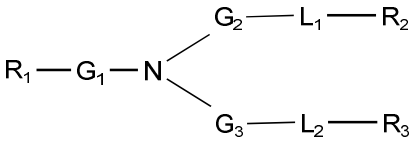
CLAIMS

1. A compound represented by formula (I)



(I),

(a) wherein R_1 is selected from $-OR_4$, $-NR_4R_5$, $-NR_4C(=O)R_5$, $-C(=O)OR_5$, $-OC(=O)R_5$, $-OC(=O)OR_5$, -CN, a nitrogen-containing heterocyclic group, and guanidino;

R_4 and R_5 are each independently selected from H, C_{1-9} alkyl, C_{2-9} alkenyl, C_{2-9} alkynyl, C_{3-8} cycloalkyl, C_{3-8} cycloalkenyl, and C_{3-8} cycloalkynyl;

G_1 is selected from a chemical bond (-), C_{1-9} alkylene, C_{2-9} alkenylene, C_{3-9} alkynylene, C_{3-8} cycloalkylene, and C_{3-8} cycloalkenylene;

preferably, R_1-G_1- has no more than 10 contiguous carbon atoms;

G_2 and G_3 are each independently selected from a chemical bond (-), C_{1-12} alkylene, C_{2-12} alkenylene, C_{2-12} alkynylene, C_{3-12} cycloalkylene, C_{3-12} cycloalkenylene, C_{3-12} cycloalkynylene, and C_{6-12} arylene;

L_1 and L_2 are each independently selected from a chemical bond (-), -O-, -S-, $-O(C=O)O-$, $-(C=O)NR_a-$, $-NR_a(C=O)-$, $-O(C=O)-$, $-(C=O)O-$, -S-S-, $-S(O)_x-$, $-OS(O)_xO-$, $-C(=O)S-$, $-SC(=O)-$, $-NR_aC(=O)NR_b-$, $-OC(=O)NR_a-$, $-NR_aC(=O)O-$, $-OC(=O)S-$, $-SC(=O)O-$, $-P(O)(OR_a)O-$, $-OP(O)(OR_a)O-$, and C_{1-12} alkylene, or a combination thereof;

x is selected from 0, 1, and 2;

R_a and R_b are each independently selected from H, C_{1-12} alkyl, C_{2-12} alkenyl, and C_{2-12} alkyne;

R_2 is selected from a naturally occurring or non-naturally occurring steroid;

R_3 is selected from a naturally occurring or non-naturally occurring steroid, C_{6-24} alkyl, C_{6-24} alkenyl, C_{6-24} alkyne, and C_{6-24} alkoxy;

(b) wherein R_1 is selected from $-OR_4$, $-NR_4R_5$, pyrazolyl, imidazolyl, piperazinyl,

alkylpiperazine, piperidinyl, alkylpiperidine, guanidino, pyrrolyl, and pyrrolidinyl; R_4 and R_5 are each independently selected from H, C_{1-9} alkyl, C_{2-9} alkenyl, C_{2-9} alkynyl, C_{3-8} cycloalkyl, and C_{3-8} cycloalkenyl;

G_1 is a chemical bond (-), C_{1-9} alkylene, C_{2-9} alkenylene, C_{3-8} cycloalkylene, or C_{3-8} cycloalkenylene;

preferably, G_1 is C_{1-6} alkylene or -C_{2-6} alkenylene;

preferably, R_1-G_1- has no more than 10 contiguous carbon atoms;

G_2 and G_3 are each independently selected from a chemical bond (-), C_{1-12} alkylene, C_{2-12} alkenylene, and -C_{2-12} alkynylene;

L_1 and L_2 are each independently selected from -O(C=O)-, -(C=O)O-, -S-S-, -O(C=O)O-, -NR_aC(=O)O-, -(C=O)NR_a-, -NR_a(C=O)-, -C(=O)S-, -SC(=O)-, -OC(=O)NR_a-, and C_{1-12} alkylene, or a combination thereof;

wherein R_a is H, C_{1-12} alkyl, C_{2-12} alkenyl, or C_{2-12} alkyne;

