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(54) Titre : EMULSIONS HUILE DANS EAU CATIONIQUES
(54) Title: CATIONIC OIL-IN-WATER EMULSIONS

(57) Abrégé/Abstract:
This invention generally relates to cationic oil-in-water emulsions that contain high concentrations of cationic lipids and have a defined oihlipid ratio. The cationic lipid can interact with the negatively charged molecule thereby anchoring the molecule to the emulsion particles. The cationic emulsions described herein are useful for delivering negatively charged molecules, such as nucleic acid molecules to cells, and for formulating nucleic acid- based vaccines.

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(54) **Title**: CATIONIC OIL-IN-WATER EMULSIONS

(57) **Abstract**: This invention generally relates to cationic oil-in-water emulsions that contain high concentrations of cationic lipids and have a defined oihlipid ratio. The cationic lipid can interact with the negatively charged molecule thereby anchoring the mo-lecule to the emulsion particles. The cationic emulsions described herein are useful for delivering negatively charged molecules, such as nucleic acid molecules to cells, and for formulating nucleic acid- based vaccines.

CATIONIC OIL-IN-WATER EMULSIONS

RELATED APPLICATIONS

[001]

SEQUENCE LISTING

[002]

BACKGROUND OF THE INVENTION

[003] Nucleic acid therapeutics have promise for treating diseases ranging from inherited disorders to acquired conditions such as cancer, infectious disorders (AIDS), heart disease, arthritis, and neurodegenerative disorders (e.g., Parkinson's and Alzheimer's). Not only can functional genes be delivered to repair a genetic deficiency or induce expression of exogenous gene products, but nucleic acid can also be delivered to inhibit endogenous gene expression to provide a therapeutic effect. Inhibition of gene expression can be mediated by, e.g., antisense oligonucleotides, double-stranded RNAs (e.g., siRNAs, miRNAs), or ribozymes.

[004] A key step for such therapy is to deliver nucleic acid molecules into cells *in vivo*. However, *in vivo* delivery of nucleic acid molecules, in particular RNA molecules, faces a number of technical hurdles. First, due to cellular and serum nucleases, the half life of RNA injected *in vivo* is only about 70 seconds (see, e.g., Kurreck, Eur. J. Bioch. 270:1628-44 (2003)). Efforts have been made to increase stability of injected RNA by the use of chemical modifications; however, there are several instances where chemical alterations led to increased cytotoxic effects or loss of or decreased function. In one specific example, cells were intolerant to doses of an RNAi duplex in which every second phosphate was replaced

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by phosphorothioate (Harborth, et al, Antisense Nucleic Acid Drug Rev. 13(2): 83-105 (2003)). As such, there is a need to develop delivery systems that can deliver sufficient amounts of nucleic acid molecules (in particular RNA molecules) *in vivo* to elicit a therapeutic response, but that are not toxic to the host.

[005] Nucleic acid based vaccines are an attractive approach to vaccination. For example, intramuscular (IM) immunization of plasmid DNA encoding for antigen can induce cellular and humoral immune responses and protect against challenge. DNA vaccines offer certain advantages over traditional vaccines using protein antigens, or attenuated pathogens. For example, as compared to protein vaccines, DNA vaccines can be more effective in producing a properly folded antigen in its native conformation, and in generating a cellular immune response. DNA vaccines also do not have some of the safety problems associated with killed or attenuated pathogens. For example, a killed viral preparation may contain residual live viruses, and an attenuated virus may mutate and revert to a pathogenic phenotype.

[006] One limitation of nucleic acid based vaccines is that large doses of nucleic acid are generally required to obtain potent immune responses in non-human primates and humans. Therefore, delivery systems and adjuvants are required to enhance the potency of nucleic acid based vaccines. Various methods have been developed for introducing nucleic acid molecules into cells, such as calcium phosphate transfection, polyprene transfection, protoplast fusion, electroporation, microinjection and lipofection.

[007] Cationic lipids have been formulated as liposomes to deliver genes into cells. In addition, cationic lipid emulsions have been developed to deliver DNA molecules into cells. *See. e.g.*, Kim, et al., International Journal of Pharmaceutics, 295, 35-45 (2005).

[008] Ott et al. (Journal of Controlled Release, volume 79, pages 1-5, 2002) describes an approach involving a cationic sub-micron emulsion as a delivery system/adjuvant for DNA. The sub-micron emulsion approach is based on MF59, a potent squalene in water adjuvant that is a component of commercially approved product Fluad®. 1,2-dioleoyl-3-trimethylammonium-propane (DOTAP) was used to facilitate intracellular delivery of plasmid DNA.

[009] Yi et al. (Pharmaceutical Research, 17, 314-320 (2000)) discloses cationic oil-in-water emulsions that used soybean oil and DOTAP as the cationic lipid. Cholesterol, DOPE, and polymeric lipids were also included in some of the emulsions. The emulsions were shown to enhance the efficiency of *in vitro* transfection of DNA in the presence of up to 90% serum. The average size of the emulsion particles ranged from 181 nm to 344 nm, and the particle size increased after the emulsions were diluted in PBS buffer.

[010] Kim et al. (Pharmaceutical Research, vol. 18, pages 54-60, 2001) and Chung et al. (Journal of Controlled Release, volume 71, pages 339-350, 2001) disclose various oil-in-water emulsions that were used to enhance *in vitro* and *in vivo* transfection efficiency of DNA molecules. Among the cationic lipids tested, DOTAP formed the most stable and efficient emulsion for DNA delivery. Among the oils tested, squalene, light mineral oil, and jojoba bean oil formed stable emulsions with small particles. The efficiencies of *in vitro* transfection were shown to correlate to the stability of the emulsions (*e.g.*, the emulsion formulated by squalene at 100 mg/mL and DOTAP at 24 mg/mL showed high *in vitro* transfection efficiency). The emulsions were prepared by first mixing the cationic lipid with water to form a liposome suspension (by sonication). Liposomes were then added to the oil (such as squalene) and the mixture was sonicated to form an oil-in-water emulsion.

[011] RNA molecules encoding an antigen or a derivative thereof may also be used as vaccines. RNA vaccines offer certain advantages as compared to DNA vaccines. However, compared with DNA-based vaccines, relatively minor attention has been given to RNA-based vaccines. RNAs are highly susceptible to degradation by nucleases when administered as a therapeutic or vaccine. Additionally, RNAs are not actively transported into cells. *See, e.g.*, Vajdy, M., et al., *Mucosal adjuvants and delivery systemsfor protein-, DNA- and RNA-based vaccines*, Immunol Cell Biol, 2004. 82(6): p. 617-27.

[012] Therefore, there is a need to provide delivery systems for nucleic acid molecules or other negatively charged molecules. The delivery systems are useful for nucleic acid-based vaccines, in particular RNA-based vaccines.

SUMMARY OF THE INVENTION

[013] The invention relates to cationic oil-in-water emulsions that contain high concentrations of cationic lipids and have a defined oil:lipid ratio. The oil and cationic lipid are separate components of the emulsions, and preferably the oil is not ionic. The cationic lipid can interact with the negatively charged molecule thereby anchoring the molecule to the emulsion particles. The cationic emulsions described herein are useful for delivering negatively charged molecules, such as nucleic acid molecules (*e.g.*, an RNA molecule encoding an antigen), to cells, and for formulating nucleic acid-based vaccines.

[014] In one aspect, the invention provides an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion is characterized by: (a) the average diameter of said particles is from about 80 nm to 180 nm in diameter; (b) the emulsion comprises an oil and a cationic lipid, wherein (i) the ratio of oil:cationic lipid (mole:mole) is at least about 8:1 (mole:mole), (ii) the concentration of cationic lipid in said emulsion is at least about 2.5 mM, and (iii) with the proviso that the cationic lipid is not DC-Cholesterol. Preferably, the oil-in-water emulsion is stable. In some embodiments, the ratio of oil:lipid (mole:mole) is from about 10:1 (mole:mole) to about 43:1 (mole:mole). The oil in water emulsion can contain from about 0.2% to about 8% (w/v) oil. In some embodiments, the oil is squalene or squalane.

[015] In another aspect, the invention provides an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion is characterized by: (a) the average diameter of said particles is from about 80 nm to 180 nm in diameter; (b) the emulsion comprises an oil and a cationic lipid, wherein (i) the ratio of oil:cationic lipid (mole:mole) is at least about 4:1 (mole:mole), (ii) the concentration of cationic lipid in said emulsion is at least about 2.5 mM, (iii) the oil is present from about 0.2% to about 8% (w/v); and (iv) with the proviso that the cationic lipid is not DC-Cholesterol. Preferably, the oil-in-water emulsion is stable. In some embodiments, the ratio of oil:lipid (mole:mole) is from about 4:1 (mole:mole) to about 43:1 (mole:mole). In some embodiments, the oil is squalene or squalane. In some embodiments, the oil is present from 0.6% to 4% (w/v). In some embodiments, the oil is present from about 1% to about 3.2% (w/v).

[016] The oil-in-water emulsion of this aspect can further comprise a surfactant, such as a nonionic surfactant. Preferably, the surfactant is not a Polyethylene Glycol (PEG)-lipid. The surfactant can be present in an amount from about 0.01% to about 2.5% (w/v). In some embodiments, the surfactant is SPAN85 (Sorbtian Trioleate), Tween 80 (polysorbate 80), or a combination thereof. In some embodiments, the oil-in-water emulsion contains equal amounts of SPAN85 (Sorbtian Trioleate) and Tween 80 (polysorbate 80), for example 0.5% (w/v) of each.

[017] Preferably the head group of the cationic lipid comprises a quaternary amine. For example, in some embodiments the cationic lipid is selected from the group consisting of: 1,2-dioleoyloxy-3-(trimethylammonio)propane (DOTAP), 1,2-dioleoyl-sn-glycero-3-ethylphosphocholine (DOEPC), N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC), and N-[1-(2, 3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA).

[018] In some embodiments, the emulsion is characterized by: (a) the average diameter of the emulsion particles is from about 80 nm to 180 nm in diameter; (b) the emulsion comprises an oil and DOTAP, wherein (i) the ratio of oil:DOTAP (mole:mole) is at least about 8:1 (mole:mole), and (ii) the concentration of DOTAP in said emulsion is at least about 2.58 mM (1.8 mg/mL), or from about 2.58 mM (1.8 mg/mL) to about 7.16 mM (5 mg/mL). The oil can be squalene or squalane.

[019] In some embodiments, the emulsion is characterized by: (a) the average diameter of the emulsion particles is from about 80 nm to 180 nm in diameter; (b) the emulsion comprises an oil and DOTAP, wherein (i) the ratio of oil:DOTAP (mole:mole) is at least about 4:1 (mole:mole), (ii) the concentration of DOTAP in said emulsion is at least about 2.58 mM (1.8 mg/mL), and (iii) the oil is present from about 0.2% to about 8% (w/v). In some embodiments, the oil is squalene or squalane. In some embodiments, the concentration of DOTAP from about 2.58 mM (1.8 mg/mL) to about 7.16 mM (5 mg/mL). In some embodiments, the oil is present from 0.6% to 4% (w/v). In some embodiments, the oil is present from about 1% to about 3.2% (w/v).

[020] The invention also provides a method for preparing an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion is characterized by: (a) the average diameter of said particles is from about 80 nm to

180 nm in diameter; (b) the emulsion comprises an oil and a cationic lipid, wherein (i) the ratio of oil:cationic lipid (mole:mole) is at least about 8:1 (mole:mole), (ii) the concentration of cationic lipid in said emulsion is at least about 2.5 mM, and (iii) with the proviso that the cationic lipid is not DC-Cholesterol, the method comprises (a) directly dissolving the cationic lipid in the oil to form an oil phase; (b) providing an aqueous phase of the emulsion; and (c) dispersing the oil phase in the aqueous phase by homogenization. The oil can be heated to a temperature between about 30°C to about 65°C to facilitate dissolution of the cationic lipid in the oil. Higher temperatures may also be used, as long as there is no significant degradation of oil or the cationic lipid.

[021] The invention also provides a method for preparing an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion is characterized by: (a) the average diameter of said particles is from about 80 nm to 180 nm in diameter; (b) the emulsion comprises an oil and a cationic lipid, wherein (i) the ratio of oil:cationic lipid (mole:mole) is at least about 4:1 (mole:mole), (ii) the concentration of cationic lipid in said emulsion is at least about 2.5 mM, (iii) the oil is present from about 0.2% to about 8% (w/v); and (iv) with the proviso that the cationic lipid is not DC-Cholesterol, the method comprises (a) directly dissolving the cationic lipid in the oil to form an oil phase; (b) providing an aqueous phase of the emulsion; and (c) dispersing the oil phase in the aqueous phase by homogenization. The oil can be heated to a temperature between about 30°C to about 65°C to facilitate dissolution of the cationic lipid in the oil. Higher temperatures may also be used, as long as there is no significant degradation of oil or the cationic lipid.

[022] In another aspect, the invention provides a composition comprising a nucleic acid molecule (preferably an RNA molecule) complexed with a particle of a cationic oil-in-water emulsion, wherein the particle comprises an oil that is in liquid phase at 25°C, and a cationic lipid; and (i) the ratio of oil:lipid (mole:mole) is at least about 8:1 (mole:mole); (ii) the concentration of cationic lipid in said composition is at least about 1.25 mM; and (iii) with the proviso that the cationic lipid is not DC-Cholesterol. Preferably, the average diameter of the emulsion particles is from about 80 nm to 180 nm, or about 80 nm to 150 nm, or about 80 nm to about 130 nm, and the N/P ratio of the composition is at least about 4:1, or from about 4:1 to about 20:1, or from about 4:1 to about 15:1. In certain embodiments, the ratio of oil:lipid (mole:mole) is from about 10:1 (mole:mole) to about 43:1

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(mole:mole). The oil in water emulsion can contain from about 0.1% to about 5% (w/v) oil. In some embodiments, the oil is squalene or squalane.

[023] In another aspect, the invention provides a composition comprising a nucleic acid molecule (preferably an RNA molecule) complexed with a particle of a cationic oil-in-water emulsion, wherein the particle comprises an oil that is in liquid phase at 25°C, and a cationic lipid; and (i) the ratio of oil:lipid (mole:mole) is at least about 4:1 (mole:mole); (ii) the concentration of cationic lipid in said composition is at least about 1.25 mM; (iii) the oil is present from about 0.1% to about 4% (w/v); and (iv) with the proviso that the cationic lipid is not DC-Cholesterol. Preferably, the average diameter of the emulsion particles is from about 80 nm to 180 nm, or about 80 nm to 150 nm, or about 80 nm to about 130 nm, and the N/P ratio of the composition is at least about 4:1, or from about 4:1 to about 20:1, or from about 4:1 to about 15:1. In certain embodiments, the ratio of oil:lipid (mole:mole) is from about 4:1 (mole:mole) to about 43:1 (mole:mole). In some embodiments, the oil is squalene or squalane. In some embodiments, the oil is present from 0.6% to 4% (w/v). In some embodiments, the oil is present from about 1% to about 3.2% (w/v).

[024] The oil-in-water emulsion of this aspect can further comprise a surfactant, such as a nonionic surfactant. Preferably, surfactant is not a Polyethylene Glycol (PEG)-lipid. The surfactant can be present in an amount from about 0.005% to about 1.25% (w/v). In some embodiments, the surfactant is SPAN85 (Sorbtian Trioleate), Tween 80 (polysorbate 80), or a combination thereof. In some embodiments, the oil-in-water emulsion contains equal amounts of SPAN85 (Sorbtian Trioleate) and Tween 80 (polysorbate 80), for example 0.25% or 0.5% (w/v) of each.

[025] Preferably the head group of the cationic lipid comprises a quaternary amine. For example, in some embodiments the cationic lipid is selected from the group consisting of: 1,2-dioleoyloxy-3-(trimethylammonio)propane (DOTAP), 1,2-dioleoyl-sn-glycero-3-ethylphosphocholine (DOEPC), N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC), and N-[1-(2, 3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA).

[026] In some embodiments, the invention provides a composition comprising a nucleic acid molecule (preferably an RNA molecule) complexed with a particle of a cationic oil-in-water emulsion, wherein the particle comprises an oil that is in liquid phase at 25°C and DOTAP; and (i) the ratio of oil:DOTAP (mole:mole) is at least about 8:1 (mole:mole); (ii) the concentration of DOTAP in said composition is at least about 1.29 mM, or from about 1.29 mM (0.9 mg/mL) to about 3.58 mM (2.5 mg/mL). The oil can be squalene or squalane. Optionally, the N/P ratio is at least 4:1.

[027] In preferred embodiments, the composition is buffered (e.g., with a citrate buffer, succinate buffer, acetate buffer) and has a pH of about 6.0 to about 8.0, preferably about 6.2 to about 6.8. The composition can further comprise an inorganic salt, and the concentration of inorganic salt is preferably no greater than 30 mM. Optionally, the composition can further comprise a nonionic tonicifying agent, and preferably is isotonic.

[028] The invention also provides a method for preparing a composition comprising a nucleic acid molecule (preferably an RNA molecule) complexed with a particle of a cationic oil-in-water emulsion, comprising:(i) providing an oil-in-water emulsion as described herein; (ii) providing an aqueous solution comprising the RNA molecule; and (iii) combining the oil-in-water emulsion of (i) and the aqueous solution of (ii), thereby preparing the composition. In some embodiments, the cationic oil-in-water emulsion and RNA solution are combined at about 1:1 (v/v) ratio. The aqueous solution comprising the RNA molecule is preferably buffered (e.g., with a citrate buffer, succinate buffer, acetate buffer), can contain a inorganic salt (e.g. NaCl), which is preferably present at about 20 mM or less. In one embodiment, the aqueous solution comprising the RNA molecule contains 2mM citrate buffer and 20 mM NaCl. Optionally, the aqueous solution comprising the RNA molecule further comprises an nonionic tonicifying agent, and is isotonic. In one embodiment, the aqueous solution further comprises about 560 mM sucrose. Optionally, the aqueous solution comprising the RNA molecule further comprises a polymer or nonionic surfactant, such as Pluronic® F127, at from about 0.05% to about 20% (w/v).

[029] In another aspect, the invention provides an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion comprises an oil and a cationic lipid, the average diameter of said particles is from about 80 nm to 180 nm, the oil is present from 0.6% to 4% (w/v); and the concentration of cationic lipid in said emulsion is at least about 1.25 mM. Preferably, the oil-in-water emulsion is

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stable. In some embodiments, the concentration of cationic lipid in said emulsion is at least about 2.5 mM. In some embodiments, the oil is squalene or squalane.

[030] The oil-in-water emulsion of this aspect can further comprise a surfactant, such as a nonionic surfactant. Preferably, surfactant is not a Polyethylene Glycol (PEG)-lipid. The surfactant can be present in an amount from about 0.01% to about 2.5% (w/v). In some embodiments, the surfactant is SPAN85 (Sorbtian Trioleate), Tween 80 (polysorbate 80), or a combination thereof. In some embodiments, the oil-in-water emulsion contains equal amounts of SPAN85 (Sorbtian Trioleate) and Tween 80 (polysorbate 80), for example 0.25% or 0.5% (w/v) of each.

[031] Preferably the head group of the cationic lipid comprises a quaternary amine. For example, in some embodiments the cationic lipid is selected from the group consisting of: 1,2-dioleoyloxy-3-(trimethylammonio)propane (DOTAP), 1,2-dioleoyl-sn-glycero-3-ethylphosphocholine (DOEPC), N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC), and N-[1-(2, 3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA).

[032] The invention provides a composition comprising a nucleic acid molecule (preferably an RNA molecule) complexed with a particle of an oil-in-water emulsion that contains particles that are dispersed in an aqueous continuous phase, wherein the emulsion comprises an oil and a cationic lipid, the average diameter of said particles is from about 80 nm to 180 nm, the oil is present from 0.6% to 4% (w/v); and the concentration of cationic lipid in said emulsion is at least about 1.25 mM. Preferably, the oil-in-water emulsion is stable. In some embodiments, the concentration of cationic lipid in said emulsion is at least about 2.5 mM. In some embodiments, the oil s squalene or squalane. Preferably, the N/P ratio of the composition is at least about 4:1.

[033] In preferred embodiments, the composition is buffered (e.g., with a citrate buffer, succinate buffer, acetate buffer) and has a pH of about 6.0 to about 8.0, preferably about 6.2 to about 6.8. The composition can further comprise an inorganic salt, and the concentration of inorganic salt is preferably no greater than 30 mM. Optionally, the composition can further comprise a nonionic tonicifying agent, and preferably is isotonic.

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[034] The invention also relates to a method of generating an immune response in a subject, comprising administering to a subject in need thereof the composition as described herein. Preferably the amount of the cationic lipid administered to the subject (as a component of the composition) in a single administration is no more than about 30 mg. In particular embodiments, the cationic lipid is DOTAP and the total amount of DOTAP administered to the subject in a single administration is no more than about 24 mg, or no more than about 4 mg.

BRIEF DESCRIPTON OF THE DRAWINGS

[035] FIG. 1 is a schematic of pentacistronic RNA replicons, A526, A527, A554, A555 and A556, that encode five CMV proteins. Subgenomic promoters are shown by arrows, other control elements are labeled.

[036] FIG. 2 is a fluorescence histogram showing that BHKV cells transfected with the A527 RNA replicon express the gH/gL/UL128/UL130/UL131 pentameric complex. Cell stain was performed using an antibody that binds a conformational epitope present on the pentameric complex.

[037] FIG. 3 is a schematic and graph. The schematic shows bicistronic RNA replicons, A160 and A531-A537, that encode CMV gH and gL. The graph shows neutralizing activity of immune sera from mice immunized with VRPs that contained the replicons.

[038] FIG. 4 is a graph showing anti-VZV protein antibody response in immune sera from mice immunized with monocistronic RNA replicons that encoded VZV proteins or bicistronic RNA replicons that encoded VZV gE and gI, or gH and gL. The mice were immunized with 7 μg RNA formulated with CMF32.

DETAILED DESCRIPTION OF THE INVENTION

1. OVERVIEW

[039] This invention generally relates to cationic oil-in-water emulsions that contain high concentrations of cationic lipids and have a defined oil:cationic lipid ratio. The oil and cationic lipid are separate components of the emulsions, and preferably the oil is not

ionic. The cationic lipid can interact with a negatively charged molecule, such as a nucleic acid, thereby anchoring the negatively charged molecule to the emulsion particles. The cationic emulsions described herein are useful for delivering negatively charged molecules, such as nucleic acid molecules (*e.g.*, an RNA molecule encoding a protein or peptide, small interfering RNA, self-replicating RNA, and the like), to cells *in vivo*, and for formulating nucleic acid-based vaccines.

[040] In particular, the present invention is based on the discovery that stable cationic oil-in-water emulsions that contain high concentrations of cationic lipids and have a defined oil:cationic lipid ratio can be successfully made. Emulsions that contain high concentrations of cationic lipids allow more negatively charged molecules (such as RNA molecules) to be formulated with emulsion particles, thereby increasing the efficiency of delivery. In particular, for many therapeutics such as vaccines small volumes (e.g., 0.5 mL per dose) are preferred for administration. Emulsions that contain high concentrations of cationic lipids and have a defined oil:cationic lipid ratio, as described herein, will allow for the delivery of a higher dose of RNA within a specified volume.

[041] In preferred embodiments, an RNA molecule is complexed with a particle of the oil-in-water emulsion. The complexed RNA molecule is stabilized and protected from RNase-mediated degradation, and is more efficiently taken up by cells relative to free ("naked") RNA.

[042] In addition, when the RNA is delivered to induce expression of an encoded protein, such as in the context of an RNA vaccine, emulsions that contain high concentrations of cationic lipids can increase the amount of RNA molecules that are complexed with emulsion particles. As more RNA molecules are delivered to host cells, higher amount of the encoded protein antigen is produced, which in turn enhances the potency and immunogenicity of the RNA vaccine. Finally, the immunogenicity of the encoded protein can be enhanced due to adjuvant effects of the emulsion. Therefore, in addition to more efficient delivery of a negatively charged molecule (e.g., an RNA molecule that encodes an antigen), the cationic emulsions can also enhance the immune response through adjuvant activity. For example, as described and exemplified herein, formulations in which RNA molecules (encoding respiratory syncytial virus (RSV) F protein) were complexed with high-

DOTAP emulsions generated higher immune responses in a mouse model and a cotton rat model of RSV, as compared to RNA molecules complexed with low-DOTAP emulsions.

[043] Accordingly, in one aspect, the invention provides an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion is characterized by: (a) the average diameter of said particles is from about 80 nm to 180 nm; (b) the emulsion comprises an oil and a cationic lipid, wherein (i) the ratio of oil:cationic lipid (mole:mole) is at least about 8:1 (mole:mole), (ii) the concentration of cationic lipid in said emulsion is at least about 2.5 mM, and (iii) the cationic lipid is not DC-Cholesterol.

[044] In another aspect, the invention provides an oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the emulsion is characterized by: (a) the average diameter of said particles is from about 80 nm to 180 nm; (b) the emulsion comprises an oil and a cationic lipid, wherein (i) the ratio of oil:cationic lipid (mole:mole) is at least about 4:1 (mole:mole), (ii) the concentration of cationic lipid in said emulsion is at least about 2.5 mM, (iii) the oil is present from about 0.2% to about 8% (w/v); and (iv) with the proviso that the cationic lipid is not DC-Cholesterol.

[045] The cationic emulsion may further comprise a surfactant (*e.g.*, Tween 80, SPAN85, or a combination thereof).

[046] In another aspect, the invention also provides several specific formulations of cationic oil-in-water emulsions that contain high concentrations of cationic lipids and can be used to deliver negatively charged molecules.

[047] In another aspect, the invention provides a method of preparing an oil-in-water emulsion, comprising: (1) directly dissolving a cationic lipid in an oil to form an oil phase; (2) providing an aqueous phase of the emulsion; and (3) dispersing the oil phase in the aqueous phase (*e.g.*, by homogenization). If desired, the oil may be heated to a temperature between about 30°C to about 65°C to facilitate the dissolving of the lipid in the oil. Preferably, the ratio of oil:cationic lipid (mole:mole) in the oil phase is at least about 8:1 (mole:mole), and alternatively or in addition, the average diameter of said particles is from about 80 nm to 180 nm, and/or the concentration of cationic lipid in the oil phase is at least about 5 mM.

[048] In another aspect, the invention provides a method of preparing a composition that comprises a negatively charged molecule (such as an RNA molecule) complexed with a particle of a cationic oil-in-water emulsion, comprising: (i) providing an oil-in-water emulsion as described herein; (ii) providing an aqueous solution comprising the RNA molecule; and (iii) combining the aqueous solution of (ii) and the oil-in-water emulsion of (i), thereby preparing the composition. If desired, the aqueous solution comprising the RNA molecule may comprise a salt (*e.g.*, NaCl), a buffer (*e.g.*, a citrate buffer), a nonionic tonicifying agent (*e.g.*, sucrose, trehalose, sorbitol, or dextrose), a polymer (*e.g.*, Pluronic® F127), or any combination thereof.

[049] The cationic emulsions of the invention can be used to deliver a negatively charge molecule, such as a nucleic acid (e.g., RNA). The compositions may be administered to a subject in need thereof to generate or potentiate an immune response. The compositions can also be co-delivered with another immunogenic molecule, immunogenic composition or vaccine to enhance the effectiveness of the induced immune response.

2. DEFINITIONS

[050] The term "about", as used here, refers to +/- 5% of a value.

[051] An "antigen" refers to a molecule containing one or more epitopes (either linear, conformational or both).

[052] A "buffer" refers to an aqueous solution that resists changes in the pH of the solution.

[053] As used herein, "nucleotide analog" or "modified nucleotide" refers to a nucleotide that contains one or more chemical modifications (*e.g.*, substitutions) in or on the nitrogenous base of the nucleoside (*e.g.*, cytosine (C), thymine (T) or uracil (U)), adenine (A) or guanine (G)).

[054] As used herein, an emulsion "particle" refers to a oil droplet suspended in the aqueous (continuous) phase of an oil-in-water emulsion. The particle further comprises a cationic liquid, and optionally additional components, such as a surfactant.

[055] The term "polymer" refers to a molecule consisting of individual chemical moieties, which may be the same or different, that are joined together. As used herein, the term "polymer" refers to individual chemical moieties that are joined end-to-end to form a linear molecule, as well as individual chemical moieties joined together in the form of a branched (e.g., a "multi-arm" or "star-shaped") structure. Exemplary polymers include, e.g., poloxamers. Poloxamers are nonionic triblock copolymers having a central hydrophobic chain of polyoxypropylene (poly(propylene oxide)) flanked by two hydrophilic chains of polyoxyethylene (poly(ethylene oxide)).

[056] As use herein, "saccharide" encompasses monosaccharides, oligosaccharides, or polysaccharides in straight chain or ring forms, or a combination thereof to form a saccharide chain. Oligosaccharides are saccharides having two or more monosaccharide residues. Examples of saccharides include glucose, maltose, maltotriose, maltotetraose, sucrose and trehalose.

[057] An emulsion is "stable" when the emulsion particles remain separated without significant agglomeration or coalescence for at least one month, preferably at least two months, at 4°C. The average particle diameter (average number diameter) of a stable emulsion does not change by more than 10% when the emulsion is stored at 4°C for one month, or preferably two months.

[058] The term "surfactant" is a term of art and generally refers to any molecule having both a hydrophilic group (e.g., a polar group), which energetically prefers solvation by water, and a hydrophobic group which is not well solvated by water. The term "nonionic surfactant" is a known term in the art and generally refers to a surfactant molecule whose hydrophilic group (e.g., polar group) is not electrostatically charged.

[059] The "Zeta potential" of an emulsion is determined by the electrophoretic mobility of the emulsion particles. The velocity of a particle in a unit electric field is referred to as its electrophoretic mobility. Zeta potential is related to the electrophoretic mobility by the Henry equation:

$$U_E = \frac{2\varepsilon z f(ka)}{3\eta}$$

where U_E=electrophoretic mobility, z=zeta potential, ε=dielectric constant, η=viscosity and $f(ka)$=Henry's function. Zeta potential is typically measured using an electrophoretic mobility apparatus, such as a Zetasizer Nano Z (Malvern Instruments Ltd, United Kingdom).

