009). In addition to Stat3, other oncogenic molecules produced by the tumor myeloid/B cell compartment are also critical in promoting cancer growth and resistance to various therapies. Therefore, being able to target the tumor stromal myeloid cells/B cells through CpG-siRNA conjugate molecules is highly desirable for cancer therapies. In addition to normal immune cells, several types of tumor cells, including those of B cell origin, and some solid tumor cells, are also positive for TLR9 (Jahrsdorfer et al., 2005; Spaner et al., 2008). Our preliminary results suggested the feasibility of CpG-siRNA approach to silence genes in TLR9⁺ tumor cells. For example, treating human TLR9⁺ tumors in NOD/SCID/*IL-2R γ* KO mice with CpG-*Stat3* siRNA resulted in tumor cell apoptosis and tumor growth inhibition (Kortylewski and Yu, unpublished data).

[0135] Our results indicated that the gene silencing effects by CpG-siRNA in cultured cells requires high concentrations of the conjugates and are suboptimal relative to *in vivo* treatment. Work is underway to determine the possible cause(s) of this difference, which might include serum-dependent degradation of CpG-siRNAs or reduction of the overall silencing effect in rapidly dividing cell populations. It is possible that *in vivo* repeated treatments allow accumulative gene silencing effects, and the crosstalk between various cells in the tumor microenvironment could lead to secondary effects on Stat3 activity (Lee et al., 2009). The half-life of the constructs at present is limited. Although the CpG ODN in the construct is phosphorothioated, which should resist serum degradation, the siRNA in the chimeric construct

is unmodified and negatively charged. Chemically modifying the siRNA to prolong serum stability and to neutralize the negative charge of the siRNA to facilitate endosomal release may improve the efficacy of TLR agonist-siRNA approach. Our results show the use of oligonucleotide TLR agonists for siRNA delivery into tumor-associated myeloid cells and B cells to inhibit expression of tumor-promoting/immunosuppressive molecules while activating TLR(s) for immune activation.

[0136] The proof-of-principle experiments provided evidence that systemically delivered CpG(A)-*STAT3* siRNA (i.e., CpG(D19)-*STAT3* siRNA) can target human TLR9⁺ cells *in vivo*. The intravenously injected CpG(A)-*STAT3* siRNA led to *STAT3* gene silencing in human MV4-11 acute myeloid leukemia (AML) cells residing in the bone-marrow of immunodeficient NOD/SCID/IL-2R γ ^{null} (NSG) mice (Fig. 1A). In other preliminary studies, effects of CpG(A)-siRNAs targeting oncogenic and/or prosurvival genes injected intratumorally into KMS-11 multiple myeloma (MM) (Fig. 1B) or MonoMac6 and MV4-11 AML (Fig. 1C and Fig. 1D) tumors growing *s.c.* in NSG mice were compared. The repeated local administration of CpG(A)-siRNAs specific for either *STAT3* or *BCL-X_L* genes resulted in gene-specific silencing, induced tumor cell death and reduced growth of xenotransplanted tumors (Figs. 1B-1D). Sequences of single stranded constructs are listed below.

[0137] CpG(D19)-human *STAT3* siRNA (antisense strand; underlined are deoxyribonucleotides, asterisks indicate phosphothioated sites, X indicates single C3 carbon chain linker)

5' G*GTGCATCGATGCAGG*G*G*G*G-XXXXX-UCAGUCGUAUCUUUCUGCAGCUU
CCGU 3' (SEQ ID NO:5-XXXXX-SEQ ID NO:6).

[0138] Human *Stat3* siRNA (sense strand ; underlined are deoxyribonucleotides)

5' GGAAGCUGCAGAAAGAUACGACUGA 3' (SEQ ID NO:4)

[0139] CpG(D19)-Luciferase siRNA (antisense strand; underlined are deoxyribonucleotides, asterisks indicate phosphothioated sites, X indicates single C3 carbon chain linker)

5' G*GTGCATCGATGCAGG*G*G*G*G-XXXXX-UGUAAAAGCAAUUGUCCAGGA
ACCAG 3' (SEQ ID NO:5-XXXXX-SEQ ID NO:11)

[0140] Luciferase siRNA (sense strand ; underlined are deoxyribonucleotides)