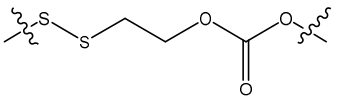
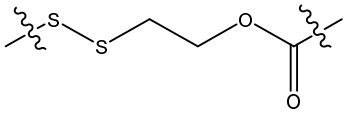
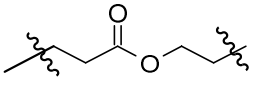
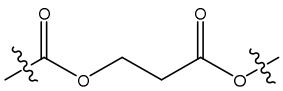
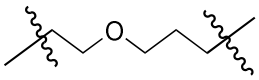
(c) wherein R_1 is selected from -OR_4, -NR_4R_5, imidazolyl, piperazinyl, and guanidino;

R_4 and R_5 are each independently selected from H and C_{1-5} alkyl;

G_1 is an unsubstituted C_{1-6} alkylene;

preferably, R_1-G_1- has no more than 10 contiguous carbon atoms;

G_2 and G_3 are each independently selected from a chemical bond (-) and C_{1-10} alkylene;

L_1 and L_2 are each independently selected from -O-, -O(C=O)-, -O(C=O)O-, -(C=O)O-, -(C=O)S-, -NHC(=O)O-, -NHC(=O)-, , , , , and ; or

(d) wherein R_2 is a sterol;

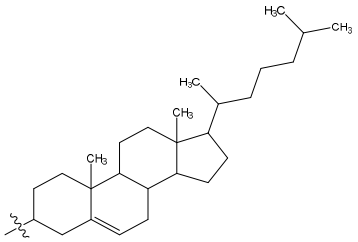
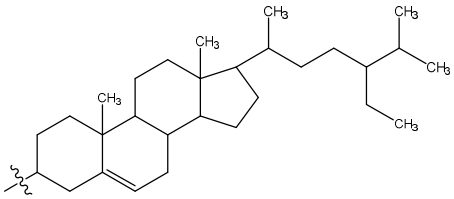
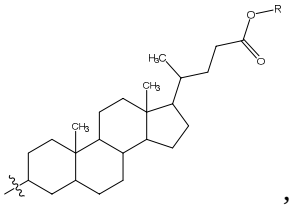
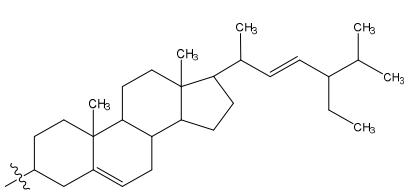
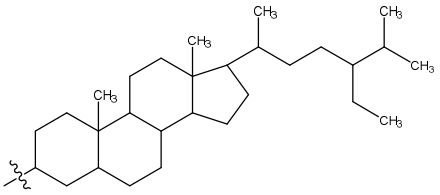
preferably, the sterol is a zoosterol or an oxidized or reduced form thereof; and/or the sterol is a phytosterol or an oxidized or reduced form thereof; and/or the sterol is a synthetic sterol or an oxidized or reduced form thereof;

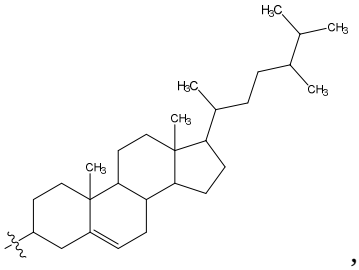
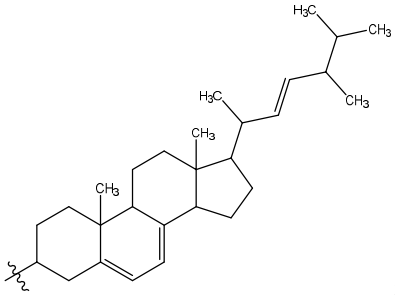
more preferably, the sterol is selected from cholesterol, an oxidized form of cholesterol, a reduced form of cholesterol, alkyl lithocholate, stigmasterol, stigmastanol, campesterol, ergosterol, and sitosterol;

more preferably, the sterol is an oxidized form of cholesterol, a reduced form of cholesterol, alkyl lithocholate, stigmasterol, stigmastanol, campesterol, ergosterol, or sitosterol;

more preferably, the sterol is selected from avenasterol, β-sitosterol, brassicasterol, ergocalciferol, campesterol, cholestanol, cholesterol, coprosterol, dehydrocholesterol, desmosterol, dihydroergocalciferol, dihydrocholesterol, dihydroergosterol, dinosterol, epicholesterol, ergosterol, fucosterol, hexahydrolumisterol, hydroxycholesterol, lanosterol, lumisterol, saringosterol, sitostanol, sitosterol, stigmastanol, stigmasterol, cholic acid, glycocholic acid, taurocholic acid, deoxycholic acid, and lithocholic acid;