3. CATIONIC OIL-IN-WATER EMULSIONS

[060] The cationic oil-in-water emulsions disclosed herein are generally described in the manner that is conventional in the art, by concentrations of components that are used to prepare the emulsions. It is understood in the art that during the process of producing emulsions, including sterilization and other downstream processes, small amounts of oil (*e.g.*, squalene), cationic lipid (*e.g.*, DOTAP), or other components may be lost, and the actual concentrations of these components in the final product (*e.g.*, a packaged, sterilized emulsion that is ready for administration) might be slightly lower than starting amounts, sometimes by up to about 10%, by up to about 20%, by up to about 25%, or by up to about 35%.

[061] This invention generally relates to cationic oil-in-water emulsions that contain high concentrations of cationic lipids and a defined oil:cationic lipid ratio. The emulsions are particularly suitable for delivering negatively charged molecules, such as an RNA molecule, to a cell. The cationic lipid can interact with the negatively charged molecule, for example through electrostatic forces and hydrophobic/hydrophilic interactions, thereby anchoring the molecule to the emulsion particles. The cationic emulsions described herein are useful for delivering a negatively charged molecule, such as an RNA molecule encoding an antigen or small interfering RNA to cells *in vivo*. For example, the cationic emulsions described herein provide advantages for delivering RNA molecules that encode one or more antigens, including self-replicating RNAs, as vaccines.

[062] The discrete phase (or dispersed phase) of the emulsion comprises an oil and a cationic lipid, wherein the cationic lipid facilitates dispersing the oil in the aqueous (continuous) phase. One or more optional components may be present in the emulsion, such as surfactants (e.g., nonionic surfactants) as described below.

[063] The particles of the oil-in-water emulsions have an average diameter (i.e., average number diameter) of 1 micrometer or less. It is particularly desirable that the average particle diameter of the cationic emulsions is about 180 nm or less, about 170 nm or less, about 160 nm or less, about 150 nm or less, about 140 nm or less, about 130 nm or less, about 120 nm or less, about 110 nm or less, or about 100 nm or less; for example, from about 80 nm to 180 nm, from about 80 nm to 170 nm, from about 80 nm to 160 nm, from about 80 nm to 150 nm, from about 80 nm to 140 nm, from about 80 nm to 130 nm, from about 80 nm to 120 nm; from about 80 nm to 110 nm, or from about 80 nm to 100 nm. Particularly preferred average particle diameter is about 100 nm, or from about 100 nm to about 130 nm.

[064] The size (average diameter) of the emulsion particles can be varied by changing the ratio of surfactant to oil (increasing the ratio decreases particle size), operating pressure of homogenization (increasing operating pressure of homogenization typically reduces particle size), temperature (increasing temperature decreases particle size), changing the type of oil, inclusion of certain types of buffers in the aqueous phase, and other process parameters, as described in detail below. In some cases, the size of the emulsion particles may affect the immunogenicity of the RNA-emulsion complex, as exemplified herein.

[065] The oil-in-water emulsions described herein are stable.

[066] The particles of the emulsions described herein can be complexed with a negatively charged molecule. Prior to complexation with the negatively charged molecule, the overall net charge of the particles (typically measured as zeta-potential) should be positive (cationic). The overall net charge of the particles may vary, depending on the type of the cationic lipid and the amount of the cationic lipid in the emulsion, the amount of oil in the emulsion (*e.g.*, higher percentage of oil typically results in less charge on the surface of the particles), and may also be affected by any additional component (*e.g.*, surfactant(s)) that is present in the emulsion. Preferably, the zeta-potential of the pre-complexation particles are no more than about 50 mV, no more than about 45 mV, no more than about 40 mV, no more than about 35 mV, no more than about 30 mV, no more than about 25 mV, no more than about 20 mV; from about 5 mV to about 50 mV, from about 10 mV to about 50 mV, from about 10 mV to about 45 mV, from about 10 mV to about 40 mV; from about 10 mV to about 35 mV, from about 10 mV to about 30 mV, from about 10 mV to about 25 mV, or from about 10 mV to about 20 mV. Zeta potential can be affected by (i) pH of the emulsion, (ii) conductivity of the emulsion (*e.g.*, salinity), and (iii) the concentration of the various components of the emulsion (polymer, non-ionic surfactants *etc.*). The Zeta potential of the cationic oil-in-water emulsions is measured using a Malvern Nanoseries Zetasizer

(Westborough, MA). The sample is diluted 1:100 in water (viscosity: 0.8872cp, RI: 1.330, Dielectric constant: 78.5) and is added to a polystyrene latex capillary cell (Malvern, Westborough, MA). Zeta potential is measured at 25°C with a 2 minute equilibration time and analyzed using the Smoluchowski model (F(Ka) value = 1.5). Data is reported in mV.

[067] An exemplary cationic emulsion of the invention is referred herein as "CMF32." The oil of CMF32 is squalene (at 4.3% w/v) and the cationic lipid is DOTAP (at 3.2 mg/mL). CMF32 also includes the surfactants SPAN85 (sorbitan trioleate at 0.5% v/v) and Tween 80 (polysorbate 80; polyoxyethuylenesorbitan monooleate; at 0.5% v/v). Thus, emulsion particles of CMF32 comprise squalene, SPAN85, Tween80, and DOTAP. RNA molecules were shown to complex with CMF32 particles efficiently at 4:1, 6:1, 8:1, 10:1, 12:1, and 14:1 N/P ratios. Other exemplary cationic emulsions include, *e.g.*, the emulsions referred to herein as "CMF34" (4.3% w/v squalene, 0.5% Tween 80, 0.5% SPAN85, and 4.4 mg/mL DOTAP), "CMF35" (4.3% w/v squalene, 0.5% Tween 80, 0.5% SPAN85, 5.0 mg/mL DOTAP), and other emulsions described herein.

[068] Certain exemplary cationic oil-in-water emulsions of the invention comprise DOTAP and squalene at concentrations of 2.1 mg/ml to 2.84 mg/ml (preferably 2.23 mg/ml to 2.71 mg/ml), and 30.92 mg/ml to 41.92 mg/ml (preferably 32.82 mg/ml to about 40.02 mg/ml), respectively, and further comprise equal amounts of SPAN85 and Tween80 (e.g., about 0.5% each). Other exemplary cationic oil-in-water emulsions of the invention comprise DOTAP and squalene at concentrations of 2.78 mg/ml to 3.76 mg/ml (preferably 2.94 mg/ml to 3.6 mg/ml), and 18.6 mg/ml to 25.16 mg/ml (preferably 19.69 mg/ml to about 24.07 mg/ml), respectively, and further comprise equal amounts of SPAN85 and Tween80 (e.g., about 0.5% each). Preferably, the particles of these emulsions have an average diameter from 80 nm to 180 nm.

[069] The individual components of the oil-in-water emulsions of the present invention are known in the art, although such compositions have not been combined in the manner described herein. Accordingly, the individual components, although described below both generally and in some-detail for preferred embodiments, are well known in the art, and the terms used herein, such as oil, surfactant, etc., are sufficiently well known to one skilled in the art without further description. In addition, while preferred ranges of the amount of the individual components of the emulsions are provided, the actual ratios of the components of a particular emulsion may need to be adjusted so that emulsion particles of desired size and physical property are properly formed. For example, if a particular amount of oil is used (e.g. 5% v/v oil), then, the amount of surfactant should be at level that is sufficient to disperse the oil particle into the aqueous phase to form a stable emulsion. The actual amount of surfactant required to disperse the oil into the aqueous phase depends on the type of surfactant and the type of oil used for the emulsion; and the amount of oil may also vary according to the desired particle size (as this changes the surface area between the two phases). The actual amounts and the relative proportions of the components of a desired emulsion can be readily determined by a skilled artisan.

A. Oil

[070] The particles of the cationic oil-in-water emulsions comprise an oil.

[071] The oil preferably is in the liquid phase at 1°C or above, and is immiscible to water.

[072] Preferably, the oil is a metabolizable, non-toxic oil; more preferably one of about 6 to about 30 carbon atoms including, but not limited to, alkanes, alkenes, alkynes, and their corresponding acids and alcohols, the ethers and esters thereof, and mixtures thereof. The oil may be any vegetable oil, fish oil, animal oil or synthetically prepared oil that can be metabolized by the body of the subject to which the emulsion will be administered, and is not toxic to the subject. The subject may be an animal, typically a mammal, and preferably a human.

[073] In certain embodiments, the oil is in liquid phase at 25°C. The oil is in liquid phase at 25°C, when it displays the properties of a fluid (as distinguished from solid and gas; and having a definite volume but no definite shape) when stored at 25°C. The emulsion, however, may be stored and used at any suitable temperature. Preferably, the oil is in liquid phase at 4°C.

[074] The oil may be any long chain alkane, alkene or alkyne, or an acid or alcohol derivative thereof either as the free acid, its salt or an ester such as a mono-, or di- or triester, such as the triglycerides and esters of 1,2-propanediol or similar poly-hydroxy alcohols. Alcohols may be acylated employing a mono- or poly-functional acid, for example acetic acid, propanoic acid, citric acid or the like. Ethers derived from long chain alcohols which are oils and meet the other criteria set forth herein may also be used.

[075] The individual alkane, alkene or alkyne moiety and its acid or alcohol derivatives will generally have from about 6 to about 30 carbon atoms. The moiety may have a straight or branched chain structure. It may be fully saturated or have one or more double or triple bonds. Where mono or poly ester- or ether-based oils are employed, the limitation of about 6 to about 30 carbons applies to the individual fatty acid or fatty alcohol moieties, not the total carbon count.

[076] Any suitable oils from an animal, fish or vegetable source may be used. Sources for vegetable oils include nuts, seeds and grains, and suitable oils peanut oil, soybean oil, coconut oil, and olive oil and the like. Other suitable seed oils include safflower oil, cottonseed oil, sunflower seed oil, sesame seed oil and the like. In the grain group, corn oil, and the oil of other cereal grains such as wheat, oats, rye, rice, teff, triticale and the like may also be used. The technology for obtaining vegetable oils is well developed and well known. The compositions of these and other similar oils may be found in, for example, the Merck Index, and source materials on foods, nutrition and food technology.

[077] About six to about ten carbon fatty acid esters of glycerol and 1,2-propanediol, while not occurring naturally in seed oils, may be prepared by hydrolysis, separation and esterification of the appropriate materials starting from the nut and seed oils. These products are commercially available under the name NEOBEES from PVO International, Inc., Chemical Specialties Division, 416 Division Street, Boongon, N.J. and others.

[078] Animal oils and fats are often in solid phase at physiological temperatures due to the fact that they exist as triglycerides and have a higher degree of saturation than oils from fish or vegetables. However, fatty acids are obtainable from animal fats by partial or complete triglyceride saponification which provides the free fatty acids. Fats and oils from mammalian milk are metabolizable and may therefore be used in the practice of this invention. The procedures for separation, purification, saponification and other means necessary for obtaining pure oils from animal sources are well known in the art.

[079] Most fish contain metabolizable oils which may be readily recovered. For example, cod liver oil, shark liver oils, and whale oil such as spermaceti exemplify several of the fish oils which may be used herein. A number of branched chain oils are synthesized biochemically in 5-carbon isoprene units and are generally referred to as terpenoids. Squalene (2,6,10,15,19,23-hexamethyl-2,6,10,14,18,22-tetracosahexaene), a branched, unsaturated terpenoid, is particularly preferred herein. A major source of squalene is shark liver oil, although plant oils (primarily vegetable oils), including amaranth seed, rice bran, wheat germ, and olive oils, are also suitable sources. Squalene can also be obtained from yeast or other suitable microbes. In some embodiments, Squalene is preferably obtained from non-animal sources, such as from olives, olive oil or yeast. Squalane, the saturated analog to squalene, is also preferred. Fish oils, including squalene and squalane, are readily available from commercial sources or may be obtained by methods known in the art.

[080] In certain embodiments, the oil comprises an oil that is selected from the group consisting of: Castor oil, Coconut oil, Corn oil, Cottonseed oil, Evening primrose oil, Fish oil, Jojoba oil, Lard oil, Linseed oil, Olive oil, Peanut oil, Safflower oil, Sesame oil, Soybean oil, Squalene, Squalane, Sunflower oil and Wheatgerm oil. In exemplary embodiments, the oil comprises Squalene or Squalane.

[081] The oil component of the emulsion may be present in an amount from about 0.2% to about 10% (v/v). For example, the cationic oil-in-water emulsion may comprise from about 0.2% to about 10% (v/v) oil, from about 0.2% to about 9% (v/v) oil, from about 0.2% to about 8% (v/v) oil, from about 0.2% to about 7% (v/v) oil, from about 0.2% to about 6% (v/v) oil, from about 0.2% to about 5% (v/v) oil, from about 0.3% to about 10% (v/v) oil, from about 0.4% to about 10% (v/v) oil, from about 0.5% to about 10% (v/v) oil, from about 1% to about 10% (v/v) oil, from about 2% to about 10% (v/v) oil, from about 3% to about 10% (v/v) oil, from about 4% to about 10% (v/v) oil, from about 5% to about 10% (v/v) oil, from about 0.2% to about 10% (w/v) oil, from about 0.2% to about 9% (w/v) oil, from about 0.2% to about 8% (w/v) oil, from about 0.2% to about 7% (w/v) oil, from about 0.2% to about 6% (w/v) oil, from about 0.2% to about 5% (w/v) oil, from about 0.2% to about 4.3% (w/v) oil, from about 0.6% to about 4% (w/v) oil, from about 0.7% to about 4% (w/v) oil, from about 0.8% to about 4% (w/v) oil, from about 0.9% to about 4% (w/v) oil, from about 1.0 % to about 4% (w/v) oil, from about 0.6% to about 3.5% (w/v) oil, from about 0.6% to about 3% (w/v) oil, about 0.5% (v/v) oil, about 0.6% (v/v) oil, about 0.7% (v/v) oil, about 0.8% (v/v) oil, about 0.9% (v/v) oil, about 1% (v/v) oil, about 1.5% (v/v) oil, about 2% (v/v) oil, about 2.5% (v/v) oil, about 3% (v/v) oil, about 3.5% (v/v) oil, about 4% (v/v) oil, about 5% (v/v) oil, about 10% (v/v) oil, about 0.5% (w/v) oil, about 1% (w/v) oil, about 1.5% (w/v) oil, about 2% (w/v) oil, about 2.5% (w/v) oil, about 3% (w/v) oil, about 3.5% (w/v) oil, about 4% (w/v) oil, about 4.3% (w/v) oil, about 5% (w/v) oil, about 5.5% (w/v) oil, about 6% (w/v) oil, about 6.5% (w/v) oil, about 7% (w/v) oil, about 7.5% (w/v) oil, or about 8% (w/v) oil.

[082] The cationic oil-in-water emulsion may also comprise from about 0.2% to about 8% (v/v) oil, for example, from 0.6% (w/v) to 4% (w/v), from about 1% (w/v) to about 3.2% (w/v), about 1% (w/v), about 1.1% (w/v), about 1.2% (w/v), about 1.3% (w/v), about 1.4% (w/v), about 1.5% (w/v), about 1.6 % (w/v), about 1.7 % (w/v), about 1.8 % (w/v), about 1.9% (w/v), about 2.0% (w/v), about 2.1% (w/v), about 2.15% (w/v), about 2.2% (w/v), about 2.3% (w/v), about 2.4% (w/v), about 2.5% (w/v), about 2.6% (w/v), about 2.7% (w/v), about 2.8% (w/v), about 2.9% (w/v), 3.0% (w/v), about 3.1% (w/v), about 3.2% (w/v), about 3.3% (w/v), about 3.4% (w/v), about 3.5% (w/v), about 3.6% (w/v), about 3.7% (w/v), about 3.8% (w/v), about 3.9% (w/v), or about 4.0% (w/v) oil.

[083] In an exemplary embodiment, the cationic oil-in-water emulsion comprises about 5% (v/v) oil. In another exemplary embodiment, the cationic oil-in-water emulsion comprises about 4.3% (w/v) squalene. In other exemplary embodiments, the cationic oil-in-water emulsion comprises from 0.6% (w/v) to 4% (w/v) squalene, for example, from about 1% (w/v) to about 3.2% (w/v) squalene, such as 1.08% (w/v), 2.15% (w/v), or 3.23% (w/v) squalene, as shown in the Examples.

[084] As noted above, the percentage of oil described above is determined based on the initial amount of the oil that is used to prepare the emulsions. It is understood in the art that the actual concentration of the oil in the final product (*e.g.*, a packaged, sterilized emulsion that is ready for administration) might be slightly lower, sometimes by up to about 10%, by up to about 20%, by up to about 25%, or by up to about 35%.

B. Cationic Lipids

[085] The emulsion particles described herein comprise a cationic lipid, which can interact with the negatively charged molecule thereby anchoring the molecule to the emulsion particles.

[086] Any suitable cationic lipid may be used. Generally, the cationic lipid contains a nitrogen atom that is positively charged under physiological conditions. The head group of the cationic lipid can comprise a tertiary amine or, preferably, a quaternary amine. Certain suitable cationic lipids comprise two saturated or unsaturated fatty acid chains (e.g., side chains having from about 10 to about 30 carbon atoms).

[087] The cationic lipid can have a positive charge at about 12 pH, about 11 pH, about 10 pH, about 9 pH, about 8 pH, about 7 pH, or about 6 pH.

[088] Suitable cationic lipids include, benzalkonium chloride (BAK), benzethonium chloride, cetrimide (which contains tetradecyltrimethylammonium bromide and possibly small amounts of dodecyltrimethylammonium bromide and hexadecyltrimethyl ammonium bromide), cetylpyridinium chloride (CPC), cetyl trimethylammonium chloride (CTAC), primary amines, secondary amines, tertiary amines, including but not limited to N,N',N'-polyoxyethylene (10)-N-tallow-1,3 -diaminopropane, other quaternary amine salts, including but not limited to dodecyltrimethylammonium bromide, hexadecyltrimethyl-ammonium bromide, mixed alkyl-trimethyl-ammonium bromide, benzyldimethyldodecylammonium chloride, benzyldimethylhexadecyl-ammonium chloride, benzyltrimethylammonium methoxide, cetyldimethylethylammonium bromide, dimethyldioctadecyl ammonium bromide (DDAB), methylbenzethonium chloride, decamethonium chloride, methyl mixed trialkyl ammonium chloride, methyl trioctylammonium chloride), N,N-dimethyl-N-[2 (2-methyl-4-(1,1,3,3tetramethylbutyl)-phenoxy]-ethoxy)ethyl]-benzenemetha-naminium chloride (DEBDA), dialkyldimetylammonium salts, [1-(2,3-dioleyloxy)-propyl]-N,N,N,trimethylammonium chloride, 1,2-diacyl-3-(trimethylammonio) propane (acyl group=dimyristoyl, dipalmitoyl, distearoyl, dioleoyl), 1,2-diacyl-3 (dimethylammonio)propane (acyl group=dimyristoyl, dipalmitoyl, distearoyl, dioleoyl), 1,2-dioleoyl-3-(4'-trimethyl- ammonio)butanoyl-sn-glycerol, 1,2-dioleoyl 3-succinyl-sn-glycerol choline ester, cholesteryl (4'-trimethylammonio) butanoate), N-alkyl pyridinium salts (e.g. cetylpyridinium bromide and cetylpyridinium chloride), N-alkylpiperidinium salts, dicationic bolaform electrolytes ($C_{12}Me_6$; $C_{12}Bu_6$), dialkylglycetylphosphorylcholine, lysolecithin, L-α dioleoylphosphatidylethanolamine, cholesterol hemisuccinate choline ester, lipopolyamines, including but not limited to dioctadecylamidoglycylspermine (DOGS), dipalmitoyl phosphatidylethanol-amidospermine (DPPES), lipopoly-L (or D)-lysine (LPLL, LPDL), poly (L (or D)-lysine conjugated to N-glutarylphosphatidylethanolamine, didodecyl glutamate ester with pendant amino group ($C_{12}GluPhC_nN^+$), ditetradecyl glutamate ester with pendant amino group ($C_{14}GluC_nN^+$), cationic derivatives of cholesterol, including but not limited to cholesteryl-3 β-oxysuccinamidoethylenetrimethylammonium salt, cholesteryl-3 β-oxysuccinamidoethylenedimethylamine, cholesteryl-3 β-carboxyamidoethylenetrimethylammonium salt, cholesteryl-3 β-carboxyamidoethylenedimethylamine, and 3γ-[N-(N',N-dimethylaminoetanecarbomoyl]cholesterol) (DC-Cholesterol), 1,2-dioleoyloxy-3-(trimethylammonio)propane (DOTAP), dimethyldioctadecylammonium (DDA), 1,2-Dimyristoyl-3-TrimethylAmmoniumPropane (DMTAP), dipalmitoyl($C_{16:0}$)trimethyl ammonium propane (DPTAP), distearoyltrimethylammonium propane (DSTAP), N-[1-(2, 3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA), N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC), 1,2-dioleoyl-sn-glycero-3-ethylphosphocholine (DOEPC), 1,2-dioleoyl-3-dimethylammonium-propane (DODAP), 1,2-dilinoleyloxy-3-dimethylaminopropane (DLinDMA), and combination thereof.

[089] In preferred embodiments, the cationic lipid is selected from the group consisting of 1,2-dioleoyloxy-3-(trimethylammonio)propane (DOTAP), 1,2-dioleoyl-sn-glycero-3-ethylphosphocholine (DOEPC), N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC), and N-[1-(2, 3-dioleyloxy)propyl]-N,N,N-trimethylammonium chloride (DOTMA). In certain embodiments, the cationic lipid is not DC-Cholesterol.

[090] Preferably, the cationic lipid selected for the emulsion is soluble in the oil that is selected for the emulsion. This permits high cationic lipid concentrations to be achieved in the emulsion, by directly dissolving the lipid in the oil prior to dispersion in the mobile phase. It is within the knowledge in the art to determine whether a particular lipid is soluble in the oil and choose an appropriate oil and lipid combination accordingly. For example, solubility can be predicted based on the structures of the lipid and oil (*e.g.*, the solubility of a lipid may be determined by the structure of its tail). For example, lipids having one or two unsaturated fatty acid chains (*e.g.*, oleoyl tails, or linolyl tails), such as

DOTAP, DOEPC, DODAC, DOTMA, are soluble in squalene or squalane. Alternatively, solubility can be determined according to the quantity of the lipid that dissolves in a given quantity of the oil to form a saturated solution. Such methods are known in the art. The solubility of exemplary saturated or unsaturated fatty acids in squalene is also provided in the Examples. Preferably, the saturation concentration of the lipid in the oil is at least about 1 mg/ml, at least about 5 mg/ml, at least about 10 mg/ml, at least about 25 mg/ml, at least about 50 mg/ml or at least about 100mg/ml.

[091] Preferably, the concentration of cationic lipid in the emulsion before the negatively charged molecule is complexed is at least about 1.25 mM, at least about 1.5 mM, at least about 1.75 mM, at least about 2.0 mM, at least about 2.25 mM, at least about 2.5 mM, at least about 2.75 mM, at least about 3.0 mM, at least about 3.25 mM, at least about 3.5 mM, at least about 3.75 mM, at least about 4.0 mM, at least about 4.25 mM, at least about 4.5 mM, at least about 4.75 mM, at least about 5.0 mM, at least about 5.25 mM, at least about 5.5 mM, at least about 5.75 mM, at least about 6 mM, at least about 6.25 mM, at least about 6.5 mM, at least about 6.75 mM, at least about 7 mM, at least about 7.25 mM, at least about 7.5 mM, at least about 7.75 mM, at least about 8 mM, at least about 8.25 mM, at least about 8.5 mM, at least about 8.75 mM, at least about 9 mM, at least about 9.25 mM, at least about 9.5 mM, at least about 9.75 mM, or at least about 10 mM.

[092] In certain embodiments, the cationic lipid is DOTAP. The cationic oil-in-water emulsion may comprise from about 0.8 mg/ml to about 10 mg/ml DOTAP. For example, the cationic oil-in-water emulsion may comprise DOTAP at from about 1.7 mg/ml to about 10 mg/ml, from about 1.8 mg/ml to about 10 mg/ml, from about 2.0 mg/ml to about 10 mg/ml, from about 2.2 mg/ml to about 10 mg/ml, from about 2.4 mg/ml to about 10 mg/ml, from about 2.6 mg/ml to about 10 mg/ml, from about 2.8 mg/ml to about 10 mg/ml, from about 3.0 mg/ml to about 10 mg/ml, from about 3.2 mg/ml to about 10 mg/ml, from about 3.4 mg/ml to about 10 mg/ml, from about 3.6 mg/ml to about 10 mg/ml, from about 4.0 mg/ml to about 10 mg/ml, from about 4.4 mg/ml to about 10 mg/ml, from about 4.8 mg/ml to about 10 mg/ml, from about 5 mg/ml to about 10 mg/ml, from about 1.7 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 6 mg/ml, from about 1.8 mg/ml to about 7 mg/ml, from about 1.8 mg/ml to about 8 mg/ml, from about 1.8 mg/ml to about 9 mg/ml, about 1.7 mg/ml, about 1.8 mg/ml, about 2.0 mg/ml, about 2.2 mg/ml, about 2.4 mg/ml, about 2.6 mg/ml, about 2.8 mg/ml, about 3.0 mg/ml, about 3.2

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mg/ml, about 3.4mg/ml, about 3.6 mg/ml, about 3.8 mg/ml, about 4.0 mg/ml, about 4.2 mg/ml, about 4.4 mg/ml, about 4.6 mg/ml, about 4.8 mg/ml, about 5.0 mg/ml, about 5.2 mg/ml, about 5.5 mg/ml, about 6.0 mg/ml, at least about 0.8 mg/ml, at least about 0.85mg/ml, at least about 0.9 mg/ml, at least about 1.0 mg/ml, at least about 1.1 mg/ml, at least about 1.2 mg/ml, at least about 1.3 mg/ml, at least about 1.4 mg/ml, at least about 1.5 mg/ml, at least about 1.6 mg/ml, at least about 1.7 mg/ml, etc.

[093] In an exemplary embodiment, the cationic oil-in-water emulsion comprises from about 1.8 mg/ml to about 5.0 mg/ml DOTAP.

[094] In certain embodiments, the cationic lipid is DOEPC. The cationic oil-in-water emulsion may comprise from about 0.8 mg/ml to about 10 mg/ml DOEPC. For example, the cationic oil-in-water emulsion may comprise DOEPC at from about 1.7 mg/ml to about 10 mg/ml, from about 1.8 mg/ml to about 10 mg/ml, from about 2.0 mg/ml to about 10 mg/ml, from about 2.2 mg/ml to about 10 mg/ml, from about 2.4 mg/ml to about 10 mg/ml, from about 2.6 mg/ml to about 10 mg/ml, from about 2.8 mg/ml to about 10 mg/ml, from about 3.0 mg/ml to about 10 mg/ml, from about 3.2 mg/ml to about 10 mg/ml, from about 3.4 mg/ml to about 10 mg/ml, from about 3.6 mg/ml to about 10 mg/ml, from about 4.0 mg/ml to about 10 mg/ml, from about 4.4 mg/ml to about 10 mg/ml, from about 4.8 mg/ml to about 10 mg/ml, from about 5 mg/ml to about 10 mg/ml, from about 1.7 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 6 mg/ml, from about 1.8 mg/ml to about 7 mg/ml, from about 1.8 mg/ml to about 8 mg/ml, from about 1.8 mg/ml to about 9 mg/ml, about 1.7 mg/ml, about 1.8 mg/ml, about 2.0 mg/ml, about 2.2 mg/ml, about 2.4 mg/ml, about 2.6 mg/ml, about 2.8 mg/ml, about 3.0 mg/ml, about 3.2 mg/ml, about 3.4mg/ml, about 3.6 mg/ml, about 3.8 mg/ml, about 4.0 mg/ml, about 4.2 mg/ml, about 4.4 mg/ml, about 4.6 mg/ml, about 4.8 mg/ml, about 5.0 mg/ml, about 5.2 mg/ml, about 5.5 mg/ml, about 6.0 mg/ml, at least about 0.8 mg/ml, at least about 0.85mg/ml, at least about 0.9 mg/ml, at least about 1.0 mg/ml, at least about 1.1 mg/ml, at least about 1.2 mg/ml, at least about 1.3 mg/ml, at least about 1.4 mg/ml, at least about 1.5 mg/ml, at least about 1.6 mg/ml, at least about 1.7 mg/ml, etc.

[095] In certain embodiments, the cationic lipid is DODAC. The cationic oil-in-water emulsion may comprise from about 0.8 mg/ml to about 10 mg/ml DODAC. For example, the cationic oil-in-water emulsion may comprise DODAC at from about 1.7 mg/ml to about 10 mg/ml, from about 1.8 mg/ml to about 10 mg/ml, from about 2.0 mg/ml to about 10 mg/ml, from about 2.2 mg/ml to about 10 mg/ml, from about 2.4 mg/ml to about 10 mg/ml, from about 2.6 mg/ml to about 10 mg/ml, from about 2.8 mg/ml to about 10 mg/ml, from about 3.0 mg/ml to about 10 mg/ml, from about 3.2 mg/ml to about 10 mg/ml, from about 3.4 mg/ml to about 10 mg/ml, from about 3.6 mg/ml to about 10 mg/ml, from about 4.0 mg/ml to about 10 mg/ml, from about 4.4 mg/ml to about 10 mg/ml, from about 4.8 mg/ml to about 10 mg/ml, from about 5 mg/ml to about 10 mg/ml, from about 1.7 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 6 mg/ml, from about 1.8 mg/ml to about 7 mg/ml, from about 1.8 mg/ml to about 8 mg/ml, from about 1.8 mg/ml to about 9 mg/ml, about 1.7 mg/ml, about 1.8 mg/ml, about 2.0 mg/ml, about 2.2 mg/ml, about 2.4 mg/ml, about 2.6 mg/ml, about 2.8 mg/ml, about 3.0 mg/ml, about 3.2 mg/ml, about 3.4mg/ml, about 3.6 mg/ml, about 3.8 mg/ml, about 4.0 mg/ml, about 4.2 mg/ml, about 4.4 mg/ml, about 4.6 mg/ml, about 4.8 mg/ml, about 5.0 mg/ml, about 5.2 mg/ml, about 5.5 mg/ml, about 6.0 mg/ml, at least about 0.8 mg/ml, at least about 0.85mg/ml, at least about 0.9 mg/ml, at least about 1.0 mg/ml, at least about 1.1 mg/ml, at least about 1.2 mg/ml, at least about 1.3 mg/ml, at least about 1.4 mg/ml, at least about 1.5 mg/ml, at least about 1.6 mg/ml, at least about 1.7 mg/ml, etc.

