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(54) Benævnelse: **Små liposomer til afgivelse af immunogen-kodende RNA**

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DESCRIPTION

TECHNICAL FIELD

[0001] This invention is in the field of non-viral delivery of RNA for immunisation.

BACKGROUND ART

[0002] The delivery of nucleic acids for immunising animals has been a goal for several years. Various approaches have been tested, including the use of DNA or RNA, of viral or non-viral delivery vehicles (or even no delivery vehicle, in a "naked" vaccine), of replicating or non-replicating vectors, or of viral or non-viral vectors.

[0003] EP1637144 and JP2007112768 relate to complexes of nucleic acids and liposomes. EP0786522, US5750390 and US5972704 describe the use of ribozymes which may be delivered in a liposome. WO99/52503 describes viral liposomes comprising nucleic acid encoding a tumour-associated antigen.

[0004] There remains a need for further and improved nucleic acid vaccines and, in particular, for improved ways of delivering nucleic acid vaccines.

DISCLOSURE OF THE INVENTION

[0005] According to the invention, nucleic acid immunisation is achieved by delivering RNA encapsulated within a liposome comprising a lipid with a cationic head group and a lipid with a zwitterionic head group. The RNA encodes an immunogen of interest which is a coronavirus spike polypeptide, and the liposome has a diameter in the range of 60-180nm, and ideally in the range 80-160nm. This size compares with, for example, a diameter of ~40nm for an unenveloped alphavirus isometric protein capsid. The combination of efficient encapsulation of a RNA (particularly a self-replicating RNA) within a small liposome allows for efficient delivery to elicit a strong immune response.

[0006] Thus the invention provides a liposome within which RNA encoding an immunogen of interest is encapsulated, wherein the liposome comprises a lipid with a cationic head group, a lipid with a zwitterionic head group and has a diameter in the range of 60-180nm, and wherein the immunogen is a coronavirus spike polypeptide. These liposomes are suitable for *in vivo* delivery of the RNA to a vertebrate cell and so they are useful as components in pharmaceutical compositions for immunising subjects against various diseases.

The liposome

[0007] The invention utilises liposomes within which immunogen-encoding RNA is encapsulated. Thus the RNA is (as in a natural virus) separated from any external medium. Encapsulation within the liposome has been found to protect RNA from RNase digestion. The liposomes can include some external RNA *(e.g.* on their surface), but at least half of the RNA (and ideally all of it) is encapsulated in the liposome's core. Encapsulation within liposomes is distinct from, for instance, the lipid/RNA complexes disclosed in reference 1, where RNA is mixed with pre-formed liposomes.

[0008] Various amphiphilic lipids can form bilayers in an aqueous environment to encapsulate a RNA-containing aqueous core as a liposome. These lipids can have an anionic, cationic or zwitterionic hydrophilic head group. Formation of liposomes from anionic phospholipids dates back to the 1960s, and cationic liposome-forming lipids have been studied since the 1990s. Some phospholipids are anionic whereas other are zwitterionic and others are cationic. Suitable classes of phospholipid include, but are not limited to, phosphatidylethanolamines, phosphatidylcholines, phosphatidylserines, and phosphatidyl-glycerols, and some useful phospholipids are listed in Table 1. Useful cationic lipids include, but are not limited to, dioleoyl trimethylammonium propane (DOTAP), 1,2-distearyloxy-N,N-dimethyl-3-aminopropane (DSDMA), 1,2-dioleyloxy-N,Ndimethyl-3-aminopropane (DODMA), 1,2-di-O-octadecenyl-3-trimethylammonium propane (DOTMA), 1,2-dilinoleyloxy-N,N-dimethyl-3-aminopropane (DLinDMA), 1,2-dilinolenyloxy-N,N-dimethyl-3-aminopropane (DLenDMA). Zwitterionic lipids include, but are not limited to, acyl zwitterionic lipids and ether zwitterionic lipids. Examples of useful zwitterionic lipids are DPPC, DOPC, DSPC, dodecylphosphocholine, 1,2-dioleoyl-sn-glycero-3-phosphatidylethanolamine (DOPE), and 1,2-diphytanoyl-sn-glycero-3-phosphoethanolamine (DPyPE). The lipids can be saturated or unsaturated. The use of at least one unsaturated lipid for preparing liposomes is preferred. If an unsaturated lipid has two tails, both tails can be unsaturated, or it can have one saturated tail and one unsaturated tail. A lipid can include a steroid group in one tail *e.g.* as in RV05 (see also FIGS. 16A & C-K).

[0009] Thus, in some embodiments, the invention provides a liposome having a lipid bilayer encapsulating an aqueous core, wherein: (i) the liposome comprises a lipid with a cationic head group, a lipid with a zwitterionic head group and has a diameter in the range of 60-180nm; and (ii) the aqueous core includes a RNA which encodes an immunogen wherein the immunogen is a coronavirus spike polypeptide.

[0010] Liposomes of the invention are formed from a mixture of lipids. A mixture may comprise both saturated and unsaturated lipids. For example, a mixture may comprise DSPC (zwitterionic, saturated), DlinDMA (cationic, unsaturated), and/or DMG (anionic, saturated). Where a mixture of lipids is used, not all of the component lipids in the mixture need to be amphiphilic e.g. amphiphilic lipids can be mixed with cholesterol.

[0011] It is preferred that the proportion of those lipids which is cationic should be between 20-80% of the total amount of lipids *e.g.* between 30-70%, or between 40-60%. The remainder can be made of *e.g.* cholesterol (*e.g.* 35-50% cholesterol) and/or DMG (optionally PEGylated) and/or

DSPC. Such mixtures are used below. These percentage values are mole percentages.

[0012] A liposome may include an amphiphilic lipid whose hydrophilic portion is PEGylated *(i.e.* modified by covalent attachment of a polyethylene glycol). This modification can increase stability and prevent non-specific adsorption of the liposomes. For instance, lipids can be conjugated to PEG using techniques such as those disclosed in reference 2 and 3. PEG provides the liposomes with a coat which can confer favourable pharmacokinetic characteristics. Various lengths of PEG can be used *e.g.* between 0.5-8kDa.

[0013] Thus a liposome can be formed from a cationic lipid *(e.g.* DlinDMA, RV05), a zwitterionic lipid *(e.g.* DSPC, DPyPE), a cholesterol, and a PEGylated lipid. A mixture of DSPC, DlinDMA, PEG-DMG and cholesterol is used in the examples, as well as several further mixtures.

[0014] Liposomes are usually divided into three groups: multilamellar vesicles (MLV); small unilamellar vesicles (SUV); and large unilamellar vesicles (LUV). MLVs have multiple bilayers in each vesicle, forming several separate aqueous compartments. SUVs and LUVs have a single bilayer encapsulating an aqueous core; SUVs typically have a diameter ≤50nm, and LUVs have a diameter >50nm. Liposomes of the invention are ideally LUVs with a diameter in the range of 60-180nm, and preferably in the range of 80-160nm. The liposomes preferably are substantially spherical. If they are not spherical, the term "diameter" refers to a liposome's largest cross-sectional diameter.

[0015] A liposome of the invention can be part of a composition comprising a plurality of liposomes, and the liposomes within the plurality can have a range of diameters. For a composition comprising a population of liposomes with different diameters: (i) at least 80% by number of the liposomes should have diameters in the range of 60-180nm, and preferably in the range of 80-160nm, and/or (ii) the average diameter (by intensity e.g. Z-average) of the population is ideally in the range of 60-180nm, and preferably in the range of 80-160nm.

[0016] Ideally, the distribution of liposome sizes (by intensity) has only one maximum *i.e.* there is a single population of liposomes distributed around an average (mode), rather than having two maxima. The diameters within a population of liposomes should ideally have a polydispersity index <0.2, and sometimes <0.1. The liposome/RNA complexes of reference 1 are expected to have a diameter in the range of 600-800nm and to have a high polydispersity.

[0017] Apparatuses for determining the average particle diameter in a suspension of liposomes, and the size distribution, are commercially available. These typically use the techniques of dynamic light scattering and/or single-particle optical sensing *e.g.* the Accusizer™ and Nicomp™ series of instruments available from Particle Sizing Systems (Santa Barbara, USA), or the Zetasizer™ instruments from Malvern Instruments (UK), or the Particle Size Distribution Analyzer instruments from Horiba (Kyoto, Japan). Dynamic light scattering is the preferred method by which liposome diameters are determined. For a population of liposomes, the preferred method for defining the average liposome diameter in a composition of the invention is a Z-average *i.e.* the intensity-weighted mean hydrodynamic size of the ensemble collection of liposomes measured by dynamic light scattering (DLS). The Z-average is derived from cumulants analysis of the measured correlation curve, wherein a single particle size (liposome diameter) is assumed and a single exponential fit is applied to the autocorrelation function. The cumulants analysis algorithm does not yield a distribution but, in addition to an intensity-weighted Z-average, gives a polydispersity index.

[0018] Techniques for preparing suitable liposomes are well known in the art *e.g.* see references 4 to 6. One useful method is described in reference 7 and involves mixing (i) an ethanolic solution of the lipids (ii) an aqueous solution of the nucleic acid and (iii) buffer, followed by mixing, equilibration, dilution and purification. Preferred liposomes of the invention are obtainable by this mixing process. To obtain liposomes with the desired diameter(s), mixing can be performed using a process in which two feed streams of aqueous RNA solution are combined in a single mixing zone with one stream of an ethanolic lipid solution, all at the same flow rate *e.g.* in a microfluidic channel as described below.

The RNA

[0019] Liposomes of the invention include a RNA molecule which (unlike siRNA) encodes an immunogen which is a coronavirus spike polypeptide. After *in vivo* administration of the particles, RNA is released from the particles and is translated inside a cell to provide the immunogen *in situ.*

[0020] The RNA is +-stranded, and so it can be translated by cells without needing any intervening replication steps such as reverse transcription. It can also bind to TLR7 receptors expressed by immune cells, thereby initiating an adjuvant effect.

[0021] Preferred +-stranded RNAs are self-replicating. A self-replicating RNA molecule (replicon) can, when delivered to a vertebrate cell even without any proteins, lead to the production of multiple daughter RNAs by transcription from itself (via an antisense copy which it generates from itself). A self-replicating RNA molecule is thus typically a +-strand molecule which can be directly translated after delivery to a cell, and this translation provides a RNA-dependent RNA polymerase which then produces both antisense and sense transcripts from the delivered RNA. Thus the delivered RNA leads to the production of multiple daughter RNAs. These daughter RNAs, as well as collinear subgenomic transcripts, may be translated themselves to provide *in situ* expression of an encoded immunogen, 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 immunogen. The overall result of this sequence of transcriptions is a huge amplification in the number of the introduced replicon RNAs and so the encoded immunogen becomes a major polypeptide product of the cells.

[0022] One suitable system for achieving self-replication is to use an alphavirus-based RNA replicon. These +-stranded replicons are 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 immunogen. Translation of the subgenomic transcript thus leads to *in situ* expression of the immunogen 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.* Mutant or wild-type viruses sequences can be used *e.g.* the attenuated TC83 mutant of VEEV has been used in replicons [8].

[0023] 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) an immunogen. The polymerase can be an alphavirus replicase e.g. comprising one or more of alphavirus proteins nsP1, nsP2, nsP3 and nsP4.

[0024] Whereas natural alphavirus genomes encode structural virion proteins in addition to the non-structural replicase polyprotein, it is preferred that a self-replicating RNA molecule of use in the invention does not encode alphavirus structural proteins. Thus a preferred 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 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 use in the invention and their place is taken by gene(s) encoding the immunogen of interest, such that the subgenomic transcript encodes the immunogen rather than the structural alphavirus virion proteins.

[0025] 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 an immunogen. In some embodiments the RNA may have additional (*e.g.* downstream) open reading frames *e.g.* to encode further immunogens (see below) or to encode accessory polypeptides.

[0026] A self-replicating RNA molecule can have a 5' sequence which is compatible with the encoded replicase.

[0027] Self-replicating RNA molecules can have various lengths but they are typically 5000-25000 nucleotides long *e.g.* 8000-15000 nucleotides, or 9000-12000 nucleotides. Thus the RNA is longer than seen in siRNA delivery.

[0028] A RNA molecule useful with the invention may have a 5' cap (*e.g.* a 7-methylguanosine). This cap can enhance *in vivo* translation of the RNA.

[0029] The 5' nucleotide of a RNA molecule useful with the invention may have a 5' triphosphate group. In a capped RNA this may be linked to a 7-methylguanosine via a 5'-to-5' bridge. A 5' triphosphate can enhance RIG-I binding and thus promote adjuvant effects.

[0030] A RNA molecule may have a 3' poly-A tail. It may also include a poly-A polymerase recognition sequence (*e.g.* AAUAAA) near its 3' end.

[0031] A RNA molecule useful with the invention will typically be single-stranded. Single-stranded RNAs can generally initiate an adjuvant effect by binding to TLR7, TLR8, RNA helicases and/or PKR. RNA delivered in double-stranded form (dsRNA) can bind to TLR3, and this receptor can also be triggered by dsRNA which is formed either during replication of a single-stranded RNA or within the secondary structure of a single-stranded RNA.

[0032] A RNA molecule useful with the invention can conveniently be prepared by *in vitro* transcription (IVT). IVT can use a (cDNA) template created and propagated in plasmid form in bacteria, or created synthetically (for example by gene synthesis and/or polymerase chain-reaction engineering methods). For instance, a DNA-dependent RNA polymerase (such as the bacteriophage T7, T3 or SP6 RNA polymerases) can be used to transcribe the RNA from a DNA template. Appropriate capping and poly-A addition reactions can be used as required (although the replicon's poly-A is usually encoded within the DNA template). These RNA polymerases can have stringent requirements for the transcribed 5' nucleotide(s) and in some embodiments these requirements must be matched with the requirements of the encoded replicase, to ensure that the IVT-transcribed RNA can function efficiently as a substrate for its self-encoded replicase.

[0033] As discussed in reference 9, the self-replicating RNA can include (in addition to any 5' cap structure) one or more nucleotides having a modified nucleobase. Thus the RNA can comprise m5C (5-methylcytidine), m5U (5-methyluridine), m6A (N6-methyladenosine), s2U (2-thiouridine), Um (2'-O-methyluridine), m1A (1-methyladenosine); m2A (2-methyladenosine); Am (2'-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); m11 (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-dimethylcytidine); 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-carboxymethylaminomethyl-2-L-Omethyluridine); 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); rn62Am (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); or ac6A (N6-acetyladenosine), hypoxanthine, inosine, 8-oxo-adenine, 7-substituted derivatives thereof, dihydrouracil, pseudouracil, 2-thiouracil, 4-thiouracil, 5-aminouracil, 5-(C1-C6)-alkyluracil, 5-methyluracil, 5-(C2-C6)-alkenyluracil, 5-(C2-C6)-alkynyluracil, 5-(hydroxymethyl)uracil, 5-chlorouracil, 5-fluorouracil, 5-bromouracil, 5-hydroxycytosine, 5-(C1-C6)-alkylcytosine, 5-methylcytosine, 5-(C2-C6)-alkenylcytosine, 5-(C2-C6)-alkynylcytosine, 5-chlorocytosine, 5-fluorocytosine, 5-bromocytosine, N2-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, or an abasic nucleotide. For instance, a self-replicating RNA can include one or more modified pyrimidine nucleobases, such as pseudouridine and/or 5-methylcytosine residues. In some embodiments, however, the RNA includes no modified nucleobases, and may include no modified nucleotides *i.e.* all of the nucleotides in the RNA are standard A, C, G and U ribonucleotides (except for any 5' cap structure, which may include a 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.

[0034] A RNA used with the invention ideally includes only phosphodiester linkages between nucleosides, but in some embodiments it can contain phosphoramidate, phosphorothioate, and/or methylphosphonate linkages.

[0035] Ideally, a liposome includes fewer than 10 different species of RNA *e.g.* 5, 4, 3, or 2 different species; most preferably, a liposome includes a single RNA species *i.e.* all RNA molecules in the liposome have the same sequence and same length.

[0036] The amount of RNA per liposome can vary. The number of individual self-replicating RNA molecules per liposome is typically ≤50 *e.g.* <20, <10, <5, or 1-4 per liposome.

The immunogen

[0037] RNA molecules used with the invention encode a polypeptide immunogen which is a coronavirus spike polypeptide. After administration of the liposomes the RNA is translated *in vivo* and the immunogen can elicit an immune response in the recipient. The immune response may comprise an antibody response (usually including IgG) and/or a cell-mediated immune response.

[0038] The RNA molecule can encode a single polypeptide immunogen or multiple polypeptides. Multiple immunogens can be presented as a single polypeptide immunogen (fusion polypeptide) or as separate polypeptides. If immunogens are expressed as separate polypeptides from a replicon then one or more of these may be provided with an upstream IRES or an additional viral promoter element. Alternatively, multiple immunogens may be expressed from a polyprotein that encodes individual immunogens fused to a short autocatalytic protease (*e.g.* foot-and-mouth disease virus 2A protein), or as inteins.

[0039] Unlike references 1 and 10, the RNA encodes an immunogen which is a coronavirus spike polypeptide. For the avoidance of doubt, the invention does not encompass RNA which encodes a firefly luciferase or which encodes a fusion protein of *E.coli* β-galactosidase or which encodes a green fluorescent protein (GFP). Such polypeptides may be useful as markers, or even in a gene therapy context, but the invention concerns delivery of RNA for eliciting an immunological response system. The optimum diameter of liposomes for gene therapy can differ from liposomes for immunisation purposes because target cells and tissues differ for these two approaches. Thus the immunogen also is not a self protein which is delivered to supplement or substitute for a defective host protein (as in gene therapy). Also, the RNA is not total mouse thymus RNA.

[0040] Viral immunogens include, but are not limited to, those derived from a SARS coronavirus.

Pharmaceutical compositions

[0041] Liposomes of the invention are useful as components in pharmaceutical compositions for immunising subjects against various diseases. These compositions will typically include a pharmaceutically acceptable carrier in addition to the liposomes. A thorough discussion of pharmaceutically acceptable carriers is available in reference 29.

[0042] A pharmaceutical composition of the invention may include one or more small molecule immunopotentiators. For example, the composition may include a TLR2 agonist (*e.g.* Pam3CSK4), a TLR4 agonist *(e.g.* an aminoalkyl glucosaminide phosphate, such as E6020), a TLR7 agonist *(e.g.* imiquimod), a TLR8 agonist *(e.g.* resiquimod) and/or a TLR9 agonist *(e.g.* IC31). Any such agonist ideally has a molecular weight of <2000Da. In some embodiments such agonist(s) are also encapsulated with the RNA inside liposomes, but in other embodiments they are unencapsulated.

[0043] Pharmaceutical compositions of the invention may include the liposomes in plain water (*e.g.* w.f.i.) or in a buffer *e.g.* a phosphate buffer, a Tris buffer, a borate buffer, a succinate buffer, a histidine buffer, or a citrate buffer. Buffer salts will typically be included in the 5-20mM range.

[0044] Pharmaceutical compositions of the invention may have a pH between 5.0 and 9.5 *e.g.* between 6.0 and 8.0.

[0045] Compositions of the invention may include sodium salts (*e.g.* sodium chloride) to give tonicity. A concentration of 10±2 mg/ml NaCl is typical *e.g.* about 9 mg/ml.

[0046] Compositions of the invention may include metal ion chelators. These can prolong RNA stability by removing ions which can accelerate phosphodiester hydrolysis. Thus a composition may include one or more of EDTA, EGTA, BAPTA, pentetic acid, *etc.*. Such chelators are typically present at between 10-500µM *e.g.* 0.1mM. A citrate salt, such as sodium citrate, can also act as a chelator, while advantageously also providing buffering activity.

[0047] Pharmaceutical compositions of the invention may have an osmolality of between 200 mOsm/kg and 400 mOsm/kg, *e.g.* between 240-360 mOsm/kg, or between 290-310 mOsm/kg.

[0048] Pharmaceutical compositions of the invention may include one or more preservatives, such as thiomersal or 2-phenoxyethanol. Mercury-free compositions are preferred, and preservative-free vaccines can be prepared.

[0049] Pharmaceutical compositions of the invention are preferably sterile.

[0050] Pharmaceutical compositions of the invention are preferably non-pyrogenic e.g. containing <1 EU (endotoxin unit, a standard measure) per dose, and preferably <0.1 EU per dose.

[0051] Pharmaceutical compositions of the invention are preferably gluten free.

[0052] Pharmaceutical compositions of the invention may be prepared in unit dose form. In some embodiments a unit dose may have a volume of between 0.1-1.0ml *e.g.* about 0.5ml.

[0053] The compositions may be prepared as injectables, either as solutions or suspensions. The composition may be prepared for pulmonary administration e.g. by an inhaler, using a fine spray. The composition may be prepared for nasal, aural or ocular administration e.g. as spray or drops. Injectables for intramuscular administration are typical.