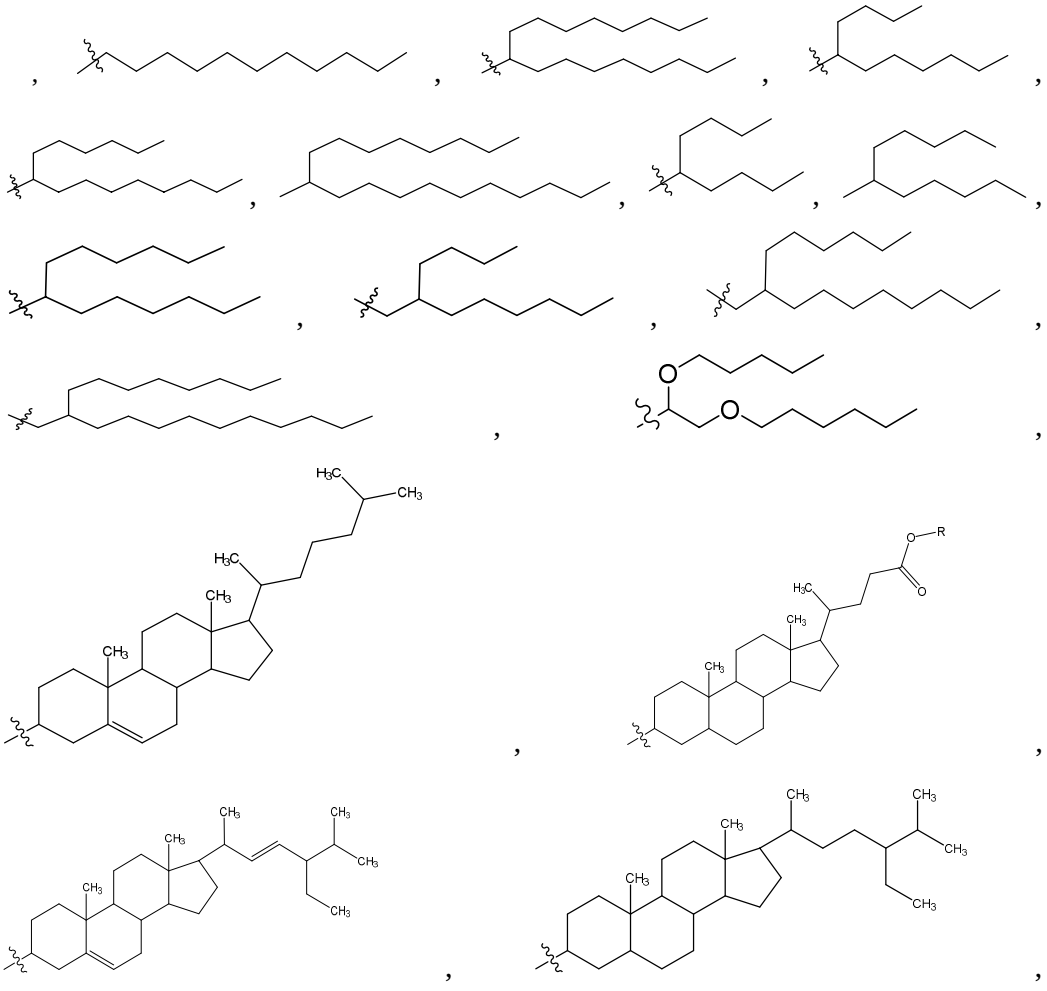
more preferably, the sterol has the following structural formula:

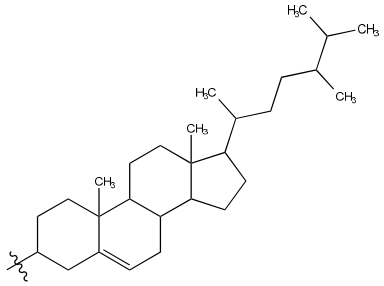
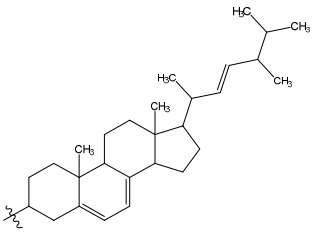
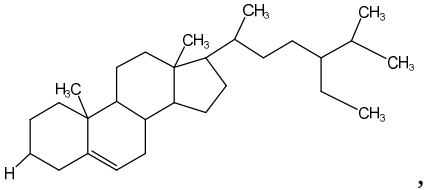
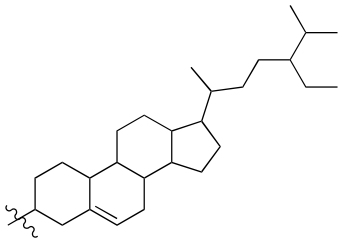