[096] In certain embodiments, the cationic lipid is DOTMA. The cationic oil-in-water emulsion may comprise from about 0.8 mg/ml to about 10 mg/ml DOTMA. For example, the cationic oil-in-water emulsion may comprise DOTMA at from about 1.7 mg/ml to about 10 mg/ml, from about 1.8 mg/ml to about 10 mg/ml, from about 2.0 mg/ml to about 10 mg/ml, from about 2.2 mg/ml to about 10 mg/ml, from about 2.4 mg/ml to about 10 mg/ml, from about 2.6 mg/ml to about 10 mg/ml, from about 2.8 mg/ml to about 10 mg/ml, from about 3.0 mg/ml to about 10 mg/ml, from about 3.2 mg/ml to about 10 mg/ml, from about 3.4 mg/ml to about 10 mg/ml, from about 3.6 mg/ml to about 10 mg/ml, from about 4.0 mg/ml to about 10 mg/ml, from about 4.4 mg/ml to about 10 mg/ml, from about 4.8 mg/ml to about 10 mg/ml, from about 5 mg/ml to about 10 mg/ml, from about 1.7 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 5 mg/ml, from about 1.8 mg/ml to about 6 mg/ml, from about 1.8 mg/ml to about 7 mg/ml, from about 1.8 mg/ml to about 8 mg/ml, from about 1.8 mg/ml to about 9 mg/ml, about 1.7 mg/ml, about 1.8 mg/ml, about 2.0 mg/ml, about 2.2 mg/ml, about 2.4 mg/ml, about 2.6 mg/ml, about 2.8 mg/ml, about 3.0 mg/ml, about 3.2 mg/ml, about 3.4mg/ml, about 3.6 mg/ml, about 3.8 mg/ml, about 4.0 mg/ml, about 4.2

mg/ml, about 4.4 mg/ml, about 4.6 mg/ml, about 4.8 mg/ml, about 5.0 mg/ml, about 5.2 mg/ml, about 5.5 mg/ml, about 6.0 mg/ml, at least about 0.8 mg/ml, at least about 0.85mg/ml, at least about 0.9 mg/ml, at least about 1.0 mg/ml, at least about 1.1 mg/ml, at least about 1.2 mg/ml, at least about 1.3 mg/ml, at least about 1.4 mg/ml, at least about 1.5 mg/ml, at least about 1.6 mg/ml, at least about 1.7 mg/ml, etc.

[097] As noted above, the concentration of a lipid described above is determined based on the initial amount of the lipid that is used to prepare the emulsions. It is understood in the art that the actual concentration of the oil in the final product (*e.g.*, a packaged, sterilized emulsion that is ready for administration) might be slightly lower, sometimes by up to about 10%, by up to about 20%, by up to about 25%, or by up to about 35%. .

C. Oil to Lipid Ratio

[098] The cationic oil-in-water emulsions of the invention have a defined oil:lipid ratio. For example, the ratio of oil:lipid (mole:mole) of the emulsion may be at least about 8:1 (mole:mole), at least about 8.5:1 (mole:mole), at least about 9:1 (mole:mole), at least about 9.5:1 (mole:mole), at least about 10:1 (mole:mole), at least about 10.5:1 (mole:mole), at least about 11:1 (mole:mole), at least about 11.5:1 (mole:mole), at least about 12:1 (mole:mole), at least about 12.5:1 (mole:mole), at least about 13:1 (mole:mole), at least about 13.5:1 (mole:mole), at least about 14:1 (mole:mole), at least about 14.5:1 (mole:mole), at least about 15:1 (mole:mole), at least about 15.5:1 (mole:mole), at least about 16:1 (mole:mole), at least about 16.5:1 (mole:mole), at least about 17:1 (mole:mole), from about 8:1 (mole:mole) to about 50:1 (mole:mole), from about 9:1 (mole:mole) to about 50:1 (mole:mole), from about 10:1 (mole:mole) to about 50:1 (mole:mole), from about 8:1 (mole:mole) to about 49:1 (mole:mole), from about 8:1 (mole:mole) to about 48:1 (mole:mole), from about 8:1 (mole:mole) to about 47:1 (mole:mole), from about 8:1 (mole:mole) to about 46:1 (mole:mole), from about 8:1 (mole:mole) to about 45:1 (mole:mole), from about 8:1 (mole:mole) to about 44:1 (mole:mole), from about 8:1 (mole:mole) to about 43:1 (mole:mole), from about 8:1 (mole:mole) to about 42:1 (mole:mole), from about 8:1 (mole:mole) to about 41:1 (mole:mole), from about 9:1 (mole:mole) to about 43:1 (mole:mole), from about 10:1 (mole:mole) to about 43:1 (mole:mole), from about 11:1 (mole:mole) to about 43:1 (mole:mole), from about 12:1 (mole:mole) to about 43:1 (mole:mole), from about 13:1 (mole:mole) to about 43:1

(mole:mole), from about 14:1 (mole:mole) to about 43:1 (mole:mole), from about 15:1 (mole:mole) to about 43:1 (mole:mole), from about 16:1 (mole:mole) to about 43:1 (mole:mole), from about 17:1 (mole:mole) to about 43:1 (mole:mole), *etc.*

[099] If desired, the ratio of oil:lipid (mole:mole) of the emulsion may be at least about 4:1 (mole:mole), at least about 4.2:1 (mole:mole), at least about 4.5:1 (mole:mole), at least about 5:1 (mole:mole), at least about 5.5:1 (mole:mole), at least about 6:1 (mole:mole), at least about 6.5:1 (mole:mole), 7:1 (mole:mole), at least about 7.5:1 (mole:mole), from about 4:1 (mole:mole) to about 50:1 (mole:mole), from about 5:1 (mole:mole) to about 50:1 (mole:mole), from about 6:1 (mole:mole) to about 50:1 (mole:mole), from about 7:1 (mole:mole) to about 50:1 (mole:mole), from about 4:1 (mole:mole) to about 49:1 (mole:mole), from about 4:1 (mole:mole) to about 48:1 (mole:mole), from about 4:1 (mole:mole) to about 47:1 (mole:mole), from about 4:1 (mole:mole) to about 46:1 (mole:mole), from about 4:1 (mole:mole) to about 45:1 (mole:mole), from about 4:1 (mole:mole) to about 44:1 (mole:mole), from about 4:1 (mole:mole) to about 43:1 (mole:mole), from about 4:1 (mole:mole) to about 42:1 (mole:mole), from about 4:1 (mole:mole) to about 41:1 (mole:mole), from about 5:1 (mole:mole) to about 43:1 (mole:mole), from about 6:1 (mole:mole) to about 43:1 (mole:mole), from about 7:1 (mole:mole) to about 43:1 (mole:mole), *etc.*

[0100] Sometimes, there may be a need to strike a balance between the desire to increase the concentration of a cationic lipid (thereby increasing the amount of nucleic acid molecules loaded to the emulsion particle), and toxicity or tolerability of the lipid when administered *in vivo*. For example, it has been reported that high doses of DOTAP can have toxic effects. *See, e.g.*, Lappalainen et al., Pharm. Res., vol. 11(8):1127-31 (1994). The optimal range of lipid dose in a particular emulsion can be determined in accordance with the knowledge of a skilled clinician.

[0101] If the oil comprises a mixture of molecules, the molar concentration of the oil can be calculated based on the average molecular weight of the oil. For example, the average molecular weight of soybean oil (292.2) can be calculated according to the average fatty acid distribution (12% weight percentage of palmitic acid; 52% weight percentage of linolenic acid; etc), and the molecular weight of each component.

C. Additional Components

[0102] The cationic oil-in-water emulsions described herein may further comprise additional components. For example, the emulsions may comprise components that can promote particle formation, improve the complexation between the negatively charge molecules and the cationic particles, or increase the stability of the negatively charge molecule (e.g., to prevent degradation of an RNA molecule). If desired, the cationic oil-in-water emulsion can contain an antioxidant, such as citrate, ascorbate or salts thereof.

Surfactants

[0103] In certain embodiments, the cationic oil-in-water emulsion as described herein further comprises a surfactant.

[0104] A substantial number of surfactants have been used in the pharmaceutical sciences. These include naturally derived materials such as gums from trees, vegetable protein, sugar-based polymers such as alginates, and the like. Certain oxypolymers or polymers having a hydroxide or other hydrophilic substituent on the carbon backbone have surfactant activity, for example, povidone, polyvinyl alcohol, and glycol ether-based mono- and poly-functional compounds. Ionic or nonionic detergents and long chain fatty-acid-derived compounds can also be used in this invention.

[0105] Specific examples of suitable surfactants include the following:

[0106] 1. Water-soluble soaps, such as the sodium, potassium, ammonium and alkanol-ammonium salts of higher fatty acids (C_{10}-C_{22}), in particular sodium and potassium tallow and coconut soaps.

[0107] 2. Anionic synthetic non-soap surfactants, which can be represented by the water-soluble salts of organic sulfuric acid reaction products having in their molecular structure an alkyl radical containing from about 8 to 22 carbon atoms and a radical selected from the group consisting of sulfonic acid and sulfuric acid ester radicals. Examples of these are the sodium or potassium alkyl sulfates, derived from tallow or coconut oil; sodium or potassium alkyl benzene sulfonates; sodium alkyl glyceryl ether sulfonates; sodium coconut oil fatty acid monoglyceride sulfonates and sulfates; sodium or potassium salts of sulfuric acid esters of the reaction product of one mole of a higher fatty alcohol and about 1 to 6 moles of ethylene oxide; sodium or potassium alkyl phenol ethylene oxide ether sulfonates, with 1 to 10 units of ethylene oxide per molecule and in which the alkyl radicals contain from 8 to 12 carbon atoms; the reaction product of fatty acids esterified with isethionic acid and neutralized with sodium hydroxide; sodium or potassium salts of fatty acid amide of a methyl tauride; and sodium and potassium salts of SO_3-sulfonated C_{10}-C_{24} α-olefins.

[0108] 3. Nonionic synthetic surfactants made by the condensation of alkylene oxide groups with an organic hydrophobic compound. Typical hydrophobic groups include condensation products of propylene oxide with propylene glycol, alkyl phenols, condensation product of propylene oxide and ethylene diamine, aliphatic alcohols having 8 to 22 carbon atoms, and amides of fatty acids.

[0109] 4. Nonionic surfactants, such as amine oxides, phosphine oxides and sulfoxides, having semipolar characteristics. Specific examples of long chain tertiary amine oxides include dimethyldodecylamine oxide and bis-(2-hydroxyethyl) dodecylamine. Specific examples of phosphine oxides are found in U.S. Pat. No. 3,304,263, issued February 14, 1967, and include dimethyldodecylphosphine oxide and dimethyl-(2hydroxydodecyl) phosphine oxide.

[0110] 5. Long chain sulfoxides, including those corresponding to the formula R^1—SO—R^2 wherein R^1 and R^2 are substituted or unsubstituted alkyl radicals, the former containing from about 10 to about 28 carbon atoms, whereas R^2 contains from 1 to 3 carbon atoms. Specific examples of these sulfoxides include dodecyl methyl sulfoxide and 3-hydroxy tridecyl methyl sulfoxide.

[0111] 6. Ampholytic synthetic surfactants, such as sodium 3-dodecylaminopropionate and sodium 3-dodecylaminopropane sulfonate.

[0112] 7. Zwitterionic synthetic surfactants, such as 3-(N,N-dimethyl-N-hexadecylammonio)propane-1-sulfonate and 3-(N,N-dimethyl-N-hexadecylammonio)-2-hydroxy propane-1-sulfonate.

[0113] Additionally, all of the following types of surfactants can be used in a composition of the present invention: (a) soaps (i.e., alkali salts) of fatty acids, rosin acids, and tall oil; (b) alkyl arene sulfonates; (c) alkyl sulfates, including surfactants with both branched-chain and straight-chain hydrophobic groups, as well as primary and secondary sulfate groups; (d) sulfates and sulfonates containing an intermediate linkage between the hydrophobic and hydrophilic groups, such as the fatty acylated methyl taurides and the sulfated fatty monoglycerides; (e) long-chain acid esters of polyethylene glycol, especially the tall oil esters; (f) polyethylene glycol ethers of alkylphenols; (g) polyethylene glycol ethers of long-chain alcohols and mercaptans; and (h) fatty acyl diethanol amides. Since surfactants can be classified in more than one manner, a number of classes of surfactants set forth in this paragraph overlap with previously described surfactant classes.

[0114] There are a number of surfactants specifically designed for and commonly used in biological situations. Such surfactants are divided into four basic types: anionic, cationic, zwitterionic (amphoteric), and nonionic. Exemplary anionic surfactants include, e.g., perfluorooctanoate (PFOA or PFO), perfluorooctanesulfonate (PFOS), alkyl sulfate salts such as sodium dodecyl sulfate (SDS) or ammonium lauryl sulfate, sodium laureth sulfate (also known as sodium lauryl ether sulfate, SLES), alkyl benzene sulfonate, and fatty acid salts. Exemplary cationic surfactants include, e.g., alkyltrimethylammonium salts such as cetyl trimethylammonium bromide (CTAB, or hexadecyl trimethyl ammonium bromide), cetylpyridinium chloride (CPC), polyethoxylated tallow amine (POEA), benzalkonium chloride (BAC), benzethonium chloride (BZT). Exemplary zwitterionic (amphoteric) surfactants include, e.g., dodecyl betaine, cocamidopropyl betaine, and coco ampho glycinate. Exemplary nonionic surfactants include, e.g., alkyl poly(ethylene oxide), alkylphenol poly(ethylene oxide), copolymers of poly(ethylene oxide) and poly(propylene oxide) (commercially called poloxamers or poloxamines), Aayl polyglucosides (e.g., octyl glucoside or decyl maltoside), fatty alcohols (e.g., cetyl alcohol or oleyl alcohol), cocamide MEA, cocamide DEA, Pluronic® F-68 (polyoxyethylene-polyoxypropylene block copolymer), and polysorbates, such as Tween 20 (polysorbate 20), Tween 80 (polysorbate 80; polyoxyethuylenesorbitan monooleate), dodecyl dimethylamine oxide, and vitamin E tocopherol propylene glycol succinate (Vitamin E TPGS).

[0115] A particularly useful group of surfactants are the sorbitan-based non-ionic surfactants. These surfactants are prepared by dehydration of sorbitol to give 1,4-sorbitan which is then reacted with one or more equivalents of a fatty acid. The fatty-acid-substituted moiety may be further reacted with ethylene oxide to give a second group of surfactants.

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[0116] The fatty-acid-substituted sorbitan surfactants are made by reacting 1,4-sorbitan with a fatty acid such as lauric acid, palmitic acid, stearic acid, oleic acid, or a similar long chain fatty acid to give the 1,4-sorbitan mono-ester, 1,4-sorbitan sesquiester or 1,4-sorbitan triester. The common names for these surfactants include, for example, sorbitan monolaurate, sorbitan monopalmitate, sorbitan monoestearate, sorbitan monooleate, sorbitan sesquioleate, and sorbitan trioleate. These surfactants are commercially available under the name SPAN® or ARLACEL®, usually with a letter or number designation which distinguishes between the various mono, di- and triester substituted sorbitans.

[0117] SPAN® and ARLACEL® surfactants are hydrophilic and are generally soluble or dispersible in oil. They are also soluble in most organic solvents. In water they are generally insoluble but dispersible. Generally these surfactants will have a hydrophilic-lipophilic balance (HLB) number between 1.8 to 8.6. Such surfactants can be readily made by means known in the art or are commercially available.

[0118] A related group of surfactants comprises olyoxyethylene sorbitan monoesters and olyoxyethylene sorbitan triesters. These materials are prepared by addition of ethylene oxide to a 1,4-sorbitan monester or triester. The addition of polyoxyethylene converts the lipophilic sorbitan mono- or triester surfactant to a hydrophilic surfactant generally soluble or dispersible in water and soluble to varying degrees in organic liquids.

[0119] These materials, commercially available under the mark TWEEN®, are useful for preparing oil-in-water emulsions and dispersions, or for the solubilization of oils and making anhydrous ointments water-soluble or washable. The TWEEN® surfactants may be combined with a related sorbitan monester or triester surfactants to promote emulsion stability. TWEEN® surfactants generally have a HLB value falling between 9.6 to 16.7. TWEEN® surfactants are commercially available.

[0120] A third group of non-ionic surfactants which could be used alone or in conjunction with SPANS, ARLACEL® and TWEEN® surfactants are the polyoxyethylene fatty acids made by the reaction of ethylene oxide with a long-chain fatty acid. The most commonly available surfactant of this type is solid under the name MYRJ® and is a polyoxyethylene derivative of stearic acid. MYRJ® surfactants are hydrophilic and soluble or dispersible in water like TWEEN® surfactants. The MYRJ® surfactants may be blended with TWEEN® surfactants or with TWEEN®/SPAN® or ARLACEL® surfactant mixtures for use in forming emulsions. MYRJ® surfactants can be made by methods known in the art or are available commercially.

[0121] A fourth group of polyoxyethylene based non-ionic surfactants are the polyoxyethylene fatty acid ethers derived from lauryl, acetyl, stearyl and oleyl alcohols. These materials are prepared as above by addition of ethylene oxide to a fatty alcohol. The commercial name for these surfactants is BRIJ®. BRIJ® surfactants may be hydrophilic or lipophilic depending on the size of the polyoxyethylene moiety in the surfactant. While the preparation of these compounds is available from the art, they are also readily available from commercial sources.

[0122] Other non-ionic surfactants which could potentially be used are, for example, polyoxyethylene, polyol fatty acid esters, polyoxyethylene ether, polyoxypropylene fatty ethers, bee's wax derivatives containing polyoxyethylene, polyoxyethylene lanolin derivative, polyoxyethylene fatty glycerides, glycerol fatty acid esters or other polyoxyethylene acid alcohol or ether derivatives of long-chain fatty acids of 12-22 carbon atoms.

[0123] As the emulsions and formulations of the invention are intended to be multi-phase systems, it is preferable to choose an emulsion-forming non-ionic surfactant which has an HLB value in the range of about 7 to 16. This value may be obtained through the use of a single non-ionic surfactant such as a TWEEN® surfactant or may be achieved by the use of a blend of surfactants such as with a sorbitan mono, di- or triester based surfactant; a sorbitan ester polyoxyethylene fatty acid; a sorbitan ester in combination with a polyoxyethylene lanolin derived surfactant; a sorbitan ester surfactant in combination with a high HLB polyoxyethylene fatty ether surfactant; or a polyethylene fatty ether surfactant or polyoxyethylene sorbitan fatty acid.

[0124] In certain embodiments, the emulsion comprises a single non-ionic surfactant, most particularly a TWEEN® surfactant, as the emulsion stabilizing non-ionic surfactant. In an exemplary embodiment, the emulsion comprises TWEEN® 80, otherwise known as polysorbate 80 or polyoxyethylene 20 sorbitan monooleate. In other embodiments, the emulsion comprises two or more non-ionic surfactants, in particular a TWEEN® surfactant and a SPAN® surfactant. In an exemplary embodiment, the emulsion comprises TWEEN® 80 and SPAN®85.

[0125] The oil-in-water emulsions can contain from about 0.01% to about 2.5% surfactant (w/v), about 0.01% to about 2% surfactant, 0.01% to about 1.5% surfactant, 0.01% to about 1% surfactant, 0.01% to about 0.5% surfactant, 0.05% to about 0.5% surfactant, 0.08% to about 0.5% surfactant, about 0.08% surfactant, about 0.1% surfactant, about 0.2% surfactant, about 0.3% surfactant, about 0.4% surfactant, about 0.5% surfactant, about 0.6% surfactant, about 0.7% surfactant, about 0.8% surfactant, about 0.9% surfactant, or about 1% surfactant.

[0126] Alternatively or in addition, the oil-in-water emulsions can contain 0.05% to about 1%, 0.05% to about 0.9%, 0.05% to about 0.8%, 0.05% to about 0.7%, 0.05% to about 0.6%, 0.05% to about 0.5%, about 0.08%, about 0.1%, about 0.2%, about 0.3%, about 0.4%, about 0.5%, about 0.6%, about 0.7%, about 0.8%, about 0.9%, or about 1% (w/v) Tween 80 (polysorbate 80; polyoxyethuylenesorbitan monooleate).

[0127] In an exemplary embodiment, the oil-in-water emulsion contains 0.08% (w/v) Tween 80 (polysorbate 80; polyoxyethuylenesorbitan monooleate).

[0128] Alternatively or in addition, the oil-in-water emulsions can contain 0.05% to about 1%, 0.05% to about 0.9%, 0.05% to about 0.8%, 0.05% to about 0.7%, 0.05% to about 0.6%, 0.05% to about 0.5%, about 0.08%, about 0.1%, about 0.2%, about 0.3%, about 0.4%, about 0.5%, about 0.6%, about 0.7%, about 0.8%, about 0.9%, or about 1% (w/v) SPAN85 (sorbitan trioleate).

[0129] The oil-in-water emulsions can contain a combination of surfactants described herein. For example, a combination of Tween 80 (polysorbate 80; polyoxyethuylenesorbitan monooleate) and SPAN85 (sorbitan trioleate) may be used. The emulsions may contain various amounts of Tween 80 and SPAN85 (e.g., those exemplified above) or equal amounts. For example, the oil-in-water emulsions can contain (w/v) about 0.05% Tween 80 and about 0.05% SPAN85, about 0.1% Tween 80 and about 0.1% SPAN85, about 0.2% Tween 80 and about 0.2% SPAN85, about 0.3% Tween 80 and about 0.3% SPAN85, about 0.4% Tween 80 and about 0.4% SPAN85, about 0.5% Tween 80 and about 0.5% SPAN85, about 0.6% Tween 80 and about 0.6% SPAN85, about 0.7% Tween 80 and about 0.7% SPAN85, about 0.8% Tween 80 and about 0.8% SPAN85, about 0.9% Tween 80 and about 0.9% SPAN85, or about 1% Tween 80 and about 1.0% SPAN85.

[0130] In certain embodiments, the surfactant is a Polyethylene Glycol (PEG)-lipid. In other embodiments, the emulsion does not comprise a PEG-lipid. PEG-lipids, such as PEG coupled to dialkyloxypropyls (PEG-DAA), PEG coupled to diacylglycerol (PEG-DAG), PEG coupled to phosphatidylethanolamine (PE) (PEG-PE) or some other phospholipids (PEG-phospholipids), PEG conjugated to ceramides (PEG-Cer), or a combination thereof, may also be used as surfactants (see, e.g., U.S. Pat. No. 5,885,613; U.S. patent application publication Nos. 2003/0077829, 2005/0175682 and 2006/0025366). Other suitable PEG-lipids include, e.g., PEG-dialkyloxypropyl (DAA) lipids or PEG-diacylglycerol (DAG) lipids. Exemplary PEG-DAG lipids include, e.g., PEG-dilauroylglycerol (C_{12}) lipids, PEG-dimyristoylglycerol (C_{14}) lipids, PEG-dipalmitoylglycerol (C_{16}) lipids, or PEG-distearoylglycerol (C_{18}) lipids. Exemplary PEG-DAA lipids include, e.g., PEG-dilauryloxypropyl (C_{12}) lipids, PEG-dimyristyloxypropyl (C_{14}) lipids, PEG-dipalmityloxypropyl (C_{16}) lipids, or PEG-distearyloxypropyl (C_{18}) lipids.

[0131] PEGs are classified by their molecular weights; for example, PEG 2000 has an average molecular weight of about 2,000 daltons, and PEG 5000 has an average molecular weight of about 5,000 daltons. PEGs are commercially available from Sigma Chemical Co. as well as other companies and include, for example, the following: monomethoxypolyethylene glycol (MePEG-OH), monomethoxypolyethylene glycol-succinate (MePEG-S), monomethoxypolyethylene glycol-succinimidyl succinate (MePEG-S-NHS), monomethoxypolyethylene glycol-amine (MePEG-NH_2), monomethoxypolyethylene glycol-tresylate (MePEG-TRES), and monomethoxypolyethylene glycol-imidazolyl-carbonyl (MePEG-IM). In addition, monomethoxypolyethyleneglycol-acetic acid (MePEG-CH_2COOH), is particularly useful for preparing the PEG-lipid conjugates including, e.g., PEG-DAA conjugates.

D. Aqueous phase (Continuous phase)

[0132] The aqueous phase (continuous phase) of the oil-in-water emulsions is water, or an aqueous solution that can contain a salt (*e.g.*, NaCl), a buffer (*e.g.*, a citrate buffer), a nonionic tonicifying agent (*e.g.*, a saccharide), a polymer, a surfactant, or any combination thereof. The aqueous phase of the pre-complexed emulsions (oil-in-water emulsions before the addition of the negatively charged molecules) can differ from the aqueous phase of the post-complexed emulsions (oil-in-water emulsions in which the

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negatively charged molecules are complexed with the emulsion particles). In general, the pre-complexed emulsions are prepared in an aqueous solvent that promotes the formation of particles with desired properties (e.g., average diameter, and the like). The pre-complexed emulsions are diluted with an aqueous solution that contains the negatively charged molecule, and other desired components, to produce the final cationic oil-in-water emulsion, which contains the final aqueous phase with desired osmolarity and tonicity. The aqueous phase can contain an antioxidant, such as citrate, ascorbate or salts thereof.

[0133] When the emulsions are formulated for *in vivo* administration, it is preferable to make up the final solution so that the tonicity and osmolarity of the emulsion are substantially the same as normal physiological fluids in order to prevent undesired post-administration consequences, such as swelling or rapid absorption of the composition. It is also preferable to buffer the aqueous phase in order to maintain a pH compatible with normal physiological conditions. Also, in certain instances, it may be desirable to maintain the pH at a particular level in order to insure the stability of certain components of the emulsion. For example, it may be desirable to prepare an emulsion that is isotonic and isosmotic. To control tonicity, the emulsion may comprise a physiological salt, such as a sodium salt. Sodium chloride (NaCl), for example, may be used at about 0.9% (w/v) (physiological saline). Other salts that may be present include potassium chloride, potassium dihydrogen phosphate, disodium phosphate, magnesium chloride, calcium chloride, *etc.* Non-ionic tonicifying agents can also be used to control tonicity. A number of non-ionic tonicity modifying agents ordinarily known to those in the art. These are typically carbohydrates of various classifications (see, for example, Voet and Voet (1990) Biochemistry (John Wiley & Sons, New York). Monosaccharides classified as aldoses such as glucose, mannose, arabinose, and ribose, as well as those classified as ketoses such as fructose, sorbose, and xylulose can be used as non-ionic tonicifying agents in the present invention. Disaccharides such a sucrose, maltose, trehalose, and lactose can also be used. In addition, alditols (acyclic polyhydroxy alcohols, also referred to as sugar alcohols) such as glycerol, mannitol, xylitol, and sorbitol are non-ionic tonicifying agents useful in the present invention. Non-ionic tonicity modifying agents can be present at a concentration of from about 0.1% to about 10% or about 1% to about 10%, depending upon the agent that is used.

[0134] The aqueous phase may be buffered. Any physiologically acceptable buffer may be used herein, such as water, citrate buffers, phosphate buffers, acetate buffers, tris buffers, bicarbonate buffers, carbonate buffers, succinate buffer, or the like. The pH of the aqueous component will preferably be between 6.0-8.0, more preferable about 6.2 to about 6.8. In an exemplary embodiment, the buffer is 10mM citrate buffer with a pH at 6.5. In another exemplary embodiment, the aqueous phase is, or the buffer prepared using, RNase-free water or DEPC treated water. In some cases, high salt in the buffer might interfere with complexation of negatively charged molecule to the emulsion particle therefore is avoided. In other cases, certain amount of salt in the buffer may be included.

[0135] In an exemplary embodiment, the buffer is 10mM citrate buffer with a pH at 6.5. If desired the aqueous phase is, or the buffer is prepared using, RNase-free water or DEPC treated water.

[0136] The aqueous phase may also comprise additional components such as molecules that change the osmolarity of the aqueous phase or molecules that stabilizes the negatively charged molecule after complexation. Preferably, the osmolarity of the aqueous phase is adjusted using a non-ionic tonicifying agent, such as a sugar (*e.g.*, trehalose, sucrose, dextrose, fructose, reduced palatinose, etc.), a sugar alcohol (such as mannitol, sorbitol, xylitol, erythritol, lactitol, maltitol, glycerol, etc.). If desired a nonionic polymer polymer (*e.g.*, a poly(alkyl glycol) such as polyethylene glycol, polypropylene glycol, or polybutlyene glycol) or nonionic surfactant can be used.

[0137] In certain embodiments, the aqueous phase of the cationic oil-in-water emulsion may comprise a polymer or a surfactant, or a combination thereof. In an exemplary embodiment, the oil-in-water emulsion contains a poloxamer. Poloxamers are nonionic triblock copolymers having a central hydrophobic chain of polyoxypropylene (poly(propylene oxide)) flanked by two hydrophilic chains of polyoxyethylene (poly(ethylene oxide)). Poloxamers are also known by the trade name Pluronic® polymers. Poloxamer polymers may lead to greater stability and increased RNase resistance of the RNA molecule after RNA complexation.