[0054] Compositions comprise an immunologically effective amount of liposomes, as well as any other components, as needed. By 'immunologically effective amount', it is meant that the administration of that amount to an individual, either in a single dose or as part of a series, is effective for treatment or prevention. This amount varies depending upon the health and physical condition of the individual to be treated, age, the taxonomic group of individual to be treated *(e.g.* non-human primate, primate, *etc.),* the capacity of the individual's immune system to synthesise antibodies, the degree of protection desired, the formulation of the vaccine, the treating doctor's assessment of the medical situation, and other relevant factors. It is expected that the amount will fall in a relatively broad range that can be determined through routine trials. The liposome and RNA content of compositions of the invention will generally be expressed in terms of the amount of RNA per dose. A preferred dose has ≤100μg RNA (*e.g.* from 10-100μg, such as about 10μg, 25μg, 50μg, 75μg or 100μg), but expression can be seen at much lower levels *e.g.* ≤1μg/dose, ≤100ng/dose, ≤10ng/dose, ≤1ng/dose, *etc*

[0055] The invention also provides a delivery device (*e.g.* syringe, nebuliser, sprayer, inhaler, dermal patch, *etc.)* containing a pharmaceutical composition of the invention. This device can be used to administer the composition to a vertebrate subject.

[0056] Liposomes of the invention do not contain ribosomes.

Medical uses

[0057] In contrast to the particles disclosed in reference 10, liposomes and pharmaceutical compositions of the invention are for *in vivo* use for eliciting an immune response against an immunogen of interest.

[0058] The invention also provides a liposome or pharmaceutical composition of the invention for use in a method for raising an immune response in a vertebrate.

[0059] By raising an immune response in the vertebrate by these uses, the vertebrate can be protected against various diseases and/or infections. The liposomes and compositions are immunogenic, and are more preferably vaccine compositions. Vaccines according to the invention may either be prophylactic (*i.e.* to prevent infection) or therapeutic *(i.e.* to treat infection), but will typically be prophylactic.

[0060] The vertebrate is preferably a mammal, such as a human or a large veterinary mammal (*e.g.* horses, cattle, deer, goats, pigs). Where the vaccine is for prophylactic use, the human is preferably a child *(e.g.* a toddler or infant) or a teenager; 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.*

[0061] Vaccines prepared according to the invention may be used to treat both children and adults. Thus a human patient may be less than 1 year old, less than 5 years old, 1-5 years old, 5-15 years old, 15-55 years old, or at least 55 years old. Preferred patients for receiving the vaccines are the elderly *(e.g.* ≥50 years old, ≥60 years old, and preferably ≥65 years), the young *(e.g.* ≤5 years old), hospitalised patients, healthcare workers, armed service and military personnel, pregnant women, the chronically ill, or immunodeficient patients. The vaccines are not suitable solely for these groups, however, and may be used more generally in a population.

[0062] Compositions of the invention will generally be administered directly to a patient. Direct delivery may be accomplished by parenteral injection (*e.g.* subcutaneously, intraperitoneally, intravenously, intramuscularly, intradermally, or to the interstitial space of a tissue; unlike reference 1, intraglossal injection is not typically used with the present invention). Alternative delivery routes include rectal, oral (*e.g.* tablet, spray), buccal, sublingual, vaginal, topical, transdermal or transcutaneous, intranasal, ocular, aural, pulmonary or other mucosal administration. Intradermal and intramuscular administration are two preferred routes. Injection may be via a needle *(e.g.* a hypodermic needle), but needle-free injection may alternatively be used. A typical intramuscular dose is 0.5 ml.

[0063] The invention may be used to elicit systemic and/or mucosal immunity, preferably to elicit an enhanced systemic and/or mucosal immunity.

[0064] Dosage can be by a single dose schedule or a multiple dose schedule. Multiple doses may be used in a primary immunisation schedule and/or in a booster immunisation 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.).* In one embodiment, multiple doses may be administered approximately 6 weeks, 10 weeks and 14 weeks after birth, e.g. at an age of 6 weeks, 10 weeks and 14 weeks, as often used in the World Health Organisation's Expanded Program on Immunisation ("EPI"). In an alternative embodiment, two primary doses are administered about two months apart, e.g. about 7, 8 or 9 weeks apart, followed by one or more booster doses about 6 months to 1 year after the second primary dose, e.g. about 6, 8, 10 or 12 months after the second primary dose. In a further embodiment, three primary doses are administered about two months apart, e.g. about 7, 8 or 9 weeks apart, followed by one or more booster doses about 6 months to 1 year after the third primary dose, e.g. about 6, 8, 10, or 12 months after the third primary dose.

General

[0065] The practice of the present invention will employ, unless otherwise indicated, conventional methods of chemistry, biochemistry, molecular biology, immunology and pharmacology, within the skill of the art. Such techniques are explained fully in the literature. See, *e.g.,* references 30-36, *etc.*

[0066] The term "comprising" encompasses "including" as well as "consisting" e.g. a composition "comprising" X may consist exclusively of X or may include something additional e.g. X + Y.

[0067] The term "about" in relation to a numerical value x is optional and means, for example, *x* ±10%.

[0068] The word "substantially" does not exclude "completely" e.g. a composition which is "substantially free" from Y may be completely free from Y. Where necessary, the word "substantially" may be omitted from the definition of the invention.

[0069] References to charge, to cations, to anions, to zwitterions, *etc.,* are taken at pH 7.

[0070] TLR3 is the Toll-like receptor 3. It is a single membrane-spanning receptor which plays a key role in the innate immune system. Known TLR3 agonists include poly(I:C). "TLR3" is the approved HGNC name for the gene encoding this receptor, and its unique HGNC ID is HGNC: 11849. The RefSeq sequence for the human TLR3 gene is GI:2459625.

[0071] TLR7 is the Toll-like receptor 7. It is a single membrane-spanning receptor which plays a key role in the innate immune system. Known TLR7 agonists include e.g. imiquimod. "TLR7" is the approved HGNC name for the gene encoding this receptor, and its unique HGNC ID is HGNC: 15631. The RefSeq sequence for the human TLR7 gene is GI:67944638.

[0072] TLR8 is the Toll-like receptor 8. It is a single membrane-spanning receptor which plays a key role in the innate immune system. Known TLR8 agonists include e.g. resiquimod. "TLR8" is the approved HGNC name for the gene encoding this receptor, and its unique HGNC ID is HGNC:15632. The RefSeq sequence for the human TLR8 gene is GI:20302165.

[0073] The RIG-I-like receptor ("RLR") family includes various RNA helicases which play key roles in the innate immune system[37]. RLR-1 (also known as RIG-I or retinoic acid inducible gene I) has two caspase recruitment domains near its N-terminus. The approved HGNC name for the gene encoding the RLR-1 helicase is "DDX58" (for DEAD (Asp-Glu-Ala-Asp) box polypeptide 58) and the unique HGNC ID is HGNC:19102. The RefSeq sequence for the human RLR-1 gene is GI:77732514. RLR-2 (also known as MDA5 or melanoma differentiation-associated gene 5) also has two caspase recruitment domains near its N-terminus. The approved HGNC name for the gene encoding the RLR-2 helicase is "IFIH1" (for interferon induced with helicase C domain 1) and the unique HGNC ID is HGNC: 18873. The RefSeq sequence for the human RLR-2 gene is GI: 27886567. RLR-3 (also known as LGP2 or laboratory of genetics and physiology 2) has no caspase recruitment domains. The approved HGNC name for the gene encoding the RLR-3 helicase is "DHX58" (for DEXH (Asp-Glu-X-His) box polypeptide 58) and the unique HGNC ID is HGNC:29517. The RefSeq sequence for the human RLR-3 gene is GI:149408121.

[0074] PKR is a double-stranded RNA-dependent protein kinase. It plays a key role in the innate immune system. "EIF2AK2" (for eukaryotic translation initiation factor 2-alpha kinase 2) is the approved HGNC name for the gene encoding this enzyme, and its unique HGNC ID is HGNC:9437. The RefSeq sequence for the human PKR gene is GI:208431825.

BRIEF DESCRIPTION OF DRAWINGS

[0075]

FIG. 1 shows a gel with stained RNA. Lanes show (1) markers (2) naked replicon (3) replicon after RNase treatment (4) replicon encapsulated in liposome (5) liposome after RNase treatment (6) liposome treated with RNase then subjected to phenol/chloroform extraction.

FIG. 2 is an electron micrograph of liposomes.

FIG. 3 shows protein expression (as relative light units, RLU) at days 1, 3 and 6 after delivery of RNA in large (lower line) or small (upper line) liposomes.

FIG. 4 shows a gel with stained RNA. Lanes show (1) markers (2) naked replicon (3) replicon encapsulated in liposome (4) liposome treated with RNase then subjected to phenol/chloroform extraction.

FIG. 5 shows protein expression at days 1, 3 and 6 after delivery of RNA as a virion-packaged replicon (squares), as naked RNA (diamonds), or in liposomes (+ = 0.1µg, x = 1µg).

FIG. 6 shows protein expression at days 1, 3 and 6 after delivery of four different doses of liposome-encapsulated RNA.

FIG. 7 shows anti-F IgG titers in animals receiving virion-packaged replicon (VRP or VSRP), 1µg naked RNA, and 1µg liposome-encapsulated RNA.

FIG. 8 shows anti-F IgG titers in animals receiving VRP, 1µg naked RNA, and 0.1g or 1µg liposome-encapsulated RNA.

FIG. 9 shows neutralising antibody titers in animals receiving VRP or either 0.1g or 1µg liposome-encapsulated RNA.

FIG. 10 shows expression levels after delivery of a replicon as naked RNA (circles), liposome-encapsulated RNA (triangle & square), or as a lipoplex (inverted triangle).

FIG. 11 shows F-specific IgG titers (2 weeks after second dose) after delivery of a replicon as naked RNA (0.01-1µg), liposome-encapsulated RNA (0.01-10µg), or packaged as a virion (VRP, 10^6 infectious units or IU).

FIG. 12 shows F-specific IgG titers (circles) and PRNT titers (squares) after delivery of a replicon as naked RNA (1µg), liposome-encapsulated RNA (0.1 or 1µg), or packaged as a virion (VRP, 10^6 IU).

Titers in naïve mice are also shown. Solid lines show geometric means.

FIG. 13 shows intracellular cytokine production after restimulation with synthetic peptides representing the major epitopes in the F protein, 4 weeks after a second dose. The y-axis shows the % cytokine+ of CD8+CD4-.

FIG. 14 shows F-specific IgG titers (mean $\log_{10}$ titers ± std dev) over 210 days after immunisation of calves. The three lines are easily distinguished at day 63 and are, from bottom to top: PBS negative control; liposome-delivered RNA; and the "Triangle 4" product.

FIG. 15 shows anti-F titers expression (relative) two weeks after a first dose of replicon encoding F protein. The titers are plotted against liposome Z average diameter (nm).

FIGS. 16A to 16M show the structure of alternative cationic lipids: (A) RV05; (B) RV02; (C) RV04;

(D) RV07; (E) RV03; (F) RV08; (G) RV09; (H) RV14; (I) RV10; (J) RV11; (K) RV15; (L) RV16; (M) RV17.

FIG. 17 shows the structure of a useful "split" PEG-conjugated lipid. The total molecular weight of PEG inside the box is 2000 in the tested liposomes.

FIGS. 18A to18E show structures of various PEG-conjugated lipids, where R is PEG of a desired length.

REFERENCE EXAMPLES

RNA replicons

[0076] Various replicons are used below. In general these are based on a hybrid alphavirus genome with non-structural proteins from venezuelan equine encephalitis virus (VEEV), a packaging signal from VEEV, and a 3' UTR from Sindbis virus or a VEEV mutant. The replicon is about 10kb long and has a poly-A tail.

[0077] Plasmid DNA encoding alphavirus replicons (named: pT7-mVEEV-FL.RSVF or A317; pT7-mVEEV-SEAP or A306; pSP6-VCR-GFP or A50) served as a template for synthesis of RNA *in vitro.* The replicons contain the alphavirus genetic elements required for RNA replication but lack those encoding gene products necessary for particle assembly; the structural proteins are instead replaced by a protein of interest (either a reporter, such as SEAP or GFP, or an immunogen, such as full-length RSV F protein) and so the replicons are incapable of inducing the generation of infectious particles. A bacteriophage (T7 or SP6) promoter upstream of the alphavirus cDNA facilitates the synthesis of the replicon RNA *in vitro* and a hepatitis delta virus (HDV) ribozyme immediately downstream of the poly(A)-tail generates the correct 3'-end through its self-cleaving activity.

[0078] 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) of each of the nucleoside triphosphates (ATP, CTP, GTP and UTP) following the instructions provided by the manufacturer (Ambion). Following transcription the template DNA was digested with TURBO DNase (Ambion). 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 m7G Capping System (Epicentre Biotechnologies) as outlined in the user manual; replicons capped in this way are given the "v" prefix e.g. vA317 is the A317 replicon capped by VCE. Post-transcriptionally capped RNA was precipitated with LiCl and reconstituted in nuclease-free water. The concentration of the RNA samples was determined by measuring OD_{260nm}. Integrity of the *in vitro* transcripts was confirmed by denaturing agarose gel electrophoresis.

Liposomal encapsulation

[0079] RNA was encapsulated in liposomes made essentially by the method of references 7 and 38. The liposomes were made of 10% DSPC (zwitterionic), 40% DlinDMA (cationic), 48% cholesterol and 2% PEG-conjugated DMG (2kDa PEG). These proportions refer to the % moles in the total liposome.

[0080] DlinDMA (1,2-dilinoleyloxy-N,N-dimethyl-3-aminopropane) was synthesized using the procedure of reference 2. DSPC (1,2-Diastearoyl-sn-glycero-3-phosphocholine) was purchased from Genzyme. Cholesterol was obtained from Sigma-Aldrich. PEG-conjugated DMG (1,2-dimyristoyl-sn-glycero-3-phosphoethanolamine-N-[methoxy(polyethylene glycol), ammonium salt), DOTAP (1,2-dioleoyl-3-trimethylammonium-propane, chloride salt) and DC-chol (3β-[N-(N',N'-dimethylaminoethane)-carbamoyl]cholesterol hydrochloride) were from Avanti Polar Lipids.

[0081] Briefly, lipids were dissolved in ethanol (2ml), a RNA replicon was dissolved in buffer (2ml, 100mM sodium citrate, pH 6) and these were mixed with 2ml of buffer followed by 1 hour of equilibration.

[0082] The mixture was diluted with 6ml buffer then filtered. The resulting product contained liposomes, with ~95% encapsulation efficiency.

[0083] For example, in one particular method, fresh lipid stock solutions were prepared in ethanol. 37 mg of DlinDMA, 11.8 mg of DSPC, 27.8 mg of cholesterol and 8.07 mg of PEG-DMG were weighed and dissolved in 7.55 mL of ethanol. The freshly prepared lipid stock solution was gently rocked at 37°C for about 15 min to form a homogenous mixture. Then, 755 µL of the stock was added to 1.245 mL ethanol to make a working lipid stock solution of 2 mL. This amount of lipids was used to form liposomes with 250 µg RNA. A 2 mL working solution of RNA was also prepared from a stock solution of ~1µg/µL in 100 mM citrate buffer (pH 6). Three 20 mL glass vials (with stir bars) were rinsed with RNase Away solution (Molecular BioProducts) and washed with plenty of MilliQ water before use to decontaminate the vials of RNases. One of the vials was used for the RNA working solution and the others for collecting the lipid and RNA mixes (as described later). The working lipid and RNA solutions were heated at 37°C for 10 min before being loaded into 3cc luer-lok syringes. 2 mL citrate buffer (pH 6) was loaded in another 3 cc syringe. Syringes containing RNA and the lipids were connected to a T mixer (PEEK™ 500 µm ID junction, Idex Health Science) using FEP tubing (fluorinated ethylene-propylene; all FEP tubing used had a 2mm internal diameter and a 3mm outer diameter; obtained from Idex Health Science). The outlet from the T mixer was also FEP tubing. The third syringe containing the citrate buffer was connected to a separate piece of tubing. All syringes were then driven at a flow rate of 7 mL/min using a syringe pump. The tube outlets were positioned to collect the mixtures in a 20 mL glass vial (while stirring). The stir bar was taken out and the ethanol/aqueous solution was allowed to equilibrate to room temperature for 1 hour. 4 ml of the mixture was loaded into a 5 cc syringe, which was connected to a piece of FEP tubing and in another 5 cc syringe connected to an equal length of FEP tubing, an equal amount of 100 mM citrate buffer (pH 6) was loaded. The two syringes were driven at 7mL/min flow rate using the syringe pump and the final mixture collected in a 20 mL glass vial (while stirring). Next, the mixture collected from the second mixing step (liposomes) were passed through a Mustang Q membrane (an anion-exchange support that binds and removes anionic molecules, obtained from Pall Corporation). Before using this membrane for the liposomes, 4 mL of 1 M NaOH, 4 mL of 1 M NaCl and 10 mL of 100 mM citrate buffer (pH 6) were successively passed through it. Liposomes were warmed for 10 min at 37°C before passing through the membrane. Next, liposomes were concentrated to 2 mL and dialyzed against 10-15 volumes of IX PBS using by tangential flow filtration before recovering the final product. The TFF system and hollow fiber filtration membranes were purchased from Spectrum Labs (Rancho Dominguez) and were used according to the manufacturer's guidelines. Polysulfone hollow fiber filtration membranes with a 100 kD pore size cutoff and 8 cm^2 surface area were used. For *in vitro* and *in vivo* experiments formulations were diluted to the required RNA concentration with IX PBS.

[0084] FIG. 2 shows an example electron micrograph of liposomes prepared by these methods. These liposomes contain encapsulated RNA encoding full-length RSV F antigen. Dynamic light scattering of one batch showed an average diameter of 141nm (by intensity) or 78nm (by number).

[0085] The percentage of encapsulated RNA and RNA concentration were determined by Quant-iT RiboGreen RNA reagent kit (Invitrogen), following manufacturer's instructions. The ribosomal RNA standard provided in the kit was used to generate a standard curve. Liposomes were diluted 10x or 100x in IX TE buffer (from kit) before addition of the dye. Separately, liposomes were diluted 10x or 100x in IX TE buffer containing 0.5% Triton X before addition of the dye (to disrupt the liposomes and thus to assay total RNA). Thereafter an equal amount of dye was added to each solution and then ~180 µL of each solution after dye addition was loaded in duplicate into a 96 well tissue culture plate. The fluorescence (Ex 485 nm, Em 528 nm) was read on a microplate reader. All liposome formulations were dosed *in vivo* based on the encapsulated amount of RNA.

[0086] Encapsulation in liposomes was shown to protect RNA from RNase digestion. Experiments used 3.8mAU of RNase A per microgram of RNA, incubated for 30 minutes at room temperature. RNase was inactivated with Proteinase K at 55°C for 10 minutes. A 1:1 v/v mixture of sample to 25:24:1 v/v/v, phenol:chloroform:isoamyl alcohol was then added to extract the RNA from the lipids into the aqueous phase. Samples were mixed by vortexing for a few seconds and then placed on a centrifuge for 15 minutes at 12k RPM. The aqueous phase (containing the RNA) was removed and used to analyze the RNA. Prior to loading (400 ng RNA per well) all the samples were incubated with formaldehyde loading dye, denatured for 10 minutes at 65°C and cooled to room temperature. Ambion Millennium markers were used to approximate the molecular weight of the RNA construct. The gel was run at 90 V. The gel was stained using 0.1% SYBR gold according to the manufacturer's guidelines in water by rocking at room temperature for 1 hour. FIG. 1 shows that RNase completely digests RNA in the absence of encapsulation (lane 3). RNA is undetectable after encapsulation (lane 4), and no change is seen if these liposomes are treated with RNase (lane 4). After RNase-treated liposomes are subjected to phenol extraction, undigested RNA is seen (lane 6). Even after 1 week at 4°C the RNA could be seen without any fragmentation (FIG. 4, arrow). Protein expression *in vivo* was unchanged after 6 weeks at 4 °C and one freeze-thaw cycle. Thus liposome-encapsulated RNA is stable.

[0087] To assess *in vivo* expression of the RNA a reporter enzyme (SEAP; secreted alkaline phosphatase) was encoded in the replicon, rather than an immunogen. Expression levels were measured in sera diluted 1:4 in IX Phospha-Light dilution buffer using a chemiluminescent alkaline phosphate substrate. 8-10 week old BALB/c mice (5/group) were injected intramuscularly on day 0, 50µl per leg with 0.1µg or 1µg RNA dose. The same vector was also administered without the liposomes (in RNase free IX PBS) at 1µg. Virion-packaged replicons were also tested. Virion-packaged replicons used herein (referred to as "VRPs") were obtained by the methods of reference 39, where the alphavirus replicon is derived from the mutant VEEV or a chimera derived from the genome of VEEV engineered to contain the 3' UTR of Sindbis virus and a Sindbis virus packaging signal (PS), packaged by co-electroporating them into BHK cells with defective helper RNAs encoding the Sindbis virus capsid and glycoprotein genes.

[0088] As shown in FIG. 5, encapsulation increased SEAP levels by about ½ log at the 1µg dose, and at day 6 expression from a 0.1µg encapsulated dose matched levels seen with 1µg unencapsulated dose. By day 3 expression levels exceeded those achieved with VRPs (squares). Thus expressed increased when the RNA was formulated in the liposomes relative to the naked RNA control, even at a 10x lower dose. Expression was also higher relative to the VRP control, but the kinetics of expression were very different (see FIG. 5). Delivery of the RNA with electroporation resulted in increased expression relative to the naked RNA control, but these levels were lower than with liposomes.