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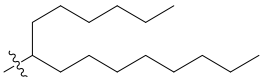
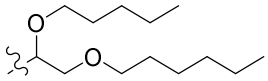
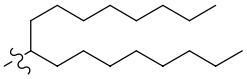
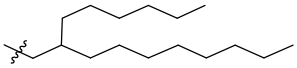
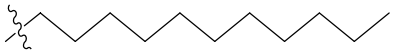
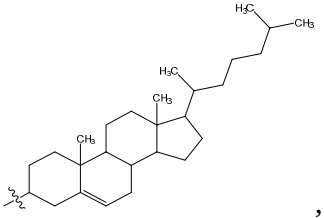
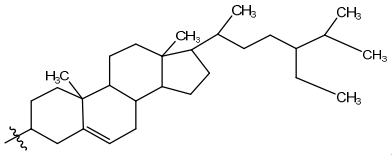
wherein R is $C_{1\text{-}20}$ alkyl.

2. The compound according to claim 1, wherein R_3 is selected from:

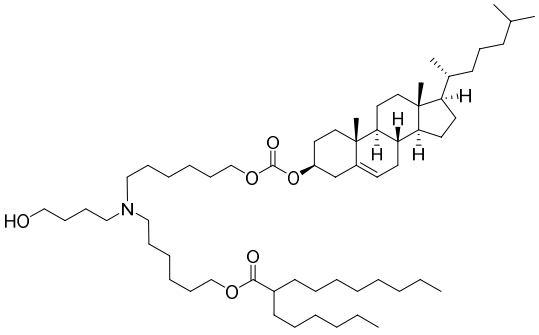
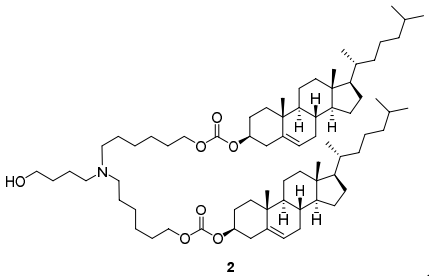


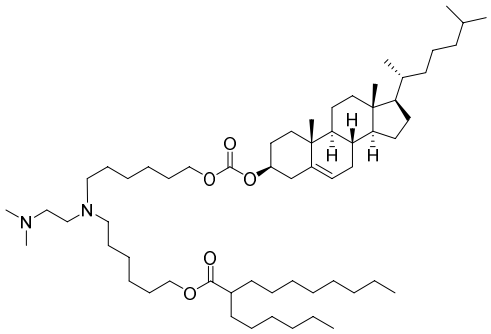

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preferably, R_3 is selected from:


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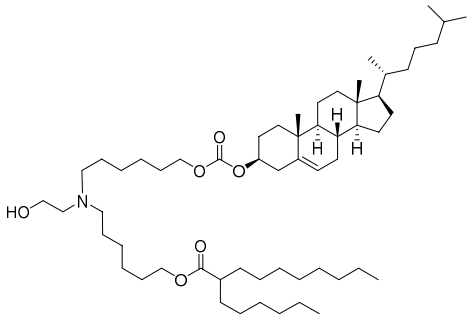
3. The compound according to claim 1 or 2, wherein the compound is selected from:


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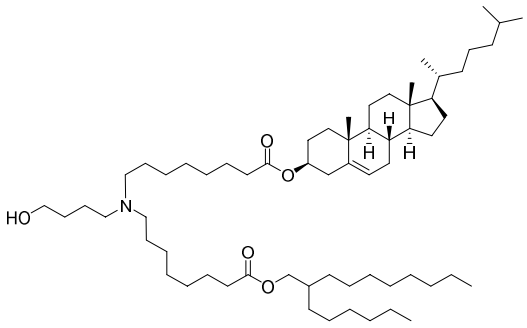
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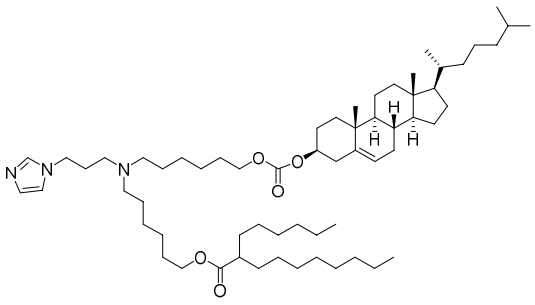
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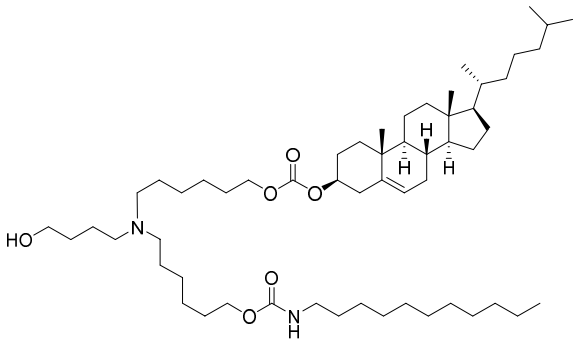
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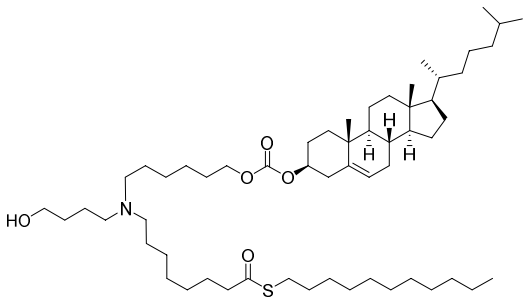
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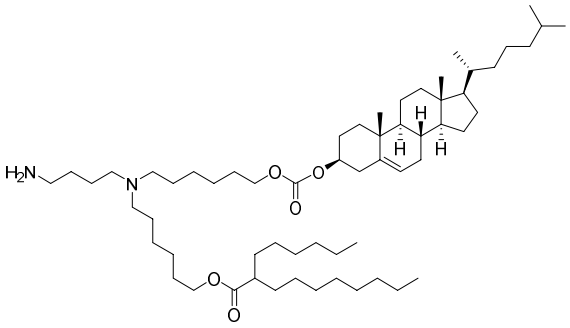
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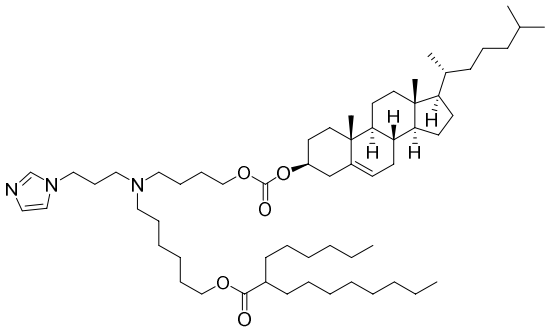
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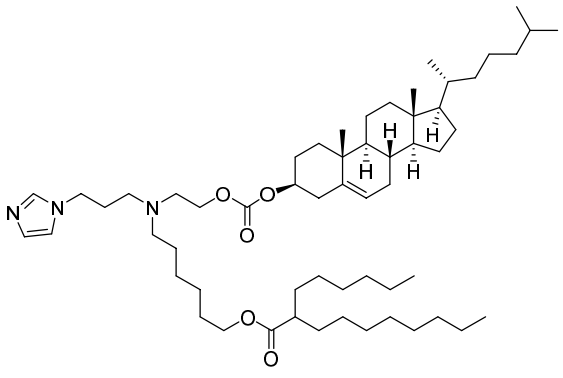