[0138] Alternatively or in addition, the cationic oil-in-water emulsion may comprise from about 0.1% to about 20% (w/v) polymer, or from about 0.05% to about 10% (w/v) polymer. For example, the cationic oil-in-water emulsion may comprise a polymer (e.g., a poloxamer such as Pluronic® F127 ((Ethylene Oxide/Propylene Oxide Block Copolymer: $H(OCH_2CH_2)_x(OCH_3CH(CH_3))_y(OCH_2CH_2)_zOH$)) at from about 0.1% to about

20% (w/v), from about 0.1% to about 10% (w/v), from about 0.05% to about 10% (w/v), or from about 0.05% to about 5% (w/v).

[0139] In an exemplary embodiment, the oil-in-water emulsion comprises about 4% (w/v), or about 8% (w/v) Pluronic® F127.

[0140] The quantity of the aqueous component employed in these compositions will be that amount necessary to bring the value of the composition to unity. That is, a quantity of aqueous component sufficient to make 100% will be mixed, with the other components listed above in order to bring the compositions to volume.

4. NEGATIVELY CHARGED MOLECULES

[0141] When a negatively charged molecule is to be delivered, it can be complexed with the particles of the cationic oil-in-water emulsions. The negatively charged molecule is complexed with the emulsion particles by, for example, interactions between the negatively charged molecule and the cationic lipid on the surface of the particles, as well as hydrophobic/hydrophilic interactions between the negatively charged molecule and the surface of the particles. Although not wishing to be bound by any particular theory, it is believed that the negatively charged molecules interact with the cationic lipid through non-covalent, ionic charge interactions (electrostatic forces), and the strength of the complex as well as the amount of negatively charged compound that can be complexed to a particle are related to the amount of cationic lipid in the particle. Additionally, hydrophobic/hydrophilic interactions between the negatively charged molecule and the surface of the particles may also play a role.

[0142] Examples of negatively charged molecules include negatively charged peptides, polypeptides or proteins, nucleic acid molecules (e.g., single or double stranded RNA or DNA), small molecules (e.g., small molecule immune potentiators (SMIPs), phosphonate, fluorophosphonate, etc.) and the like. In preferred aspects, the negatively charged molecule is an RNA molecule, such as an RNA that encodes a peptide, polypeptide or protein, including self-replicating RNA molecules, or a small interfering RNA.

[0143] The complex can be formed by using techniques known in the art, examples of which are described herein. For example, a nucleic acid-particle complex can be formed by mixing a cationic emulsion with the nucleic acid molecule, for example by vortexing. The amount of the negatively charged molecule and cationic lipid in the emulsions may be adjusted or optimized to provide desired strength of binding and binding capacity. For example, as described and exampled herein, exemplary RNA-particle complexes were produced by varying the RNA: cationic lipid ratios (as measured by the "N/P ratio"). The term N/P ratio refers to the amount (moles) of protonatable nitrogen atoms in the cationic lipid divided by the amount (moles) of phosphates on the RNA.

[0144] Preferred N/P ratios are from about 1:1 to about 20:1, from about 2:1 to about 18:1, from about 3:1 to 16:1, from about 4:1 to about 14:1, from about 6:1 to about 12:1, about 3:1, about 4:1, about 5:1, about 6:1, about 7:1, about 8:1, about 9:1, about 10:1, about 11:1, about 12:1, about 13:1, about 14:1, about 15:1, or about 16:1. Alternatively, preferred N/P ratios are at least about 3:1, at least about 4:1, at least about 5:1, at least about 6:1, at least about 7:1, at least about 8:1, at least about 9:1, at least about 10:1, at least about 11:1, at least about 12:1, at least about 13:1, at least about 14:1, at least about 15:1, or at least about 16:1. A more preferred N/P ratio is about 4:1 or higher.

[0145] Each emulsion may have its own optimal or preferred N/P ratio to produce desired effects (e.g., desired level of expression of the complexed RNA), which can be determined experimentally (e.g., using the assays as described herein or other techniques known in the art, such as measuring expression level of a protein that is encoded by the RNA, or measuring the percentage of the RNA molecules being released from the complex in the presence of heparin). Generally, the N/P ratio should be at a value that at least about 5%, about 10%, about 15%, about 20%, about 25%, about 30%, about 35%, about 40%, about 45%, about 50%, about 55%, about 60%, about 65%, about 70%, about 75%, about 80%, about 85%, about 90%, or about 95% of the RNA molecules are released from the RNA-particle complexes when the RNA-particle complexes are taken up by cells. In some embodiments, the N/P ratio is a value that provides for release of at least 0.5% or at least 1% of the RNA molecules are released from the RNA-particle complexes when the RNA-particle complexes are taken up by cells.

[0146] The expression level of an antigen encoded by the RNA molecule may not necessarily correlate with the immunogenicity of the antigen. In such cases, optimal or preferred N/P ratio fore immunogenicity may be determined by, *e.g.*, measuring specific antibody titers.

[0147] The cationic oil-in-water emulsions described herein are particularly suitable for formulating nucleic acid-based vaccines (e.g., DNA vaccines, RNA vaccines). The formation of a nucleic acid-emulsion particle complex facilitates the uptake of the nucleic acid into host cells, and protects the nucleic acid molecule from nuclease degradation. Transfected cells can then express the antigen encoded by the nucleic acid molecule, which can produce an immune response to the antigen. Like live or attenuated viruses, nucleic acid-based vaccines can effectively engage both MHC-I and MHC-II pathways allowing for the induction of $CD8^+$ and $CD4^+$ T cell responses, whereas antigen present in soluble form, such as recombinant protein, generally induces only antibody responses.

[0148] In certain embodiments, the negatively charged molecule described herein is an RNA molecule. In certain embodiments, the RNA molecule encodes an antigen (peptide, polypeptide or protein) and the cationic oil in water emulsion is suitable for use as an RNA-based vaccine. The composition can contain more than one species of RNA molecule encoding an antigen, e.g., two, three, five, or ten different species of RNA molecules that are complexed to the emulsion particles. That is, the composition can contain one or more different species of RNA molecules, each encoding a different antigen. Alternatively or in addition, one RNA molecule may also encode more than one antigen, e.g., a bicistronic, or tricistronic RNA molecule that encodes different or identical antigens. Accordingly, the cationic oil in water emulsion is suitable for use as an RNA-based vaccine, that is monovalent or multivalent. If desired, the RNA molecule can be polycistronic.

[0149] The sequence of the RNA molecule may be codon optimized or deoptimized for expression in a desired host, such as a human cell.

[0150] The sequence of the RNA molecule may be modified if desired, for example to increase the efficacy of expression or replication of the RNA, or to provide additional stability or resistance to degradation. For example, the RNA sequence can be modified with respect to its codon usage, for example, to increase translation efficacy and half-life of the RNA. A poly A tail (e.g., of about 30 adenosine residues or more) (SEQ ID NO: 28) may be attached to the 3' end of the RNA to increase its half-life. The 5' end of the RNA may be capped with a modified ribonucleotide with the structure m7G (5') ppp (5') N (cap 0 structure) or a derivative thereof, which can be incorporated during RNA synthesis or can be enzymatically engineered after RNA transcription (e.g., by using Vaccinia Virus Capping Enzyme (VCE) consisting of mRNA triphosphatase, guanylyl- transferase and guanine-7-methytransferase, which catalyzes the construction of N7-monomethylated cap 0 structures). Cap 0 structure plays an important role in maintaining the stability and translational efficacy of the RNA molecule. The 5' cap of the RNA molecule may be further modified by a 2 '-O-Methyltransferase which results in the generation of a cap 1 structure (m7Gppp [m2 '-O] N), which may further increases translation efficacy.

[0151] If desired, the RNA molecule can comprise one or more modified nucleotides in addition to any 5' cap structure. There are more than 96 naturally occurring nucleoside modifications found on mammalian RNA. See, e.g., Limbach *et al., Nucleic Acids Research*, 22(12):2183-2196 (1994). The preparation of nucleotides and modified nucleotides and nucleosides are well-known in the art, *e.g.* from US Patent Numbers 4373071, 4458066, 4500707, 4668777, 4973679, 5047524, 5132418, 5153319, 5262530, 5700642 , and many modified nucleosides and modified nucleotides are commercially available.

[0152] Modified nucleobases which can be incorporated into modified nucleosides and nucleotides and be present in the RNA molecules include: m5C (5-methylcytidine), m5U (5-methyluridine), m6A (N6-methyladenosine), s2U (2-thiouridine), Um (2'-O-methyluridine), m1A (l-methyladenosine); m2A (2-methyladenosine); Am (2-1-O-methyladenosine); ms2m6A (2-methylthio-N6-methyladenosine); i6A (N6-isopentenyladenosine); ms2i6A (2-methylthio-N6isopentenyladenosine); io6A (N6-(cis-hydroxyisopentenyl)adenosine); ms2io6A (2-methylthio-N6-(cis-hydroxyisopentenyl) adenosine); g6A (N6-glycinylcarbamoyladenosine); t6A (N6-threonyl carbamoyladenosine); ms2t6A (2-methylthio-N6-threonyl carbamoyladenosine); m6t6A (N6-methyl-N6-threonylcarbamoyladenosine); hn6A(N6-hydroxynorvalylcarbamoyl adenosine); ms2hn6A (2-methylthio-N6-hydroxynorvalyl carbamoyladenosine); Ar(p) (2'-O-ribosyladenosine (phosphate)); I (inosine); m1I (1-methylinosine); m'Im (1,2'-O-dimethylinosine); m3C (3-methylcytidine); Cm (2T-O-methylcytidine); s2C (2-thiocytidine); ac4C (N4-acetylcytidine); f5C (5-fonnylcytidine); m5Cm (5,2-O-dimethy lcytidine); ac4Cm (N4acetyl2TOmethylcytidine); k2C (lysidine); m1G (1-methylguanosine); m2G (N2-methylguanosine); m7G (7-methylguanosine); Gm (2'-O-methylguanosine); m22G (N2,N2-

dimethylguanosine); m2Gm (N2,2'-O-dimethylguanosine); m22Gm (N2,N2,2'-O-trimethylguanosine); Gr(p) (2'-O-ribosylguanosine (phosphate)); yW (wybutosine); o2yW (peroxywybutosine); OHyW (hydroxywybutosine); OHyW* (undermodified hydroxywybutosine); imG (wyosine); mimG (methylguanosine); Q (queuosine); oQ (epoxyqueuosine); galQ (galtactosyl-queuosine); manQ (mannosyl-queuosine); preQo (7-cyano-7-deazaguanosine); preQi (7-aminomethyl-7-deazaguanosine); G* (archaeosine); D (dihydrouridine); m5Um (5,2'-O-dimethyluridine); s4U (4-thiouridine); m5s2U (5-methyl-2-thiouridine); s2Um (2-thio-2'-O-methyluridine); acp3U (3-(3-amino-3-carboxypropyl)uridine); ho5U (5-hydroxyuridine); mo5U (5-methoxyuridine); cmo5U (uridine 5-oxyacetic acid); mcmo5U (uridine 5-oxyacetic acid methyl ester); chm5U (5-(carboxyhydroxymethyl)uridine)); mchm5U (5-(carboxyhydroxymethyl)uridine methyl ester); mcm5U (5-methoxycarbonyl methyluridine); mcm5Um (S-methoxycarbonylmethyl-2-O-methyluridine); mcm5s2U (5-methoxycarbonylmethyl-2-thiouridine); nm5s2U (5-aminomethyl-2-thiouridine); mnm5U (5-methylaminomethyluridine); mnm5s2U (5-methylaminomethyl-2-thiouridine); mnm5se2U (5-methylaminomethyl-2-selenouridine); ncm5U (5-carbamoylmethyl uridine); ncm5Um (5-carbamoylmethyl-2'-O-methyluridine); cmnm5U (5-carboxymethylaminomethyluridine); cnmm5Um (5-carboxymethy l aminomethyl-2-L-Omethy l uridine); cmnm5s2U (5-carboxymethylaminomethyl-2-thiouridine); m62A (N6,N6-dimethyladenosine); Tm (2'-O-methylinosine); m4C (N4-methylcytidine); m4Cm (N4,2-O-dimethylcytidine); hm5C (5-hydroxymethylcytidine); m3U (3-methyluridine); cm5U (5-carboxymethyluridine); m6Am (N6,T-O-dimethyladenosine); m62Am (N6,N6,O-2-trimethyladenosine); m2'7G (N2,7-dimethylguanosine); m2'2'7G (N2,N2,7-trimethylguanosine); m3Um (3,2T-O-dimethyluridine); m5D (5-methyldihydrouridine); f5Cm (5-formyl-2'-O-methylcytidine); m1Gm (1,2'-O-dimethylguanosine); m'Am (1,2-O-dimethyl adenosine) irinomethyluridine); tm5s2U (S-taurinomethyl-2-thiouridine)); imG-14 (4-demethyl guanosine); imG2 (isoguanosine); ac6A (N6-acetyladenosine), hypoxanthine, inosine, 8-oxo-adenine, 7-substituted derivatives thereof, dihydrouracil, pseudouracil, 2-thiouracil, 4-thiouracil, 5-aminouracil, 5-(C_1-C_6)-alkyluracil, 5-methyluracil, 5-(C_2-C_6)-alkenyluracil, 5-(C_2-C_6)-alkynyluracil, 5-(hydroxymethyl)uracil, 5-chlorouracil, 5-fluorouracil, 5-bromouracil, 5-hydroxycytosine, 5-(C_1-C_6)-alkylcytosine, 5-methylcytosine, 5-(C_2-C_6)-alkenylcytosine, 5-(C_2-C_6)-alkynylcytosine, 5-chlorocytosine, 5-fluorocytosine, 5-bromocytosine, N^2-dimethylguanine, 7-deazaguanine, 8-azaguanine, 7-deaza-7-substituted guanine, 7-deaza-7-

(C2-C6)alkynylguanine, 7-deaza-8-substituted guanine, 8-hydroxyguanine, 6-thioguanine, 8-oxoguanine, 2-aminopurine, 2-amino-6-chloropurine, 2,4-diaminopurine, 2,6-diaminopurine, 8-azapurine, substituted 7-deazapurine, 7-deaza-7-substituted purine, 7-deaza-8-substituted purine, hydrogen (abasic residue), m5C, m5U, m6A, s2U, W, or 2'-O-methyl-U. Many of these modified nucleobases and their corresponding ribonucleosides are available from commercial suppliers. See, e.g., WO 2011/005799 .

[0153] If desired, the RNA molecule can contain phosphoramidate, phosphorothioate, and/or methylphosphonate linkages.

[0154] In some embodiments, the RNA molecule does not include modified nucleotides, *e.g.*, does not include modified nucleobases, and all of the nucleotides in the RNA molecule are conventional standard ribonucleotides A, U, G and C, with the exception of an optional 5' cap that may include, for example, 7-methylguanosine. In other embodiments, the RNA may include a 5' cap comprising a 7'-methylguanosine, and the first 1, 2 or 3 5' ribonucleotides may be methylated at the 2' position of the ribose.

A. Self-replicating RNA

[0155] In some aspects, the cationic oil in water emulsion contains a self-replicating RNA molecule. In certain embodiments, the self-replicating RNA molecule is derived from or based on an alphavirus.

[0156] Self-replicating RNA molecules are well known in the art and can be produced by using replication elements derived from, *e.g.*, alphaviruses, and substituting the structural viral proteins with a nucleotide sequence encoding a protein of interest. Cells transfected with self-replicating RNA briefly produce antigen before undergoing apoptotic death. This death is a likely result of requisite double-stranded (ds) RNA intermediates, which also have been shown to super-activate Dendritic Cells. Thus, the enhanced immunogenicity of self-replicating RNA may be a result of the production of pro-inflammatory dsRNA, which mimics an RNA-virus infection of host cells.

[0157] Advantageously, the cell's machinery is used by self-replicating RNA molecules to generate an exponential increase of encoded gene products, such as proteins or antigens, which can accumulate in the cells or be secreted from the cells. Overexpression of proteins or antigens by self-replicating RNA molecules takes advantage of the immunostimulatory adjuvant effects, including stimulation of toll-like receptors (TLR) 3, 7 and 8 and non TLR pathways (e.g, RIG-1, MD-5) by the products of RNA replication and amplification, and translation which induces apoptosis of the transfected cell.

[0158] The self-replicating RNA generally contains at least one or more genes selected from the group consisting of viral replicases, viral proteases, viral helicases and other nonstructural viral proteins, and also comprise 5'- and 3'-end *cis*-active replication sequences, and if desired, a heterologous sequences that encode a desired amino acid sequences (*e.g.*, an antigen of interest). A subgenomic promoter that directs expression of the heterologous sequence can be included in the self-replicating RNA. If desired, the heterologous sequence (*e.g.*, an antigen of interest) may be fused in frame to other coding regions in the self-replicating RNA and/or may be under the control of an internal ribosome entry site (IRES).

[0159] In certain embodiments, the self-replicating RNA molecule is not encapsulated in a virus-like particle. Self-replicating RNA molecules of the invention can be designed so that the self-replicating RNA molecule cannot induce production of infectious viral particles. This can be achieved, for example, by omitting one or more viral genes encoding structural proteins that are necessary for the production of viral particles in the self-replicating RNA. For example, when the self-replicating RNA molecule is based on an alpha virus, such as Sinebis virus (SIN), Semliki forest virus and Venezuelan equine encephalitis virus (VEE), one or more genes encoding viral structural proteins, such as capsid and/or envelope glycoproteins, can be omitted.

[0160] If desired, self-replicating RNA molecules of the invention can also be designed to induce production of infectious viral particles that are attenuated or virulent, or to produce viral particles that are capable of a single round of subsequent infection.

[0161] When delivered to a vertebrate cell, a self-replicating RNA molecule can lead to the production of multiple daughter RNAs by transcription from itself (or from an antisense copy of itself). The self-replicating RNA can be directly translated after delivery to a cell, and this translation provides a RNA-dependent RNA polymerase which then produces transcripts from the delivered RNA. Thus the delivered RNA leads to the production of multiple daughter RNAs. These transcripts are antisense relative to the delivered RNA and may be translated themselves to provide *in situ* expression of a gene product, or may be transcribed to provide further transcripts with the same sense as the delivered RNA which are translated to provide *in situ* expression of the gene product.

[0162] One suitable system for achieving self-replication is to use an alphavirus-based RNA replicon. Alphaviruses comprise a set of genetically, structurally, and serologically related arthropod-borne viruses of the Togaviridae family. Twenty-six known viruses and virus subtypes have been classified within the alphavirus genus, including, Sindbis virus, Semliki Forest virus, Ross River virus, and Venezuelan equine encephalitis virus. As such, the self-replicating RNA of the invention may incorporate a RNA replicase derived from semliki forest virus (SFV) , sindbis virus (SIN), Venezuelan equine encephalitis virus (VEE), Ross-River virus (RRV), or other viruses belonging to the alphavirus family.

[0163] An alphavirus-based "replicon" expression vectors can be used in the invention. Replicon vectors may be utilized in several formats, including DNA, RNA, and recombinant replicon particles. Such replicon vectors have been derived from alphaviruses that include, for example, Sindbis virus (Xiong et al. (1989) Science 243:1188-1191; Dubensky et al., (1996) J. Virol. 70:508-519; Hariharan et al. (1998) J. Virol. 72:950-958; Polo et al. (1999) PNAS 96:4598-4603), Semliki Forest virus (Liljestrom (1991) Bio/Technology 9:1356-1361; Berglund et al. (1998) Nat. Biotech. 16:562-565), and Venezuelan equine encephalitis virus (Pushko et al. (1997) Virology 239:389-401). Alphaviruses-derived replicons are generally quite similar in overall characteristics (e.g., structure, replication), individual alphaviruses may exhibit some particular property (e.g., receptor binding, interferon sensitivity, and disease profile) that is unique. Therefore, chimeric alphavirus replicons made from divergent virus families may also be useful.

[0164] Alphavirus-based replicons are (+)-stranded replicons that can be translated after delivery to a cell to give of a replicase (or replicase-transcriptase). The replicase is translated as a polyprotein which auto-cleaves to provide a replication complex which creates genomic (−)-strand copies of the +-strand delivered RNA. These (−)-strand transcripts can themselves be transcribed to give further copies of the (+)-stranded parent RNA and also to give a subgenomic transcript which encodes the desired gene product. Translation of the subgenomic transcript thus leads to *in situ* expression of the desired gene product by the infected cell. Suitable alphavirus replicons can use a replicase from a sindbis virus, a semliki forest virus, an eastern equine encephalitis virus, a venezuelan equine encephalitis virus, *etc.*

[0165] A preferred self-replicating RNA molecule thus encodes (i) a RNA-dependent RNA polymerase which can transcribe RNA from the self-replicating RNA molecule and (ii) a polypeptide antigen. The polymerase can be an alphavirus replicase *e.g.* comprising alphavirus protein nsP4.

[0166] Whereas natural alphavirus genomes encode structural virion proteins in addition to the non-structural replicase, it is preferred that an alphavirus based self-replicating RNA molecule of the invention does not encode alphavirus structural proteins. Thus the self-replicating RNA can lead to the production of genomic RNA copies of itself in a cell, but not to the production of RNA-containing alphavirus virions. The inability to produce these virions means that, unlike a wild-type alphavirus, the self-replicating RNA molecule cannot perpetuate itself in infectious form. The alphavirus structural proteins which are necessary for perpetuation in wild-type viruses are absent from self-replicating RNAs of the invention and their place is taken by gene(s) encoding the desired gene product, such that the subgenomic transcript encodes the desired gene product rather than the structural alphavirus virion proteins.

[0167] Thus a self-replicating RNA molecule useful with the invention may have two open reading frames. The first (5') open reading frame encodes a replicase; the second (3') open reading frame encodes a polypeptide antigen. In some embodiments the RNA may have additional (downstream) open reading frames *e.g.* that encode another desired gene products. A self-replicating RNA molecule can have a 5' sequence which is compatible with the encoded replicase.

[0168] In other aspects, the self-replicating RNA molecule is derived from or based on a virus other than an alphavirus, preferably, a positive-stranded RNA virus, and more preferably a picornavirus, flavivirus, rubivirus, pestivirus, hepacivirus, calicivirus, or coronavirus. Suitable wild-type alphavirus sequences are well-known and are available from sequence depositories, such as the American Type Culture Collection, Rockville, Md. Representative examples of suitable alphaviruses include Aura (ATCC VR-368), Bebaru virus (ATCC VR-600, ATCC VR-1240), Cabassou (ATCC VR-922), Chikungunya virus (ATCC VR-64, ATCC VR-1241), Eastern equine encephalomyelitis virus (ATCC VR-65, ATCC VR-1242), Fort Morgan (ATCC VR-924), Getah virus (ATCC VR-369, ATCC VR-1243), Kyzylagach (ATCC VR-927), Mayaro (ATCC VR-66), Mayaro virus (ATCC VR-1277), Middleburg (ATCC VR-370), Mucambo virus (ATCC VR-580, ATCC VR-1244), Ndumu (ATCC VR-371), Pixuna virus (ATCC VR-372, ATCC VR-1245), Ross River virus (ATCC VR-373, ATCC VR-1246), Semliki Forest (ATCC VR-67, ATCC VR-1247), Sindbis virus (ATCC VR-68, ATCC VR-1248), Tonate (ATCC VR-925), Triniti (ATCC VR-469), Una (ATCC VR-374), Venezuelan equine encephalomyelitis (ATCC VR-69, ATCC VR-923, ATCC VR-1250 ATCC VR-1249, ATCC VR-532), Western equine encephalomyelitis (ATCC VR-70, ATCC VR-1251, ATCC VR-622, ATCC VR-1252), Whataroa (ATCC VR-926), and Y-62-33 (ATCC VR-375).

[0169] The self-replicating RNA molecules of the invention are larger than other types of RNA (*e.g.* mRNA). Typically, the self-replicating RNA molecules of the invention contain at least about 4kb. For example, the self-replicating RNA can contain at least about 5kb, at least about 6kb, at least about 7kb, at least about 8kb, at least about 9kb, at least about 10kb, at least about 11kb, at least about 12kb or more than 12kb. In certain examples, the self-replicating RNA is about 4kb to about 12kb, about 5kb to about 12kb, about 6kb to about 12kb, about 7kb to about 12kb, about 8kb to about 12kb, about 9kb to about 12kb, about 10kb to about 12kb, about 11kb to about 12kb, about 5kb to about 11kb, about 5kb to about 10kb, about 5kb to about 9kb, about 5kb to about 8kb, about 5kb to about 7kb, about 5kb to about 6kb, about 6kb to about 12kb, about 6kb to about 11kb, about 6kb to about 10kb, about 6kb to about 9kb, about 6kb to about 8kb, about 6kb to about 7kb, about 7kb to about 11kb, about 7kb to about 10kb, about 7kb to about 9kb, about 7kb to about 8kb, about 8kb to about 11kb, about 8kb to about 10kb, about 8kb to about 9kb, about 9kb to about 11kb, about 9kb to about 10kb, or about 10kb to about 11kb.

[0170] The self-replicating RNA molecules of the invention may comprise one or more modified nucleotides (*e.g.*, pseudouridine, N6-methyladenosine, 5-methylcytidine, 5-methyluridine).

[0171] The self-replicating RNA molecule may encode a single polypeptide antigen or, optionally, two or more of polypeptide antigens linked together in a way that each of the sequences retains its identity (*e.g.*, linked in series) when expressed as an amino acid sequence. The polypeptides generated from the self-replicating RNA may then be produced as a fusion polypeptide or engineered in such a manner to result in separate polypeptide or peptide sequences.

[0172] The self-replicating RNA of the invention may encode one or more polypeptide antigens that contain a range of epitopes. Preferably epitopes capable of eliciting either a helper T-cell response or a cytotoxic T-cell response or both.

[0173] The self-replicating RNA molecules described herein may be engineered to express multiple nucleotide sequences, from two or more open reading frames, thereby allowing co-expression of proteins, such as a two or more antigens together with cytokines or other immunomodulators, which can enhance the generation of an immune response. Such a self-replicating RNA molecule might be particularly useful, for example, in the production of various gene products (*e.g.*, proteins) at the same time, for example, as a bivalent or multivalent vaccine.

[0174] The self-replicating RNA molecules of the invention can be prepared using any suitable method. Several suitable methods are known in the art for producing RNA molecules that contain modified nucleotides. For example, a self-replicating RNA molecule that contains modified nucleotides can be prepared by transcribing (*e.g., in vitro* transcription) a DNA that encodes the self-replicating RNA molecule using a suitable DNA-dependent RNA polymerase, such as T7 phage RNA polymerase, SP6 phage RNA polymerase, T3 phage RNA polymerase, and the like, or mutants of these polymerases which allow efficient incorporation of modified nucleotides into RNA molecules. The transcription reaction will contain nucleotides and modified nucleotides, and other components that support the activity of the selected polymerase, such as a suitable buffer, and suitable salts. The incorporation of nucleotide analogs into a self-replicating RNA may be engineered, for example, to alter the stability of such RNA molecules, to increase resistance against RNases, to establish replication after introduction into appropriate host cells ("infectivity" of the RNA), and/or to induce or reduce innate and adaptive immune responses.

[0175] Suitable synthetic methods can be used alone, or in combination with one or more other methods (*e.g.*, recombinant DNA or RNA technology), to produce a self-replicating RNA molecule of the invention. Suitable methods for *de novo* synthesis are well-known in the art and can be adapted for particular applications. Exemplary methods include, for example, chemical synthesis using suitable protecting groups such as CEM (Masuda *et* *al.*, (2007) *Nucleic Acids Symposium Series 51*:3-4), the β-cyanoethyl phosphoramidite method (Beaucage S L *et al.* (1981) *Tetrahedron Lett* 22:1859); nucleoside H-phosphonate method (Garegg P *et al.* (1986) *Tetrahedron Lett* 27:4051-4; Froehler B C *et al.* (1986) *Nucl Acid Res* 14:5399-407; Garegg P *et al.* (1986) *Tetrahedron Lett* 27:4055-8; Gaffney B L *et al.* (1988) *Tetrahedron Lett* 29:2619-22). These chemistries can be performed or adapted for use with automated nucleic acid synthesizers that are commercially available. Additional suitable synthetic methods are disclosed in Uhlmann *et al.* (1990) *Chem Rev* 90:544-84, and Goodchild J (1990) *Bioconjugate Chem* 1: 165. Nucleic acid synthesis can also be performed using suitable recombinant methods that are well-known and conventional in the art, including cloning, processing, and/or expression of polynucleotides and gene products encoded by such polynucleotides. DNA shuffling by random fragmentation and PCR reassembly of gene fragments and synthetic polynucleotides are examples of known techniques that can be used to design and engineer polynucleotide sequences. Site-directed mutagenesis can be used to alter nucleic acids and the encoded proteins, for example, to insert new restriction sites, alter glycosylation patterns, change codon preference, produce splice variants, introduce mutations and the like. Suitable methods for transcription, translation and expression of nucleic acid sequences are known and conventional in the art. (See generally, Current Protocols in Molecular Biology, Vol. 2, Ed. Ausubel, *et al.*, Greene Publish. Assoc. & Wiley Interscience, Ch. 13, 1988; Glover, DNA Cloning, Vol. II, IRL Press, Wash., D.C., Ch. 3, 1986; Bitter, *et al.*, in Methods in Enzymology 153:516-544 (1987); The Molecular Biology of the Yeast Saccharomyces, Eds. Strathern *et al.*, Cold Spring Harbor Press, Vols. I and II, 1982; and Sambrook *et al.*, Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Press, 1989.)