5' GGUUCCUGGAACAAUUGCUUUUACA 3' (SEQ ID NO:23)

[0141] In preliminary studies, the silencing efficacy of CpG-siRNA conjugates based on CpG oligodeoxynucleotides from either class A or class B were also compared. As shown in Fig. 2 top and bottom, class A-based CpG(D19)-*STAT3* siRNA induced more pronounced target gene

silencing effect (Fig. 2 top) and higher degree of tumor cell death (Fig. 2 bottom) than the class B-based CpG(7909)-*STAT3* siRNA in comparison to matching control class A and class B CpG-*Luciferase* siRNAs, respectively. Sequences of single stranded constructs are listed below.

[0142] CpG(7909)-human *STAT3* siRNA (antisense strand; underlined are deoxyribonucleotides, asterisks indicate phosphothioated sites, X indicates single C3 carbon chain linker)

5' T*C*G*T*C*G*T*T*T*T*G*T*C*G*T*T*T*T*G*T*C*G*T*T-XXXXX-UCAGUCGUA
UCUUUCUGCAGCUUCCGU 3' (SEQ ID NO:13-XXXXX-SEQ ID NO:6)

[0143] CpG(7909)-*Luciferase* siRNA (antisense strand; underlined are deoxyribonucleotides, asterisks indicate phosphothioated sites, X indicates single C3 carbon chain linker)

5' T*C*G*T*C*G*T*T*T*T*G*T*C*G*T*T*T*T*G*T*C*G*T*T-XXXXX-UGUAAAAG
CAAUUGUCCAGGAACCAG 3' (SEQ ID NO:13-XXXXX-SEQ ID NO:11)

[0144] To assess the potential safety of CpG-siRNAs for normal human immune cells, cultured human peripheral blood mononuclear cells (PBMCs) were used. Multiplex assays indicated that CpG(D19)-*STAT3* siRNA induced more desirable cytokine expression profile comparing to the class B-based CpG(7909)-*STAT3* siRNA and class C-based CpG(2429)-*STAT3* siRNA (Fig. 3). Although inflammatory cytokines/chemokines, such as IFN α , IP-10, MCP-1, were induced at similar levels by all three conjugates, both CpG(7909)- and CpG(2429)-*STAT3* siRNAs also led to production of potentially tumorigenic/tolerogenic IL-6 and IL-10 that could dampen the overall immunostimulatory effect. Importantly, the *in vitro* studies on human PBMCs demonstrated that CpG(A)-*STAT3* siRNA was immunostimulatory but not immunotoxic for normal immune cells. The siRNA conjugation to CpG(D19) eliminated the exacerbated interferon type I responses typical for class A of CpG ODNs (Fig. 4), which hindered their clinical application. Sequences of single stranded constructs are listed below.

[0145] CpG(2429)-human *STAT3* siRNA (antisense strand; underlined are deoxyribonucleotides, asterisks indicate phosphothioated sites, X indicates single C3 carbon chain linker)

5' T*C*G*T*C*G*T*T*T*T*G*T*C*G*G*C*G*G*C*C*G*C*C*G-XXXXX-UCAGUCGUAUC
UUUCUGCAGCUUCCGU 3' (SEQ ID NO:14-XXXXX-SEQ ID NO:6)

[0146] CpG(2429)-*Luciferase* siRNA (antisense strand; underlined are deoxyribonucleotides, asterisks indicate phosphothioated sites, X indicates single C3 carbon chain linker)

5' T*C*G*T*C*G*T*T*T*T*C*G*G*C*G*G*C*C*G*C*C*G-XXXXX-GUAAAAGCAAU
UGUUC CAGGA ACCAG 3' (SEQ ID NO:14-XXXXX-SEQ ID NO:11)

[0147] The use of the terms “a” and “an” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0148] Embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

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WHAT IS CLAIMED IS:

1. A chimeric molecule comprising a human STAT3 sense strand and a human CpG(D19)-STAT3 antisense strand, wherein the human STAT3 sense strand comprises an oligonucleotide having nucleotides set forth in SEQ ID NO:4, wherein the human CpG(D19)-STAT3 antisense strand comprises (a) a first oligonucleotide having the nucleotides set forth in SEQ ID NO:5, (b) a C3 carbon chain or propanediol linker and (c) a second oligonucleotide having the nucleotides set forth in SEQ ID NO:6 that is the antisense strand, and wherein the sense strand and the antisense strand anneal to form a double stranded siRNA.
2. An oligonucleotide comprising a modified human STAT3 sense strand comprising an oligonucleotide having the nucleotides set forth in SEQ ID NO:7, wherein the modifications are selected from the group consisting of 2'F, 2'OMe, LNA, nucleotides and other modifications described herein.
3. A chimeric molecule comprising a modified human STAT3 sense strand and a human CpG(D19)-STAT3 antisense strand, wherein the modified human STAT3 sense strand is the oligonucleotide of claim 2, wherein the human CpG(D19)-STAT3 antisense strand comprises (a) a first oligonucleotide having the nucleotides set forth in SEQ ID NO:5, (b) a C3 carbon chain or propanediol linker and (c) a second oligonucleotide having the nucleotides set forth in SEQ ID NO:6 that is the antisense strand, and wherein the sense strand and the antisense strand anneal to form a double stranded siRNA.
4. A chimeric molecule comprising a human STAT3 sense strand-overhang, a human CpG(D19)-overhang and a human STAT3 antisense strand, wherein the human STAT3 sense strand-overhang comprises (a) an oligonucleotide having the nucleotides set forth in SEQ ID NO:8 that is the sense strand, (b) a C3 carbon chain or propanediol linker and (c) an oligonucleotide having the nucleotides set forth in SEQ ID NO:9 that is the overhang, wherein the human CpG(D19)-overhang comprises (a) an oligonucleotide having the nucleotides set forth in SEQ ID NO:5, (b) a C3 carbon chain or propanediol linker and (c) an oligonucleotide having the nucleotides set forth in SEQ ID NO:10 that is the overhang, wherein the human STAT3 antisense strand comprises an

oligonucleotide having the nucleotides set forth in SEQ ID NO:6, wherein the modifications are selected from the group consisting of 2'F, 2'OMe, LNA, nucleotides and other modifications described herein, wherein the overhangs anneal to form a double stranded RNA, and wherein the sense strand and the antisense strand anneal to form a double stranded siRNA.

5. A composition comprising the chimeric molecule of claim 1, 3 or 4 and a physiologically acceptable carrier.
6. The chimeric molecule of claim 1, 3 or 4 for treatment of a disease in an individual in need thereof, wherein the disease is one that can be treated by regulating the Stat3 pathway or genes under control of Stat3.
7. The method of claim 6, wherein the disease is selected from the group consisting of cancer, an infectious disease and an autoimmune disease.