[0089] To assess whether the effect seen in the liposome groups was due merely to the liposome components, or was linked to the encapsulation, the replicon was administered in encapsulated form (with two different purification protocols, 0.1µg RNA), or mixed with the liposomes after their formation (a non-encapsulated "lipoplex", 0.1µg RNA), or as naked RNA (1µg). FIG. 10 shows that the lipoplex gave the lowest levels of expression, showing that shows encapsulation is essential for potent expression.

[0090] Further SEAP experiments showed a clear dose response *in vivo,* with expression seen after delivery of as little as 1ng RNA (FIG. 6). Further experiments comparing expression from encapsulated and naked replicons indicated that 0.01µg encapsulated RNA was equivalent to 1µg of naked RNA. At a 0.5µg dose of RNA the encapsulated material gave a 12-fold higher expression at day 6; at a 0.1µg dose levels were 24-fold higher at day 6.

[0091] Rather than looking at average levels in the group, individual animals were also studied. Whereas several animals were non-responders to naked replicons, encapsulation eliminated non-responders.

[0092] Further experiments replaced DlinDMA with DOTAP. Although the DOTAP liposomes gave better expression than naked replicon, they were inferior to the DlinDMA liposomes (2- to 3-fold difference at day 1).

[0093] To assess *in vivo* immunogenicity a replicon was constructed to express full-length F protein from respiratory syncytial virus (RSV). This was delivered naked (1μg), encapsulated in liposomes (0.1 or 1μg), or packaged in virions (10^6 IU; "VRP") at days 0 and 21. FIG. 7 shows anti-F IgG titers 2 weeks after the second dose, and the liposomes clearly enhance immunogenicity. FIG. 8 shows titers 2 weeks later, by which point there was no statistical difference between the encapsulated RNA at 0.1μg, the encapsulated RNA at 1μg, or the VRP group. Neutralisation titers (measured as 60% plaque reduction, "PRNT60") were not significantly different in these three groups 2 weeks after the second dose (FIG. 9). FIG. 12 shows both IgG and PRNT titers 4 weeks after the second dose.

[0094] FIG. 13 confirms that the RNA elicits a robust CD8 T cell response.

[0095] Further experiments compared F-specific IgG titers in mice receiving VRP, 0.1μg liposome-encapsulated RNA, or 1μg liposome-encapsulated RNA. Titer ratios (VRP: liposome) at various times after the second dose were as follows:

	2 weeks	**4 weeks**	**8 weeks**
0.1μg	2.9	1.0	1.1
1μg	2.3	0.9	0.9

[0096] Thus the liposome-encapsulated RNA induces essentially the same magnitude of immune response as seen with virion delivery.

[0097] Further experiments showed superior F-specific IgG responses with a 10μg dose, equivalent responses for 1μg and 0.1μg doses, and a lower response with a 0.01μg dose. FIG. 11 shows IgG titers in mice receiving the replicon in naked form at 3 different doses, in liposomes at 4 different doses, or as VRP (10^6 IU). The response seen with 1μg liposome-encapsulated RNA was statistically insignificant (ANOVA) when compared to VRP, but the higher response seen with 10μg liposome-encapsulated RNA was statistically significant ($p<0.05$) when compared to both of these groups.

[0098] A further study confirmed that the 0.1μg of liposome-encapsulated RNA gave much higher anti-F IgG responses (15 days post-second dose) than 0.1μg of delivered DNA, and even was more immunogenic than 20μg plasmid DNA encoding the F antigen, delivered by electroporation (Elgen™ DNA Delivery System, Inovio).

Cotton rats

[0099] A study was performed in cotton rats *(Sigmodon hispidis)* instead of mice. At a 1μg dose liposome encapsulation increased F-specific IgG titers by 8.3-fold compared to naked RNA and increased PRNT titers by 9.5-fold. The magnitude of the antibody response was equivalent to that induced by 5×10^6 IU VRP. Both naked and liposome-encapsulated RNA were able to protect the cotton rats from RSV challenge (1×10^5 plaque forming units), reducing lung viral load by at least 3.5 logs. Encapsulation increased the reduction by about 2-fold.

[0100] Further work in cotton rats used four different replicons: vA317 expresses full-length RSV-F; vA318 expresses truncated (transmembrane and cytoplasmic tail removed) RSV-F; vA142 expresses RSV-F with its fusion peptide deleted; vA140 expresses the truncated RSV-F also without its peptide. Cotton rats, 4 to 8 animals per group, were given intramuscular vaccinations (100 µL in one leg) on days 0 and 21 with the four different replicons at two doses (1.0 and 0.1µg) formulated in liposomes made using 2kDa PEG-conjugated DMG by method (D), but with a 150 µg RNA batch size. Control groups received a RSV-F subunit protein vaccine (5 µg) adjuvanted with alum (8 animals/group), VRPs expressing full-length RSV-F (1×10^6 IU, 8 animals/group), or naïve control (4 animals/group). Serum was collected for antibody analysis on days 0, 21 and 34.

[0101] F-specific serum IgG titers and RSV serum neutralizing antibody titers on day 21 and 34 were:

Group	IgG, day 21	IgG, day 34	NT, day 21	NT, day 34
1 µg vA317	915	2249	115	459
0.1 µg vA317	343	734	87	95
1 µg vA318	335	1861	50	277
0.1 µg vA318	129	926	66	239
1 µg vA142	778	4819	92	211
0.1 µg vA142	554	2549	78	141
1 µg vA140	182	919	96	194
0.1 µg vA140	61	332	29	72
5 µg F trimer subunit/alum	13765	86506	930	4744
1×10^6 IU VRP-F full	1877	19179	104	4528
Naïve	5	5	10	15

[0102] All four replicons evaluated in this study (vA317, vA318, vA142, vA140) were immunogenic in cotton rats when delivered by liposome, although serum neutralization titers were at least ten-fold lower than those induced by adjuvanted protein vaccines or by VRPs. The liposome/RNA vaccines elicited serum F-specific IgG and RSV neutralizing antibodies after the first vaccination, and a second vaccination boosted the response effectively. F-specific IgG titers after the second vaccination with 1µg replicon were 2- to 3-fold higher than after the second vaccination with 0.1 µg replicon. The four replicons elicited comparable antibody titers, suggesting that full length and truncated RSV-F, each with or without the fusion peptide, are similarly immunogenic in cotton rats.

[0103] Further work in cotton rats again used the vA317, vA318 and vA142 replicons. Cotton rats, 2-8 animals per group, were given intramuscular vaccinations (100 µL in one leg) on days 0 and 21 with the replicons (0.1 or 1µg) encapsulated in RV01 liposomes (with PEG-2000) made by method (D) but with a 150µg RNA batch size. Control groups received the RSV-F subunit protein vaccine (5 µg) adjuvanted with alum or VRPs expressing full-length RSV-F (1×10^6 IU, 8 animals/group). All these animals received a third vaccination (day 56) with RSV-F subunit protein vaccine (5 µg) adjuvanted with alum. In addition there was a naïve control (4 animals/group). In addition, an extra group was given bilateral intramuscular vaccinations (50 µL per leg) on days 0 and 56 with 1µg vA317 RNA in liposomes but did not receive a third vaccination with the subunit protein vaccine.

[0104] Serum was collected for antibody analysis on days 0, 21, 35, 56, 70, plus days 14, 28 & 42 for the extra group. F-specific serum IgG titers (GMT) were as follows:

	Day 21	**Day 35**	**Day 56**	**Day 70**
1 µg vA318	260	1027	332	14263
0.1 µg vA318	95	274	144	2017
1 µg vA142	483	1847	1124	11168
0.1 µg vA142	314	871	418	11023
1 µg vA317	841	4032	1452	13852
1×10^6 VRP (F-full)	2075	3938	1596	14574
5 µg F trimer subunit/alum	12685	54526	25846	48864
Naive	5	5	5	5

[0105] Serum neutralisation titers were as follows (60% RSV neutralization titers for 2 pools of 3-4 animals per group, GMT of these 2 pools per group):

	Day 21	**Day 35**	**Day 56**	**Day 70**
1 µg vA318	58	134	111	6344
0.1 µg vA318	41	102	63	6647
1 µg vA142	77	340	202	5427
0.1 µg vA142	35	65	56	2223
1 µg vA317	19	290	200	4189
1×10^6 VRP (F-full)	104	1539	558	2876
5 µg F trimer subunit/alum	448	4457	1630	3631
Naive	10	10	10	

[0106] Serum titers and neutralising titers for the extra group were as follows:

Day	14	21	28	35	42	56	70
IgG	397	561	535	501	405	295	3589
NT	52	82	90	106	80	101	1348

[0107] Thus the replicons are confirmed as immunogenic in cotton rats, eliciting serum F-specific IgG and RSV neutralizing antibodies after the first vaccination. A second vaccination boosted the responses effectively. F-specific IgG titers after the second vaccination with 1.0 µg replicon were 1.5 to 4-fold higher than after the second vaccination with 0.1 µg replicon.

[0108] The third vaccination (protein at day 56) did not boost titers in cotton rats previously vaccinated with F trimer subunit + alum, but it did provide a large boost to titers in cotton rats previously vaccinated with replicon. In most cases the RSV serum neutralization titers after two replicon vaccinations followed by protein boost were equal to or greater than titers induced by two or three sequential protein vaccinations.

[0109] This study also evaluated the kinetics of the antibody response to 1.0 µg vA317. F-specific serum IgG and RSV neutralization titers induced by a single vaccination reached their peak around day 21 and were maintained through at least day 56 (50-70% drop in F-specific IgG titer, little change in RSV neutralization titer). A homologous second vaccination was given to these animals on day 56, and boosted antibody titers to a level at least equal to that achieved when the second vaccination was administered on day 21.

[0110] Further experiments involved a viral challenge. The vA368 replicon encodes the full-length wild type surface fusion glycoprotein of RSV with the fusion peptide deleted, with expression driven by the EV71 IRES. Cotton rats, 7 per group, were given intramuscular vaccinations (100 µL per leg) on days 0 and 21 with vA368 in liposomes prepared by method (H), 175 µg RNA batch size, or with VRPs having the same replicon. The liposomes included 2kDa PEG, conjugated to DMG. A control group received 5µg alum-adjuvanted protein, and a naïve control group was also included.

[0111] All groups received an intranasal challenge (i.n.) with 1×10^6 PFU RSV four weeks after the final immunization. Serum was collected for antibody analysis on days 0, 21, 35. Viral lung titers were measured 5 days post challenge. Results were as follows:

	Liposome	VRP	Protein	Naive
F-specific Serum IgG titers (GMT)				
Day 21	370	1017	28988	5
Day 35	2636	2002	113843	5
Neutralising titers (GMT)				
Day 21	47	65	336	10
Day 35	308	271	5188	10

Lung viral load (pfu per gram of lung)				
Day 54	422	225	124	694110

[0112] Thus the RNA vaccine reduced the lung viral load by over three logs, from approximately 10^6 PFU/g in unvaccinated control cotton rats to less than 10^3 PFU/g in vaccinated cotton rats.

Large mammal study

[0113] A large-animal study was performed in cattle. Calves (4-6 weeks old, ~60-80 kg, 5 per group) were immunised with 66μg of replicon vA317 encoding full-length RSV F protein at days 0, 21, 86 and 146. The replicons were formulated inside liposomes made by method (E) but with a 1.5 mg RNA batch size; they had 40% DlinDMA, 10% DSPC, 48% cholesterol, and 2% PEG-2000 conjugated to DMG. PBS alone was used as a negative control, and a licensed vaccine was used as a positive control ("Triangle 4" from Fort Dodge, containing killed virus). All calves received 15μg F protein adjuvanted with the MF59 emulsion on day 146.

[0114] The RNA vaccines encoded human RSV F whereas the "Triangle 4" vaccine contains bovine RSV F, but the RSV F protein is highly conserved between BRSV and HRSV.

[0115] Calves received 2ml of each experimental vaccine, administered intramuscularly as 2×1ml on each side of the neck. In contrast, the "Triangle 4" vaccine was given as a single 2ml dose in the neck.

[0116] Serum was collected for antibody analysis on days 0, 14, 21, 35, 42, 56, 63, 86, 100, 107, 114, 121, 128, 135, 146, 160, 167, 174, 181, 188, 195, and 202. If an individual animal had a titer below the limit of detection it was assigned a titer of 5.

[0117] FIG. 14 shows F-specific IgG titers over 210 days. Over the first 63 days the RNA replicon was immunogenic in the cows via liposomes, although it gave lower titers than the licensed vaccine. All vaccinated cows showed F-specific antibodies after the second dose, and titers were very stable from the period of 2 to 6 weeks after the second dose (and were particularly stable for the RNA vaccines). Titres up to day 202 were as follows:

	D0	**3wpl D21**	**2wp2 D35**	**5wp2 D56**	**~9wp2 D86**	**2wp3 D100**	**5wp3 D121**	**8wp3 D146**	**2wp4 D160**	**5wp4 D181**	**8wp4 D202**
PBS	5	5	5	5	5	5	5	5	46	98	150
Liposome	5	5	12	11	20	768	428	74	20774	7022	2353
Triangle 4	5	5	1784	721	514	3406	2786	336	13376	4775	2133

[0118] RSV serum neutralizing antibody titers were as follows:

	D0	2wp2 D35	5wp2 D56	2wp3 D100	3wp3 D107	4wp3 D114	8wp3 D146	2wp4 D160	3wp4 D167	4wp4 D174
PBS	12	10	10	14	18	20	14	10	10	10
Liposome	13	10	10	20	13	17	13	47	26	21
Triangle 4	12	15	13	39	38	41	13	24	26	15

[0119] The material used for the second liposome dose was not freshly prepared, and the same lot of RNA showed a decrease in potency in a mouse immunogenicity study. Therefore it is possible that the vaccine would have been more immunogenic if fresh material had been used for all vaccinations.

[0120] When assayed with complement, neutralizing antibodies were detected in all vaccinated cows. In this assay, all vaccinated calves had good neutralizing antibody titers after the second RNA vaccination Furthermore, the RNA vaccine elicited F-specific serum IgG titers that were detected in a few calves after the second vaccination and in all calves after the third.

[0121] MF59-adjuvanted RSV-F was able to boost the IgG response in all previously vaccinated calves, and to boost complement-independent neutralization titers of calves previously vaccinated with RNA.

[0122] Proof of concept for RNA vaccines in large animals is particularly important in light of the loss in potency observed previously with DNA-based vaccines when moving from small animal models to larger animals and humans. A typical dose for a cow DNA vaccine would be 0.5-1 mg [40, 41] and so it is very encouraging that immune responses were induced with only 66μg of RNA.

Effect of liposome diameter

[0123] To obtain smaller liposomes the syringe/tube method was replaced by a method in which the lipid and RNA solutions are mixed in channels on a microfluidic chip.

[0124] Fresh lipid stock solutions in ethanol were prepared. 37 mg of DlinDMA, 11.8 mg of DSPC, 27.8 mg of cholesterol and 8.07 mg of PEG-DMG were weighed and dissolved in 7.55 mL of ethanol. The freshly prepared lipid stock solution was gently rocked at 37°C for about 15 min to form a homogenous mixture. Then, 226.7 μL of the stock was added to 1.773 mL ethanol to make a working lipid stock solution of 2 mL. A 4 mL working solution of RNA was also prepared from a stock solution of ~ 1μg/μL in 100 mM citrate buffer (pH 6). Four 20 mL glass vials (with stir bars) were rinsed with RNase Away solution and washed with plenty of MilliQ water before use to decontaminate the vials of RNAses. Two of the vials were used for the RNA working solution (2 mL in each vial) and the others for collecting the lipid and RNA mixes. The working lipid and RNA solutions were heated at 37°C for 10 min before being loaded into 3cc luer-lok syringes. Syringes containing RNA and the lipids were connected to a Mitos Droplet junction Chip (a glass microfluidic device obtained from Syrris, Part no. 3000158) using PTFE tubing 0.03 inches ID x 1/16 inch OD, (Syrris) using a 4-way edge connector. Two RNA streams and one lipid stream were driven by syringe pumps and the mixing of the ethanol and aqueous phase was done at the X junction (100 µm x 105 µm) of the chip. The flow rate of all three streams was kept at 1.5 mL/min, hence the ratio of total aqueous to ethanolic flow rate was 2:1. The tube outlet was positioned to collect the mixtures in a 20 mL glass vial (while stirring). The stir bar was taken out and the ethanol/aqueous solution was allowed to equilibrate to room temperature for 1 hour. Then the mixture was loaded in a 5 cc syringe which was fitted to a piece of PTFE tubing 0.03 inches ID x 1/16inches OD and in another 5 cc syringe with equal length of PTFE tubing, an equal volume of 100 mM citrate buffer (pH 6) was loaded. The two syringes were driven at 3mL/min flow rate using a syringe pump and the final mixture collected in a 20 mL glass vial (while stirring). Next, liposomes were concentrated to 2 mL and dialyzed against 10-15 volumes of 1X PBS using the TFF system before recovering the final product. Hollow fiber filtration membranes with a 100 kDa pore size cutoff and 20cm^2 surface area were used. For *in vitro* and *in vivo* experiments, formulations were diluted to the required RNA concentration with IX PBS.

[0125] Whereas liposomes prepared using the syringe/tube method with 75µg RNA had a Z average diameter of 148nm and a polydispersity index of 0.122, the chip mixing gave liposomes with a Z average diameter of 97nm and a polydispersity index of 0.086. The proportion of encapsulated RNA decreased slightly from 90% to 87%. These diameters and polydispersity indices were measured using a Zetasizer Nano ZS (Malvern Instruments, Worcestershire, UK) according to the manufacturer's instructions. Liposomes were diluted in IX PBS before measurement.

[0126] The liposomes were administered to 8-10 week old BALB/c mice by intramuscular injection on day 0, 50µl per leg. Sinus orbital bleeds were taken on days 1&3, and a terminal bleed on day 6. Serum SEAP levels were measured by chemiluminescent assay. As shown in FIG. 3, the smaller liposomes increased SEAP levels by ~2-fold at day 1 and by ~5-fold at day 6.

[0127] Liposomes prepared by the two different methods were also assessed for delivery of a replicon encoding full-length RSV-F protein. F-specific serum IgG titers of mice, 8 animals per group, were measured after intramuscular vaccinations on days 0 and 21. Sera were collected for antibody analysis on days 14 (2wp1) and 35 (2wp2). If an individual animal had a titer of <25 (limit of detection) it was assigned a titer of 5. Data are shown below as geometric mean titers of each group:

Formulation	Naked	Syringe/tube liposomes	Chip liposomes
2wp1 GMT	35	2421	4695
2wp2 GMT	457	10757	19773

[0128] Thus the smaller chip-mixed liposomes gave ~2-fold higher GMTs at 2wp1 and 2wp2.

[0129] Various different liposomes with different diameters were also used to deliver a replicon encoding full-length RSV F protein. Total IgG titers against F protein two weeks after the first dose are plotted against liposome diameter in FIG. 15.

Liposome manufacturing methods

[0130] In general, eight different methods have been used for preparing liposomes. These are referred to in the text as methods (A) to (H) and they differ mainly in relation to filtration and TFF steps. Details are as follows:

1. (A) Fresh lipid stock solutions in ethanol were prepared. 37 mg of DlinDMA, 11.8 mg of DSPC, 27.8 mg of Cholesterol and 8.07 mg of PEG DMG 2000 were weighed and dissolved in 7.55 mL of ethanol. The freshly prepared lipid stock solution was gently rocked at 37°C for about 15 min to form a homogenous mixture. Then, 755 µL of the stock was added to 1.245 mL ethanol to make a working lipid stock solution of 2 mL. This amount of lipids was used to form liposomes with 250 µg RNA. A 2 mL working solution of RNA was also prepared from a stock solution of ~ 1µg/µL in 100 mM citrate buffer (pH 6). Three 20 mL glass vials (with stir bars) were rinsed with RNase Away solution (Molecular BioProducts, San Diego, CA) and washed with plenty of MilliQ water before use to decontaminate the vials of RNases. One of the vials was used for the RNA working solution and the others for collecting the lipid and RNA mixes (as described later). The working lipid and RNA solutions were heated at 37°C for 10 min before being loaded into 3cc luer-lok syringes. 2 mL of citrate buffer (pH 6) was loaded in another 3 cc syringe. Syringes containing RNA and the lipids were connected to a T mixer (PEEK™ 500 µm ID junction, Idex Health Science, Oak Harbor, WA) using FEP tubing (fluorinated ethylene-propylene; al FEP tubing has a 2mm internal diameter x 3mm outer diameter, supplied by Idex Health Science). The outlet from the T mixer was also FEP tubing. The third syringe containing the citrate buffer was connected to a separate piece of FEP tubing. All syringes were then driven at a flow rate of 7 mL/min using a syringe pump. The tube outlets were positioned to collect the mixtures in a 20 mL glass vial (while stirring). The stir bar was taken out and the ethanol/aqueous solution was allowed to equilibrate to room temperature for 1 hour. 4 ml of the mixture was loaded into a 5 cc syringe, which was connected to a piece of FEP tubing and in another 5 cc syringe connected to an equal length of FEP tubing, an equal amount of 100 mM citrate buffer (pH 6) was loaded. The two syringes were driven at 7mL/min flow rate using the syringe pump and the final mixture collected in a 20 mL glass vial (while stirring). Next, the mixture collected from the second mixing step (liposomes) were passed through a Mustang Q membrane (an anion-exchange support that binds and removes anionic molecules, obtained from Pall Corporation, AnnArbor, MI, USA). Before passing the liposomes, 4 mL of 1 M NaOH, 4 mL of 1 M NaCl and 10 mL of 100 mM citrate buffer (pH 6) were successively passed through the Mustang membrane. Liposomes were warmed for 10 min at 37°C before passing through the membrane. Next, liposomes were concentrated to 2 mL and dialyzed against 10-15 volumes of IX PBS using TFF before recovering the final product. The TFF system and hollow fiber filtration membranes were purchased from Spectrum Labs and were used according to the manufacturer's guidelines. Polysulfone hollow fiber filtration membranes

(part number P/N: X1AB-100-20P) with a 100 kD pore size cutoff and 8 cm^2 surface area were used. For *in vitro* and *in vivo* experiments, formulations were diluted to the required RNA concentration with IX PBS.