[0176] The presence and/or quantity of one or more modified nucleotides in a self-replicating RNA molecule can be determined using any suitable method. For example, a self-replicating RNA can be digested to monophosphates (*e.g.*, using nuclease P1) and dephosphorylated (*e.g.*, using a suitable phosphatase such as CIAP), and the resulting nucleosides analyzed by reversed phase HPLC (*e.g.*, usings a YMC Pack ODS-AQ column (5 micron, 4.6 X 250 mm) and elute using a gradient, 30% B (0-5 min) to 100 % B (5 – 13 min) and at 100 % B (13-40) min, flow Rate (0.7 ml/min), UV detection (wavelength: 260 nm), column temperature (30°C). Buffer A (20mM acetic acid – ammonium acetate pH 3.5), buffer B (20mM acetic acid – ammonium acetate pH 3.5 / methanol [90/10])).

[0177] Optionally, the self-replicating RNA molecules of the invention may include one or more modified nucleotides so that the self-replicating RNA molecule will have less immunomodulatory activity upon introduction or entry into a host cell (*e.g.*, a human cell) in comparison to the corresponding self-replicating RNA molecule that does not contain modified nucleotides.

[0178] If desired, the self-replicating RNA molecules can be screened or analyzed to confirm their therapeutic and prophylactic properties using various *in vitro* or *in vivo* testing methods that are known to those of skill in the art. For example, vaccines comprising self-replicating RNA molecule can be tested for their effect on induction of proliferation or effector function of the particular lymphocyte type of interest, *e.g.*, B cells, T cells, T cell lines, and T cell clones. For example, spleen cells from immunized mice can be isolated and the capacity of cytotoxic T lymphocytes to lyse autologous target cells that contain a self replicating RNA molecule that encodes a polypeptide antigen. In addition, T helper cell differentiation can be analyzed by measuring proliferation or production of TH1 (IL-2 and IFN-γ) and /or TH2 (IL-4 and IL-5) cytokines by ELISA or directly in CD4+ T cells by cytoplasmic cytokine staining and flow cytometry.

[0179] Self-replicating RNA molecules that encode a polypeptide antigen can also be tested for ability to induce humoral immune responses, as evidenced, for example, by induction of B cell production of antibodies specific for an antigen of interest. These assays can be conducted using, for example, peripheral B lymphocytes from immunized individuals. Such assay methods are known to those of skill in the art. Other assays that can be used to characterize the self-replicating RNA molecules of the invention can involve detecting expression of the encoded antigen by the target cells. For example, FACS can be used to detect antigen expression on the cell surface or intracellularly. Another advantage of FACS selection is that one can sort for different levels of expression; sometimes-lower expression may be desired. Other suitable method for identifying cells which express a particular antigen involve panning using monoclonal antibodies on a plate or capture using magnetic beads coated with monoclonal antibodies.

B. Antigens

[0180] In certain embodiments, the negatively charged molecule described herein is a nucleic acid molecule (e.g., an RNA molecule) that encodes an antigen. Suitable antigens include, but are not limited to, a bacterial antigen, a viral antigen, a fungal antigen, a protazoan antigen, a plant antigen, a cancer antigen, or a combination thereof.

[0181] Suitable antigens include proteins and peptides from a pathogen such as a virus, bacteria, fungus, protozoan, plant or from a tumor. Viral antigens and immunogens that can be encoded by the self-replicating RNA molecule include, but are not limited to, proteins and peptides from a Orthomyxoviruses, such as Influenza A, B and C; Paramyxoviridae viruses, such as Pneumoviruses (RSV), Paramyxoviruses (PIV), Metapneumovirus and Morbilliviruses (e.g., measles); Pneumoviruses, such as Respiratory syncytial virus (RSV), Bovine respiratory syncytial virus, Pneumonia virus of mice, and Turkey rhinotracheitis virus; Paramyxoviruses, such as Parainfluenza virus types 1 – 4 (PIV), Mumps virus, Sendai viruses, Simian virus 5, Bovine parainfluenza virus, Nipahvirus, Henipavirus and Newcastle disease virus; Poxviridae, including a Orthopoxvirus such as *Variola vera* (including but not limited to, *Variola major* and *Variola minor*); Metapneumoviruses, such as human metapneumovirus (hMPV) and avian metapneumoviruses (aMPV); Morbilliviruses, such as Measles; Picornaviruses, such as Enteroviruses, Rhinoviruses, Heparnavirus, Parechovirus, Cardioviruses and Aphthoviruses; Enteroviruseses, such as Poliovirus types 1, 2 or 3, Coxsackie A virus types 1 to 22 and 24, Coxsackie B virus types 1 to 6, Echovirus (ECHO) virus types 1 to 9, 11 to 27 and 29 to 34 and Enterovirus 68 to 71, Bunyaviruses, including a Orthobunyavirus such as California encephalitis virus; a Phlebovirus, such as Rift Valley Fever virus; a Nairovirus, such as Crimean-Congo hemorrhagic fever virus; Heparnaviruses, such as, Hepatitis A virus (HAV); Togaviruses (Rubella), such as a Rubivirus, an Alphavirus, or an Arterivirus; Flaviviruses, such as Tick-borne encephalitis (TBE) virus, Dengue (types 1, 2, 3 or 4) virus, Yellow Fever virus, Japanese encephalitis virus, Kyasanur Forest Virus, West Nile encephalitis virus, St. Louis encephalitis virus, Russian spring-summer encephalitis virus, Powassan encephalitis virus; Pestiviruses, such as Bovine viral diarrhea (BVDV), Classical swine fever (CSFV) or Border disease (BDV); Hepadnaviruses, such as Hepatitis B virus, Hepatitis C virus; Rhabdoviruses, such as a Lyssavirus (Rabies virus) and Vesiculovirus (VSV), Caliciviridae, such as Norwalk virus, and Norwalk-like Viruses, such as Hawaii Virus and Snow Mountain Virus; Coronaviruses, such as SARS, Human respiratory coronavirus, Avian infectious bronchitis (IBV), Mouse hepatitis virus (MHV), and Porcine transmissible gastroenteritis virus (TGEV); Retroviruses such as an Oncovirus, a Lentivirus or a Spumavirus; Reoviruses, as an Orthoreovirus, a Rotavirus, an Orbivirus, or a Coltivirus; Parvoviruses, such as Parvovirus B19; Delta hepatitis virus (HDV); Hepatitis E virus (HEV); Hepatitis G virus (HGV); Human Herpesviruses, such as, by way Herpes Simplex Viruses (HSV), Varicella-zoster virus (VZV), Epstein-Barr virus (EBV), Cytomegalovirus (CMV), Human Herpesvirus 6 (HHV6), Human Herpesvirus 7 (HHV7), and Human Herpesvirus 8 (HHV8); Papovaviruses, such as Papillomaviruses and Polyomaviruses, Adenoviruess and Arenaviruses.

[0182] In some embodiments, the antigen elicits an immune response against a virus which infects fish, such as: infectious salmon anemia virus (ISAV), salmon pancreatic disease virus (SPDV), infectious pancreatic necrosis virus (IPNV), channel catfish virus (CCV), fish lymphocystis disease virus (FLDV), infectious hematopoietic necrosis virus (IHNV), koi herpesvirus, salmon picorna-like virus (also known as picorna-like virus of atlantic salmon), landlocked salmon virus (LSV), atlantic salmon rotavirus (ASR), trout strawberry disease virus (TSD), coho salmon tumor virus (CSTV), or viral hemorrhagic septicemia virus (VHSV).

[0183] In some embodiments the antigen elicits an immune response against a parasite from the Plasmodium genus, such as *P.falciparum, P.vivax, P.malariae* or *P.ovale*. Thus the invention may be used for immunizing against malaria. In some embodiments the antigen elicits an immune response against a parasite from the Caligidae family, particularly those from the Lepeophtheirus and Caligus genera e.g. sea lice such as *Lepeophtheirus salmonis* or *Caligus rogercresseyi*.

[0184] Bacterial antigens and immunogens that can be encoded by the self-replicating RNA molecule include, but are not limited to, proteins and peptides from *Neisseria meningitides, Streptococcus pneumoniae, Streptococcus pyogenes, Moraxella catarrhalis, Bordetella pertussis, Burkholderia sp.* (e.g., *Burkholderia mallei, Burkholderia pseudomallei* and *Burkholderia cepacia*), *Staphylococcus aureus, Staphylococcus epidermis, Haemophilus influenzae, Clostridium tetani* (Tetanus), *Clostridium perfringens, Clostridium botulinums* (Botulism), *Cornynebacterium diphtheriae* (Diphtheria), *Pseudomonas aeruginosa, Legionella pneumophila, Coxiella burnetii, Brucella* sp. (e.g., *B. abortus, B. canis, B. melitensis, B. neotomae, B. ovis, B. suis and B. pinnipediae,), Francisella sp. (e.g., F. novicida, F. philomiragia* and *F. tularensis*), *Streptococcus agalactiae, Neiserria* *gonorrhoeae, Chlamydia trachomatis, Treponema pallidum* (Syphilis), *Haemophilus ducreyi, Enterococcus faecalis, Enterococcus faecium, Helicobacter pylori, Staphylococcus saprophyticus, Yersinia enterocolitica, E. coli* (such as enterotoxigenic *E. coli* (ETEC), enteroaggregative *E. coli* (EAggEC), diffusely adhering *E. coli* (DAEC), enteropathogenic *E. coli* (EPEC), extraintestinal pathogenic *E. coli* (ExPEC; such as uropathogenic *E.coli* (UPEC) and meningitis/sepsis-associated *E.coli* (MNEC)), and/or enterohemorrhagic *E. coli* (EHEC), *Bacillus anthracis* (anthrax), *Yersinia pestis* (plague), *Mycobacterium tuberculosis, Rickettsia, Listeria monocytogenes, Chlamydia pneumoniae, Vibrio cholerae, Salmonella typhi* (typhoid fever), *Borrelia burgdorfer, Porphyromonas gingivalis, Klebsiella, Mycoplasma pneumoniae*, etc.

[0185] Fungal antigens and immunogens that can be encoded by the self-replicating RNA molecule include, but are not limited to, proteins and peptides from Dermatophytres, including: *Epidermophyton floccusum, Microsporum audouini, Microsporum canis, Microsporum distortum, Microsporum equinum, Microsporum gypsum, Microsporum nanum, Trichophyton concentricum, Trichophyton equinum, Trichophyton gallinae, Trichophyton gypseum, Trichophyton megnini, Trichophyton mentagrophytes, Trichophyton quinckeanum, Trichophyton rubrum, Trichophyton schoenleini, Trichophyton tonsurans, Trichophyton verrucosum, T. verrucosum* var. album, var. discoides, var. ochraceum, *Trichophyton violaceum*, and/or *Trichophyton faviforme;* or from *Aspergillus fumigatus, Aspergillus flavus, Aspergillus niger, Aspergillus nidulans, Aspergillus terreus, Aspergillus sydowi, Aspergillus flavatus, Aspergillus glaucus, Blastoschizomyces capitatus, Candida albicans, Candida enolase, Candida tropicalis, Candida glabrata, Candida krusei, Candida parapsilosis, Candida stellatoidea, Candida kusei, Candida parakwsei, Candida lusitaniae, Candida pseudotropicalis, Candida guilliermondi, Cladosporium carrionii, Coccidioides immitis, Blastomyces dermatidis, Cryptococcus neoformans, Geotrichum clavatum, Histoplasma capsulatum, Klebsiella pneumoniae, Microsporidia, Encephalitozoon* spp., *Septata intestinalis* and *Enterocytozoon bieneusi*; the less common are *Brachiola* spp, *Microsporidium* spp., *Nosema* spp., *Pleistophora* spp., *Trachipleistophora* spp., *Vittaforma* spp *Paracoccidioides brasiliensis, Pneumocystis carinii, Pythiumn insidiosum, Pityrosporum ovale, Sacharomyces cerevisae, Saccharomyces boulardii, Saccharomyces pombe, Scedosporium apiosperum, Sporothrix schenckii, Trichosporon beigelii, Toxoplasma gondii, Penicillium marneffei, Malassezia spp., Fonsecaea spp., Wangiella spp., Sporothrix spp.,* *Basidiobolus spp., Conidiobolus spp., Rhizopus spp, Mucor spp, Absidia spp, Mortierella spp, Cunninghamella spp, Saksenaea spp., Alternaria spp, Curvularia spp, Helminthosporium spp, Fusarium spp, Aspergillus spp, Penicillium spp, Monolinia spp, Rhizoctonia spp, Paecilomyces spp, Pithomyces spp, and Cladosporium spp.*

[0186] Protazoan antigens and immunogens that can be encoded by the self-replicating RNA molecule include, but are not limited to, proteins and peptides from *Entamoeba histolytica, Giardia lambli, Cryptosporidium parvum, Cyclospora cayatanensis and Toxoplasma.*

[0187] Plant antigens and immunogens that can be encoded by the self-replicating RNA molecule include, but are not limited to, proteins and peptides from *Ricinus communis.*

[0188] Suitable antigens include proteins and peptides from a virus such as, for example, human immunodeficiency virus (HIV), hepatitis A virus (HAV), hepatitis B virus (HBV), hepatitis C virus (HCV), herpes simplex virus (HSV), cytomegalovirus (CMV), influenza virus (flu), respiratory syncytial virus (RSV), parvovorus, norovirus, human papilloma virus (HPV), rhinovirus, yellow fever virus, rabies virus, Dengue fever virus, measles virus, mumps virus, rubella virus, varicella zoster virus, enterovirus (e.g., enterovirus 71), ebola virus, and bovine diarrhea virus. Preferably, the antigenic substance is selected from the group consisting of HSV glycoprotein gD, HIV glycoprotein gp120, HIV glycoprotein gp 40, HIV p55 gag, and polypeptides from the pol and tat regions. In other preferred embodiments of the invention, the antigen is a protein or peptide derived from a bacterium such as, for example, *Helicobacter pylori, Haemophilus influenza, Vibrio cholerae* (cholera), *C. diphtheriae* (diphtheria), *C. tetani* (tetanus), *Neisseria meningitidis, B. pertussis, Mycobacterium tuberculosis*, and the like.

[0189] HIV antigens that can be encoded by the self-replicating RNA molecules of the invention are described in U.S. application Ser. No. 490,858, filed Mar. 9, 1990, and published European application number 181150 (May 14, 1986), as well as U.S. application Ser. Nos. 60/168,471; 09/475,515; 09/475,504; and 09/610,313

[0190] Cytomegalovirus antigens that can be encoded by the self-replicating RNA molecules of the invention are described in U.S. Pat. No. 4,689,225, U.S. application Ser. No.

367,363, filed Jun. 16, 1989 and PCT Publication WO 89/07143.

[0191] Hepatitis C antigens that can be encoded by the self-replicating RNA molecules of the invention are described in PCT/US88/04125, published European application number 318216 (May 31, 1989), published Japanese application number 1-500565 filed Nov. 18, 1988, and EPO 388,232. A different set of HCV antigens is described in European patent publication EP0388232 B1, and U.S. Patent No. 5,350,671, and PCT/US90/01348.

[0192] In some embodiments, the antigen is derived from an allergen, such as pollen allergens (tree-, herb, weed-, and grass pollen allergens); insect or arachnid allergens (inhalant, saliva and venom allergens, *e.g.* mite allergens, cockroach and midges allergens, hymenopthera venom allergens); animal hair and dandruff allergens (from *e.g.* dog, cat, horse, rat, mouse, *etc.*); and food allergens (*e.g.* a gliadin). Important pollen allergens from trees, grasses and herbs are such originating from the taxonomic orders of Fagales, Oleales, Pinales and platanaceae including, but not limited to, birch (Betula), alder (Alnus), hazel (Corylus), hornbeam (Carpinus) and olive (Olea), cedar (Cryptomeria and Juniperus), plane tree (Platanus), the order of Poales including grasses of the genera Lolium, Phleum, Poa, Cynodon, Dactylis, Holcus, Phalaris, Secale, and Sorghum, the orders of Asterales and Urticales including herbs of the genera Ambrosia, Artemisia, and Parietaria. Other important inhalation allergens are those from house dust mites of the genus Dermatophagoides and Euroglyphus, storage mite *e.g.* Lepidoglyphys, Glycyphagus and Tyrophagus, those from cockroaches, midges and fleas *e.g.* Blatella, Periplaneta, Chironomus and Ctenocepphalides, and those from mammals such as cat, dog and horse, venom allergens including such originating from stinging or biting insects such as those from the taxonomic order of Hymenoptera including bees (*Apidae*), wasps (*Vespidea*), and ants (*Formicoidae*).

[0193] In certain embodiments, a tumor immunogen or antigen, or cancer immunogen or antigen, can be encoded by the self-replicating RNA molecule. In certain embodiments, the tumor immunogens and antigens are peptide-containing tumor antigens, such as a polypeptide tumor antigen or glycoprotein tumor antigens.

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[0194] Tumor immunogens and antigens appropriate for the use herein encompass a wide variety of molecules, such as (a) polypeptide-containing tumor antigens, including polypeptides (which can range, for example, from 8-20 amino acids in length, although lengths outside this range are also common), lipopolypeptides and glycoproteins.

[0195] In certain embodiments, tumor immunogens are, for example, (a) full length molecules associated with cancer cells, (b) homologs and modified forms of the same, including molecules with deleted, added and/or substituted portions, and (c) fragments of the same. Tumor immunogens include, for example, class I-restricted antigens recognized by CD8+ lymphocytes or class II-restricted antigens recognized by CD4+ lymphocytes.

[0196] In certain embodiments, tumor immunogens include, but are not limited to, (a) cancer-testis antigens such as NY-ESO-1, SSX2, SCP1 as well as RAGE, BAGE, GAGE and MAGE family polypeptides, for example, GAGE-1, GAGE-2, MAGE-1, MAGE-2, MAGE-3, MAGE-4, MAGE-5, MAGE-6, and MAGE-12 (which can be used, for example, to address melanoma, lung, head and neck, NSCLC, breast, gastrointestinal, and bladder tumors), (b) mutated antigens, for example, p53 (associated with various solid tumors, e.g., colorectal, lung, head and neck cancer), p21/Ras (associated with, e.g., melanoma, pancreatic cancer and colorectal cancer), CDK4 (associated with, e.g., melanoma), MUM1 (associated with, e.g., melanoma), caspase-8 (associated with, e.g., head and neck cancer), CIA 0205 (associated with, e.g., bladder cancer), HLA-A2-R1701, beta catenin (associated with, e.g., melanoma), TCR (associated with, e.g., T-cell non-Hodgkins lymphoma), BCR-abl (associated with, e.g., chronic myelogenous leukemia), triosephosphate isomerase, KIA 0205, CDC-27, and LDLR-FUT, (c) over-expressed antigens, for example, Galectin 4 (associated with, e.g., colorectal cancer), Galectin 9 (associated with, e.g., Hodgkin's disease), proteinase 3 (associated with, e.g., chronic myelogenous leukemia), WT 1 (associated with, e.g., various leukemias), carbonic anhydrase (associated with, e.g., renal cancer), aldolase A (associated with, e.g., lung cancer), PRAME (associated with, e.g., melanoma), HER-2/neu (associated with, e.g., breast, colon, lung and ovarian cancer), alpha-fetoprotein (associated with, e.g., hepatoma), KSA (associated with, e.g., colorectal cancer), gastrin (associated with, e.g., pancreatic and gastric cancer), telomerase catalytic protein, MUC-1 (associated with, e.g., breast and ovarian cancer), G-250 (associated with, e.g., renal cell carcinoma), p53 (associated with, e.g., breast, colon cancer), and carcinoembryonic antigen (associated with, e.g., breast cancer, lung cancer, and cancers of the gastrointestinal tract such as colorectal cancer), (d) shared antigens, for example, melanoma-melanocyte differentiation antigens such as MART-1/Melan A, gp100, MC1R, melanocyte-stimulating hormone receptor, tyrosinase, tyrosinase related protein-1/TRP1 and tyrosinase related protein-2/TRP2 (associated with, e.g., melanoma), (e) prostate associated antigens such as PAP, PSA, PSMA, PSH-P1, PSM-P1, PSM-P2, associated with e.g., prostate cancer, (f) immunoglobulin idiotypes (associated with myeloma and B cell lymphomas, for example).

[0197] In certain embodiments, tumor immunogens include, but are not limited to, p15, Hom/Mel-40, H-Ras, E2A-PRL, H4-RET, IGH-IGK, MYL-RAR, Epstein Barr virus antigens, EBNA, human papillomavirus (HPV) antigens, including E6 and E7, hepatitis B and C virus antigens, human T-cell lymphotropic virus antigens, TSP-180, p185erbB2, p180erbB-3, c-met, mn-23H1, TAG-72-4, CA 19-9, CA 72-4, CAM 17.1, NuMa, K-ras, p16, TAGE, PSCA, CT7, 43-9F, 5T4, 791 Tgp72, beta-HCG, BCA225, BTAA, CA 125, CA 15-3 (CA 27.29\BCAA), CA 195, CA 242, CA-50, CAM43, CD68\KP1, CO-029, FGF-5, Ga733 (EpCAM), HTgp-175, M344, MA-50, MG7-Ag, MOV18, NB/70K, NY-CO-1, RCAS1, SDCCAG16, TA-90 (Mac-2 binding protein\cyclophilin C-associated protein), TAAL6, TAG72, TLP, TPS, and the like.

C. Formulations for the negatively charged molecule

[0198] The negatively charged molecule (such as RNA) is generally provided in the form of an aqueous solution, or a form that can be readily dissolved in an aqueous solution (*e.g.*, lyophilized). The aqueous solution can be water, or an aqueous solution that comprises a salt (*e.g.*, NaCl), a buffer (*e.g.*, a citrate buffer), a nonionic tonicifying agent (*e.g.*, a saccharide), a polymer, a surfactant, or a combination thereof. If the formulation is intended for *in vivo* administration, it is preferable that the aqueous solution is a physiologically acceptable buffer that maintains a pH that is compatible with normal physiological conditions. Also, in certain instances, it may be desirable to maintain the pH at a particular level in order to insure the stability of certain components of the formulation.

[0199] For example, it may be desirable to prepare an aqueous solution that is isotonic and/or isosmotic. Hypertonic and hypotonic solutions sometimes could cause complications and undesirable effects when injected, such as post-administration swelling or rapid absorption of the composition because of differential ion concentrations between the composition and physiological fluids. To control tonicity, the emulsion may comprise a physiological salt, such as a sodium salt. Sodium chloride (NaCl), for example, may be used at about 0.9% (w/v) (physiological saline). Other salts that may be present include potassium chloride, potassium dihydrogen phosphate, disodium phosphate dehydrate, magnesium chloride, calcium chloride, *etc.* In an exemplary embodiment, the aqueous solution comprises 10 mM NaCl and other salts or non-ionic tonicifying agents. As described herein, non-ionic tonicifying agents can also be used to control tonicity.

[0200] The aqueous solution may be buffered. Any physiologically acceptable buffer may be used herein, such as citrate buffers, phosphate buffers, acetate buffers, succinate buffer, tris buffers, bicarbonate buffers, carbonate buffers, or the like. The pH of the aqueous solution will preferably be between 6.0-8.0, more preferably about 6.2 to about 6.8. In some cases, certain amount of salt may be included in the buffer. In other cases, salt in the buffer might interfere with complexation of negatively charged molecule to the emulsion particle, and therefore is avoided.

[0201] The aqueous solution may also comprise additional components such as molecules that change the osmolarity of the aqueous solution or molecules that stabilizes the negatively charged molecule after complexation. For example, the osmolality can be adjusted using a non-ionic tonicifying agent, which are generally carbohydrates but can also be polymers. (See, e.g., Voet and Voet (1990) Biochemistry (John Wiley & Sons, New York.) Examples of suitable non-ionic tonicifying agents include sugars (*e.g.*, a monosaccharide, a disaccharide, or a polysaccharide, such as trehalose, sucrose, dextrose, fructose), sugar alcohols (*e.g.*, mannitol, sorbitol, xylitol, erythritol, lactitol, maltitol, glycerol, reduced palatinose), and combinations thereof. If desired, a nonionic polymer (*e.g.*, a poly(alkyl glycol), such as polyethylene glycol, polypropylene glycol, or polybutlyene glycol), or nonionic surfactant can be used. These types of agents, in particular sugar and sugar alcohols, are also cryoprotectants that can protect RNA, and other negatively charged molecules, when lyophilized. In exemplary embodiments, the buffer comprises from about 560 nM to 600 mM of trehalose, sucrose, sorbitol, or dextrose. In other exemplary embodiments, the buffer comprises from about 500 nM to 600 mM of trehalose, sucrose, sorbitol, or dextrose.

[0202] In some case, it may be preferable to prepare an aqueous solution comprising the negatively charged molecule as a hypertonic solution, and to prepare the cationic emulsion using unadulterated water or a hypotonic buffer. When the emulsion and the negatively charged molecule are combined, the mixture becomes isotonic. For example, an aqueous solution comprising RNA can be a 2X hypertonic solution, and the cationic emulsion can be prepared using 10mM Citrate buffer. When the RNA solution and the emulsion are mixed at 1:1 (v/v) ratio, the composition becomes isotonic. Based on desired relative amounts of the emulsion to the aqueous solution that comprises the negatively charged molecule (*e.g.*, 1:1 (v/v) mix, 2:1 (v/v) mix, 1:2 (v/v) mix, *etc.*), one can readily determine the tonicity of the aqueous solution that is required in order to achieve an isotonic mixture.

[0203] Similarly, compositions that have physiological osmolality may be desirable for *in vivo* administration. Physiological osmolality is from about 255 mOsm/kg water to about 315 mOsm/kg water. Sometimes, it may be preferable to prepare an aqueous solution comprising the negatively charged molecule as a hyperosmolar solution, and to prepare the cationic emulsion using unadulterated water or a hypoosmolar buffer. When the emulsion and the negatively charged molecule are combined, physiological osmolality is achieved. Based on desired relative amounts of the emulsion to the aqueous solution that comprises the negatively charged molecule (*e.g.*, 1:1 (v/v) mix, 2:1 (v/v) mix, 1:2 (v/v) mix, *etc.*), one can readily determine the osmolality of the aqueous solution that is required in order to achieve an iso-osmolar mixture.

[0204] In certain embodiments, the aqueous solution comprising the negatively charged molecule may further comprise a polymer or a surfactant, or a combination thereof. In an exemplary embodiment, the oil-in-water emulsion contains a poloxamer. In particular, the inventors have observed that adding Pluronic® F127 to the RNA aqueous solution prior to complexation to cationic emulsion particles led to greater stability and increased RNase resistance of the RNA molecule. Addition of pluronic F127 to RNA aqueous solution was also found to decrease the particle size of the RNA/CNE complex. Poloxamer polymers may also facilitate appropriate decomplexation/release of the RNA molecule, prevent aggregation of the emulsion particles, and have immune modulatory effect. Other polymers that may be used include, e.g., Pluronic® F68 or PEG300.

[0205] Alternatively or in addition, the aqueous solution comprising the negatively charged molecule may comprise from about 0.05% to about 20% (w/v) polymer.

For example, the cationic oil-in-water emulsion may comprise a polymer (e.g., a poloxamer such as Pluronic® F127, Pluronic® F68, or PEG300) at from about 0.05% to about 10% (w/v), such as 0.05%, 0.5%, 1%, or 5%.

[0206] The buffer system may comprise any combination of two or more molecules described above (salt, buffer, saccharide, polymer, *etc*). In an preferred embodiment, the buffer comprises 560 mM sucrose, 20 mM NaCl, and 2 mM Citrate, which can be mixed with a cationic oil in water emulsion described herein to produce a final aqueous phase that comprises 280 mM sucrose, 10 mM NaCl and 1 mM citrate.

5. METHODS OF PREPARATION

[0207] In another aspect, the invention provides a method of preparing the oil-in-water emulsions as described herein, comprising: (1) combining the oil and the cationic lipid to form the oil phase of the emulsion; (2) providing an aqueous solution to form the aqueous phase of the emulsion; and (3) dispersing the oil phase in the aqueous phase, for example, by homogenization. Homogenization may be achieved in any suitable way, for example, using a commercial homogenizer (e.g., IKA T25 homogenizer, available at VWR International (West Chester, PA).

[0208] In certain embodiments, the oil-in-water emulsions are prepared by (1) directly dissolving the cationic lipid in the oil to form an oil phase; (2) providing the aqueous phase of the emulsion; and (3) dispersing the oil phase in the aqueous phase by homogenization. The method does not use an organic solvent (such as chloroform ($CHCl_3$), dichloromethane (DCM), ethanol, acetone, Tetrahydrofuran (THF), 2,2,2 trifluoroethanol, acetonitrile, ethyl acetate, hexane, Dimethylformamide (DMF), Dimethyl sulfoxide (DMSO), etc.) to solubilize the cationic lipid first before adding the lipid to the oil.

[0209] It may be desirable to heat the oil to a temperature between about 37°C to about 65°C to facilitate the dissolving of the lipid. Desired amount of the cationic lipid (e.g., DOTAP) can be measured and added directly to the oil to reach a desired final concentration.

[0210] If the emulsion comprises one or more surfactants, the surfactant(s) may be included in the oil phase or the aqueous phase according to the conventional practice in the art. For example, SPAN85 can be dissolved in the oil phase (*e.g.*, squalene), and Tween 80 may be dissolved in the aqueous phase (*e.g.*, in a citrate buffer).

[0211] In another aspect, the invention provides a method of preparing a composition that comprises a negatively charged molecule (such as RNA) complexed with a particle of a cationic oil-in-water emulsion, comprising: (i) providing a cationic oil-in-water emulsion as described herein; (ii) providing a aqueous solution comprising the negatively charged molecule (such as RNA); and (iii) combining the oil-in-water emulsion of (i) and the aqueous solution of (iii), so that the negatively charged molecule complexes with the particle of the emulsion.