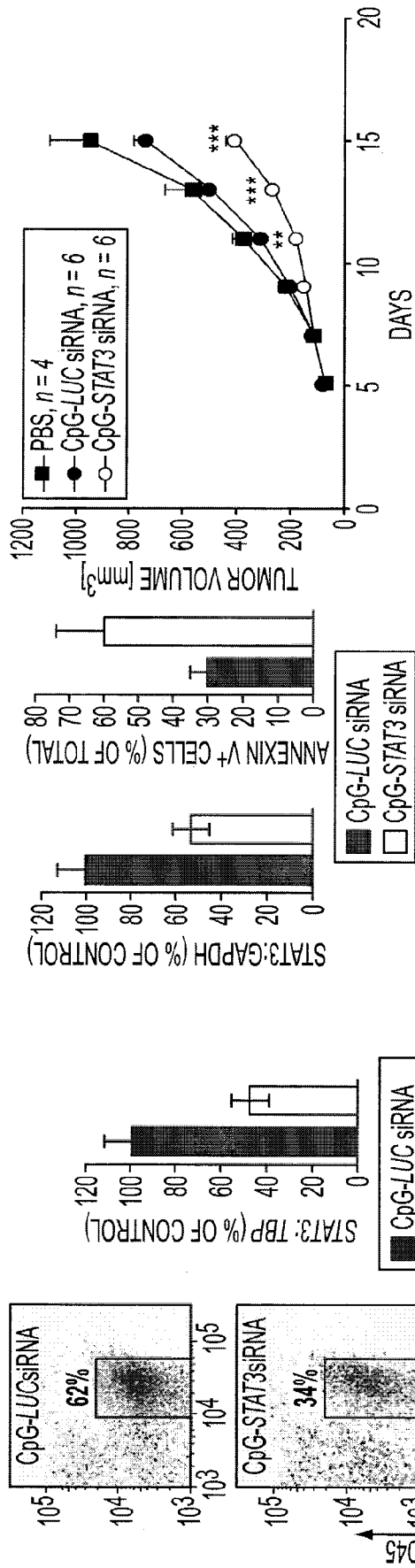


FIG. 1B

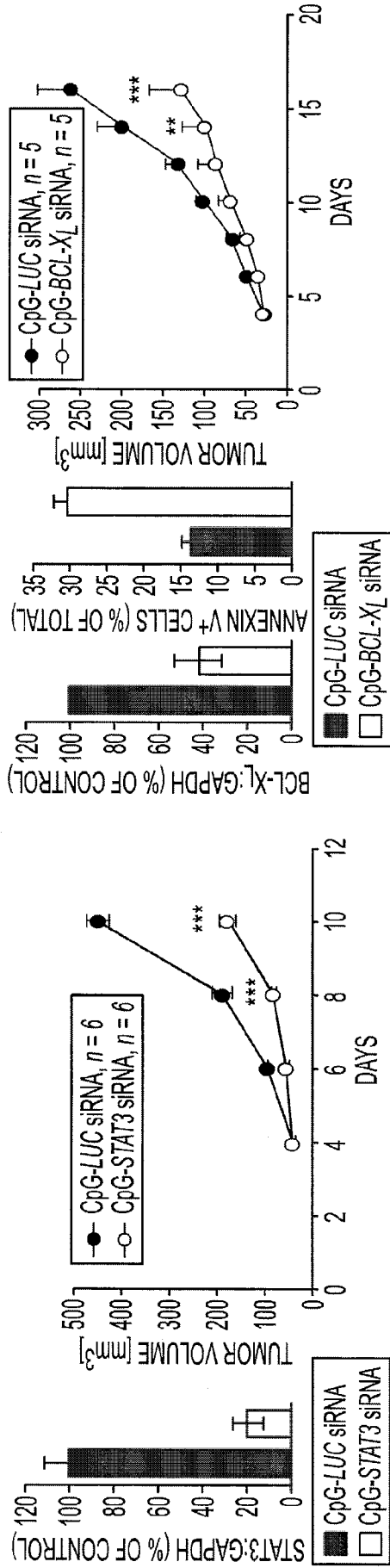


FIG. 1D

FIG. 1A

FIG. 1C

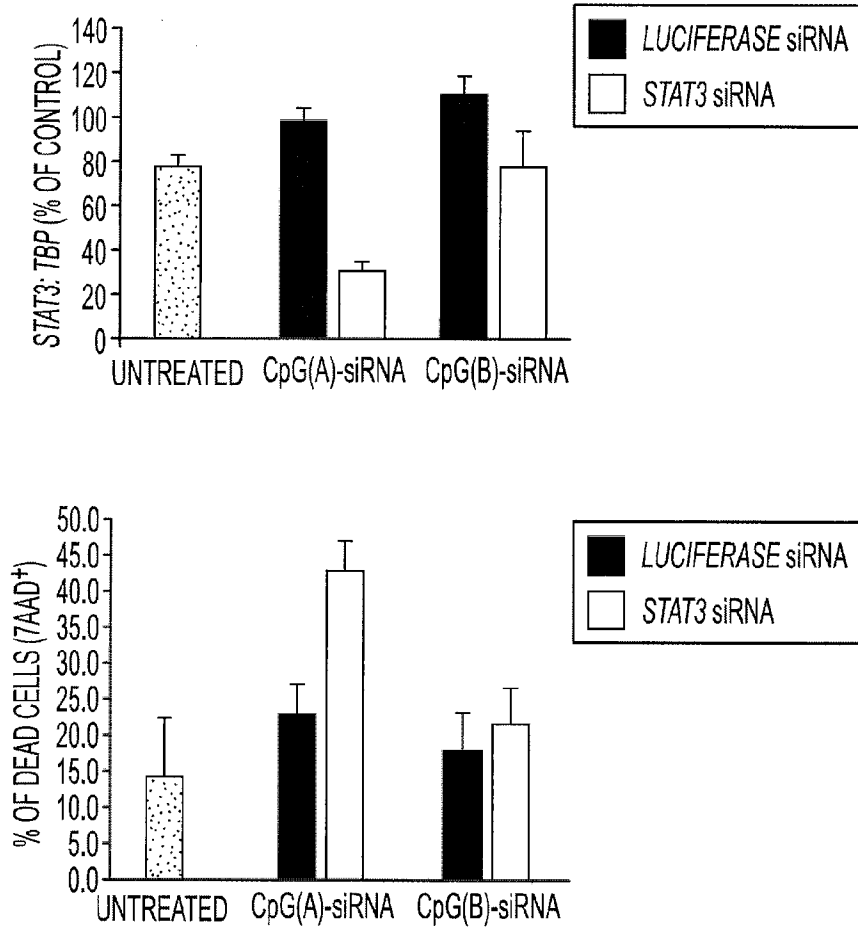


FIG. 2

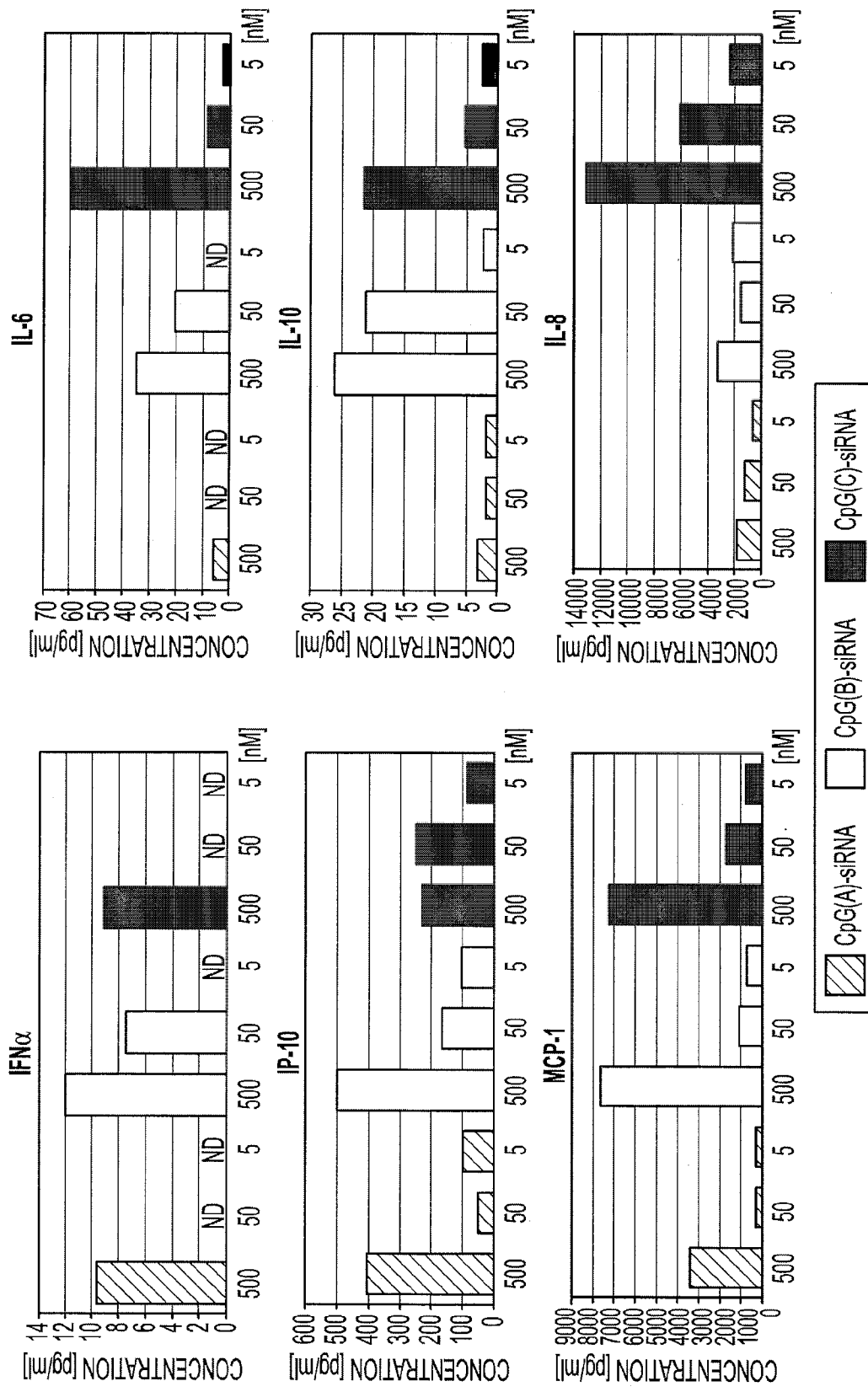


FIG. 3

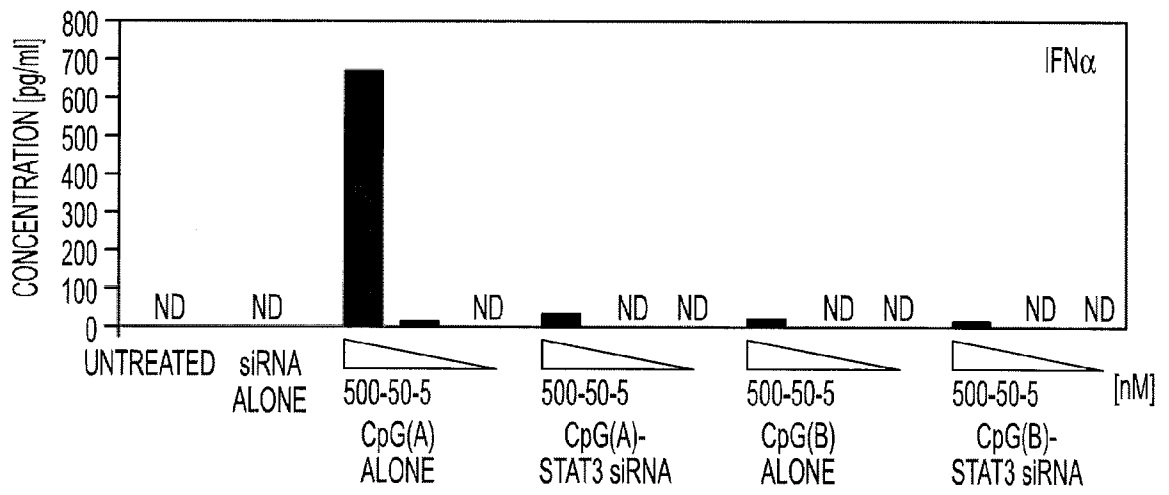


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/51042

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - C12N 15/11; C07H 21/04 (2012.01) USPC - 514/44A; 536/23.1, 536/24.5 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) IPC(8) - C12N 15/11; C07H 21/04 (2012.01) USPC - 514/44A; 536/23.1, 536/24.5 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched IPC(8) - C12N 15/11; C07H 21/04 (2012.01) - see keyword below USPC - 514/44A; 536/23.1, 536/24.5 - see keyword below Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PubWEST(USPT,PGPB,EPAB,JPAB); Medline, Google: chimeric, oligonucleotide, sense, antisense, STAT3, CpG(D19), ODN, CpG, D19, TLR9, C3, carbon chain, conjugate, link, propanediol linker, modification, 2'F, 2'OMe, 2'-O-methyl, 2'-fluoro, LNA, carrier, cancer, infection, autoimmune, modification, stability, in vivo, pathway, treat, administer		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2008/0214436 A1 (YU et al.) 04 September 2008 (04.09.2008), Abstract, para [0008], [0009], [0020], [0021], [0028], [0035], [0045], [0047], [0048], [0059], [0061], [0066], [0072], [0083], [0084],[0092], [0093], [0094], [0096], [0104], [0122], and SEQ ID NO: 4 and SEQ ID NO: 5	2 ----- 1, 3, 5-7/(1,3)
Y	US 2003/0060440 A1 (KLINMAN et al.) 27 March 2003 (27.03.2007), para [0014], [0016], and SEQ ID NO: 1	1, 3, 5-7/(1,3)
A	HOENE et al. Human monocyte-derived dendritic cells express TLR9 and react directly to the CpG-A oligonucleotide D19. J Leukoc Biol. 2006, Vol. 80(6), p. 1328-36. Abstract; pg 1328, col 2, middle para and last para; pg 1331, col 2, middle para and last para; and pg 1333, col 2, para 1	1-3, 5-7/(1,3)
A	CHIU et al. siRNA function in RNAi: A chemical modification analysis. RNA. 2003, Vol. 9(9), p. 1034-48. Entire documentation, especially Abstract and Result.	1-3, 5-7/(1,3)
A	US 2010/0298409 A1 (XIE et al.) 25 November 2010 (25.11.2010), para [0057]	1-3, 5-7/(1,3)
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/>		
* 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 06 March 2012 (06.03.2012)		Date of mailing of the international search report 26 MAR 2012
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/51042