2. (B) As method (A) except that, after rocking, 226.7 µL of the stock was added to 1.773 mL ethanol to make a working lipid stock solution of 2 mL, thus modifying the lipid:RNA ratio.
3. (C) As method (B) except that the Mustang filtration was omitted, so liposomes went from the 20 mL glass vial into the TFF dialysis.
4. (D) As method (C) except that the TFF used polyethersulfone (PES) hollow fiber membranes (part number P-C1-100E-100-01N) with a 100 kD pore size cutoff and 20 cm^2 surface area.
5. (E) As method (D) except that a Mustang membrane was used, as in method (A).
6. (F) As method (A) except that the Mustang filtration was omitted, so liposomes went from the 20 mL glass vial into the TFF dialysis.
7. (G) As method (D) except that a 4 mL working solution of RNA was prepared from a stock solution of ~ 1µg/µL in 100 mM citrate buffer (pH 6). Then four 20 mL glass vials were prepared in the same way. Two of them were used for the RNA working solution (2 mL in each vial) and the others for collecting the lipid and RNA mixes, as in (C). Rather than use T mixer, syringes containing RNA and the lipids were connected to a Mitos Droplet junction Chip (a glass microfluidic device obtained from Syrris, Part no. 3000158) using PTFE tubing (0.03 inches internal diameter x 1/16 inch outer diameter) using a 4-way edge connector (Syrris). Two RNA streams and one lipid stream were driven by syringe pumps and the mixing of the ethanol and aqueous phase was done at the X junction (100 µm x 105 µm) of the chip. The flow rate of all three streams was kept at 1.5 mL/min, hence the ratio of total aqueous to ethanolic flow rate was 2:1. The tube outlet was positioned to collect the mixtures in a 20 mL glass vial (while stirring). The stir bar was taken out and the ethanol/aqueous solution was allowed to equilibrate to room temperature for 1 h. Then the mixture was loaded in a 5 cc syringe, which was fitted to another piece of the PTFE tubing; in another 5 cc syringe with equal length of PTFE tubing, an equal volume of 100 mM citrate buffer (pH 6) was loaded. The two syringes were driven at 3mL/min flow rate using a syringe pump and the final mixture collected in a 20 mL glass vial (while stirring). Next, liposomes were concentrated to 2 mL and dialyzed against 10-15 volumes of 1X PBS using TFF, as in (D).
8. (H) As method (A) except that the 2mL working lipid stock solution was made by mixing 120.9 µL of the lipid stock with 1.879 mL ethanol. Also, after mixing in the T mixer the liposomes from the 20mL vial were loaded into Pierce Slide-A-Lyzer Dialysis Cassette (Thermo Scientific, extra strength, 0.5-3 mL capacity) and dialyzed against 400-500 mL of 1X PBS overnight at 4°C in an autoclaved plastic container before recovering the final product.

RSV immunogenicity

[0131] The vA317 self-replicating replicon encoding RSV F protein was administered to BALB/c mice, 4 or 8 animals per group, by bilateral intramuscular vaccinations (50 µL per leg) on days 0 and 21 with the replicon (1µg) alone or formulated as liposomes with DlinDMA ("RV01") or DOTAP ("RV13") or the lipid shown in FIGS. 16A to 16M ("RV05"). The RV01 liposomes had 40% DlinDMA, 10%DSPC, 48% cholesterol and 2% PEG-DMG, but with differing amounts of RNA. The RV05 liposomes had either 40% RV05, 10% DSPC, 48% cholesterol and 2% PEG-DMG or 60% RV05, 38% cholesterol and 2% PEG-DMG. The RV13 liposomes had 40% DOTAP, 10% DOPE, 48% cholesterol and 2% PEG-DMG. For comparison, naked plasmid DNA (20 µg) expressing the same RSV-F antigen was delivered either using electroporation or with RV01(10) liposomes (0.1µg DNA). Four mice were used as a naïve control group.

[0132] Liposomes were prepared by method (A) or method (B). For some liposomes made by method (A) a double or half amount of RNA was used. Z average particle diameter and polydispersity index were:

RV	Zav (nm)	pdI	Preparation
RV01 (10)	158.6	0.088	(A)
RV01 (08)	156.8	0.144	(A)
RV01 (05)	136.5	0.136	(B)
RV01 (09)	153.2	0.067	(A)
RV01 (10)	134.7	0.147	(A)
RV05 (01)	148	0.127	(A)
RV05 (02)	177.2	0.136	(A)
RV13 (02)	128.3	0.179	(A)

[0133] Serum was collected for antibody analysis on days 14, 36 and 49. Spleens were harvested from mice at day 49 for T cell analysis.

[0134] F-specific serum IgG titers (GMT) were as follows:

RV	Day 14	Day 36
Naked DNA plasmid	439	6712
Naked A317 RNA	78	2291
RV01 (10)	3020	26170
RV01 (08)	2326	9720
RV01 (05)	5352	54907
RV01 (09)	4428	51316
RV05 (01)	1356	5346
RV05 (02)	961	6915
RV01 (10) DNA	5	13
RV13 (02)	644	3616

[0135] The proportion of T cells which are cytokine-positive and specific for RSV F51-66 peptide are as follows, showing only figures which are statistically significantly above zero:

RV	CD4+CD8-				CD4-CD8+			
	IFNγ	IL2	IL5	TNFα	IFNγ	IL2	IL5	TNFα
Naked DNA plasmid	0.04	0.07		0.10	0.57	0.29		0.66
Naked A317 RNA	0.04	0.05		0.08	0.57	0.23		0.67
RV01 (10)	0.07	0.10		0.13	1.30	0.59		1.32
RV01 (08)	0.02	0.04		0.06	0.46	0.30		0.51
RV01 (05)	0.08	0.12		0.15	1.90	0.68		1.94
RV01 (09)	0.06	0.08		0.09	1.62	0.67		1.71
RV01 (10) DNA				0.03				0.08
RV13 (02)	0.03	0.04		0.06	1.15	0.41		1.18

[0136] Thus the liposome formulations significantly enhanced immunogenicity relative to the naked RNA controls, as determined by increased F-specific IgG titers and T cell frequencies. Plasmid DNA formulated with liposomes, or delivered naked using electroporation, was significantly less immunogenic than liposome-formulated self-replicating RNA.

[0137] Further RV01 liposomes were prepared by method (H), using either short (2kDa) or long (5kDa) PEG conjugated to the DMG, and either encapsulating 150μg RNA (vA375 replicon encoding surface fusion glycoprotein of RSV) or encapsulating only buffer. Thus these liposomes had 40% DlinDMA, 10% DSPC, 48% Chol, and 2% PEG-DMG. Sizes and encapsulation were as follows:

RV	PEG	Zav (nm)	pdI	RNA	Encapsulat^{n}
RV01 (36)	2 kDa	152.1	0.053	+	92.5%
RV01 (36)	2 kDa	144	0.13	-	-
RV01 (43)	5 kDa	134	0.136	+	71.6%
RV01 (43)	5 kDa	130.3	0.178	-	-

[0138] The liposomes were administered to BALB/c mice (10 per group) by bilateral intramuscular injection (50μl per leg) on days 0 & 21. Doses were 0.01, 0.03, 0.1, 0.3 or 1μg. F-specific serum IgG and PRNT60 titers (GMT) were as follows, 2 weeks after the first or second injection:

RV	RNA (μg)	2wp1	2wp2	PRNT60 (2wp2)
Buffer control	0	-	-	10
RV01 (36)	0	-	-	10
RV01 (36)	0.01	3399	50691	37

RV	RNA (µg)	2wp1	2wp2	PRNT60 (2wp2)
RV01 (36)	0.03	3446	53463	83
RV01 (36)	0.1	8262	76808	238
RV01 (36)	0.3	5913	82599	512
RV01 (36)	1	8213	85138	441
RV01 (43)	0	-	-	10
RV01 (43)	0.01	3959	37025	51
RV01 (43)	0.03	5842	50763	180
RV01 (43)	0.1	7559	122555	314
RV01 (43)	0.3	5712	126619	689
RV01 (43)	1	9434	199991	1055

Liposomes - requirement for encapsulation

[0139] As mentioned above, with reference to FIG. 10, encapsulation is essential for potent expression. Further experiments used three different RNAs: (i) 'vA317' replicon that expresses RSV-F *i.e.* the surface fusion glycoprotein of RSV; (ii) 'vA17' replicon that expresses GFP; and (iii) 'vA336' that is replication-defective and encodes GFP. RNAs were delivered either naked or with liposomes made by method (D). Empty liposomes were made by method (D) but without any RNA. Liposome formulations had these characteristics:

RNA	Particle Size Zav (nm)	Polydispersity	RNA Encapsulation
vA317	155.7	0.113	86.6%
vA17	148.4	0.139	92%
vA336	145.1	0.143	92.9%
Empty	147.9	0.147	-

[0140] BALB/c mice, 5 animals per group, were given bilateral intramuscular vaccinations (50 µL per leg) on days 0 and 21 with:

<u>Group 1</u> naked self-replicating RSV-F RNA (vA317, 0.1µg)

<u>Group 2</u> self-replicating RSV-F RNA (vA317, 0.1 µg) encapsulated in liposomes

<u>Group 3</u> self-replicating RSV-F RNA (vA317, 0.1 µg) added to empty liposomes

<u>Group 4</u> F subunit protein (5 µg)

[0141] Serum was collected for antibody analysis on days 14, 35 and 51. F-specific specific serum IgG titers (GMT) were measured; if an individual animal had a titer of <25 (limit of detection), it was assigned a titer of 5. In addition, spleens were harvested from mice at day 51 for T cell analysis, to determine cells which were cytokine-positive and specific for RSV F51-66 peptide (CD4+) or for RSV F peptides F85-93 and F249-258 (CD8+).

[0142] IgG titers were as follows in the 10 groups and in non-immunised control mice:

Day	1	2	3	4	-
14	22	1819	5	5	5
35	290	32533	9	19877	5
51	463	30511	18	20853	5

[0143] RSV serum neutralization titers at day 51 were as follows:

Day	1	2	3	4
51	35	50	24	38

[0144] Animals showing RSV F-specific CD4+ splenic T cells on day 51 were as follows, where a number (% positive cells) is given only if the stimulated response was statistically significantly above zero:

Cytokine	1	2	3	4
IFN-γ		0.04		
IL2	0.02	0.06		0.02
IL5				
TNFα	0.03	0.05		

[0145] Animals showing RSV F-specific CD8+ splenic T cells on day 51 were as follows, where a number is given only if the stimulated response was statistically significantly above zero:

Cytokine	1	2	3	4
IFN-γ	0.37	0.87		
IL2	0.11	0.40		0.04
IL5				
TNFα	0.29	0.79		0.06

[0146] Thus encapsulation of RNA within the liposomes is necessary for high immunogenicity, as a simple admixture of RNA and the liposomes (group 3) was not immunogenic (in fact, less immunogenic than naked RNA).

Different cationic lipids with vA317 RSV replicon

[0147] Further experiments compared four different cationic lipids (DlinDMA, RV02, RV04 & RV07). All liposomes contained 2% PEG-DMG 2000 but remaining lipid compositions varied. The compositions and physical characteristics were as follows:

Name	Lipid 1	Other lipids	Zav diam (nm)	pdI	% encap^n
A	DlinDMA, 40%	10% DSPC, 48% cholesterol	158.6	0.088	90.7
B	RV02, 40%	10% DSPC, 48% cholesterol	146.8	0.084	97.5
C	RV04, 40%	10% DSPC, 48% cholesterol	136.7	0.165	67.3
D	RV04, 60%	38% cholesterol	176.3	0.157	55.2
E	RV07, 40%	10% DSPC, 48% cholesterol	144.9	0.204	82
F	RV07, 60%	38% cholesterol	124.1	0.195	80

[0148] BALB/c mice, 8 per group, were given bilateral intramuscular vaccinations (50 µL per leg) on days 0 and 21 with naked replicon (1µg) or 0.1µg encapsulated RNA. F-specific serum IgG titers (GMT) 2 weeks after these two injections were as follows:

Liposomes	Day 14	Day 35
Naked A317 RNA	111	469
A	1834	30519
B	1050	5681
C	430	4127
D	779	4693
E	586	6424
F	121	2568

[0149] For RV07 the absence of DSPC caused a large decrease in immunogenicity.

[0150] Further lipids (RV03, RV08, RV09, RV14 [42]) were tested in the same way:

Name	Lipid 1	Other lipids	Zav diam (nm)	pdI	% encap^n
G	DlinDMA, 40%	10% DSPC, 48% cholesterol	158.6	0.088	90.7
H	RV03, 40%	10% DSPC, 48%	150.3	0.188	83.1

Name	Lipid 1	Other lipids	Zav diam (nm)	pdI	% encap^n
		cholesterol			
I	RV03, 60%	38% cholesterol	161.1	0.239	68.4
J	RV08, 40%	10% DSPC, 48% cholesterol	191.1	0.227	51.7
K	RV09, 40%	10% DSPC, 48% cholesterol	161.6	0.209	64.5
L	RV09, 60%	38% cholesterol	170.7	0.121	82.4
M	RV14, 60%	30% DSPC	155.5	0.238	63.3
N	RV01, 40%	10% DSPC, 48% cholesterol	96.14	0.087	92

Liposomes	Day 14	Day 35
Naked A317 RNA	35	457
G	2421	10757
H	15	52
I	16	85
J	991	1921
K	1082	1421
L	146	286
M	27	212
N	4695	19773

[0151] Liposome M (with DC-cholesterol) performed poorly, even below the naked RNA control. In contrast, the remaining cationic lipids gave useful results. Liposome N was prepared by a different mixing method (method (G) with a microfluidic chip) from liposome G (method (D)) and this smaller liposome gave better results with approximately the same encapsulation.

[0152] Further lipids (RV01, RV10, RV11, RV15) were tested in the same way:

Name	Lipid 1	Other lipids	Zav diam (nm)	pdI	% encap^n
P	DlinDMA, 40%	10% DSPC, 48% cholesterol	158.6	0.088	90.7
Q	RV10, 40%	10% DSPC, 48% cholesterol	123.6	0.14	80.3
R	RV11, 40%	10% DSPC, 48% cholesterol	137.1	0.155	81
S	RV11, 60%	38% cholesterol	135.4	0.175	79.7
T	RV15, 40%	38% cholesterol	111	0.167	76.4

Liposomes	Day 14	Day 35
Naked A317 RNA	185	982
P	2787	27416
Q	24	161
R	633	1715
S	405	2733
T	761	2459

[0153] Except for liposome Q each of these liposomes performed better than the control. The RV10 lipid in liposome Q has a pKa of 7.86 which seems too high to be useful *in vivo*. Even inside the useful pKa range of 5.0 to 7.6, however, although results were good, none of the lipids with one alkyl tail and one steroid-containing tail gave results as good as RV01.

[0154] Further liposomes were made with RV05. The liposomes all had 40% RV05 and 2% PEGylated lipid, but the remaining components varied (although cholesterol was always included). Physical characteristics were:

Name	PEGylated lipid	Other components	Zav (nm)	pdI	% encapsul^{n}
U	DMG	10% DSPC, 48% chol	102.2	0.12	76.81
V	Cholesterol	10% DSPC, 46% chol, 2% αGC	103.7	0.107	72.58
W	DMG	10% DPyPE, 48% chol	99.6	0.115	78.34
X	DMG	10% 18:3 PC, 48% chol	130	0.14	87.92
Y	DMG	10% 18:2 PC, 48% chol	101.1	0.133	76.64
Z	DMG	30% 18:2 PC, 28% chol	134.3	0.158	57.76
αGC = α-galactosylceramide					

[0155] BALB/c mice were tested as before:

Injection	Day 14	Day 35
Naked RNA	321	915
U	551	955
V	342	2531
W	1127	3881
X	364	1741
Y	567	5679
Z	1251	5303

[0156] For a cationic lipid with an asymmetrical lipid tails (alkyl + cholesterol), changing the neutral lipid from DSPC (saturated C18 lipid tail) to 18:2 or 18:3 PC (with 2 and 3 unsaturated double bonds per tail) increased total IgG titers. Comparable results were observed by replacing DSPC with DPyPE.

Further different cationic lipids with vA317 RSV replicon

[0157] Cationic lipids disclosed in reference 43 were also used for preparing liposomes for the vA317 replicon. These cationic lipids have a pKa between 5.8 and 6.1. For comparison DODMA, DlinDMA and DOTMA were also tested. Cationic lipid was always present at 40%. All liposomes included cholesterol and 2% PEGylated DMG (PEG2000, except liposomes E which had PEG5000) and were made by method (H). Physical characteristics were as follows:

	Cationic lipid	**Other lipids**	**Zav (nm)**	**pdI**	**Encaps^{n} %**
A	DlinDMA	10% DSPC, 48% chol	122.3	0.068	95.23
B	RV16	10% DSPC, 48% chol	148.5	0.088	69.34
C	RV17	10% DSPC, 48% chol	138	0.098	67.99
D	DODMA	10% DSPC, 48% chol	107.4	0.151	96.61
E	DlinDMA	10% DSPC, 48% chol	106.1	0.136	61.61
F	DOTMA	10% DSPC, 48% chol	89.32	0.164	98.87
G	DlinDMA	10% 18:2 PC, 48% chol	115.8	0.111	95.67
H	DlinDMA	10% LPC, 48% chol	116.7	0.143	94.84
I	DlinDMA	10% DPyPE, 48% chol	134	0.163	96.33
J	RV05	10% 18:2 PC, 8% chol, 40% DPyPE	124.7	0.17	61.51

[0158] These liposomes were used to vaccinate BALB/c mice as before. F-specific serum IgG titers (GMT) were as follows:

Group	**Day 14**	**Day 35**
Naked RNA	28	721
A	2237	12407
B	1107	13981
C	2109	22147
D	2175	24881
E	5654	39927
F	285	6362
G	1058	3467

Group	Day 14	Day 35
H	1475	10211
I	557	1363
J	703	1732

[0159] Thus the RV05 liposomes were more immunogenic than naked RNA, but less immunogenic than RV01 liposomes.

[0160] Spleens were harvested at day 49 for T cell analysis. All liposomes gave F-specific cytokine-positive T cell frequencies (CD4+ and CD8+) which were statistically significantly above zero.

Different lipids and PEG lengths

[0161] The vA317 replicon was administered in liposomes having a variety of different lipids with different PEG lengths. The liposomes all had 40% DlinDMA, 10% DSPC and 48% cholesterol, but the remaining 2% was varied, with different PEGylated lipids *(e.g.* FIGS. 18A to18E) and different PEG lengths.

[0162] Physical characteristics of the liposomes, made by method (H), were:

Name	PEGylated lipid	PEG length	Zav (nm)	pdI	% encapsulat^n
A	DMG	2000	136.3	0.087	85.35
B	DMG	3000	120.9	0.087	72.06
C	DMG	1000	175.9	0.111	92.52
D	FIG. 18A	2000	157.9	0.094	97.44
E	FIG. 18D	2000	122.2	0.122	77.84
F	FIG. 18E	2000	129.8	0.125	82.57
G	Cholesterol	2000	122.9	0.087	87.1
H	FIG. 18C	2000	138	0.137	78.48
I	FIG. 18B	2000	113.4	0.091	89.12

[0163] BALB/c mice, 8 per group, were given bilateral intramuscular vaccinations (50 µL per leg) on days 0 and 21 with the replicon, either naked (1µg) or encapsulated (0.1 µg). Serum was collected for antibody analysis on days 14, and 35.

[0164] F-specific serum IgG titers (GMT) were as follows, 2 weeks after the two injections (2wp1):

RV	2wp1	2wp2
Naked RNA	216	1356
A	3271	15659
B	3860	22378
C	1691	7412
D	1025	1767
E	1618	9536
F	2684	11221
G	3514	10566
H	4142	22810
I	952	10410

[0165] The results show a trend, indicating that higher molecular weight PEG head groups are more immunogenic. As the length of DMG-conjugated PEG increases from 1000Da to 3000Da the 2wp2 F-specific IgG titers increase from 7412 to 15659 to 22378.

[0166] Changing the linker region from ester to ether did not impact the titers substantially. Also, at the same molecular weight of the head group (2000) there was a trend that increasing the length of the lipid tails lowers the titers (H with C14 dialkyl *vs.* I with C18 dialkyl). Replacing a PEG di-alkyl lipid tail with cholesterol had little impact on immunogenicity (A with DMG *vs.* G with cholesterol).