[0212] For example, a cationic oil-in-water emulsion may be combined with an aqueous RNA solution in any desired relative amounts, *e.g.*, about 1:1 (v/v), about 1.5:1 (v/v), about 2:1 (v/v), about 2.5:1 (v/v), about 3:1 (v/v), about 3.5:1 (v/v), about 4:1 (v/v), about 5:1 (v/v), about 10:1 (v/v), about 1:1.5 (v/v), about 1:2 (v/v), about 1:2.5 (v/v), about 1:3 (v/v), about 1:3.5 (v/v), about 1:4 (v/v), about 1:1.5 (v/v), or about 1:1.10 (v/v), *etc.*

[0213] Additional optional steps to promote particle formation, to improve the complexation between the negatively charge molecules and the cationic particles, to increase the stability of the negatively charge molecule (e.g., to prevent degradation of an RNA molecule), to facilitate appropriate decomplexation/release of the negatively charged molecules (such as an RNA molecule), or to prevent aggregation of the emulsion particles may be included. For example, a polymer (e.g., Pluronic® F127) or a surfactant may be added to the aqueous solution that comprises the negatively charged molecule (such as RNA).

[0214] The size of the emulsion particles can be varied by changing the ratio of surfactant to oil (increasing the ratio decreases particle size), operating pressure (increasing operating pressure reduces particle size), temperature (increasing temperature decreases particle size), and other process parameters. Actual particle size will also vary with the particular surfactant, oil, and cationic lipid used, and with the particular operating conditions selected. Emulsion particle size can be verified by use of sizing instruments, such as the commercial Sub-Micron Particle Analyzer (Model N4MD) manufactured by the Coulter Corporation, and the parameters can be varied using the guidelines set forth above until the average diameter of the particles is less than less than about 200 nm, less than about 150 nm, or less than about 100 nm. Preferably, the particles have an average diameter of about 180 nm or less, about 150 nm or less, about 140 nm or less, or about 130 nm or less, about 120 nm or less, or about 100 nm or less, from about 50 nm to 200 nm, from about 80 nm to 200 nm, from about 50 nm to 180 nm, from about 60 nm to 180 nm, from about 70 to 180 nm, or from about 80 nm to 180 nm, from about 80 nm to about 170 nm, from about 80 nm to about 160 nm, from about 80 nm to about 150 nm, from about 80 nm to about 140 nm, from about 80 nm to about 130 nm, from about 80 nm to about 120 nm, from about 80 nm to about 110 nm, or from about 80 nm to about 100 nm. Emulsions wherein the mean particle size is about 200 nm or less allow for sterile filtration.

[0215] Optional processes for preparing the cationic oil-in-water emulsion (pre-complexation emulsion), or the negatively charged molecule-emulsion complex, include, *e.g.*, sterilization, particle size selection (e.g., removing large particles), filling, packaging, and labeling, etc. For example, if the pre-complexation emulsion, or the negatively charged molecule-emulsion complex, is formulated for *in vivo* administration, it may be sterilized. For example, the formulation can be sterilized by filtering through a sterilizing grade filter (*e.g.*, through a 0.22 micron filter). Other sterilization techniques include a thermal process, or a radiation sterilization process, or using pulsed light to produce a sterile composition.

[0216] The cationic oil-in-water emulsion described herein can be used to manufacture vaccines. Sterile and/or clinical grade cationic oil-in-water emulsions can be prepared using similar methods as described for MF59. *See, e.g.*, Ott et al., Methods in Molecular Medicine, 2000, Volume 42, 211-228, in VACCINE ADJUVANTS (O'Hagan ed.), Humana Press. For example, similar to the manufacturing process of MF59, the oil phase and the aqueous phase of the emulsion can be combined and processed in a rotor stator homogenizer, or an inline homogenizer, to yield a coarse emulsion. The coarse emulsion can then be fed into a microfluidizer, where it can be further processed to obtain a stable submicron emulsion. The coarse emulsion can be passed through the interaction chamber of the microfluidizer repeatedly until the desired particle size is obtained. The bulk emulsion can then be filtered (*e.g.*, though a 0.22-μm filter under nitrogen) to remove large particles, yielding emulsion bulk that can be filled into suitable containers (*e.g.*, glass bottles). For vaccine antigens that have demonstrated long-term stability in the presence of oil-in-water emulsion for self storage, the antigen and emulsion may be combined and sterile-filtered (*e.g.*, though a 0.22-μm filter membrane). The combined single vial vaccine can be filled into single-dose containers. For vaccine antigens where long-term stability has not been demonstrated, the emulsion can be supplied as a separate vial. In such cases, the emulsion bulk can be filtered-sterilized (*e.g.*, though a 0.22-μm filter membrane), filled, and packaged in final single-dose vials.

[0217] Quality control may be optionally performed on a small sample of the emulsion bulk or admixed vaccine, and the bulk or admixed vaccine will be packaged into doses only if the sample passes the quality control test.

6. Kits, Pharmaceutical Compositions and Administration

[0218] In another aspect, the invention provides a pharmaceutical composition comprising a negatively charged molecule (such as RNA) complexed with a particle of a cationic oil-in-water emulsion, as described herein, and may further comprise one or more pharmaceutically acceptable carriers, diluents, or excipients. In preferred embodiments, the pharmaceutical composition is an immunogenic composition, which can be used as a vaccine.

[0219] Alternatively, the compositions described herein may be used to deliver a negatively charged molecule to cells. For example, nucleic acid molecules (*e.g.*, DNA or RNA) can be delivered to cells for a variety of purposes, such as to induce production of a desired gene product (e.g., protein), to regulate expression of a gene, for gene therapy and the like. The compositions described herein may also be used to deliver a nucleic acid molecule (e.g., DNA or RNA) to cells for therapeutic purposes, such as to treat a disease such as cancers or proliferative disorders, metabolic diseases, cardiovascular diseases, infections, allergies, to induce an immune response and the like. For example, nucleic acid molecules may be delivered to cells to inhibit the expression of a target gene. Such nucleic acid molecules include, e.g., antisense oligonucleotides, double-stranded RNAs, such as small interfering RNAs and the like. Double-stranded RNA molecules, such as small interfering RNAs, can trigger RNA interference, which specifically silences the corresponding target gene (gene knock down). Antisense oligonucleotides are single strands of DNA or RNA that are complementary to a chosen sequence. Generally, antisense RNA can prevent protein translation of certain messenger RNA strands by binding to them. Antisense DNA can be used to target a specific, complementary (coding or non-coding) RNA. Therefore, the cationic emulsions described herein are useful for delivering antisense oligonucleotides or double-stranded RNAs for treatment of, for example, cancer by inhibiting production of an oncology target.

[0220] The invention also provides kits, wherein the negatively charged molecule (such as RNA) and the cationic oil-in-water emulsion are in separate containers. For example, the kit can contain a first container comprising a composition comprising the negatively charged molecule (such as RNA), and a second container comprising cationic oil-in-water emulsion. The two components may be mixed prior to administration, *e.g.*, within about 72 hours, about 48 hours, about 24 hours, about 12 hours, about 10 hours, about 9 hours, about 8 hours, about 7 hours, about 6 hours, about 5 hours, about 4 hours, about 3 hours, about 2 hours, about 1 hour, about 45 minutes, about 30 minutes, about 15 minutes, about 10 minutes, about 5 minutes prior to administration. The two components may also be mixed about 1 minute or immediately prior to administration.

[0221] The negatively charged molecule (e.g., RNA) may be in liquid form or can be in solid form (*e.g.*, lyophilized). If in solid form, the kit may comprise a third container comprising a suitable aqueous solution to rehydrate the negatively charged molecule. Suitable aqueous solutions include pharmaceutically-acceptable buffers such as phosphate-buffered saline, Ringer's solution, dextrose solution, or any one of the aqueous solutions described above. In certain embodiments, sterile water may be used as the aqueous solution for rehydration, in particular in cases where additional components, such as tonicifying agents and/or osmolality adjusting agents are lyophilized along with the negatively charged molecule (e.g., RNA). Alternatively, the lyophilized negatively charged molecule (e.g., RNA) may be mixed directly with the cationic emulsion.

[0222] If the composition (e.g., a vaccine) comprises a negatively charged molecule (e.g., RNA) and an additional component, such as a protein immunogen, both components can be frozen and lyophilized (either separately, or as a mixture), and reconstituted and mixed with the cationic emulsion prior to administration.

[0223] The kit can further comprise other materials useful to the end-user, including other pharmaceutically acceptable formulating solutions such as buffers, diluents, filters, needles, and syringes or other delivery device. For example, the kit may include a dual chamber syringe that contain water or the emulsion in one chamber, and the negatively charged molecule (e.g., RNA) is provided in solid (e.g. lyophilized) form in the other chamber.

[0224] The kit may further include another container comprising an adjuvant (such as an aluminum containing adjuvant or MF59). In general, aluminum containing adjuvants are not preferred because they may interfere with the complexation of the negatively charged molecule with the cationic emulsion.

[0225] Suitable containers for the compositions include, for example, bottles, vials, syringes, and test tubes. Containers can be formed from a variety of materials, including glass or plastic. A container may have a sterile access port (for example, the container may be an intravenous solution bag or a vial having a stopper pierceable by a hypodermic injection needle). Dual-chamber syringe may also be used, wherein the negatively charged molecule (e.g., RNA) is lyophilized, and either reconstituted with water in the syringe, or reconstituted directly with a cationic emulsion described herein.

[0226] The kit can also comprise a package insert containing written instructions for methods of inducing immunity or for treating infections. The package insert can be an unapproved draft package insert or can be a package insert approved by the Food and Drug Administration (FDA) or other regulatory body.

[0227] The invention also provides a delivery device pre-filled with the compositions described above.

[0228] The pharmaceutical compositions provided herein may be administered singly or in combination with one or more additional therapeutic agents. The method of administration include, but are not limited to, oral administration, rectal administration, parenteral administration, subcutaneous administration, intravenous administration, intravitreal administration, intramuscular administration, inhalation, intranasal administration, topical administration, ophthalmic administration, or otic administration.

[0229] A therapeutically effective amount of the compositions described herein will vary depending on, among others, the disease indicated, the severity of the disease, the age and relative health of the subject, the potency of the compound administered, the mode of administration and the treatment desired.

[0230] In other embodiments, the pharmaceutical compositions described herein can be administered in combination with one or more additional therapeutic agents. The

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additional therapeutic agents may include, but are not limited to antibiotics or antibacterial agents, antiemetic agents, antifungal agents, anti-inflammatory agents, antiviral agents, immunomodulatory agents, cytokines, antidepressants, hormones, alkylating agents, antimetabolites, antitumour antibiotics, antimitotic agents, topoisomerase inhibitors, cytostatic agents, anti-invasion agents, antiangiogenic agents, inhibitors of growth factor function inhibitors of viral replication, viral enzyme inhibitors, anticancer agents, α-interferons, β-interferons, ribavirin, hormones, and other toll-like receptor modulators, immunoglobulins (Igs), and antibodies modulating Ig function (such as anti-IgE (omalizumab)).

[0231] In certain embodiments, the pharmaceutical compositions provided herein are used in the treatment of infectious diseases including, but not limited to, disease cased by the pathogens disclosed herein, including viral diseases such as genital warts, common warts, plantar warts, rabies, respiratory syncytial virus (RSV), hepatitis B, hepatitis C, Dengue virus, yellow fever, herpes simplex virus (by way of example only, HSV-I, HSV-II, CMV, or VZV), molluscum contagiosum, vaccinia, variola, lentivirus, human immunodeficiency virus (HIV), human papilloma virus (HPV), hepatitis virus (hepatitis C virus, hepatitis B virus, hepatitis A virus), cytomegalovirus (CMV), varicella zoster virus (VZV), rhinovirus, enterovirus (e.g. EV71), adenovirus, coronavirus (e.g., SARS), influenza, para-influenza, mumps virus, measles virus, rubella virus, papovavirus, hepadnavirus, flavivirus, retrovirus, arenavirus (by way of example only, LCM, Junin virus, Machupo virus, Guanarito virus and Lassa Fever) and filovirus (by way of example only, ebola virus or marburg virus).

[0232] In certain embodiments, the pharmaceutical compositions provided herein are used in the treatment of bacterial, fungal, and protozoal infections including, but not limited to, malaria, tuberculosis and mycobacterium avium, leprosy; pneumocystis carnii, cryptosporidiosis, histoplasmosis, toxoplasmosis, trypanosome infection, leishmaniasis, infections caused by bacteria of the genus *Escherichia, Enterobacter, Salmonella, Staphylococcus, Klebsiella, Proteus, Pseudomonas, Streptococcus, and Chlamydia*, and fungal infections such as candidiasis, aspergillosis, histoplasmosis, and cryptococcal meningitis.

[0233] In certain embodiments, the pharmaceutical compositions provided herein are used in the treatment of respiratory diseases and/or disorders, dermatological disorders,

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ocular diseases and/or disorders, genitourinary diseases and/or disorders including, allograft rejection, auto-immune and allergic, cancer, or damaged or ageing skin such as scarring and wrinkles.

[0234] In another aspect, the invention provides a method for generating or potentiating an immune response in a subject in need thereof, such as a mammal, comprising administering an effective amount of a composition as disclosed herein. The immune response is preferably protective and preferably involves antibodies and/or cell-mediated immunity. The method may be used to induce a primary immune response and/or to boost an immune response.

[0235] In certain embodiments, the compositions disclosed herein may be used as a medicament, *e.g.*, for use in raising or enhancing an immune response in a subject in need thereof, such as a mammal.

[0236] In certain embodiments, the compositions disclosed herein may be used in the manufacture of a medicament for generating or potentiating an immune response in a subject in need thereof, such as a mammal.

[0237] The mammal is preferably a human, but may be, *e.g.*, a cow, a pig, a chicken, a cat or a dog, as the pathogens covered herein may be problematic across a wide range of species. Where the vaccine is for prophylactic use, the human is preferably a child (*e.g.*, a toddler or infant), a teenager, or an adult; where the vaccine is for therapeutic use, the human is preferably a teenager or an adult. A vaccine intended for children may also be administered to adults, *e.g.*, to assess safety, dosage, immunogenicity, etc.

[0238] One way of checking efficacy of therapeutic treatment involves monitoring pathogen infection after administration of the compositions or vaccines disclosed herein. One way of checking efficacy of prophylactic treatment involves monitoring immune responses, systemically (such as monitoring the level of IgG1 and IgG2a production) and/or mucosally (such as monitoring the level of IgA production), against the antigen. Typically, antigen-specific serum antibody responses are determined post-immunization but pre-challenge whereas antigen-specific mucosal antibody responses are determined post-immunization and post-challenge.

[0239] Another way of assessing the immunogenicity of the compositions or vaccines disclosed herein where the nucleic acid molecule (e.g., the RNA) encodes a protein antigen is to express the protein antigen recombinantly for screening patient sera or mucosal secretions by immunoblot and/or microarrays. A positive reaction between the protein and the patient sample indicates that the patient has mounted an immune response to the protein in question. This method may also be used to identify immunodominant antigens and/or epitopes within protein antigens.

[0240] The efficacy of the compositions can also be determined *in vivo* by challenging appropriate animal models of the pathogen of interest infection.

[0241] Dosage can be by a single dose schedule or a multiple dose schedule. Multiple doses may be used in a primary immunization schedule and/or in a booster immunization schedule. In a multiple dose schedule the various doses may be given by the same or different routes, *e.g.*, a parenteral prime and mucosal boost, a mucosal prime and parenteral boost, etc. Multiple doses will typically be administered at least 1 week apart (*e.g.*, about 2 weeks, about 3 weeks, about 4 weeks, about 6 weeks, about 8 weeks, about 10 weeks, about 12 weeks, about 16 weeks, etc.).

[0242] In certain embodiments, the total amount of cationic lipid, such as DOTAP, that is administered to the subject in a single administration is no more than about 30 mg, or no more than about 24 mg.

[0243] In certain embodiments, the total amount of cationic lipid, such as DOTAP, that is administered to the subject in a single administration is no more than 4 mg.

[0244] The compositions disclosed herein that include one or more antigens or are used in conjunction with one or more antigens may be used to treat both children and adults. Thus a human subject may be less than 1 year old, 1-5 years old, 5-15 years old, 15-55 years old, or at least 55 years old. Preferred subjects for receiving the compositions are the elderly (*e.g.*, >50 years old, >60 years old, and preferably >65 years), the young (*e.g.*, <5 years old), hospitalized patients, healthcare workers, armed service and military personnel, pregnant women, the chronically ill, or immunodeficient patients. The compositions are not suitable solely for these groups, however, and may be used more generally in a population.

[0245] The compositions disclosed herein that include one or more antigens or are used in conjunction with one or more antigens may be administered to patients at substantially the same time as (*e.g.*, during the same medical consultation or visit to a healthcare professional or vaccination centre) other vaccines, *e.g.*, at substantially the same time as a measles vaccine, a mumps vaccine, a rubella vaccine, a MMR vaccine, a varicella vaccine, a MMRV vaccine, a diphtheria vaccine, a tetanus vaccine, a pertussis vaccine, a DTP vaccine, a conjugated *H. influenzae* type b vaccine, an inactivated poliovirus vaccine, a hepatitis B virus vaccine, a meningococcal conjugate vaccine (such as a tetravalent A C W135 Y vaccine), a respiratory syncytial virus vaccine, etc.

[0246] In certain embodiments, the compositions provided herein include or optionally include one or more immunoregulatory agents such as adjuvants. Exemplary adjuvants include, but are not limited to, a TH1 adjuvant and/or a TH2 adjuvant, further discussed below. In certain embodiments, the adjuvants used in the immunogenic compositions provide herein include, but are not limited to:

1. Mineral-Containing Compositions;
2. Oil Emulsions;
3. Saponin Formulations;
4. Virosomes and Virus-Like Particles;
5. Bacterial or Microbial Derivatives;
6. Bioadhesives and Mucoadhesives;
7. Liposomes;
8. Polyoxyethylene Ether and Polyoxyethylene Ester Formulations;
9. Polyphosphazene (PCPP);
10. Muramyl Peptides;
11. Imidazoquinolone Compounds;
12. Thiosemicarbazone Compounds;
13. Tryptanthrin Compounds;
14. Human Immunomodulators;
15. Lipopeptides;
16. Benzonaphthyridines;
17. Microparticles

18. Immunostimulatory polynucleotide (such as RNA or DNA; e.g., CpG-containing oligonucleotides)

EXEMPLIFICATION

[0247] The invention now being generally described, it will be more readily understood by reference to the following examples, which are included merely for purposes of illustration of certain aspects and embodiments of the present invention, and are not intended to limit the invention.

EXAMPLE 1: DEVELOPMENT OF CATIONIC OIL-IN-WATER EMULSIONS

[0248] In this Example, cationic nanoemulsions (referred herein as "CNEs") that contain high concentrations of cationic lipid (DOTAP) were developed for the delivery of self replicating RNA.

[0249] The CNE formulations are summarized in Table 1 below, and were modified based on CNE01. CNE01, CMF40, CNE16, CNE02, and CNE17 were used as reference samples for comparative studies.

Table 1

	CNE	**Cationic Lipid mg/mL**	**Surfactant**	**Squalene**	**oil:Lipid ratio (mole:mole)**	**Aqueous phase**
Ref. 1	**CNE01**	DOTAP (in $CHCl_3$) 0.8	0.5% SPAN 85 0.5% Tween 80	4.3%	91.7:1	10mM citrate buffer pH 6.5
Ref. 2	**CMF40**	DOTAP (no organic solvent) 1.0	0.5% SPAN 85 0.5% Tween 80	4.3%	73.3:1	10mM citrate buffer pH 6.5
Ref. 3	**CNE16**	DOTAP (no organic solvent) 1.2	0.5% SPAN 85 0.5% Tween 80	4.3%	61.1:1	10mM citrate buffer pH 6.5
Ref. 4	**CNE02**	DOTAP (no organic solvent) 1.6	0.5% SPAN 85 0.5% Tween 80	4.3%	45.8:1	10mM citrate buffer pH 6.5
Ref. 5	**CNE17**	DOTAP (in DCM) 1.4	0.5% SPAN 85 0.5% Tween 80	4.3%	52.4:1	10mM citrate buffer pH 6.5
Example 1	**CMF41**	DOTAP (no organic solvent) 1.8	0.5% SPAN 85 0.5% Tween 80	4.3%	40.7:1	10mM citrate buffer pH 6.5

Example 2	**CMF30**	DOTAP (no organic solvent) 2.0	0.5% SPAN 85 0.5% Tween 80	4.3%	36.7:1	10mM citrate buffer pH 6.5
Example 3	**CMF31**	DOTAP (no organic solvent) 2.6	0.5% SPAN 85 0.5% Tween 80	4.3%	28.2:1	10mM citrate buffer pH 6.5
Example 4	**CMF32**	DOTAP (no organic solvent) 3.2	0.5% SPAN 85 0.5% Tween 80	4.3%	22.9:1	10mM citrate buffer pH 6.5
Example 5	**CMF33**	DOTAP (no organic solvent) 3.8	0.5% SPAN 85 0.5% Tween 80	4.3%	19.3:1	10mM citrate buffer pH 6.5
Example 6	**CMF34**	DOTAP (no organic solvent) 4.4	0.5% SPAN 85 0.5% Tween 80	4.3%	16.7:1	10mM citrate buffer pH 6.5
Example 7	**CMF35**	DOTAP (no organic solvent) 5.0	0.5% SPAN 85 0.5% Tween 80	4.3%	14.7:1	10mM citrate buffer pH 6.5
Example 8	**CMF44**	DOTAP (no organic solvent) 4.4	0.5% SPAN 85 0.5% Tween 80	3.23%	12.5:1	10mM citrate buffer pH 6.5
Example 9	**CMF45**	DOTAP (no organic solvent) 4.4	0.5% SPAN 85 0.5% Tween 80	2.15%	8.4:1	10mM citrate buffer pH 6.5
Example 10	**CMF46**	DOTAP (no organic solvent) 4.4	0.5% SPAN 85 0.5% Tween 80	1.08%	4.2:1	10mM citrate buffer pH 6.5

[0250] CNEs were prepared similar to charged MF59 as previously described (Ott et al., Journal of Controlled Release, volume 79, pages 1-5, 2002), with one major modification. DOTAP was dissolved in the squalene directly, and no organic solvent was used. It was discovered that inclusion of a solvent in emulsions that contained greater than 1.6 mg/ml DOTAP produced a foamy feedstock that could not be microfluidized to produce an emulsion. Heating squalene to 37°C allowed DOTAP to be directly dissolved in squalene, and then the oil phase could be successfully dispersed in the aqueous phase (*e.g.*, by homogenization) to produce an emulsion. DOTAP is soluble in squalene and higher concentrations of DOTAP in squalene than those listed in Table 1 may be achieved.

However, it has been reported that high dose of DOTAP can have toxic effects. *See, e.g.*, Lappalainen et al., Pharm. Res., vol. 11(8):1127-31 (1994).

[0251] Briefly, squalene was heated to 37°C, and DOTAP was dissolved directly in squalene in the presence of SPAN 85. The resulting oil phase was then combined with the aqueous phase (Tween 80 in citrate buffer) and immediately homogenized for 2 min using an IKA T25 homogenizer at 24K RPM to produce a homogeneous feedstock (primary emulsions). The primary emulsions were passed three to five times through a M-110S Microfluidizer or a M-110P Microfluidizer (Microfluidics, Newton, MA) with an ice bath cooling coil at a homogenization pressure of approximately 15K-20K PSI. The 20ml batch samples were removed from the unit and stored at 4°C.

[0252] It should be noted that the concentrations of the components of the CNEs, as describes in Table 1, are concentrations calculated according the initial amounts of these components that were used to prepare the emulsions. It is understood that during the process of producing emulsions, or during the filter sterilization process, small amounts of squalene, DOTAP, or other components may be lost, and the actual concentrations of these components in the final product (*e.g.*, a packaged, sterilized emulsion that is ready for administration) might be slightly lower, typically by up to about 20%, sometimes by up to about 25%, or up to about 35%. However, the conventional practice in the art is to describe the concentration of a particular component based on the initial amount that is used to prepare the emulsion, instead of the actual concentration in the final product.

[0253] Table 2 below shows the difference between the "theoretical" concentrations of squalene and DOTAP (calculated according the initial amounts of squalene and DOTAP that were used to prepare the emulsions), and the actual concentrations of squalene and DOTAP as measured in the final product.

Table 2

CNE	Theoretical DOTAP (mg/mL)	Actual DOTAP (mg/mL)	% of Theoretical DOTAP Yield	Theoretical Squalene (mg/mL)	Actual Squalene (mg/mL)	% of Theoretical Squalene Yield
CMF32 Batch 1	3.2	2.20	68.76	43	19.33	44.95
CMF32 Batch 2	3.2	2.57	80.32	43	34.45	80.12
CMF32 Batch 3	3.2	2.37	73.95	43	38.38	89.25

CMF34 Batch 1	4.4	2.75	62.44	43	30.46	70.84
CMF34 Batch 2	4.4	3.21	73.00	43	33.98	79.02
CMF34 Batch 3	4.4	3.08	70.08	43	32.71	76.07
CMF34 Batch 4	4.4	3.52	79.93	43	28.95	67.34

EXAMPLE 2: PREPARATION RNA-PARTICLE COMPLEXES

1. RNA synthesis

[0254] Plasmid DNA encoding an alphavirus replicon (self-replicating RNA) was used as a template for synthesis of RNA *in vitro*. Each replicon contains the genetic elements required for RNA replication but lacks sequences encoding gene products that are necessary for particle assembly. The structural genes of the alphavirus genome were replaced by sequences encoding a heterologous protein (whose expression is driven by the alphavirus subgenomic promoter). Upon delivery of the replicons to eukaryotic cells, the positive-stranded RNA is translated to produce four non-structural proteins, which together replicate the genomic RNA and transcribe abundant subgenomic mRNAs encoding the heterologous protein. Due to the lack of expression of the alphavirus structural proteins, replicons are incapable of generating infectious particles. A bacteriophage T7 promoter is located upstream of the alphavirus cDNA to facilitate the synthesis of the replicon RNA *in vitro*, and the hepatitis delta virus (HDV) ribozyme located immediately downstream of the poly(A)-tail generates the correct 3'-end through its self-cleaving activity.

[0255] Following linearization of the plasmid DNA downstream of the HDV ribozyme with a suitable restriction endonuclease, run-off transcripts were synthesized *in vitro* using T7 or SP6 bacteriophage derived DNA-dependent RNA polymerase. Transcriptions were performed for 2 hours at 37°C in the presence of 7.5 mM (T7 RNA polymerase) or 5 mM (SP6 RNA polymerase) final concentration of each of the nucleoside triphosphates (ATP, CTP, GTP and UTP) following the instructions provided by the manufacturer (Ambion, Austin, TX). Following transcription, the template DNA was digested with TURBO DNase (Ambion, Austin, TX). The replicon RNA was precipitated with LiCl and reconstituted in nuclease-free water. Uncapped RNA was capped post-transcriptionally with Vaccinia Capping Enzyme (VCE) using the ScriptCap m^7G Capping System (Epicentre Biotechnologies, Madison, WI) as outlined in the user manual. Post-transcriptionally capped RNA was precipitated with LiCl and reconstituted in nuclease-free water. Alternatively, replicons may be capped by supplementing the transcription reactions with 6 mM (for T7 RNA polymerase) or 4 mM (for SP6 RNA polymerase) $m^7G(5')ppp(5')G$, a nonreversible cap structure analog (New England Biolabs, Beverly, MA) and lowering the concentration of guanosine triphosphate to 1.5 mM (for T7 RNA polymerase) or 1 mM (for SP6 RNA polymerase). The transcripts may be then purified by TURBO DNase (Ambion, Austin, TX) digestion followed by LiCL precipitation and a wash in 75% ethanol.

[0256] The concentration of the RNA samples was determined by measuring the optical density at 260 nm. Integrity of the *in vitro* transcripts was confirmed by denaturing agarose gel electrophoresis for the presence of the full length construct.

2. *RNA complexation*

[0257] The term N/P ratio refers to the amount of nitrogen in the cationic lipid in relation to the amount of phosphates on the RNA. The nitrogen is the charge bearing element within the cationic lipids tested. The phosphate can be found on the RNA backbone. An N/P charge ratio of 10/1 indicates that there are 10 positively charged nitrogen from the cationic lipid present for each negatively charged phosphate on the RNA.

[0258] The number of nitrogens in solution was calculated from the cationic lipid concentration, DOTAP for example has one nitrogen that can be protonated per molecule. The RNA concentration was used to calculate the amount of phosphate in solution using an estimate of 3 nmols of phosphate per microgram of RNA. By varying the amount of RNA : Lipid, the N/P ratio can be modified. RNA was complexed to the CNEs in a range of nitrogen / phosphate ratios (N/P). Calculation of the N/P ratio was done by calculating the number of moles of protonatable nitrogens in the emulsion per milliliter. To calculate the number of phosphates, a constant of 3 nmols of phosphate per microgram of RNA was used. After the values were determined, the appropriate ratio of the emulsion was added to the RNA. Using these values, the RNA was diluted to the appropriate concentration and added directly into an equal volume of emulsion while vortexing lightly. The solution was allowed to sit at room temperature for approximately 2 hours. Once complexed the resulting solution was diluted to the appropriate concentration and used within 1 hour.

3. *Particle size assay*

[0259] Particle size of the emulsion was measured using a Zetasizer Nano ZS (Malvern Instruments, Worcestershire, UK) according to the manufacturer's instructions. Particle sizes are reported as the Z-Average (ZAve) with the polydispersity index (pdi). All samples were diluted in water prior to measurements. Additionally, particle size of the emulsion was measured using Horiba LA-930 particle sizer (Horiba Scientific, USA). Samples were diluted in water prior to measurements. Zeta potential was measured using Zetasizer Nano ZS using diluted samples according to the manufacturer's instructions.

4. Viral replicon particles (VRP)

[0260] To compare RNA vaccines to traditional RNA-vectored approaches for achieving in vivo expression of reporter genes or antigens, we utilized viral replicon particles (VRPs) produced in BHK cells by the methods described by Perri et al., J. Virol, 77:10394-10403 (2003). In this system, the antigen (or reporter gene) replicons consisted of alphavirus chimeric replicons (VCR) derived from the genome of Venezuelan equine encephalitis virus (VEEV) engineered to contain the 3' terminal sequences (3' UTR) of Sindbis virus and a Sindbis virus packaging signal (PS) (see Fig. 2 of Perri S., et al., J Virol 77: 10394-10403 (2003)). These replicons were packaged into VRPs by co-electroporating them into baby hamster kidney (BHK) cells along with defective helper RNAs encoding the Sindbis virus capsid and glycoprotein genes (see Fig. 2 of Perri et al). The VRPs were then harvested and titrated by standard methods and inoculated into animals in culture fluid or other isotonic buffers.