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.:
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:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: claims 1-3, 5-7 drawn to a chimeric molecule comprising a human STAT3 sense strand and a human CpG(D19)STAT3 antisense strand, wherein the human STAT3 sense strand comprises an oligonucleotide having nucleotides set forth in SEQ ID NO:4, wherein the human CpG(D19)-STAT3 antisense strand comprises (a) a first oligonucleotide having the nucleotides set forth in SEQ ID NO:5, (b) a C3 carbon chain or propanediollinker and (c) a second oligonucleotide having the nucleotides set forth in SEQ ID NO:6 that is the antisense strand, and wherein the sense strand and the antisense strand anneal to form a double stranded siRNA.

*****Continued in the extra sheet*****

- 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.:
1-3, 5-7/(1,3)

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.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/51042

Continuation of:

Box No. III (unity of invention is lacking)

Group II, claims 4-7, drawn to a chimeric molecule comprising a human ST AT3 sense strand-overhang, a human CpG(D19)-overhang and a human STAT3 antisense strand, wherein the human STAT3 sense strand-overhang comprises (a) an oligonucleotide having the nucleotides set forth in SEQ ID NO:8 that is the sense strand, (b) a C3 carbon chain or propanediollinker and (c) an oligonucleotide having the nucleotides set forth in SEQ ID NO:9 that is the overhang, wherein the human CpG(D19)-overhang comprises (a) an oligonucleotide

having the nucleotides set forth in SEQ ID NO:5, (b) a C3 carbon chain or propanediol linker and (c) an oligonucleotide having the nucleotides set forth in SEQ ID NO: 10 that is the overhang, wherein the human STAT3 antisense strand comprises an oligonucleotide having the nucleotides set forth in SEQ ID NO:6, wherein the modifications are selected from the group consisting of 2'F, 2'OMe, LNA, nucleotides and other modifications described herein, wherein the overhangs anneal to form a double stranded RNA, and wherein the sense strand and the antisense strand anneal to form a double stranded siRNA.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Group I does not include the inventive concept of an oligonucleotide having the nucleotides set forth in SEQ ID NO:8 that is the sense strand, and overhang sequences comprising SEQ ID NOs: 9-10, as required by Group II.

Group II does not include the inventive concept of the human STAT3 sense strand comprises an oligonucleotide having nucleotides set forth in SEQ ID NO:4, as required by Group I.

The inventions of Groups I-II share the technical feature of a chimeric molecule comprising a human STAT3 sense strand and a human CpG(D19)STAT3 antisense strand, wherein the human CpG(D19)-STAT3 antisense strand comprises (a) a first oligonucleotide having the nucleotides set forth in SEQ ID NO:5, (b) a C3 carbon chain or propanediollinker and (c) a second oligonucleotide having the nucleotides set forth in SEQ ID NO:6 that is the antisense strand. However, this shared technical feature does not represent a contribution over prior art as being obvious over US 2008/0214436 A1 to YU et al. (hereinafter 'Yu'), in view of US 2003/0060440 A1 to KLINMAN et al. (hereinafter 'Klinman') as follows:

Yu discloses a chimeric molecule comprising a human STAT3 sense strand and a human CpG(D19)STAT3 antisense strand (para [0096] - 'siRNA against Stat3 (SEQ ID NO:3 for sense strand; SEQ ID NO:2 for antisense strand) is linked to toll-like receptor 9 ligand, CpG oligonucleotide (ODN)', wherein 'toll-like receptor 9 ligand' comprising 'CpG(D19)'; para [0122] - 'an analogue chimeric oligonucleotide by fusion of CpG(D19) sequence optimized for activation of human TLR9-positive cells with the STAT3-specific siRNA selected for the highest silencing effect in human cells'),