[0167] Similar experiments were performed with different lipids in which the 2kDa of PEG is split into 2x 1kDa groups (FIG. 17). The vA317 replicon was again used, with BALB/c mice, 8 per group, given bilateral intramuscular vaccinations (50µL per leg) on days 0 & 21 with 1µg naked RNA or 0.1µg liposome-encapsulated RNA. The liposomes all had 40% cationic lipid (DlinDMA), 10% DSPC and 48% cholesterol, but the remaining 2% was varied, with different PEGylated lipids (but all with 2kDa PEG). They were made by method (H).

[0168] Physical characteristics of the liposomes were:

Name	PEGylated lipid	Zav (nm)	pdI	% encapsul^{n}
A	DMG	121	0.101	84.84
B	Split; R= C14 saturated	141.3	0.049	95.41
C	Split; R= C16 saturated	114.6	0.101	96.79
D	Split; R= C18 saturated	116.5	0.088	98.63
E	Split; R= C18, 1 unsaturated	129.4	0.149	93.37

[0169] Further liposomes were made with RV05. The liposomes all had 40% cationic lipid (RV05) and 2% PEGylated lipid (2kDa PEG), but the remaining components varied (although cholesterol was always included). The liposomes were made by method (H) but with pH 5. Physical characteristics were:

Name	PEGylated lipid	Other components	Zav (nm)	pdI	% encapsul^{n}
F	DMG	10% DSPC, 48% chol	102.2	0.12	76.81
G	Cholesterol	10% DSPC, 46% chol, 2% αGC	103.7	0.107	72.58
H	DMG	10% DPyPE, 48% chol	99.6	0.115	78.34
I	DMG	10% 18:3 PC, 48% chol	130	0.14	87.92
J	DMG	10% 18:2 PC, 48% chol	101.1	0.133	76.64
K	DMG	30% 18:2 PC, 28% chol	134.3	0.158	57.76
αGC = α-galactosylceramide					

[0170] BALB/c mice, 8 per group, were given bilateral intramuscular vaccinations (50 µL per leg) on days 0 and 21 with the replicon, either naked (1µg) or encapsulated (0.1µg). Serum was collected for antibody analysis on days 14, and 35. F-specific serum IgG titers (GMT) were as follows, 2 weeks after the two injections (2wp1):

RV	2wp1	2wp2
Naked RNA	321	915
A	2761	17040
B	866	3657
C	1734	5209
D	426	2079
E	2696	15794
F	551	955
G	342	2531
H	1127	3881
I	364	1741
J	567	5679
K	1251	5303

[0171] Splitting the PEG head groups thus lowered *in vivo* titers. Including a double bond (1 degree of instauration per alkyl tail) in the PEG lipid tails increased IgG titers, 6 fold at day 14 and 7 fold at day 35. For a cationic lipid with an asymmetrical lipid tails (alkyl + cholesterol), changing the neutral lipid from DSPC (saturated C18 lipid tail) to 18:2 or 18:3 PC (with 2 and 3 unsaturated double bonds per tail) increased total IgG titers. Comparable results were observed with replacement of DSPC with DPyPE.

CMV immunogenicity

[0172] RV01 liposomes with DLinDMA as the cationic lipid were used to deliver RNA replicons encoding cytomegalovirus (CMV) glycoproteins. The "vA160" replicon encodes full-length glycoproteins H and L (gH/gL), whereas the "vA322" replicon encodes a soluble form (gHsol/gL). The two proteins are under the control of separate subgenomic promoters in a single replicon; co-administration of two separate vectors, one encoding gH and one encoding gL, did not give good results.

[0173] BALB/c mice, 10 per group, were given bilateral intramuscular vaccinations (50 µL per leg) on days 0, 21 and 42 with VRPs expressing gH/gL (1×10^6 IU), VRPs expressing gHsol/gL (1×10^6 IU) and PBS as the controls. Two test groups received 1 µg of the vA160 or vA322 replicon formulated in liposomes (40% DlinDMA, 10% DSPC, 48% Chol, 2% PEG-DMG; made using method (D) but with 150µg RNA batch size).

[0174] The vA160 liposomes had a Zav diameter of 168.8nm, a pdI of 0.144, and 87.4% encapsulation. The vA322 liposomes had a Zav diameter of 162nm, a pdI of 0.131, and 90% encapsulation.

[0175] The replicons were able to express two proteins from a single vector.

[0176] Sera were collected for immunological analysis on day 63 (3wp3). CMV neutralization titers (the reciprocal of the serum dilution producing a 50% reduction in number of positive virus foci per well, relative to controls) were as follows:

gH/gL VRP	gHsol/gL VRP	gH/gL liposome	gHsol/gL liposome
4576	2393	4240	10062

[0177] RNA expressing either a full-length or a soluble form of the CMV gH/gL complex thus elicited high titers of neutralizing antibodies, as assayed on epithelial cells. The average titers elicited by the liposome-encapsulated RNAs were at least as high as for the corresponding VRPs.

[0178] Repeat experiments confirmed that the replicon was able to express two proteins from a single vector. The RNA replicon gave a 3wp3 titer of 11457, compared to 5516 with VRPs.

Table 1: useful phospholipids

DDPC	1,2- Didecanoyl-sn-Glycero-3 -phosphatidylcholine
DEPA	1,2-Dierucoyl-sn-Glycero-3 -Phosphate
DEPC	1,2-Erucoyl-sn-Glycero-3-phosphatidylcholine
DEPE	1,2-Dierucoyl-sn-Glycero-3 -phosphatidylethanolamine

DEPG	1,2-Dierucoyl-sn-Glycero-3 [Phosphatidyl-rac-(1-glycerol...)
DLOPC	1,2- Linoleoyl-sn-Glycero-3 -phosphatidylcholine
DLPA	1,2- Dilauroyl-sn -Glycero-3-Phosphate
DLPC	1,2-Dilauroyl-sn-Glycero-3 -phosphatidylcholine
DLPE	1,2-Dilauroyl-sn-Glycero-3 -phosphatidylethanolamine
DLPG	1,2-Dilauroyl-sn-Glycero-3 [Phosphatidyl-rac-(1-glycerol...)
DLPS	1,2-Dilauroyl-sn-Glycero-3 -phosphatidylserine
DMG	1,2- Dimyristoyl-sn-glycero-3 -phosphoethanolamine
DMPA	1,2- Dimyristoy l-sn -Glycero- 3 -Phosphate
DMPC	1,2-Dimyristoyl-sn-Glycero-3 -phosphatidylcholine
DMPE	1,2-Dimyristoyl-sn-Glycero-3 -phosphatidylethanolamine
DMPG	1,2-Myristoyl-sn-Glycero-3 [Phosphatidyl-rac-(1-glycerol...)
DMPS	1,2-Dimyristoyl-sn-Glycero-3 -phosphatidylserine
DOPA	1,2- Dioleoyl-sn-Glycero-3 -Phosphate
DOPC	1,2-Dioleoyl-sn-Glycero-3 -phosphatidylcholine
DOPE	1,2-Dioleoyl-sn-Glycero-3 -phosphatidylethanolamine
DOPG	1,2-Dioleoyl-sn-Glycero-3[Phosphatidyl-rac-(1-glycerol...)
DOPS	1,2-Dioleoyl-sn-Glycero-3 -phosphatidylserine
DPPA	1,2-Dipalmitoyl-sn-Glycero-3 -Phosphate
DPPC	1,2-Dipalmitoyl-sn-Glycero-3 -phosphatidylcholine
DPPE	1,2- Dipalmitoyl-sn-Glycero-3 -phosphatidylethanolamine
DPPG	1,2-Dipalmitoyl-sn-Glycero-3 [Phosphatidyl-rac-(1-glycerol...)
DPPS	1,2- Di palmi toy l-sn -Glycero- 3 -phosphati dy Iserine
DPyPE	1 ,2-diphytanoyl-sn-glycero-3 -phosphoethanolamine
DSPA	1,2- Distearoy l-sn -Glycero- 3 -Phosphate
DSPC	1,2-Distearoyl-sn-Glycero-3-phosphatidylcholine
DSPE	1,2-Diostearpyl-sn-Glycero-3 -phosphatidylethanolamine
DSPG	1,2-Distearoyl-sn-Glycero-3[Phosphatidyl-rac-(1-glycerol...)
DSPS	1,2-Distearoyl-sn-Glycero-3-phosphatidylserine
EPC	Egg-PC
HEPC	Hydrogenated Egg PC
HSPC	High purity Hydrogenated Soy PC
HSPC	Hydrogenated Soy PC
LYSOPC MYRISTIC	1-Myristoyl-sn-Glycero-3-phosphatidylcholine

LYSOPC PALMITIC	1-Palmitoyl-sn-Glycero-3-phosphatidylcholine
LYSOPC STEARIC	1-Stearoyl-sn-Glycero-3-phosphatidylcholine
Milk Sphingomyelin MPPC	1-Myristoyl,2-palmitoyl-sn-Glycero 3-phosphatidylcholine
MSPC	1-Myristoyl,2-stearoyl-sn-Glycero-3-phosphatidylcholine
PMPC	1-Palmitoyl,2-myristoyl-sn-Glycero-3-phosphatidylcholine
POPC	1-Palmitoyl,2-oleoyl-sn-Glycero-3-phosphatidylcholine
POPE	1-Palmitoyl-2-oleoyl-sn-Glycero-3 - phosphatidylethanolamine
POPG	1,2-Dioleoyl-sn-Glycero-3 [Phosphatidyl-rac-(1-glycerol)...]
PSPC	1-Palmitoyl,2-stearoyl-sn-Glycero-3-phosphatidylcholine
SMPC	1-Stearoyl,2-myristoyl-sn-Glycero-3-phosphatidylcholine
SOPC	1-Stearoyl,2-oleoyl-sn-Gly cero-3-phosphatidylcholine
SPPC	1-Stearoyl,2-palmitoyl-sn-Gly cero-3-phosphatidylcholine

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Patentkrav

1. Liposom, hvori RNA, der koder for et immunogen af interesse, er indkapslet, hvor liposomet omfatter et lipid med en kationisk hovedgruppe, et lipid med en zwitterionisk hovedgruppe og har en diameter i området 60-180nm, hvor immunogenet er et coronavirus-spike-polypeptid.

2. Liposom ifølge krav 1, hvor liposomet har en diameter i området 80-160nm.

3. Liposom ifølge enten krav 1 eller 2, hvor liposomet er dannet ud fra en blanding af lipider, hvor den andel af de lipider, som er kationisk, udgør mellem 20 og 80 mol-% af den samlede mængde lipider, hvor den resterende del er kolesterol og/eller DMG, som er eventuelt PEGyleret og/eller DSPD.

4. Liposom ifølge et af kravene 1 til 3, hvor RNAet er et selvreplikerende RNA.

5. Liposom ifølge krav 4, hvor det selvreplikerende RNA-molekyle koder for (i) en RNA-afhængig RNA-polymerase, som kan transkribere RNA fra det selvreplikerende RNA-molekyle, og (ii) et immunogen.

6. Liposom ifølge krav 5, hvor RNA-molekylet har to åbne læserammer, hvoraf den første koder for en alphavirusreplikase, og hvoraf den anden koder for immunogenet.

7. Liposom ifølge et af kravene 1 til 6, hvor RNA-molekylet er 9000-12000 nukleotider langt.

8. Farmaceutisk sammensætning omfattende et af kravene 1 til 7.

9. Farmaceutisk sammensætning omfattende en population af liposomer ifølge et af kravene 1 til 7, hvor Z-gennemsnitlige diameter af liposomerne i populationen er mellem 60nm og 180nm inklusive.

10. Farmaceutisk sammensætning ifølge krav 9, hvor diameterne inden for populationen af liposomer har et polydispersitetsindeks på <0,2.

11. Liposom ifølge et af kravene 1 til 7, til anvendelse i en fremgangsmåde til at øge et beskyttende immunrespons i et hvirveldyr, hvilken fremgangsmåde omfatter trinnet med indgivelse af en virksom mængde af liposomet i hvirveldyret.

12. Farmaceutisk sammensætning ifølge et af kravene 8 til 10, til anvendelse i en fremgangsmåde til at øge et beskyttende immunrespons i et hvirveldyr, hvilken fremgangsmåde omfatter trinnet med indgivelse af en virksom mængde af den farmaceutiske sammensætning i hvirveldyret.