EXAMPLE 3: THE EFFECT OF DOTAP CONCENTRATION ON IMMUNOGENICITY

[0261] This Example shows that cationic oil-in-water emulsions made with high concentrations of DOTAP increased the immunogenicity of an RNA replicon that encodes the RSV-F antigen in a mouse model.

1. Materials and Methods

Heparin binding assay

[0262] RNA was complexed as described above. The RNA/CNE complex was incubated with various concentrations of heparin sulfate (Alfa Aesar, Ward Hill MA) for 30 minutes at Room Temperature. The resulting solutions were then placed on an Airfuge high speed centrifuge (Beckman Coulter, Brea, CA) for 15 minutes. The centrifuge tubes were punctured with a tuberculin syringe and the subnatant was removed. The solution was then assayed for RNA concentration using the Ribogreen assay (Invitrogen, Carlsbad CA) according to the manufactures directions. The samples were analyzed on a Biotek Synergy 4 (Winooski, VT) fluorescent plate reader. Free RNA values were calculated using a standard curve.

2. The effect of DOTAP concentration on RNA-particle interactions

[0263] Table 3 shows the effect of DOTAP concentration on RNA-particle interactions (as determined by Heparin binding assay, which measured the tightness of the RNA-particle interactions) and immunogenicity.

Table 3

CNE	DOTAP concentration (mg/mL)	Heparin Binding Assay	
		N/P ratio	% of RNA release in 8X heparin Sulfate
CNE01	0.8	2:1	nt
		4:1	nt
		6:1	62.82
		8:1	54.18
		10:1	nt
		12:1	116.6
		14:1	62.79
CMF41	1.0	2:1	nt
		4:1	4.61
		6:1	33.41
		8:1	70.68
		10:1	54.92
		12:1	52.93
CNE16	1.2	2:1	nt
		4:1	1.83
		6:1	nt
		8:1	33.79
		10:1	58.86
		12:1	68.02
		14:1	55.07
CNE17	1.4	2:1	nt
		4:1	nt
		6:1	3.91
		8:1	44.00
		10:1	69.65
		12:1	61.53
		14:1	57.26

CNE	DOTAP concentration (mg/mL)	Heparin Binding Assay	
CNE02	1.6	2:1	nt
		4:1	nt
		6:1	2.01
		8:1	2.87
		10:1	7.38
		12:1	19.37
		14:1	21.44
CMF41	1.8	2:1	nt
		4:1	0.76
		6:1	1.33
		8:1	1.10
		10:1	2.69
		12:1	2.59
		14:1	3.67
CMF30	2.0	2:1	nt
		4:1	0.7
		6:1	0.81
		8:1	1.17
		10:1	2.35
		12:1	5.15
		14:1	9.44
CMF30	2.6	2:1	nt
		4:1	nt
		6:1	0.83
		8:1	1.18
		10:1	1.00
		12:1	0.96
		14:1	1.10

nt = not tested.

[0264] As shown in Table 3, RNA molecules bound strongly to emulsion particles that were made with high concentrations of DOTAP (1.8 mg/mL or higher).

3. The effect of DOTAP concentration on RNA loading

[0265] Table 4 shows the effect of DOTAP concentration on RNA loading. Increasing the concentration of DOTAP resulted in higher amount of RNA molecules being formulated into RNA-particle complexes.

Table 4

CNE	CNE17	CMF41	CMF30	CMF31	CMF32	CMF33	CMF34	CMF35
DOTAP (in 0.5ml emulsion)	0.35mg	0.45mg	0.5mg	0.65mg	0.8mg	0.95mg	1.1mg	1.25mg

N/P ratio	Amount of RNA (µg)							
4 to 1	41.8	53.7	59.6	77.5	95.4	113.3	131.2	149.1
6 to 1	27.8	35.8	39.8	51.7	63.6	75.6	87.5	99.4
8 to 1	20.9	26.8	29.8	38.8	47.7	56.7	65.6	74.6
10 to 1	16.7	21.5	23.9	31	38.2	45.3	52.5	59.6
12 to 1	13.9	17.9	19.9	25.8	31.8	37.8	43.7	49.7
14 to 1	11.9	15.3	17	22.2	27.3	32.4	37.5	42.6

4. The effect of DOTAP concentration on immunogenicity

[0266] Table 5 shows the effect of DOTAP concentration on the immunogenicity of the RSV F antigen in an *in vivo* mouse model.

[0267] The vA317 replicon that expresses the surface fusion glycoprotein of RSV (RSV-F) was used for this study. BALB/c mice, aged 8-10 weeks and weighing about 20 g, 10 animals per group, were given bilateral intramuscular vaccinations. All animals were injected in the quadriceps in the two hind legs each getting an equivalent volume (50 µL per leg) on days 0 and 21 with naked self-replicating RNA expressing RSV-F (vA317, 1 µg), 1µg of A317 formulated in a liposome that contained 40% DlinDMA, 10% DSPC, 48% Chol, 2% PEG DMG 2000 (RV01(15)), or self-replicating RNA formulated in the indicated CNEs (1 µg vA317). For each administration, the formulations were freshly prepared. Serum was collected for antibody analysis on days 14 (2wp1) and 35 (2wp2).

Table 5

CNE ([ ] DOTAP)	RNA (µg /0.5mL)	N/P ratio	DOTAP (mg/0.5mL)	2wp1 GMT (Pooled)	2wp2 GMT	2wp2/2wp1 ratio
1µg vA317	-	-	-	764	344	0.5
1µg RV01(15)	-	-	-	3898	66348	17.0
CNE01 (0.8mg/mL)	9.55	10:1	0.20	163	993	6.1
CMF40 (1.0mg/mL)	11.93	10:1	0.25	505	3350	6.6
CNE16 (1.2mg/mL)	14.32	10:1	0.30	465	3851	8.3
CNE17 (1.4mg/mL)	16.70	10:1	0.35	843	3638	4.3
CNE02 (1.6mg/mL)	19.09	10:1	0.40	1253	5507	4.4
CMF41 (1.8mg/mL)	21.48	10:1	0.45	961	5132	5.3
CMF30 (2.0mg/mL)	23.86	10:1	0.50	2021	10068	5.0

CMF31 (2.6mg/mL)	31.02	10:1	0.65	1557	11940	7.7
CMF32 (3.2mg/mL)	38.18	10:1	0.80	1124	6941	6.2

[0268] As shown in Table 5, increasing DOTAP concentration resulted in higher amount of RNA being loaded to the emulsion particles, which in turn increased the host immune response. A 3-fold increase in antibody titer (at 2wp2) for CMF31 was observed as compared to CNE17. In this model, a plateau in immunogenicity was observed at 2.6mg/mL DOTAP (CMF31).

[0269] When the amounts of RNA and DOTAP administered to each mouse were held constant (meaning for emulsions with higher concentrations of DOTAP, smaller volumes of emulsion were used to prepare the RNA/emulsion complex; then, prior to immunization, the RNA/emulsion formulations were diluted such that the volumes of the RNA/emulsion formulations injected to the mice were the same), F-specific total IgG titers were comparable with different CNE formulations (Table 6). vA317 replicon was used for all CNE formulations. RNAs were made with Ambion kit. The GMT data reflect the geometric mean titer of individual mice in each group (8 mice/group). The result shows that smaller amount of the formulations were needed for emulsions with higher concentrations of DOTAP.

Table 6

Formulation	RNA (µg/dose)	N/P ratio	DOTAP (µg/dose)	Squalene (mg/dose)	2wp1 GMT	2wp2 GMT	2wp2/2wp1 (boost)	% of max geo mean titer, 2wp2
Naked RNA	1	--	--	--	764	334	0	0
RV01 particles	1	--	--	--	3898	66348	17	-
CNE17	1	10:1	21	0.65	673	5314	8	41
CMF41	1	10:1	21	0.50	784	7083	9	55
CMF30	1	10:1	21	0.45	492	8543	17	66
CMF31	1	10:1	21	0.35	1123	6972	6	54
CMF32	1	10:1	21	0.28	1665	10498	6	82
CMF33	1	10:1	21	0.24	1351	12279	9	96
CMF34	1	10:1	21	0.20	936	12851	14	100
CMF35	1	10:1	21	0.18	628	7766	12	60

Titers from pre-immunization serum contained undetectable titers.

[0270] When the amount of squalene and N/P ratio (DOTAP:RNA) administered to each mouse were held constant, F-specific total IgG titers increased as the amount of RNA and DOTAP in the formulations increased (Table 7). The vA317 replicon was used for all CNE formulations. RNAs were made with Ambion kit. The GMT data reflect the geometric mean titer of individual mice in each group (8 mice/group). The result shows that increasing DOTAP concentration resulted in higher amount of RNA being loaded to the emulsion particles, which in turn increased the host immune response.

Table 7

Formulation	RNA (µg/dose)	N/P ratio	DOTAP (µg/dose)	Squalene (mg/dose)	2wp1 GMT	2wp2 GMT	2wp2/2wp1 (boost)	% of max geo mean titer, 2wp2
Naked	11.9	--	--	--	14	682	49	2
RV01 particles	3.3	--	--	--	3767	64889	17	-
RV01 particles	11.9	--	--	--	6562	102359	16	-
CNE17	0	--	70	2.15	5	5	1	1
CMF35	0	--	250	2.15	10	5	1	1
CNE17	3.3	10:1	70	2.15	223	8567	38	25
CMF41	4.3	10:1	90	2.15	974	7020	7	21
CMF30	4.8	10:1	100	2.15	1212	10999	9	33
CMF31	6.2	10:1	130	2.15	874	15142	17	45
CMF32	7.6	10:1	160	2.15	1816	22239	12	66
CMF33	9.1	10:1	190	2.15	1862	17445	9	52
CMF34	10.5	10:1	220	2.15	1302	33634	26	100
CMF35	11.9	10:1	250	2.15	1554	24971	16	74
Naïve	--	--	--	--	5	5	1	0

[0271] CMF32 and CMF34 were further studied using different N/P ratios. Table 8 shows the F-specific total IgG titers of the formulations. Theoretical N/P ratios reflect the N/P ratios calculated according to the initial amounts of DOTAP and RNA that were used to prepare the formulations. Actual N/P ratios were slightly lower than theoretical N/P ratios because small amounts of DOTAP were lost during preparation of the emulsions. The vA317 was used for all CNE and CMF formulations. The GMT data reflect the mean $\log_{10}$ titer of individual mice in each group (8 mice/group). All formulations were adjusted to 300 mOsm/kg with sucrose. There were no obvious tolerability issues observed (e.g., body weight, early serum cytokines) with either CMF32 or CMF34 formulations.

[0272] Actual N/P ratios were determined by quantifying DOTAP content in CNE or CMF batches using HPLC with a charged aerosol detector (Corona Ultra, Chelmsford, MA). The CNE and CMF samples were diluted in isopropanol and injected onto a XTera C18 4.6 x 150mm 3.5um column (Waters, Milford, MA). The area under the curve was taken from the DOTAP peak in the chromatogram and the concentration was interpolated off a DOTAP standard curve. Using the actual DOTAP concentration, an actual N/P ratio was be calculated.

Table 8

Formulation	RNA (μg/dose)	Theoretical N/P ratio	Actual N/P ratio	2wp1 GMT	2wp1 GMT	2wp2/2wp1 (boost)
Naked	1	--	--	68	1019	15
RV01	1	--	--	9883	68116	7
CNE17	1	10:1	--	1496	6422	4
CMF32	1	12:1	9.4:1	2617	14246	5
	1	10:1 (batch 1)	6.0:1	1537	10575	7
	1	10:1 (batch 2)	8.0:1	2047	16244	8
	1	8:1	6.3:1	2669	7656	3
	1	6:1	4.7:1	1713	4715	3
	1	4:1	3.1:1	872	3773	4
CMF34	1	12:1	7.4:1	3141	10134	3
	1	10:1 (batch 1)	6.1:1	1906	11081	6
	1	10:1 (batch 2)	7.0:1	2388	9857	4
	1	8:1	5:1	1913	8180	4
	1	6:1	3.7:1	1764	6209	4
	1	4:1	2.5:1	1148	4936	4

EXAMPLE 4: THE EFFECT OF DOTAP CONCENTRATION ON IMMUNOGENICITY

[0273] This Example shows that cationic oil-in-water emulsions made with high concentrations of DOTAP increased the immunogenicity of an RNA replicon that encodes the RSV-F antigen in a cotton rat model.

1. Materials and Methods

[0274] *RNA replicon.* The sequence of the RNA replicon, vA142 RSV-F-delFP-full ribozyme

[0275] *Vaccination of cotton rats.* Female cotton rats (*Sigmodon hispidis*) were obtained from Harlan Laboratories. All studies were approved and performed according to Novartis Animal Care and Use Committee. Groups of animals were immunized intramuscularly (i.m., 100 μl) with the indicated vaccines on day 0. Serum samples were collected 3 weeks after each immunization. Immunized or unvaccinated control animals were challenged intranasally (i.n.) with 1×10^5 PFU RSV 4 weeks after the final immunization.

[0276] *RSV-F trimer subunit vaccine.* The RSV F trimer is a recombinant protein comprising the ectodomain of RSV F with a deletion of the fusion peptide region preventing association with other trimers. The resulting construct forms a homogeneous trimer, as observed by size exclusion chromatography, and has an expected phenotype consistent with a postfusion F conformation as observed by electron microscopy. The protein was expressed in insect cells or CHO cells and purified by virtue of a HIS-tagged in fusion with the construct's C-terminus followed by size exclusion chromatography using conventional techniques. The resulting protein sample exhibits greater than 95% purity. For the in vivo evaluation of the F-subunit vaccine, 100 μg/mL trimer protein was adsorbed on 2 mg/mL alum using 10 mM Histidine buffer, pH 6.3 and isotonicity adjusted with sodium chloride to 150 mM. F-subunit protein was adsorbed on alum overnight with gentle stirring at 2-8 °C.

[0277] *RSV F-specific ELISA.* Individual serum samples were assayed for the presence of RSV F-specific IgG by enzyme-linked immunosorbent assay (ELISA). ELISA plates (MaxiSorp 96-well, Nunc) were coated overnight at 4°C with 1 μg/ml purified RSV F (delp23-furdel-trunc uncleaved) in PBS. After washing (PBS with 0.1% Tween-20), plates were blocked with Superblock Blocking Buffer in PBS (Thermo Scientific) for at least 1.5 hr at 37°C. The plates were then washed, serial dilutions of serum in assay diluent (PBS with 0.1% Tween-20 and 5% goat serum) from experimental or control cotton rats were added, and plates were incubated for 2 hr at 37°C. After washing, plates were incubated with horse radish peroxidase (HRP)-conjugated chicken anti-cotton rat IgG (Immunology Consultants Laboratory, Inc, diluted 1:5,000 in assay diluent) for 1 hr at 37°C. Finally, plates were washed and 100 μl of TMB peroxidase substrate solution (Kirkegaard & Perry Laboratories, Inc) was added to each well. Reactions were stopped by addition of 100 μl of 1M H_3PO_4, and absorbance was read at 450 nm using a plate reader. For each serum sample, a plot of optical density (OD) versus logarithm of the reciprocal serum dilution was generated by nonlinear regression (GraphPad Prism). Titers were defined as the reciprocal serum dilution at an OD of approximately 0.5 (normalized to a standard, pooled sera from RSV-infected cotton rats with a defined titer of 1:2500, that was included on every plate).

[0278] *Micro neutralization assay.* Serum samples were tested for the presence of neutralizing antibodies by a plaque reduction neutralization test (PRNT). Two-fold serial dilutions of HI-serum (in PBS with 5% HI-FBS) were added to an equal volume of RSV Long previously titered to give approximately 115 PFU/25 μl. Serum/virus mixtures were incubated for 2 hours at 37°C and 5% CO2, to allow virus neutralization to occur, and then 25 μl of this mixture (containing approximately 115 PFU) was inoculated on duplicate wells of HEp-2 cells in 96 well plates. After 2 hr at 37°C and 5% CO2, the cells were overlayed with 0.75% Methyl Cellulose/ EMEM 5% HI-FBS and incubated for 42 hours. The number of infectious virus particles was determined by detection of syncytia formation by immunostaining followed by automated counting. The neutralization titer is defined as the reciprocal of the serum dilution producing at least a 60% reduction in number of synctia per well, relative to controls (no serum).

2. The effect of DOTAP concentration on immunogenicity

[0279] Table 9 shows the effect of DOTAP concentration on the immunogenicity of the RSV F antigen in an *in vivo* cotton rat model. The first two vaccination used the RNA/CNE formulations as shown in Table 9. For the third vaccination, 3 μg of RSV F subunit protein (in alum) were used for all animals except the naïve group.

Table 9

Formulation	RNA (μg/dose)	3wp1 F-specific total IgG titers	3wp2 F-specific total IgG titers	3wp3 F-specific total IgG titers	3wp1 F-specific Neutralizing IgG titers	3wp2 F-specific Neutralizing IgG titers	3wp3 F-specific Neutralizing IgG titers
6ug F-trimer + Alum	--	16,373	64,928	84,133	327	3,565	3979

Formulation	RNA (μg/dose)	3wp1 F-specific total IgG titers	3wp2 F-specific total IgG titers	3wp3 F-specific total IgG titers	3wp1 F-specific Neutralizing IgG titers	3wp2 F-specific Neutralizing IgG titers	3wp3 F-specific Neutralizing IgG titers
1E6 IU/ 200ul VRP	--	2819	2,478	15,473	135	299	1791
CNE17 (Ambion MegaScript RNA)	0.01	112	771	23,939	28	66	689
	0.1	351	1,505	19,495	41	173	1060
	1	722	2,379	22,075	82	249	2550
CMF31 (Ambion MegaScript RNA)	0.01	184	1,015	31,082	31	67	1301
	0.1	375	1,250	16,597	51	99	2393
	1	1013	2,736	20,861	199	341	2783
	10	4556	6,867	27,299	253	672	3593
CMF34 (Ambion MegaScript RNA)	0.01	214	690	25,470	35	38	1440
	0.1	411	1,574	19,030	45	129	1835
	1	953	2,248	18,894	75	353	3224
	10	4,804	5,122	16,566	282	521	3738
CNE17 (In house synthesized RNA)	1	1,042	2,944	23,097	128	288	2086
Naïve	5	5	5	5	0	10	10

Ambion MegaScript RNA and in house synthesized RNA were prepared using different processes.

[0280] Data from Table 9 show that all CNE-RNA formulations induced dose-dependent immune responses in the hosts (total IgG titers as well as neutralizing antibody titers). Administering CMF31-RNA and CMF34-RNA formulations produced similar F-specific total IgG titers, and each was greater than that of CNE17 at each of the indicated RNA dose. In addition, all CNE-RNA formulations induced good neutralizing antibody titers at 10 μg RNA. Neutralizing antibody titers for the CMF31-RNA, CMF34-RNA, and CNE17-RNA groups were similar, except for surprisingly high titer for the 1 μg RNA/CMF31 group.

[0281] **EXAMPLE 5: ASSESSING THE EFFECTS OF BUFFER COMPOSITIONS ON IMMUNOGENICITY**

[0282] In this example, various emulsions based on CMF34 but with different buffer components were prepared.

[0283] Table 10 summarizes the results of murine immunogenicity studies when CMF34-formulated RNAs were prepared using different buffer systems.

Table 10

Group #	Description			2wp1	2wp2	2wp2/2wp1 ratio
	RNA	Emulsion	N/P ratio			
1	1 μg RSV-F*	PBS	-	100	2269	23
2	RV01 (15)	PBS	-	8388	105949	13
3	1 μg RSV-F*	CNE17 with 280mM Sucrose	10:1	898	9384	10
4		CMF34 with 280mM Sucrose	10:1	1835	10853	6
5		CMF34 with 280mM Sucrose and 1mM citrate	10:1	1751	15589	9
6		CMF34 with 280mM Sucrose and 10mM citrate	10:1	1699	17078	10
7		CMF34 with 280mM Sucrose, 1mM citrate, and 2mM NaCl	10:1	1342	16400	12
8		CMF34 with 280mM Sucrose, 10mM citrate, and 2mM NaCl	10:1	1318	10467	8
9		CMF34 with 280mM Sucrose, 1mM citrate, and 10mM NaCl	10:1	1735	12457	7
10		CMF34 with 280mM Sucrose, 10mM citrate, and 10mM NaCl	10:1	1365	14414	11

*vA375 replicon.

EXAMPLE 6: STABILITY OF THE EMULSIONS

[0284] Stability of CMF34 was assessed by measuring the average diameter of the emulsion particles and polydispersity after the emulsion was produced (T = 0) and after 1 month at 4°C (T = 1 month) and after 2 months at 4°C (T = 1 month). Stability was also assessed after 3, 6 and 12 months at 4°C. The results presented in Table 11 show that the emulsion was stabile for at least 12 months.

Table 11

	T = 0	T = 1 month	T = 2 months	T = 3 months	T = 6 months	T = 12 months
NanoZS (nm)	101.4	100.6	99.76	99.23	101.0	101.0
Polydispersity	0.109	0.102	0.096	0.103	0.080	0.094

EXAMPLE 7 Immunogenicity of Replicons Encoding Herpes Virus Proteins

A. CMV Proteins

[0285] Bicistronic and pentacistronic alphavirus replicons that express glycoprotein complexes from human cytomegalovirus (HCMV) were prepared, and are shown schematically in FIGS. 1 and 3. The alphavirus replicons were based on venezuelan equine encephalitis virus (VEE). The replicons were packaged into viral replicon particles (VRPs), encapsulated in lipid nanoparticles (LNP), or formulated with CMF34. Expression of the encoded HCMV proteins and protein complexes from each of the replicons was confirmed by immunoblot, co-immunoprecipitation, and flow cytometry. Flow cytometry was used to verify expression of the pentameric gH/gL/UL128/UL130/UL131 complex from pentameric replicons encoding the protein components of the complex, using human monoclonal antibodies specific to conformational epitopes present on the pentameric complex (Macagno et al (2010), J. Virol. 84(2):1005-13). FIG. 2 shows that these antibodies bind to BHKV cells transfected with replicon RNA expressing the HCMV gH/gL/UL128/UL130/UL131 pentameric complex (A527). Similar results were obtained when cells were infected with VRPs made from the same replicon construct. This shows that replicons designed to express the pentameric complex do indeed express the desired antigen and not the potential byproduct gH/gL.

[0286] The VRPs, RNA encaspulated in LNPs, and RNA formulated with CMF34 were used to immunize Balb/c mice by intramuscular injections in the rear quadriceps. The mice were immunized three times, three weeks apart, and serum samples were collected prior to each immunization as well as three weeks after the third and final immunization. The sera were evaluated in microneutralization assays and to measure the potency of the neutralizing antibody response that was elicited by the vaccinations. The titers are expressed as 50% neutralizing titer.

[0287] The immunogenicity of a number of different configurations of a bicistronic expression cassette for a soluble HCMV gH/gL complex in VRPs was assessed. FIG. 3 shows that VRPs expressing the membrane-anchored, full-length gH/gL complex elicited potent neutralizing antibodies at slightly higher titers than the soluble complex (gHsol/gL) expressed from a similar bicistronic expression cassette. Changing the order of the genes encoding gHsol and gL or replacing one of the subgenomic promoters with an IRES or an FMDV 2A site did not substantially improve immunogenicity.

[0288] To see if bicistronic and pentacistronic replicons expressing the gH/gL and pentameric complexes would elicit neutralizing antibodies in different formulations, cotton rats were immunized with bicistronic or pentacistronic replicons mixed with CMF34. Table 12 shows that replicons in CMF34 elicited comparable neutralizing antibody titers to the same replicons encapsulated in LNPs.

Table 12.

Neutralizing antibody titers. The sera were collected three weeks after the second immunization.

Replicon	50% Neutralizing Titer
A160 gH FL/gL VRP 10^6 IU	594
A160 gH FL/gL 1 µg LNP	141
A527 Pentameric IRES 1 µg LNP	4,416
A160 gH FL/gL 1 µg CMF34	413
A527 Pentameric IRES 1 µg CMF34	4,411

B. VZV Proteins

[0289] Nucleic acids encoding VZV proteins were cloned into a VEE replicon vector to produce monocystronic replicons that encode gB, gH, gL, gE, and gI, and to produce bicistronic replicons that encode gH/gL or gE/gI. In the bicistronic replicons, expression of each VZV open reading frame was driven by a separate subgenomic promoter.

[0290] To prepare replicon RNA, plasmid encoding the replicon was linearized by digestion with PmeI, and the linearized plasmid was extracted with phenol/chloroform/isoamylalchohol, precipitated in sodium acetate/ethanol and resuspended in 20 µl of RNase-free water.

[0291] RNA was prepared by *In vitro* transcription of 1µg of linearized DNA using the MEGAscript T7 kit (AMBION# AM1333). A 20µl reaction was set up according to the manufacturer's instruction without cap analog and incubated for 2 hours at 32°C. TURBO DNase (1µl) was added and the mixture was incubate for 30 min. at 32°C. RNase-free water (30µl) and ammonium acetate solution (30µl) were added. The solution was mixed and chilled for at least 30 min at -20°C. Then the solution was centrifuged at maximum speed for 25 min. at 4°C. The supernatant was discarded, and the pellet was rinsed with 70% ethanol, and again centrifuged at maximum speed for 10 min. at 4°C. The pellet was air dried and resuspended in 50 µl of RNase-free water. The concentration of RNA was measured and quality was check on a denaturing gel.

[0292] The RNA was capped using the ScriptCap m7G Capping System (Epicentre #SCCE0625). The reaction was scaled by combining the RNA and RNase-free water. The RNA was then denatured for 5-10 min. at 65°C. The denatured RNA was transfered quickly to ice and the following reagents were added in the following order: ScriptCap Capping Buffer, 10 mM GTP, 2 mM SAM fresh prepared, ScriptGuard RNase inhibitor, and ScriptCap Capping Enzyme. The mixture was incubatedfor 60 min. at 37°C. The reaction was stopped by adding RNase-free water and 7.5 M LiCl, mixing well and storing the mixture for at least 30 min at -20°C. Then, the mixture was centrifuged at maximum speed for 25 min. at 4°C, the pellet was rinsed with 70% ethanol, again centrifuged at maximum speed for 10 min. at 4°C and the pellet was air dried. The pellet was resuspended in RNase-free water. The concentration of RNA was measured and quality was checked on a denaturing gel.

RNA transfection

[0293] Cells (BHK-V cells) were seeded on 6-well plates brought to 90-95% confluence at the time of transfection. For each transfection 3 µg of RNA was diluted in 50 mL OPTIMEM media in a first tube. Lipofectamine 2000 was added to a second tube contained 50 mL OPTIMEM media. The firs and second tubes were combined and kept for 20 min. at room temperature. The culture media in the 6-well plates were replaced with fresh media, and the RNA-Lipofectamine complex was placed onto the cells, and mixed by gently rocking the plate. The plates were incubated for 24 hours at 37°C in a CO_2 incubator.

[0294] For immunofluorescence, transfected cells were harvested and seeded in 96 well plate, and intracellular staining was performed using commercially available mouse mAbs (dilution range 1:100 1:400). Cell pellets were fixed and permeabilized with Citofix-Citoperm solutions. A secondary reagent, Alexa488 labelled goat anti-mouse $F(ab')_2$ (1:400 final dilution), was used.

[0295] Expression of VZV proteins gE and gI was detected in cells transfected with monocistronic constructs (gE or gI), and expression of both gE and gI was detected in cells transfected with a bicistronic gE/gI construct in western blots using commercially available mouse antibodies, 13B1 for gE and 8C4 for gI. Expression of VZV protein gB was detected in cells transfected with a monocistronic construct encoding gB, by immunofluorescence using commercially available antibody 10G6. Expression of the VZV protein complex gH/gL, was detected by immunofluorescence in cells transfected with monocistronic gH and monocistronic gL, or with a bicistronic gH/gL construct. The gH/gL complex was detected using commercially available antibody SG3.

Murine immunogenicity studies

[0296] Groups of 8 female BALB/c mice aged 6-8 weeks and weighing about 20 g were immunized intramuscularly with 7.0 or 1.0 µg of replicon RNA formulated with CMF32 or LNP (RV01) at day 0, 21 and 42. Blood samples were taken from the immunized animals 3 weeks after the 2nd immunization and 3 weeks after the 3rd immunization. The groups are shown in Table 13.

Table 13

Group	Antigen	Dose (micrograms)	Formulation
1	YFP	7	CMF32
2	YFP	1	CMF32
3	gB	7	CMF32
4	gB	1	CMF32
5	gE	7	CMF32
6	gE	1	CMF32
7	gH	7	CMF32
8	gH	1	CMF32
9	gI	7	CMF32
10	gI	1	CMF32
11	gL	7	CMF32
12	gL	1	CMF32
13	gE/gI	7	CMF32
14	gE/gI	1	CMF32
15	gH/gL	7	CMF32
16	gH/gL	1	CMF32

Immune response to VZV antigens

[0297] Serum samples were tested for the presence of antibodies to gB, by intracellular staining of VZV-replicon transfected MRC-5 cells. MRC-5 cells were maintained in Dulbecco Modified Eagle's Medium with 10% fetal bovine serum. VZV Oka strain inoculum (obtained from ATCC) was used to infect MRC-5 cell culture and infected whole cells were used for subpassage of virus. The ratio between infected and un-infected cells was 1:10. 30 hrs post infection cells were trypsin-dispersed for seeding in a 96 well plate to perform an intracellular staining with pools of mice sera (dilution range 1:200 to 1:800) obtained after immunization. Commercial mAbs were used as controls to quantify the infection level. Cell pellets ware fixed and permeabilized with Citofix-Citoperm solutions. A secondary reagent, Alexa488 labelled goat anti-mouse $F(ab')_2$ was used (1:400 final dilution).