---wherein the human STAT3 sense strand comprises an oligonucleotide having nucleotides set forth in SEQ ID NO:4 (para [0020] - 'The sequences of the optimal Stat3 siRNAs are shown. Human sense strand is SEQ ID NO:4', wherein SEQ ID NO: 4 is 100% identical to the claimed SEQ ID NO: 4)

--- wherein the human CpG(D19)-STAT3 antisense strand comprises (a) a first oligonucleotide having the nucleotides of CpG(D19) (para [0096] - 'SEQ ID NO:2 for antisense strand...is linked to toll-like receptor 9 ligand, CpG oligonucleotide (ODN) (SEQ ID NO:1)', wherein SEQ ID NO: 1 is (a) the first oligonucleotide at the position of CpG(D19), which can be replaced by CpG(D19) sequence; para [0122] - 'chimeric oligonucleotide by fusion of CpG(D19) sequence'; para [0021] - 'CpG1668: SEQ ID NO:1'),

(b) a C3 carbon chain (para [0048] - 'linkers comprising multiple units of the C3 spacer'; para [0047] - linking a first moiety, e.g. a CpG ODN,... to a second moiety, e.g., a dsRNA, using multiple units of the C3 spacer as the linker (Dela et al., 1987)', wherein C3 spacer is C3 carbon chain; Specification: para [0045] - 'linking a first moiety, e.g. a CpG ODN... to a second moiety, e.g., a dsRNA, using multiple units of the C3 spacer as the linker (Dela et al., 1987)') and

(c) a second oligonucleotide having the nucleotides set forth in SEQ ID NO:6 that is the antisense strand (para [0020] - 'Human sense strand is SEQ ID NO:4; human antisense strand is SEQ ID NO:5'; Table I - 'Human STAT3 siRNA (SS) (SEQ ID NO:4) 5' GGAAGCUGCAGAAAGAUACGACUGA 3' CpG(D19)-human STAT3 siRNA (AS) (SEQ ID NO:1 -linker-SEQ ID NO:5)', wherein ' SEQ ID NO:1 -linker-SEQ ID NO:5' is ' the human CpG(1668)-STAT3 antisense strand' and wherein SEQ ID NO: 5 is 100% identical to the claimed SEQ ID NO: 6; para [0122], [0021]),

---and wherein the sense strand and the antisense strand anneal to form a double stranded siRNA (para [0020] - 'The sequences of the optimal Stat3 siRNAs are shown. Human sense strand is SEQ ID NO:4; human antisense strand is SEQ ID NO:5'). Yu does not specifically teach wherein CpG(D19) nucleotide having the nucleotides set forth in SEQ ID NO:5. Klinman discloses a CpG(D19) nucleotide sequence (para [0016] - 'CpG ODN. ... Sequences: D19'; para [0014] - 'D19 (GGTGCATCGATGCAGGGGG, SEQ ID NO: 1)', which is 100% identical to the claimed SEQ ID NO: 5.

It would have been obvious to one of ordinary skill in the art at the time the invention was made to combine the teachings of Yu and Klinman, to obtain a chimeric molecule comprising a human STAT3 sense strand and a human CpG(D19)STAT3 antisense strand, wherein the human STAT3 sense strand comprises an oligonucleotide having nucleotides set forth in SEQ ID NO:4, wherein the human CpG(D19)-STAT3 antisense strand comprises (a) a first oligonucleotide of CpG(D19), (b) a C3 carbon chain and (c) a second oligonucleotide having the nucleotides set forth in SEQ ID NO:6 that is the antisense strand, as taught by Yu, and further wherein CpG(D19) nucleotide having the nucleotides set forth in SEQ ID NO:5, based on the teaching of Klinman, in order to use the CpG(D19) disclosed in the art for facilitating the construction of the chimeric molecule based on the teaching of Yu with an expected success. Without a shared special technical feature, the inventions lack unity with one another.

Groups I-II therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.