DRAWINGS

FIG. 1

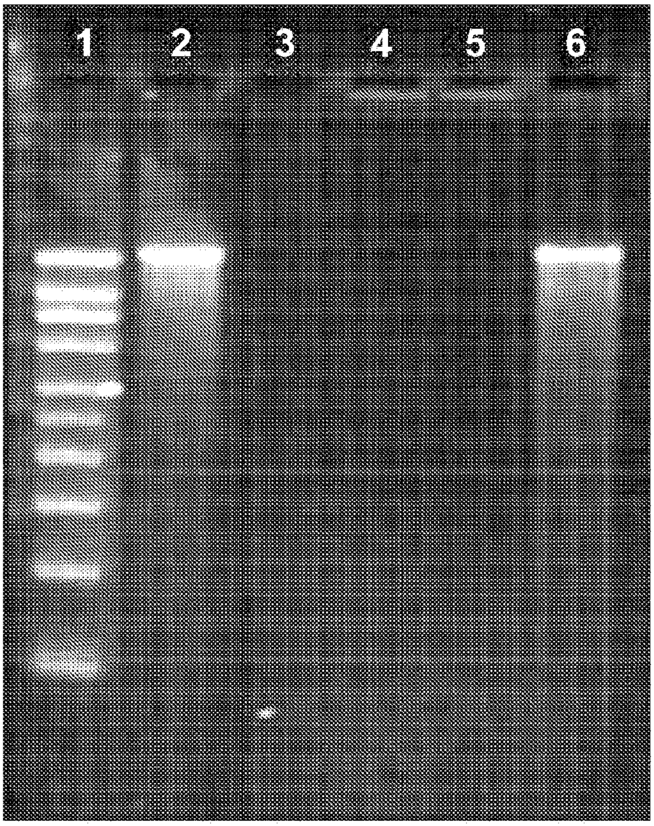


FIG. 2

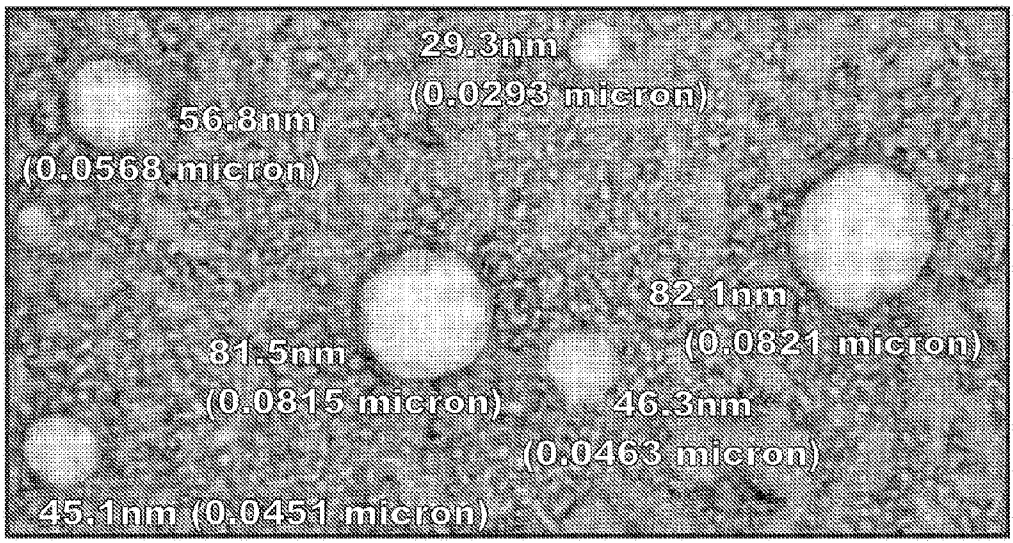


FIG. 3

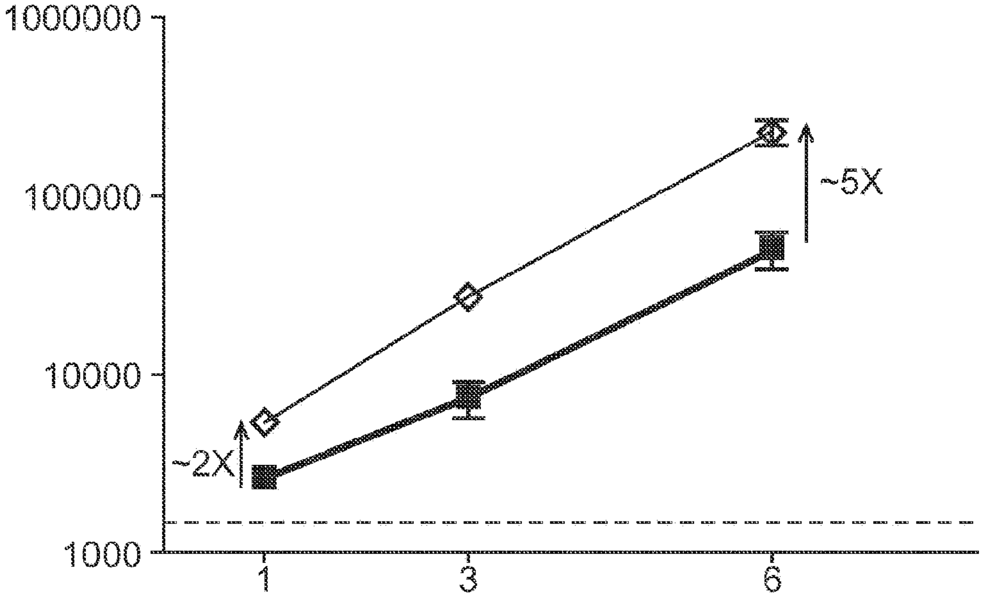


FIG. 4

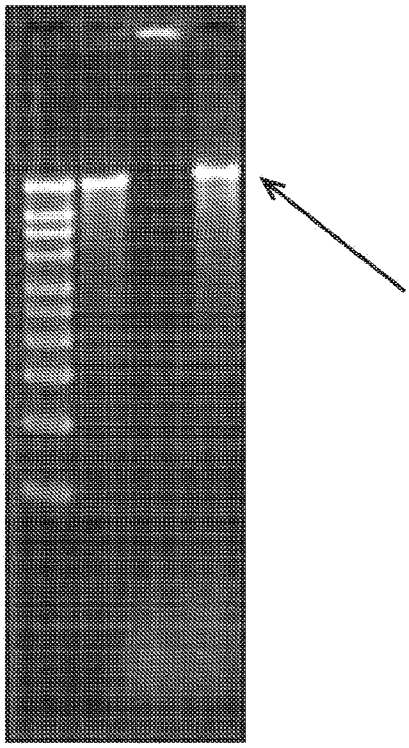


FIG. 5

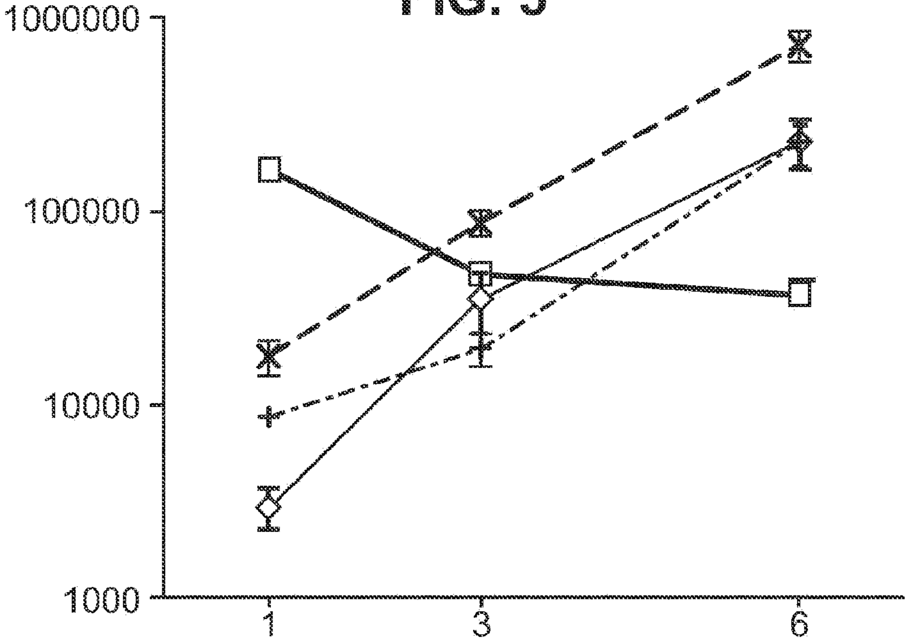

1000000
100000
10000
1000
1
3
6

FIG. 6

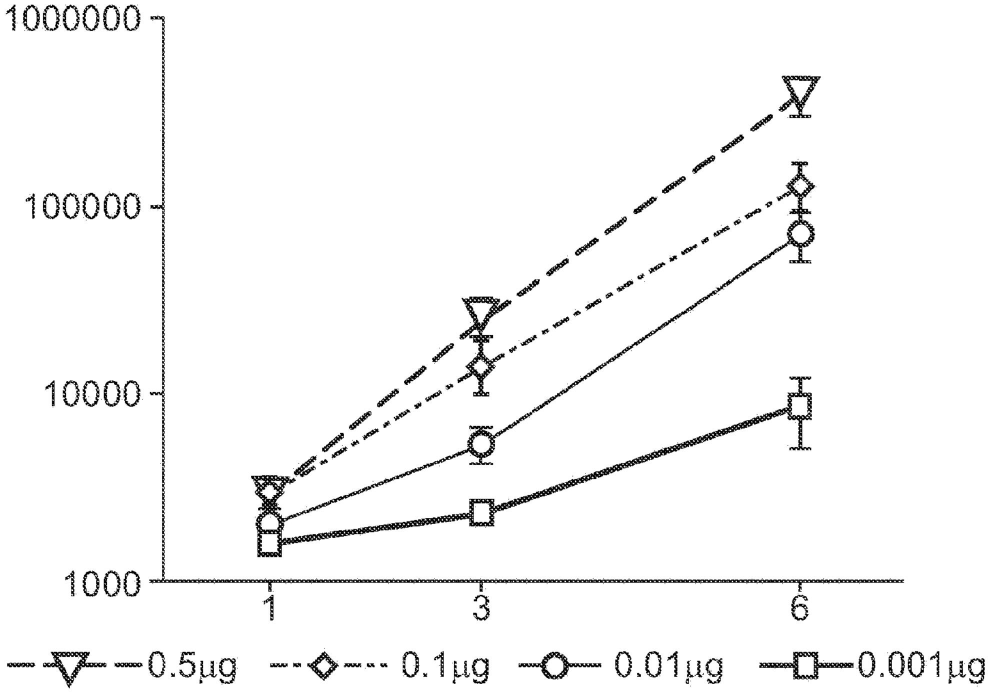

1000000
100000
10000
1000
1
3
6
0.5µg
0.1µg
0.01µg
0.001µg

FIG. 7

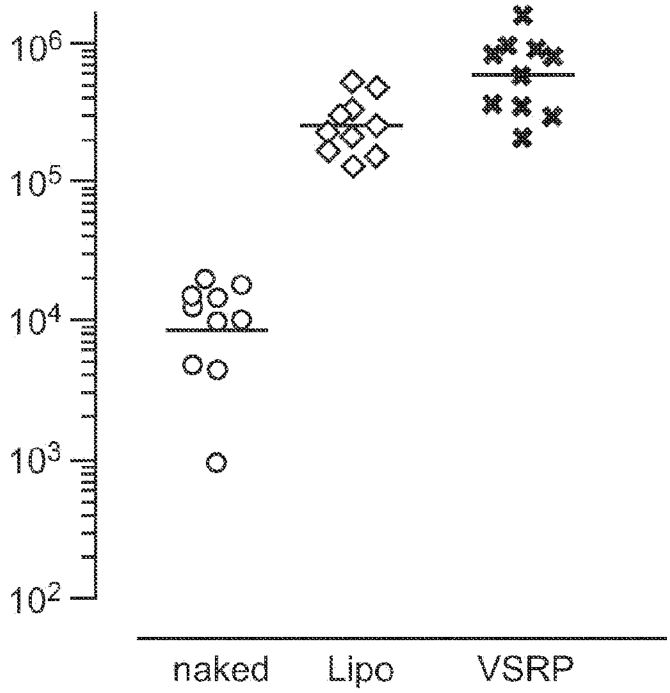

10^6
10^5
10^4
10^3
10^2
naked
Lipo
VSRP

FIG. 8

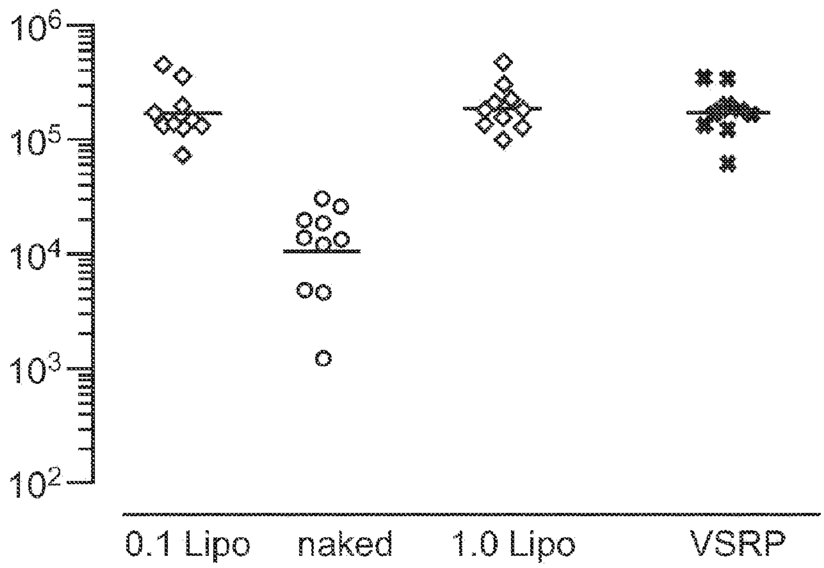

10^6
10^5
10^4
10^3
10^2
0.1 Lipo
naked
1.0 Lipo
VSRP

FIG. 9

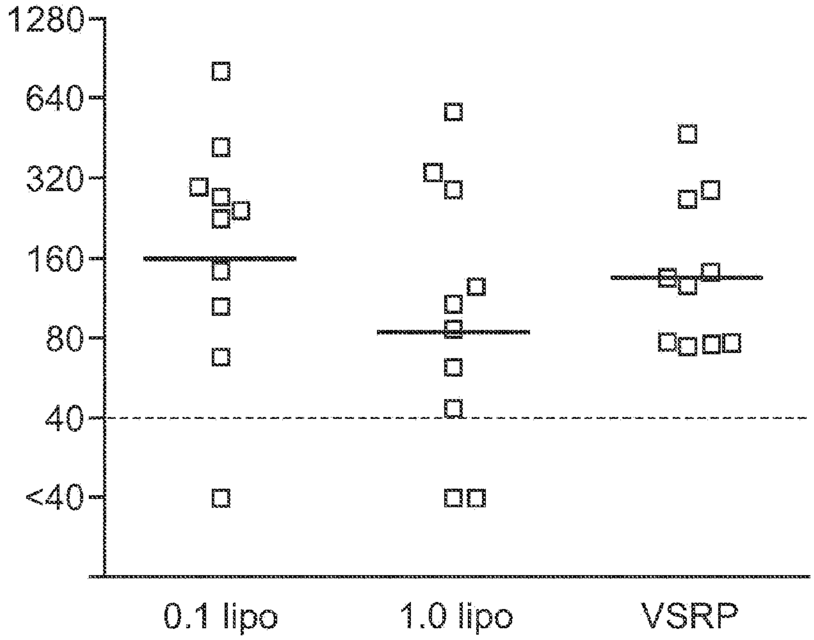

1280
640
320
160
80
40
<40
0.1 lipo
1.0 lipo
VSRP

FIG. 10

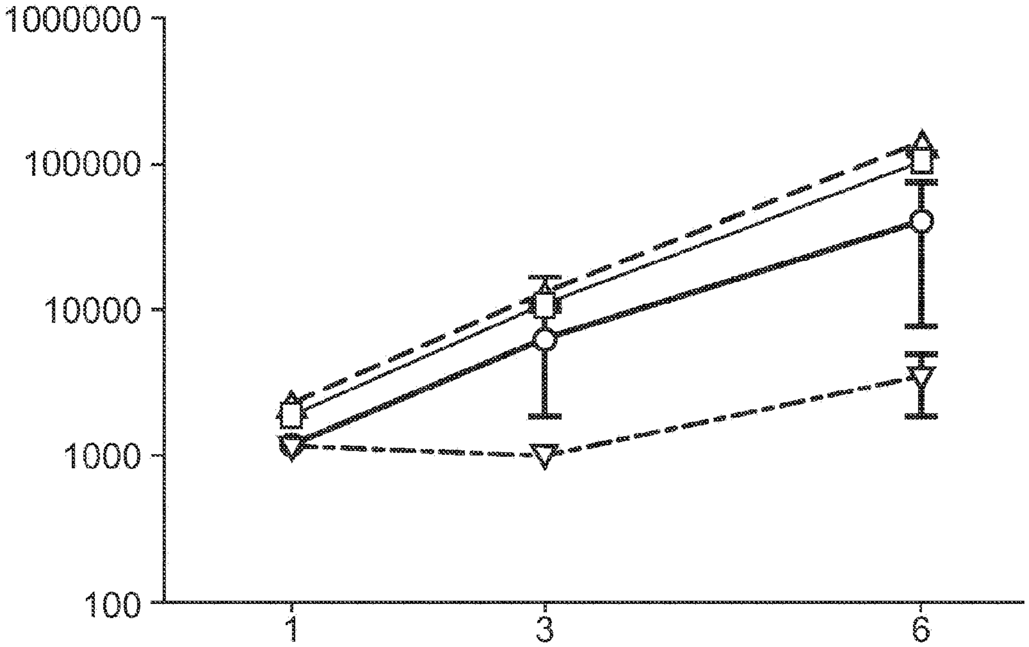

1000000
100000
10000
1000
100
1
3
6

FIG. 11

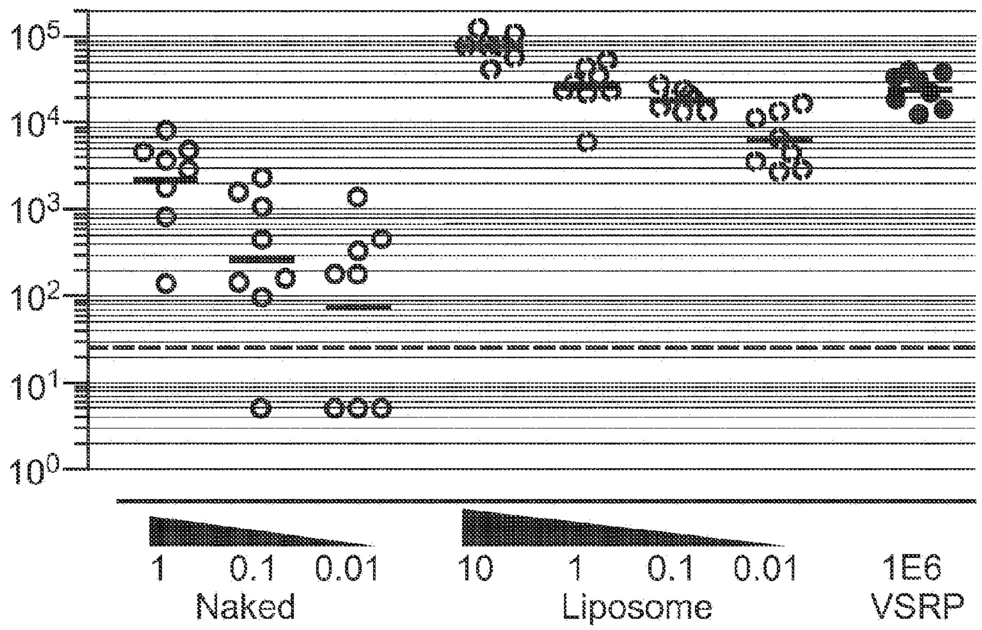

10^5
10^4
10^3
10^2
10^1
10^0
1
0.1
0.01
Naked
10
1
0.1
0.01
Liposome
1E6
VSRP

FIG. 12

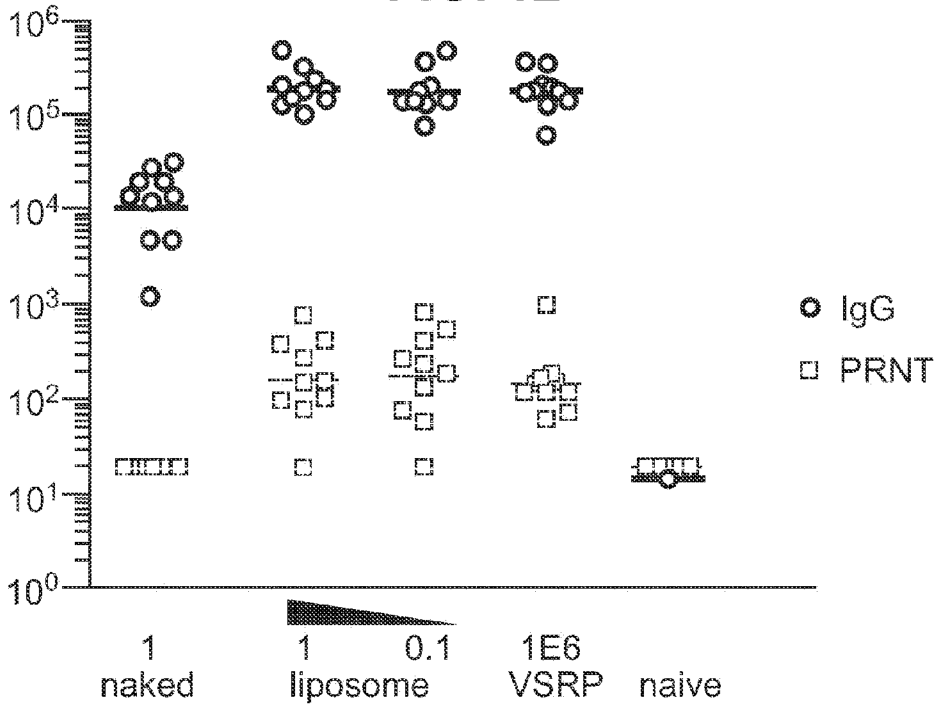

10^6
10^5
10^4
10^3
10^2
10^1
10^0
IgG
PRNT
1
naked
1
0.1
liposome
1E6
VSRP
naive

FIG. 13

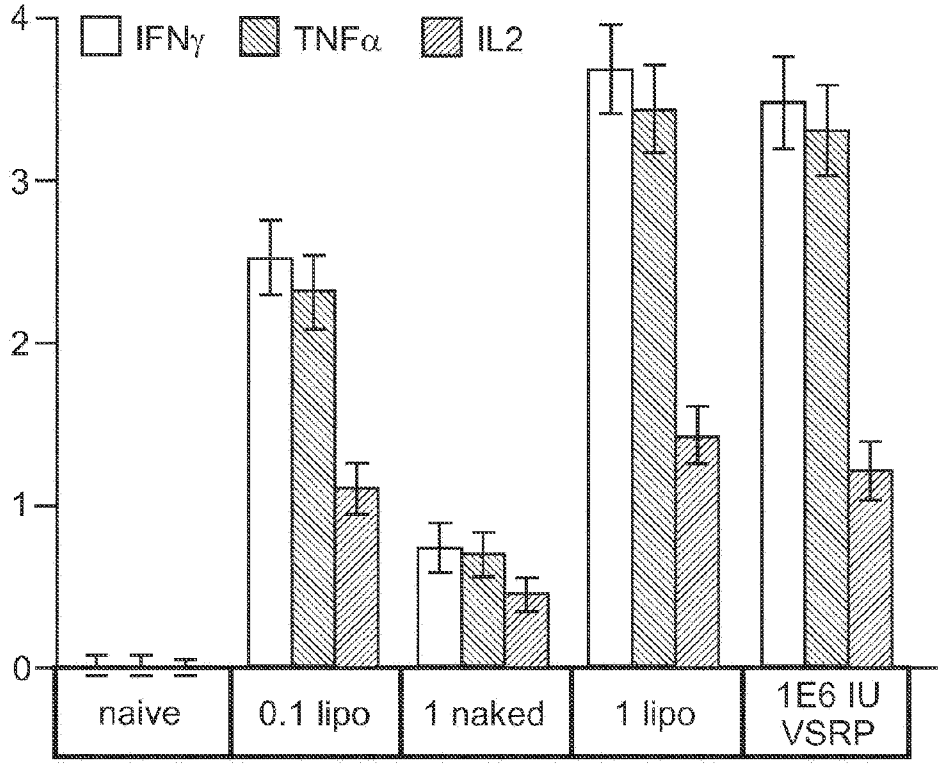

4
3
2
1
0
IFNγ
TNFα
IL2
naive
0.1 lipo
1 naked
1 lipo
1E6 IU
VSRP

FIG. 15

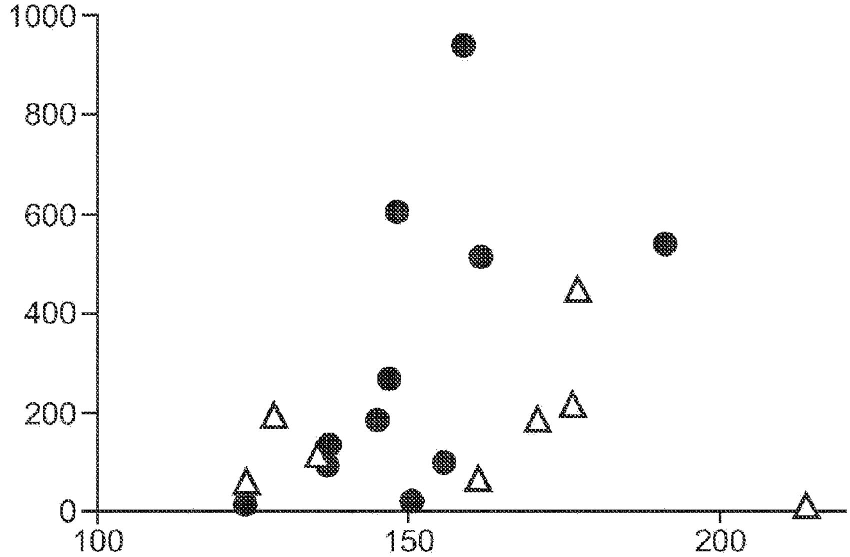
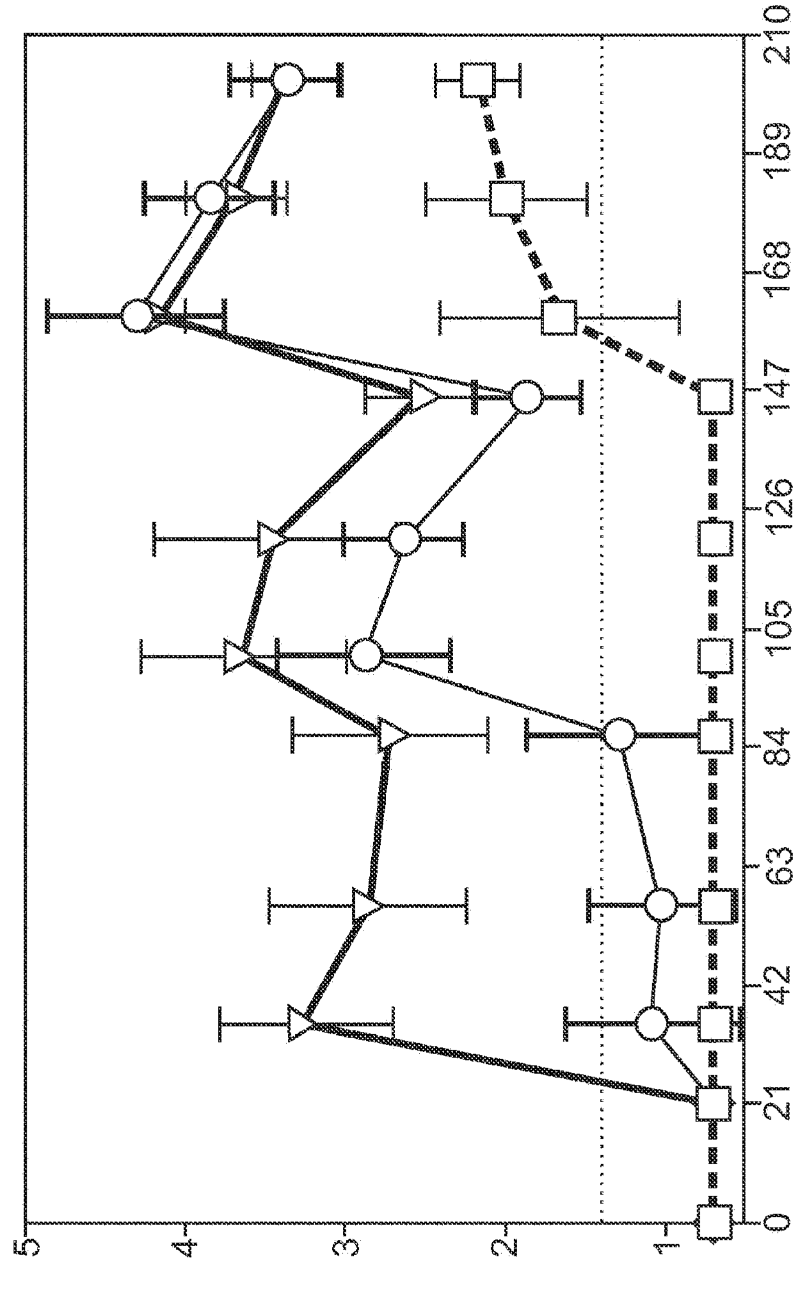