[0298] Commercial antibodies to gB (10G6), gH (SG3), and gE (13B1 (SBA) and 8612 (Millipore)) were used as positive controls, and each intracellularly stained infected MRC-5 cells. Immune sera obtained 3 weeks after the third immunization with either 1 or 7 µg of RNA formulated with CMF32 were diluted 1/200, 1/400 and 1/800 and used to intracellularly stain infected MRC-5 cells. The results are shown in FIG. 4 (Study 1, groups 1, 5, 7, 9, 11, 13 and 15, CMF32 formulation).

Neutralizing assay

[0299] Each immunized mouse serum was serially diluted by two fold increments starting at 1:20 in standard culture medium, and added to the equal volume of VZV suspension in the presence of guinea pig complement. After incubation for 1 hour at 37°C, the human epithelial cell line A549, was added. Infected cells can be measured after one week of culture by counting plaques formed in the culture under microscope. From the plaque number the % inhibition at each serum dilution was calculated. A chart for each serum sample was made by plotting the value of % inhibition against the logarithmic scale the dilution factor. Subsequently an approximate line of relationship between dilution factor and % inhibition was drawn. Then the 50% neutralization titer was determined as the dilution factor where the line crossed at the value of 50% inhibition.

[0300] Table 14 shows that sera obtained from mice immunized with monocistronic gE, bicistrnic gE/gI, and bicistronic gH/gL contained robust neutralizing antibody titers.

[0301]

Table 14 Neutralization titers of pooled sera from mice immunized with 7 µg RNA in CMF32								
Mouse ID	Control (YFP)	gB	gE	gI	gE/gI	gH	gL	gH/gL
1	<20	<20	1111	<20	440	<20	<20	1070
2	<20	<20	413	51	>2560	<20	<20	>2560
3	<20	<20	>2560	<20	1031	<20	<20	>2560
4	<20	20	2128	<20	1538	<20	<20	>2560
5	<20	20	861	<20	636	20	<20	>2560
6	<20	<20	1390	<20	2339	<20	<20	>2560
7	<20	<20	969	<20	1903	<20	<20	900
8	<20	<20	1011	20	1969	20	<20	>2560
9	<20*	<20*	<20*	<20*	<20*	<20*	<20*	<20*
* pre-immune pooled sera								

Example 8: The Solubility of Fatty Acids in Squalene

[0301] In this Example, the solubility of various fatty acids in squalene was examined, and shown in Table 15. Fatty acids at indicated amounts (40, 20, 10, or 5 mg/mL,) were mixed with squalene at 60 °C. In Table 15, (√) means that the fatty acid was soluble in squalene at the specified concentration; "x" means that the fatty acid was not soluble in squalene at the specified concentration; and "-" means that the solubility of the fatty acid at the specified concentration was not tested (because the fatty acid was soluble at a higher concentration). After the fatty acids were dissolved in squalene, the solutions were left at 4 °C overnight. The column labeled 4 °C overnight shows the solubility of the solutions in which each fatty acid was at its top concentration. For example oleic acid was soluble in squalene at 40mg/ml and remained soluble in squalene at 4 °C overnight.

Table 15

Fatty acid		40 mg/mL	20 mg/mL	10 mg/mL	5 mg/mL	4 °C (overnight)
Saturated Fatty Acids (Odd Carbon Chains)	Undecanoic Acid	√	-	-	-	√
	Tridecanoic Acid	√	-	-	-	x
	Pentadecanoic Acid	√	-	-	-	x
	Heptadecanoic Acid	x	x	x	√	x

	Nonadecanoic Acid	x	x	x	x	x
	Heneicosanoic Acid	x	x	x	x	x
	Tricosanoic Acid	x	x	x	x	x
Saturated Fatty Acids (Even Carbon Chains)	Capric acid (10:0)	√	-	-	-	√
	Lauric acid (12:0)	√	-	-	-	x
	Myristic Acid (14:0)	x	√	-	-	x
	Palmitic Acid (16:0)	x	x	x	√	x
	Stearic Acid (18:0)	x	x	x	√	x
	Arachidic Acid (20:0)	x	x	x	√	x
	Behenic Acid (22:0)	x	x	x	x	x
	Lignoceric Acid (24:0)	x	x	x	x	x
Unsaturated fatty acids	Docosahexaenoic Acid (22:6)	√	-	-	-	√
	Elaidic Acid (18:1)-trans	√	-	-	-	x
	Erucic Acid (22:1)	√	-	-	-	√
	Linoleic Acid (18:2)	√	-	-	-	√
	Linolenic Acid (18:3)	√	-	-	-	√
	Nervonic Acid (24:1)	√	-	-	-	x
	Oleic Acid (18:1)-cis	√	-	-	-	√
	Palmitoleic Acid (16:1)	√	-	-	-	√
	Petroselinic Acid (18:1)	√	-	-	-	√

Sequences

[0302] The nucleotide sequence of a DNA encoding the vA317 RNA, which encodes the RSV-F antigen (SEQ ID NO: 1).

[0303] The nucleotide sequence of a DNA encoding the vA142 RNA (SEQ ID NO: 2).

[0304] The nucleotide sequence of a DNA encoding the vA375 RNA (SEQ ID NO: 3).

[0305] A526 Vector: SGP-gH-SGP-gL-SGP-UL128-2A-UL130-2Amod-UL131 (SEQ ID NO: 4).

[0306] A527 Vector: SGP-gH-SGP-gL-SGP-UL128-EMCV-UL130-EV71-UL131 (SEQ ID NO: 5).

[0307] A531 Vector: SGP-gHsol-SGP-gL (SEQ ID NO: 6).

[0308] A532 Vector: SGP-gHsol-2A-gL (SEQ ID NO: 7).

[0309] A533 Vector: SGP-gHsol-EV71-gL (SEQ ID NO: 8).

[0310] A534 Vector: SGP-gL-EV71-gH (SEQ ID NO: 9).

[0311] A535 Vector: SGP-342-EV71-gHsol-2A-gL (SEQ ID NO: 10).

[0312] A536 Vector: SGP-342-EV71-gHsol-EMCV-gL (SEQ ID NO: 11).

[0313] A537 Vector: SGP-342-EV71-gL-EMCV-gHsol (SEQ ID NO: 12).

[0314] A554 Vector: SGP-gH-SGP-gL-SGP-UL128-SGP-UL130-SGP-UL131 (SEQ ID NO: 13).

[0315] A555 Vector: SGP-gHsol-SGP-gL-SGP-UL128-SGP-UL130-SGP-UL131 (SEQ ID NO: 14).

[0316] A556 Vector: SGP-gHsol6His-SGP-gL-SGP-UL128-SGP-UL130-SGP-UL131 (SEQ ID NO: 15).

[0317] VZV gB (SEQ ID NO: 16).

[0318] VZV gH (SEQ ID NO: 17).

[0319] VZV gL (SEQ ID NO: 18).

[0320] VZV gI (SEQ ID NO: 19).

[0321] VZV gE (SEQ ID NO: 20).

[0322] VZV VEERep.SGPgB (SEQ ID NO: 21).

[0323] VZV VEERep.SGPgH (SEQ ID NO: 22).

[0324] VZV VEERep.SGPgL (SEQ ID NO: 23).

[0325] VZV VEERep.SGPgH-SGPgL (SEQ ID NO: 24).

[0326] VZV VEERep.SGPgE (SEQ ID NO: 25).

[0327] VZV VEERep.SGPgI (SEQ ID NO: 26).

[0328] VZV VEErep.SGPgE-SGPgI (SEQ ID NO: 27).

[0329] The specification is most thoroughly understood in light of the teachings of the references cited within the specification. The embodiments within the specification provide an illustration of embodiments of the invention and should not be construed to limit the scope of the invention. The skilled artisan readily recognizes that many other embodiments are encompassed by the invention.

The citation of any references herein is not an admission that such references are prior art to the present invention.

[0330] Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the following embodiments.

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CLAIMS:

1. An oil-in-water emulsion comprising particles that are dispersed in an aqueous continuous phase, wherein the average diameter of said particles is from 80 nm to 150 nm, the emulsion comprises an oil and a cationic lipid, and wherein:

(i) the ratio of oil:lipid (mole:mole) is at least 8:1 (mole:mole);

(ii) the concentration of cationic lipid in said emulsion is at least 2.5 mM; and

(iii) the cationic lipid is selected from the group consisting of: 1,2-dioleoyloxy-3-(trimethylammonio)propane (DOTAP), 1,2-dioleoyl-sn-glycero-3-ethylphosphocholine (DOEPC), N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC), N-[1-(2,3-dioleyloxy)propyl]-N',N,N-trimethylammonium chloride (DOTMA); and dimethyldi-octadecyl ammonium bromide (DDAB).

2. The oil-in-water emulsion of claim 1, wherein the average diameter does not change by more than 10% when the emulsion is stored at 4°C for one month.

3. The oil-in-water emulsion of claim 1, wherein the average diameter of said particles is from 80 nm to 130 nm.

4. The oil-in-water emulsion of claim 1, wherein the ratio of oil:lipid is from 10:1 (mole:mole) to 43:1 (mole:mole).

5. The oil-in-water emulsion of any one of claims 1-4, wherein said oil-in-water emulsion comprises from 0.2% to 8% (w/v) oil.

6. The oil-in-water emulsion of claim 5, wherein the oil is present from 0.6% to 4% (w/v).

7. The oil-in-water emulsion of claim 5 or 6, wherein the oil is present from 1% to 3.2% (w/v).

8. The oil-in-water emulsion of any one of claims 5-7, wherein the oil is squalene or squalane.

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9. The oil-in-water emulsion of any one claims 1-8, wherein said particles further comprise a surfactant.

10. The oil-in-water emulsion of claim 9, wherein the surfactant is a nonionic surfactant.

11. The oil-in-water emulsion of any one of claims 9-10, wherein the oil-in-water emulsion comprises 0.01% to 2.5% (v/v) surfactant.

12. The oil-in-water emulsion of any one of claims 9-11, wherein the surfactant is sorbitan trioleate (SPAN85), polysorbate 80 (Tween 80), or a combination thereof.

13. The oil-in-water emulsion of any one of claims 1-12, wherein said cationic lipid is DOTAP.

14. The oil-in-water emulsion of claim 13, wherein the concentration of DOTAP in said emulsion is at least 2.58 mM (1.8 mg/mL).

15. The oil-in-water emulsion of claim 13 or 14, wherein the concentration of DOTAP in said emulsion is from 2.58 mM (1.8 mg/mL) to 7.16 mM (5 mg/mL).

16. A method for preparing the oil-in-water emulsion of any one of claims 1-15, comprising: (a) directly dissolving the cationic lipid in the oil to form an oil phase; (b) providing an aqueous phase of the emulsion; and (c) dispersing the oil phase in the aqueous phase by homogenization.

17. The method of claim 16, wherein step (a) further comprises heating the oil to a temperature between 30°C to 65°C.

18. The oil-in-water emulsion of any one of claims 1-15 comprising an RNA molecule complexed with a particle of the oil-in-water emulsion.

19. The oil-in-water emulsion of claim 18, wherein the N/P ratio of the composition is at least 4:1.

20. The oil-in-water emulsion of claim 19, wherein the N/P ratio of the composition from 4:1 to 20:1.

21. The oil-in-water emulsion of claim 19 or 20, wherein the N/P ratio of the composition from 4:1 to 15:1.

22. The oil-in-water emulsion of any one of claims 19-21, wherein the composition is buffered and has a pH of 6.0 to 8.0.

23. The oil-in-water emulsion of any one of claims 19-22, wherein the composition further comprises an inorganic salt.

24. The oil-in-water emulsion of claim 23, wherein the concentration of inorganic salt is no greater than 30 mM.

25. The oil-in-water emulsion of any one of claims 19-24, wherein the composition further comprises a nonionic tonicifying agent, and is istonic.

26. The oil-in-water emulsion of any one of claims 19-25, wherein the composition further comprises an antioxidant.

27. The oil-in-water emulsion of any one of claims 18-26, wherein the RNA molecule is a self-replicating RNA molecule that encodes an antigen.

28. A method for preparing a composition comprising an RNA molecule complexed with a particle of a cationic oil-in-water emulsion, comprising:

(i) providing an oil-in-water emulsion of any one of claims 1-15;

(ii) providing an aqueous solution comprising the RNA molecule; and

(iii) combining the oil-in-water emulsion of (i) and the aqueous solution of (ii), thereby preparing the composition.

29. The method of claim 28, wherein the cationic oil-in-water emulsion of (i) and RNA solution of (ii) are combined at 1:1 (v/v) ratio.

30. The method of claim 28 or 29, wherein the aqueous solution comprising the RNA molecule comprises a salt.

31. The method of any one of claims 28-30, wherein the aqueous solution comprising the RNA molecule is a buffer.

32. The method of any one of claims 28-31, wherein the aqueous solution comprising the RNA molecule comprises a nonionic tonicifying agent.

33. The method of claim 32, wherein the nonionic tonicifying agent is a sugar or sugar alcohol.

34. The method of any one of claims 28-33, wherein the aqueous solution comprises from 0.05% to 20% (w/v) polymer.

35. The method of claim 34, wherein the aqueous solution comprises 1% (w/v) Pluronic® F127.

36. The oil-in-water emulsion of any one of claims 18-27, wherein the RNA molecule is a polycistronic RNA encoding two or more antigens.

37. The oil-in-water emulsion of claim 36, wherein the polycistronic RNA contains a first nucleotide sequence encoding a first antigen and a second nucleotide sequence encoding a second antigen, wherein the first nucleotide sequence and the second nucleotide sequence are operably linked to control elements.

38. The oil-in-water emulsion of claim 37, wherein the first nucleotide sequence is operably linked to a first control element and the second nucleotide sequence is operably linked to a second control element.

39. The oil-in-water emulsion of claim 37 or 38, further comprising a third nucleotide sequence encoding a third protein or fragment thereof, wherein the third nucleotide sequences is operably linked to a control element.

40. The oil-in-water emulsion of claim 39, wherein the third nucleotide sequence is operably linked to a third control element.

41. The oil-in-water emulsion of claim 39 or 40, further comprising a fourth nucleotide sequence encoding a fourth protein or fragment thereof, wherein the fourth nucleotide sequences is operably linked to a control element.

42. The oil-in-water emulsion of claim 41, wherein the fourth nucleotide sequence is operably linked to a fourth control element.

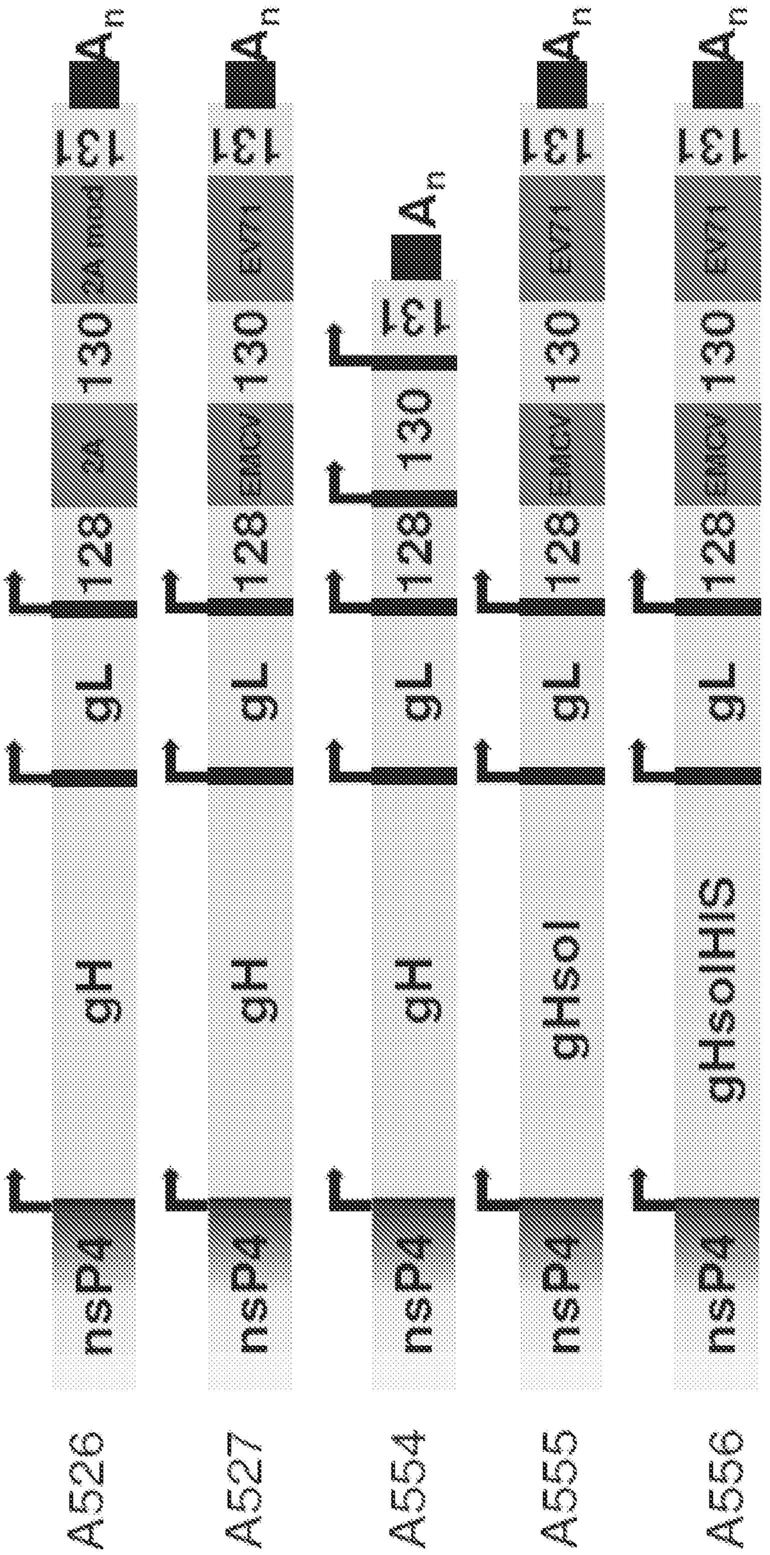
43. The oil-in-water emulsion of claim 41 or 42, further comprising a fifth nucleotide sequence encoding a fifth protein or fragment thereof, wherein the fifth nucleotide sequences is operably linked to a control element.

44. The oil-in-water emulsion of claim 43, wherein the fifth nucleotide sequence is operably linked to a fifth control element.

45. The oil-in-water emulsion of any one of claims 37-44, wherein the control elements are independently selected from the group consisting of a subgenomic promoter, an IRES, and a viral 2A site.

46. A pharmaceutical composition comprising a nucleic acid molecule complexed with a particle of the oil-in-water emulsion as defined in any one of claims 1-15, 18-27 and 36-45.

47. The pharmaceutical composition as defined in claim 46, for use as a medicament.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gL
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2A
130
2A mod
131
A_n
A527
nsP4
gH
gL
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EV71
131
A_n
A554
nsP4
gH
gL
128
130
131
A_n
A555
nsP4
gHsol
gL
128
EMCV
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EMCV
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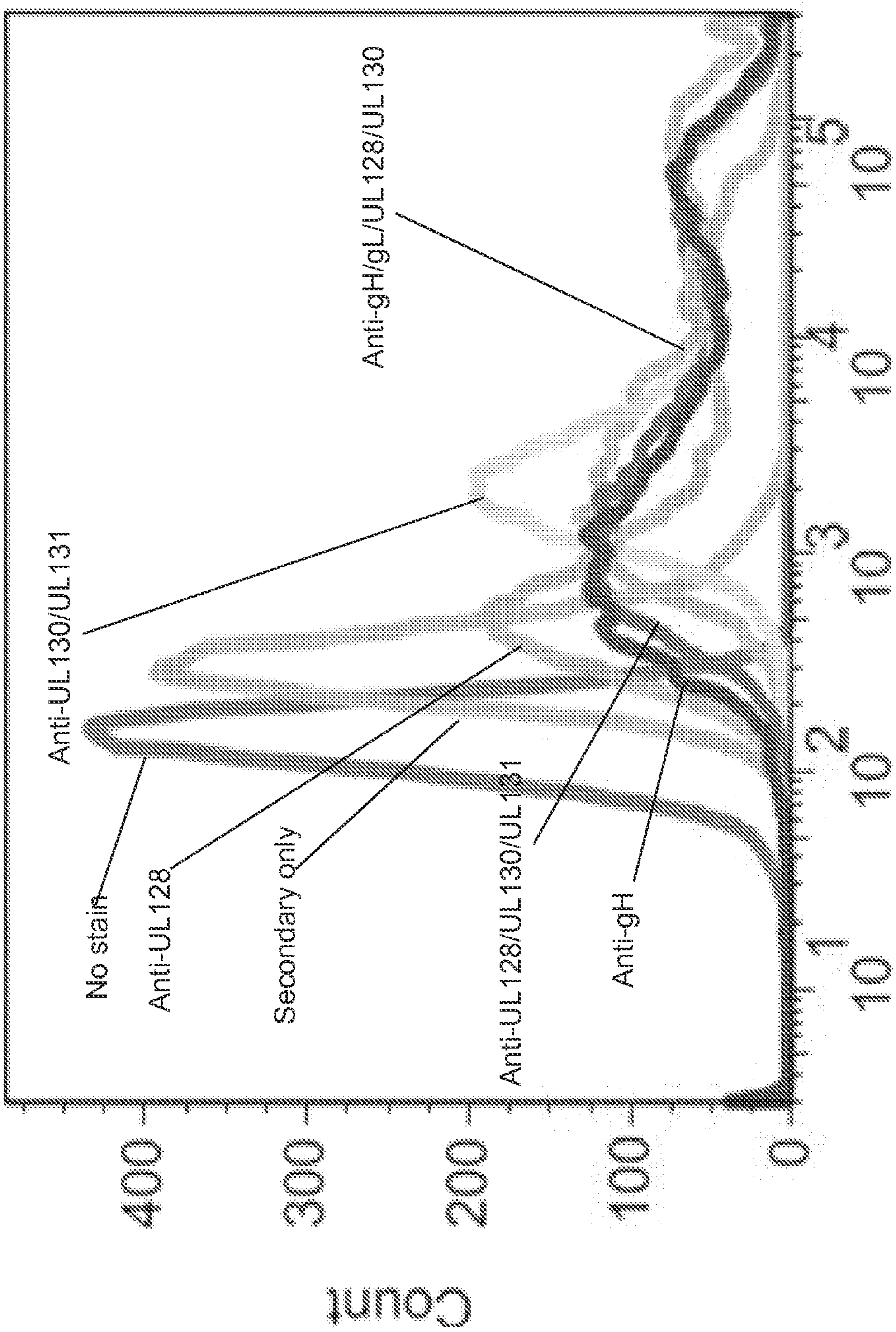
EV71
131
A_n

Figure 1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Anti-UL128
Secondary only
Anti-UL128/UL130/UL131
Anti-gH
Anti-UL130/UL131
Anti-gH/gL/UL128/UL130
Count
0
100
200
300
400
10^1
10^2
10^3
10^4
10^5

Figure 2

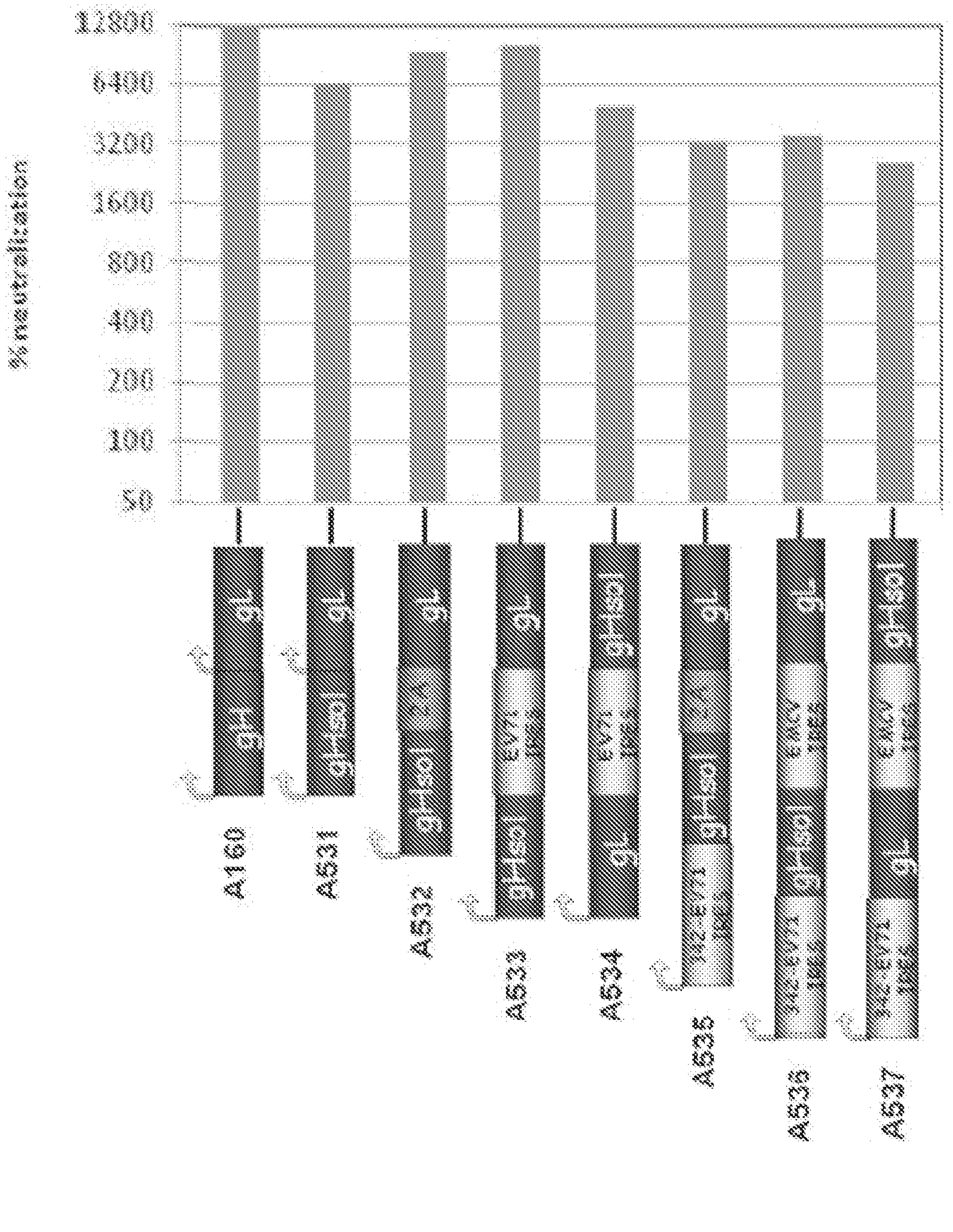
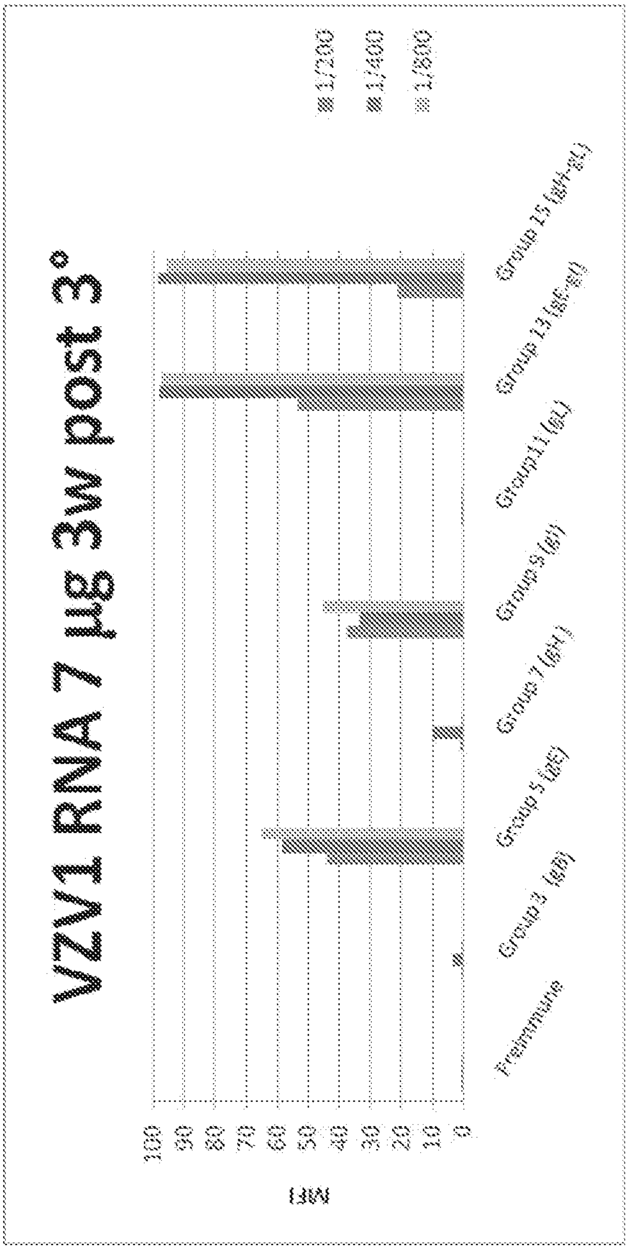

% neutralization
12800
6400
3200
1600
800
400
200
100
50
A160
A531
A532
A533
A534
A535
A536
A537
gH
gL
gH-sol
2A
EV71 IRES
EMCV IRES
342-EV71 IRES

Figure 3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1/200
1/400
1/800
MFI
100
90
80
70
60
50
40
30
20
10
0
Preimmune
Group 3 (gB)
Group 5 (gE)
Group 7 (gH)
Group 9 (gI)
Group11 (gL)
Group 13 (gE-gI)
Group 15 (gH-gL)

Figure 4