1000
800
600
400
200
0
100
150
200

FIG. 14



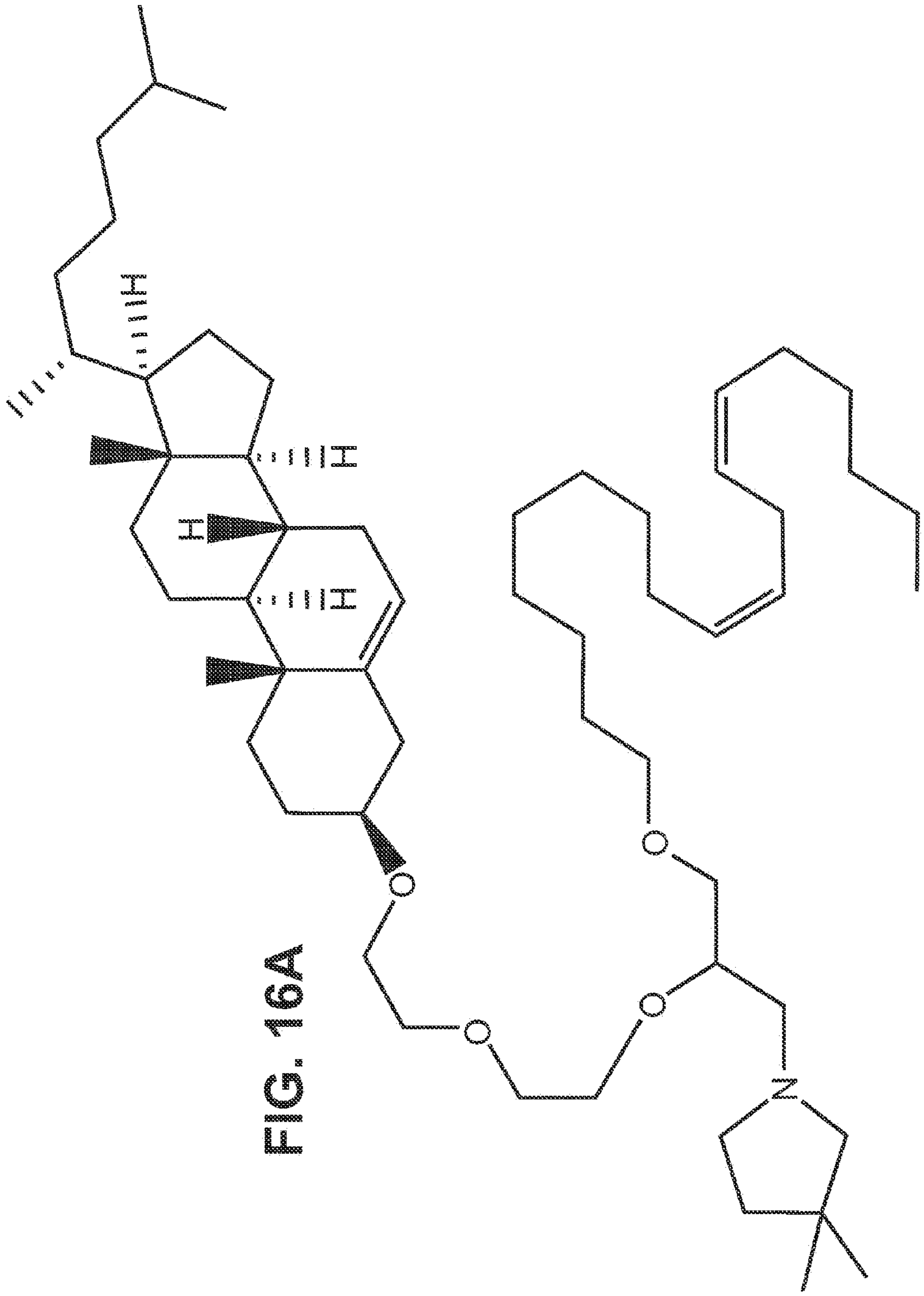


FIG. 16A

FIG. 16B

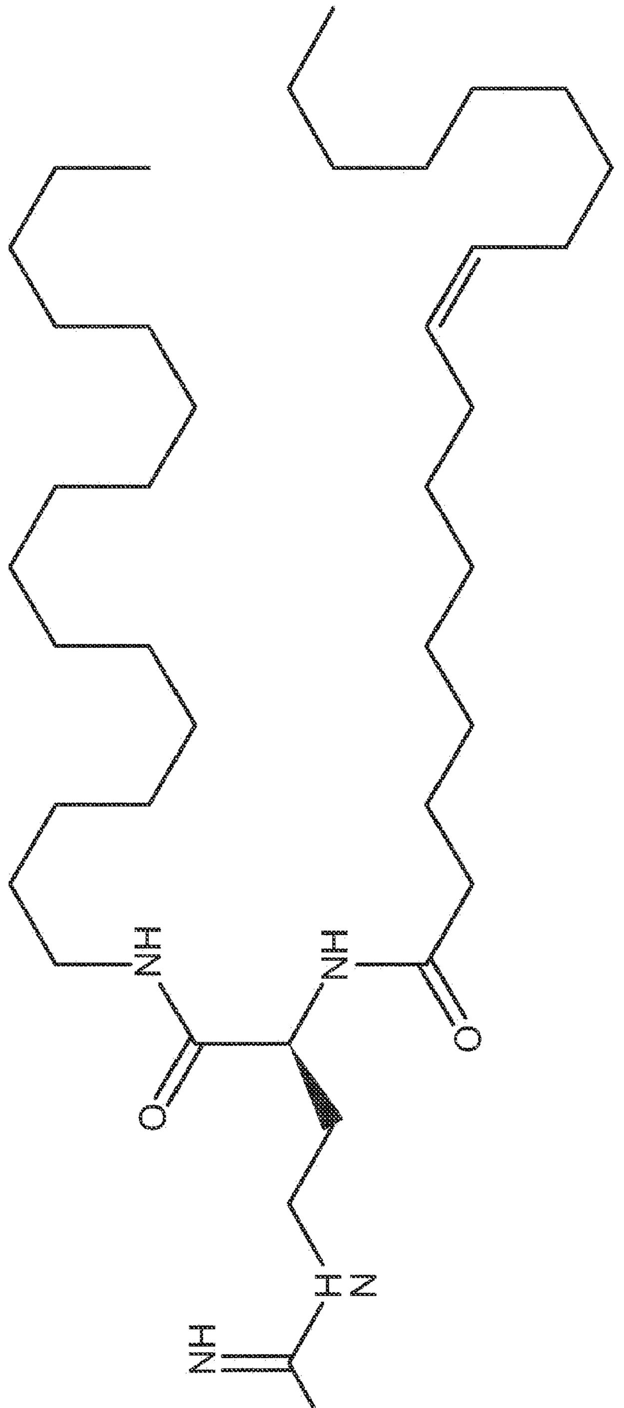
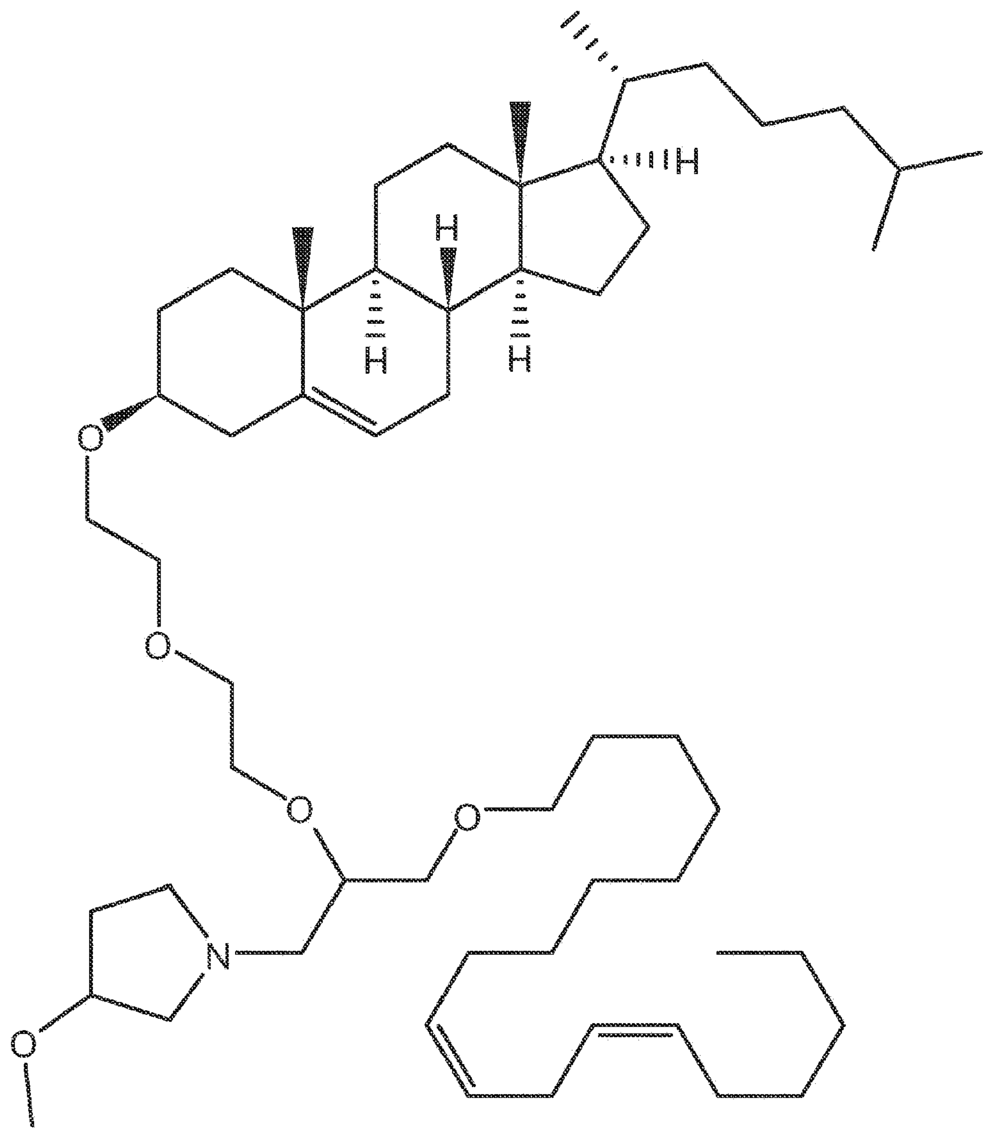


FIG. 16C



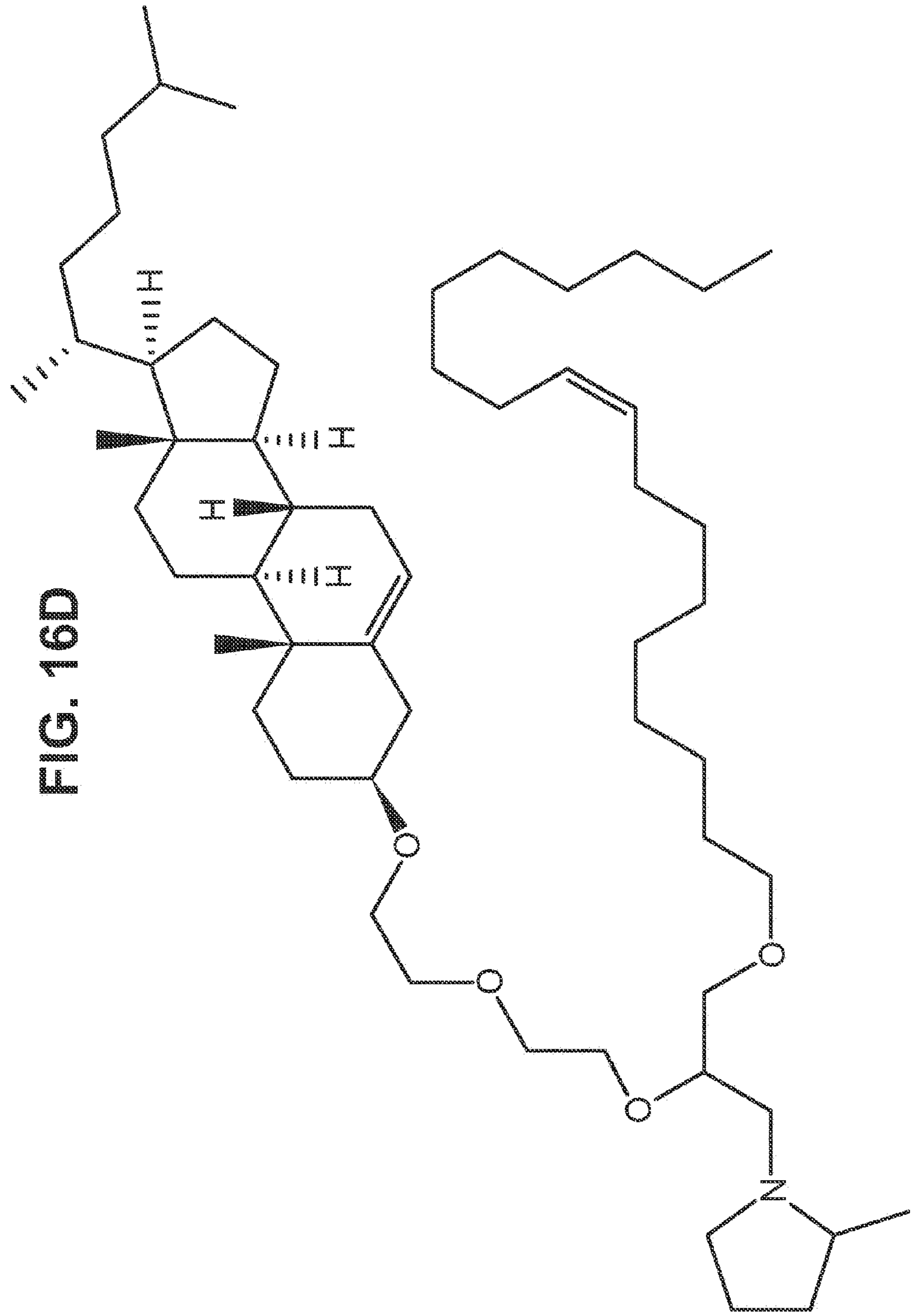
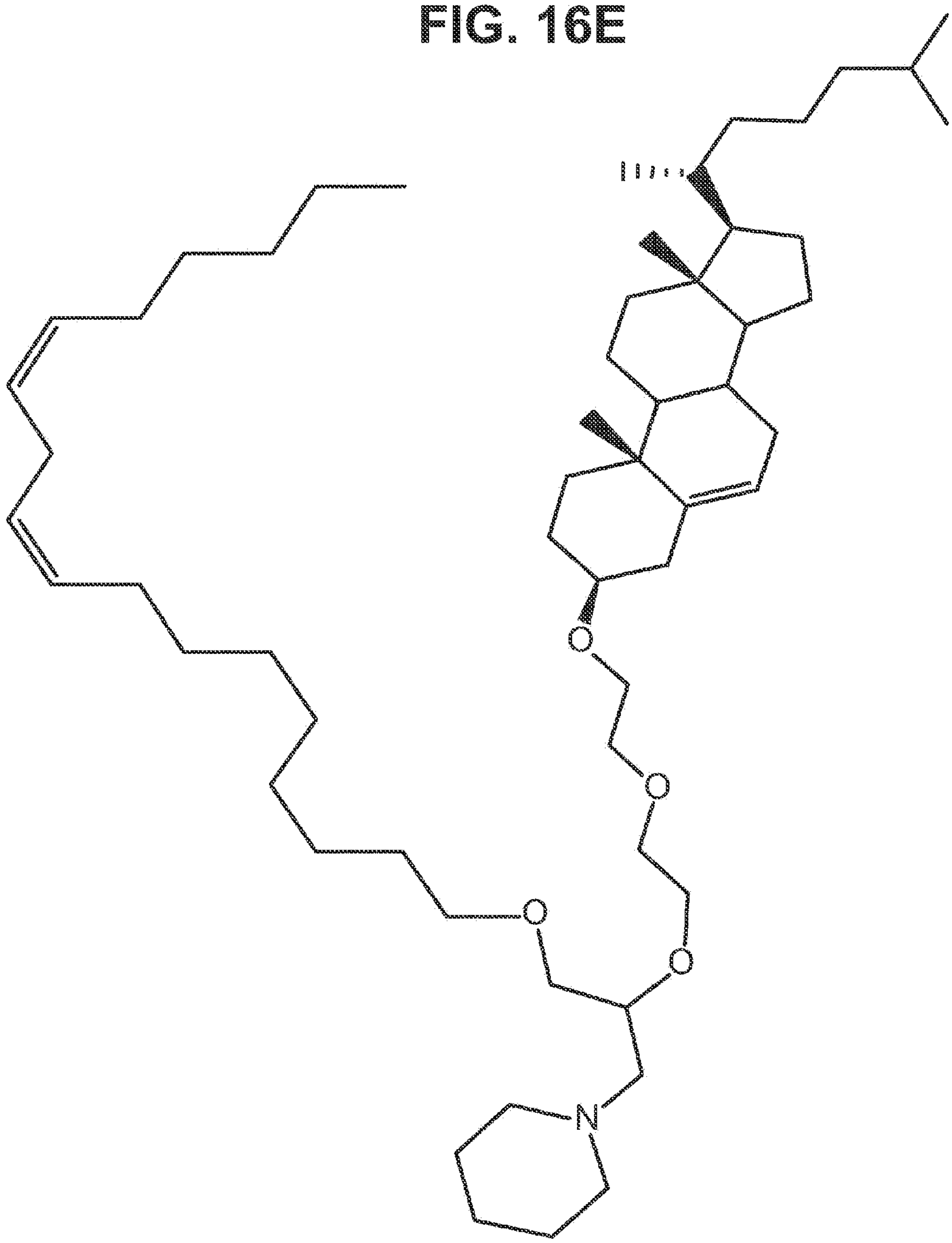


FIG. 16D

FIG. 16E



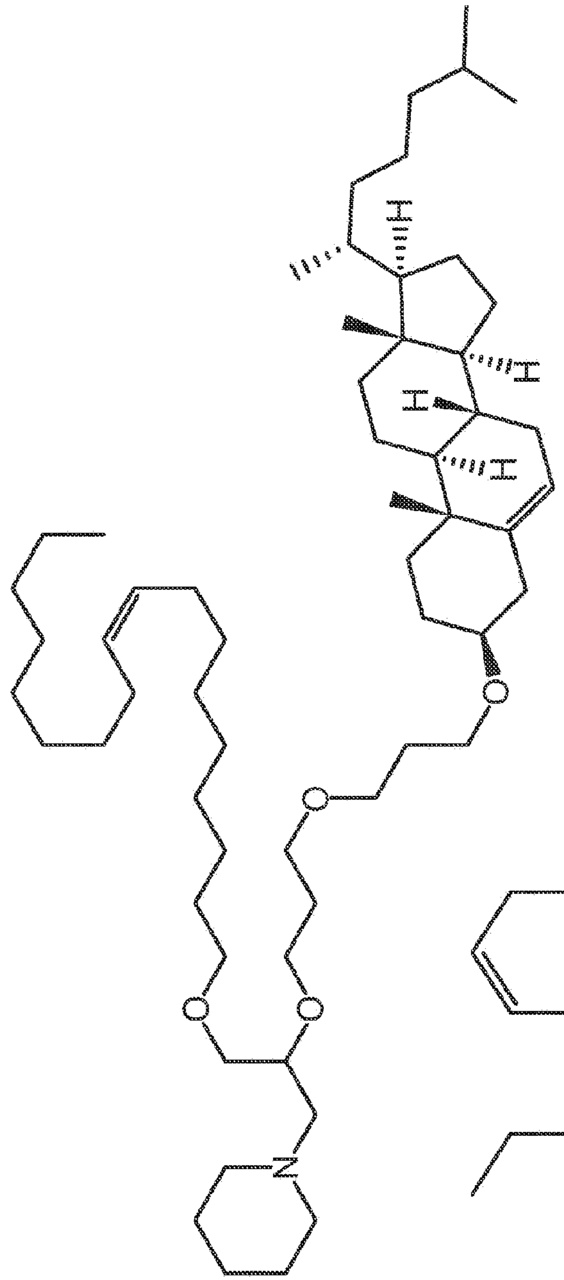


FIG. 16F

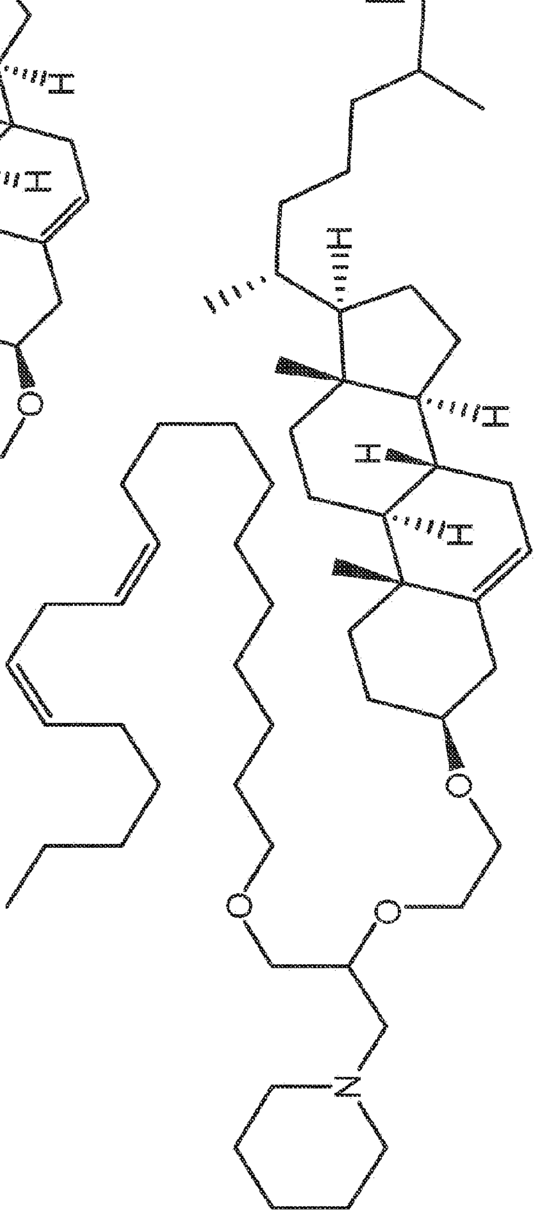


FIG. 16G

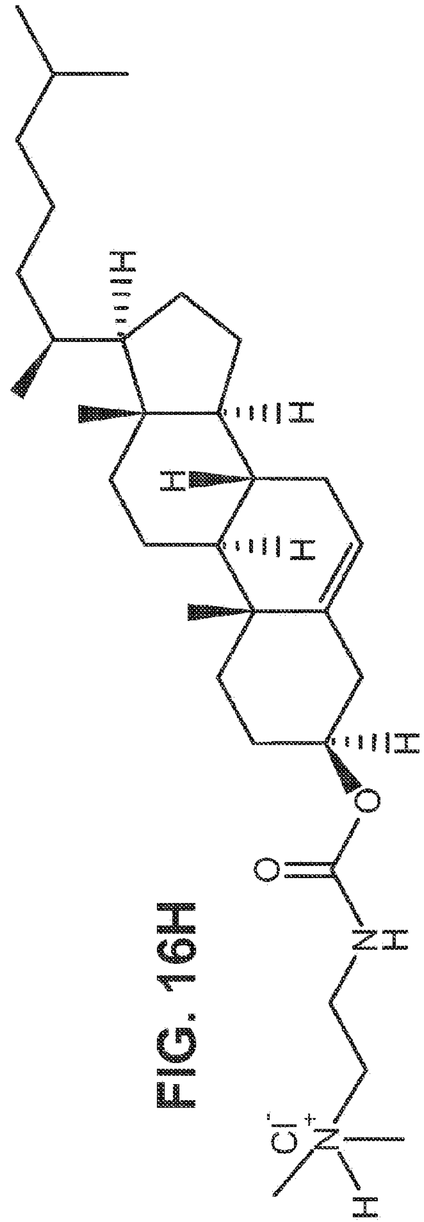


FIG. 16H

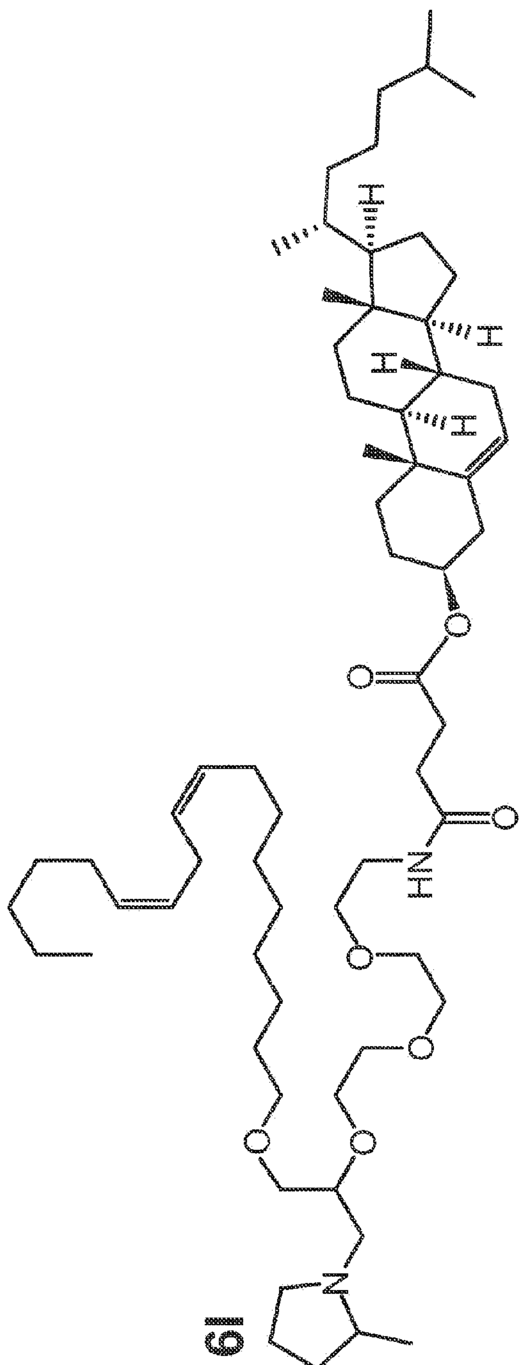


FIG. 16I

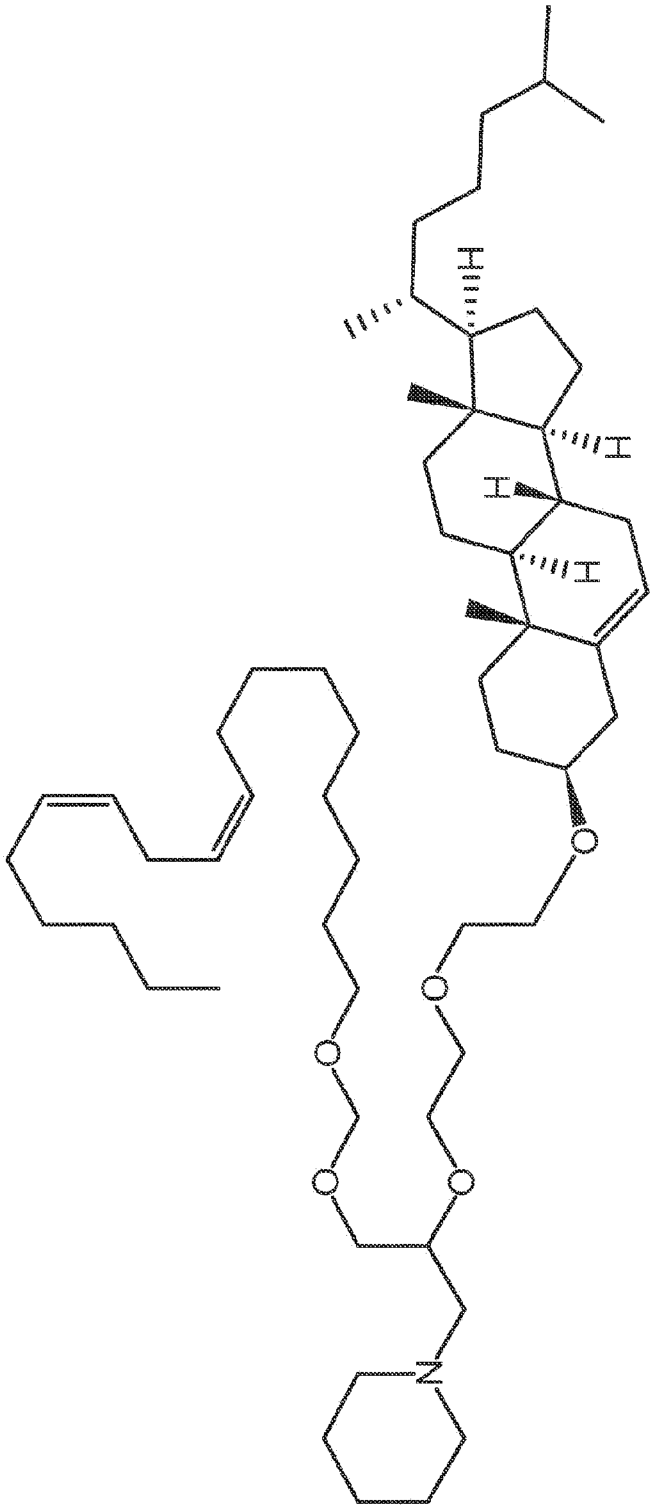


FIG. 16J

FIG. 16K

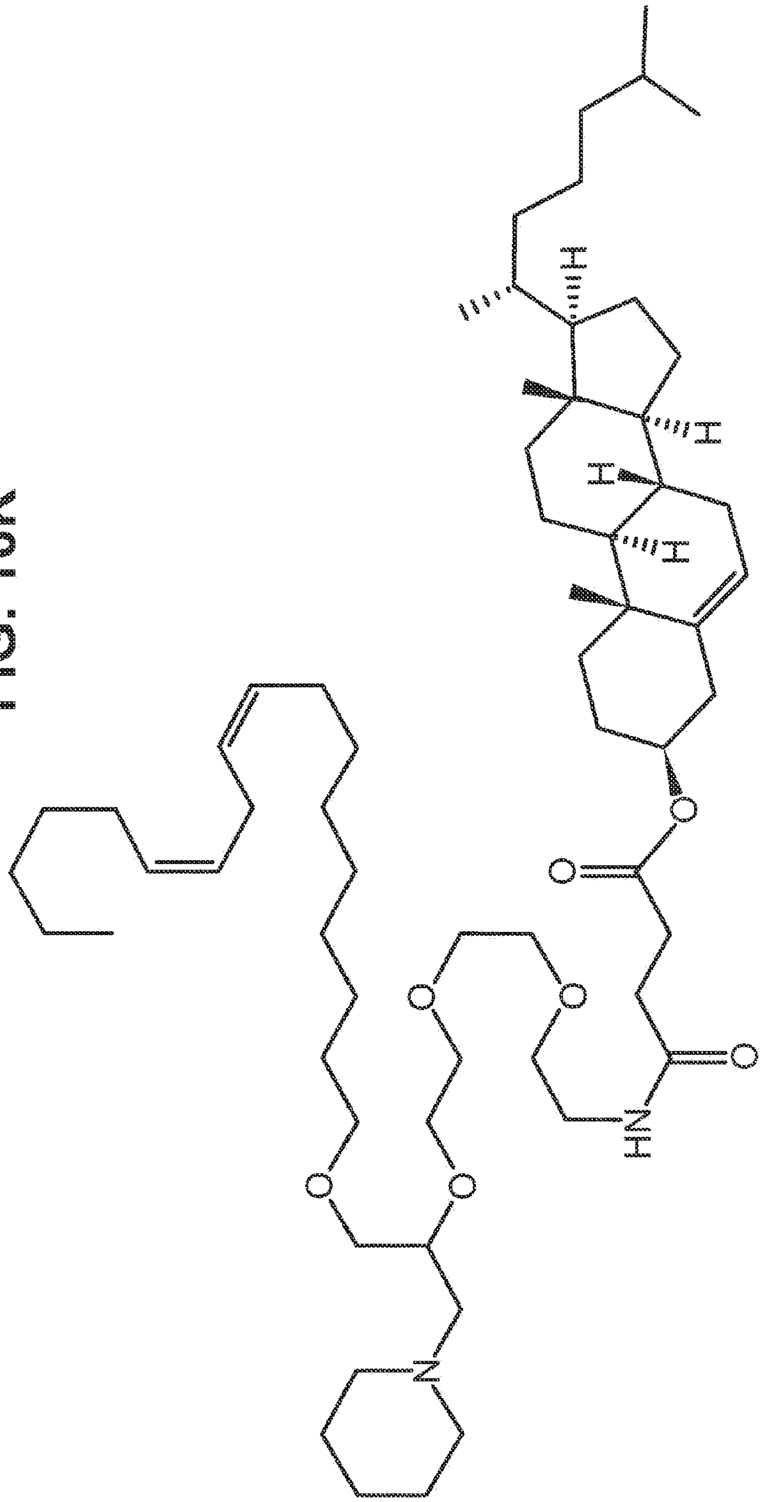


FIG. 16L

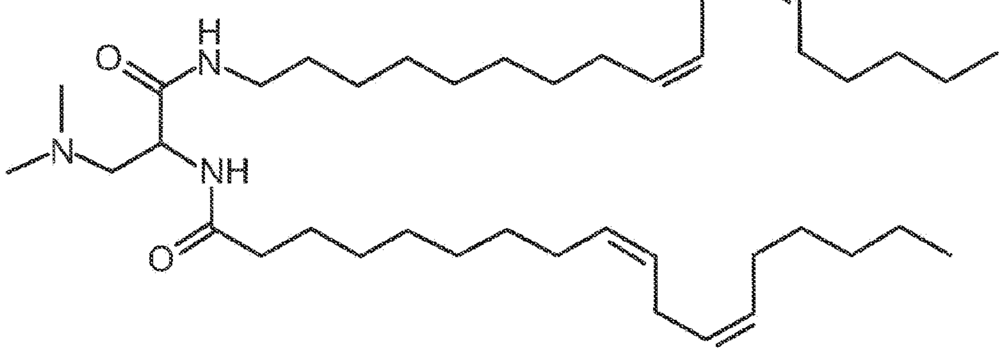


FIG. 16M

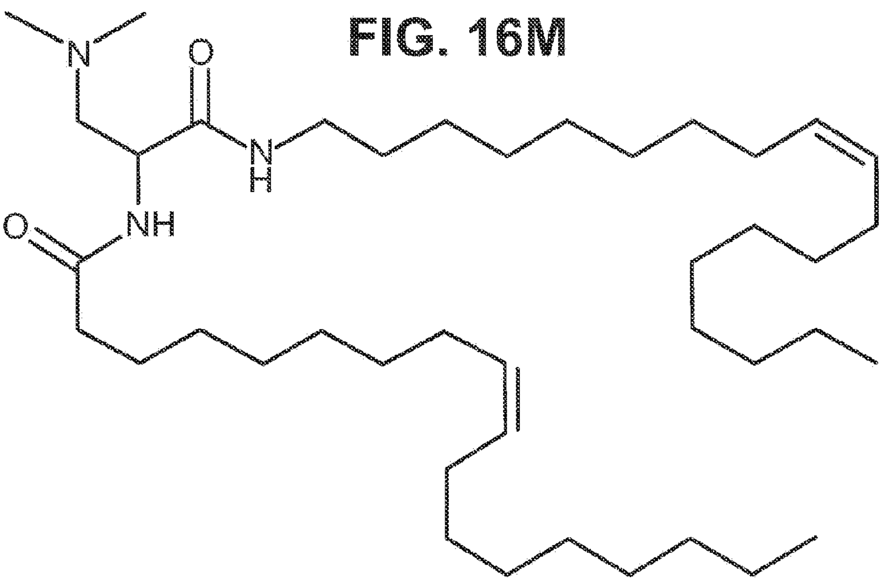
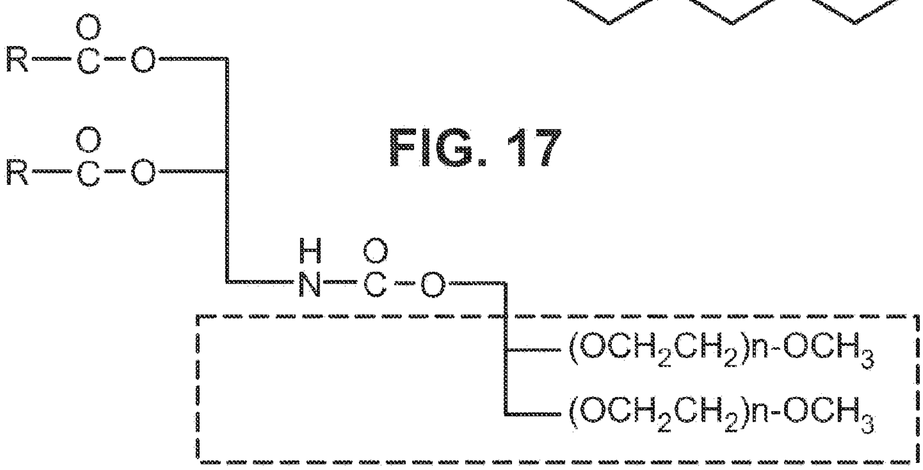


FIG. 17



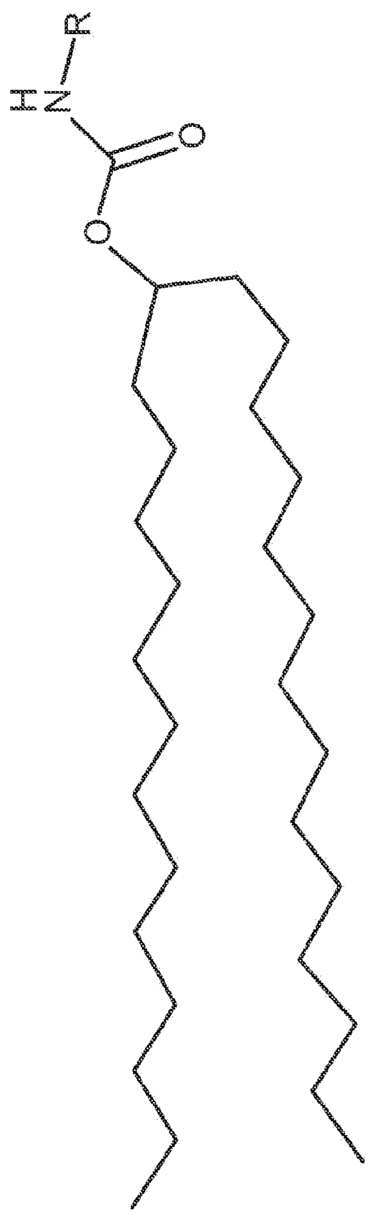


FIG. 18A

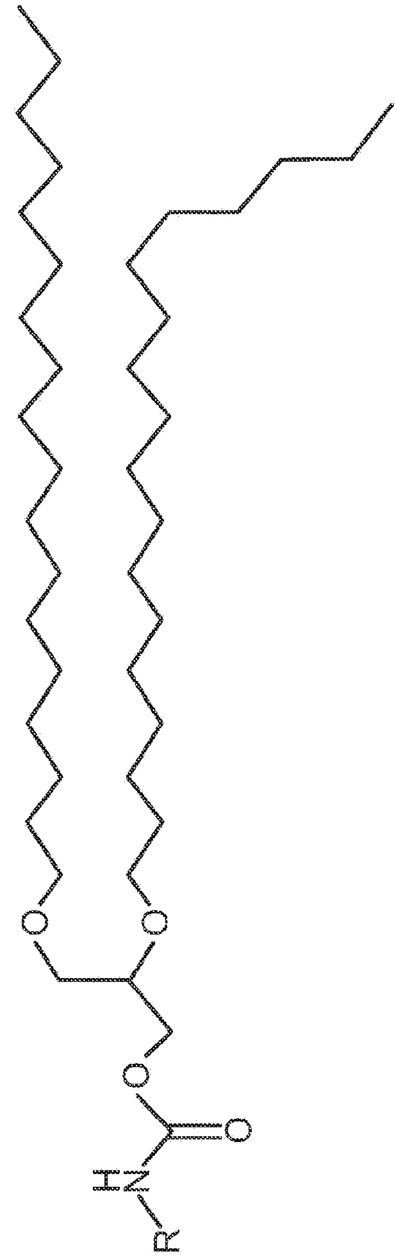


FIG. 18B

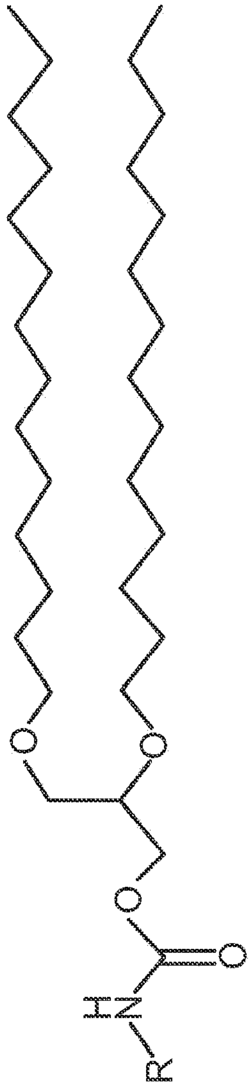


FIG. 18C

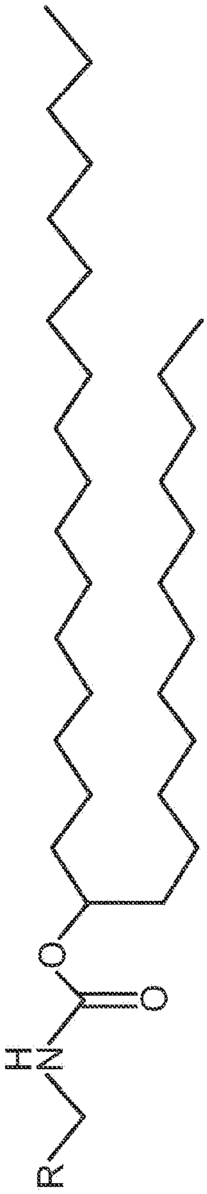


FIG. 18D

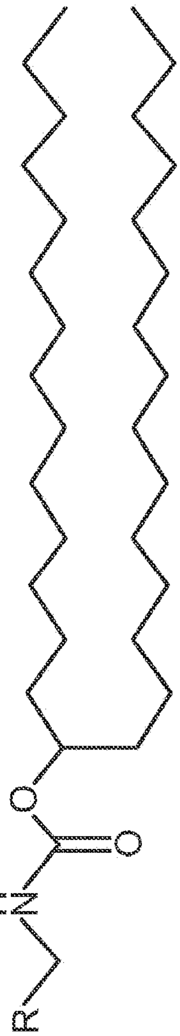


FIG. 18E