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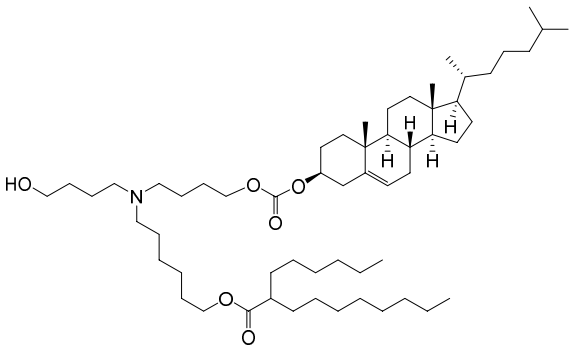
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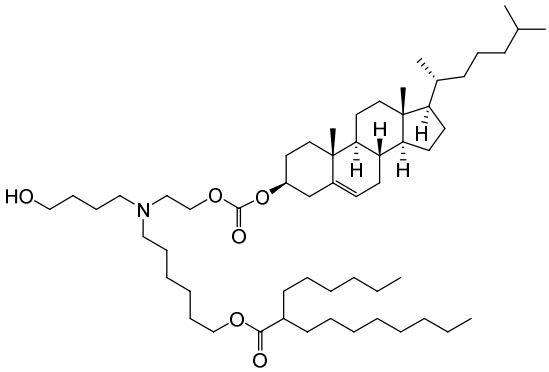
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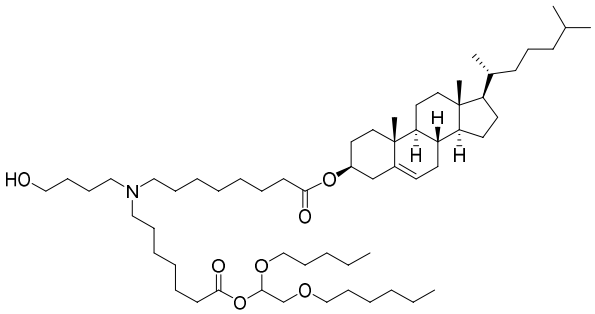
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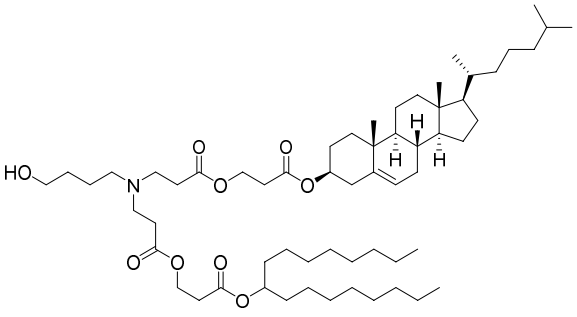
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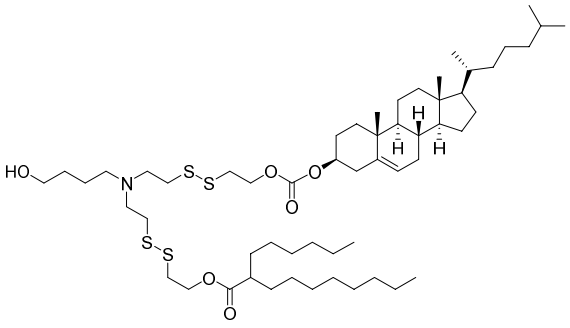
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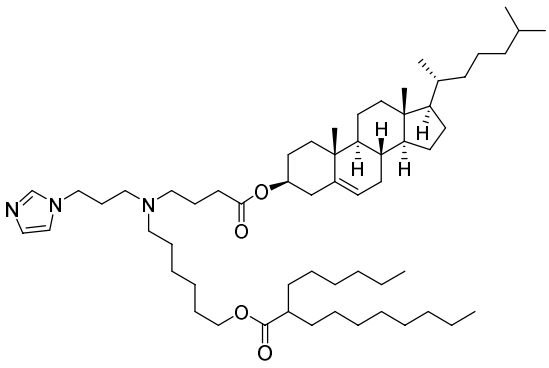


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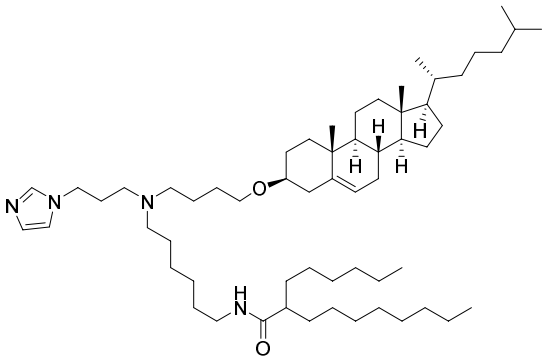
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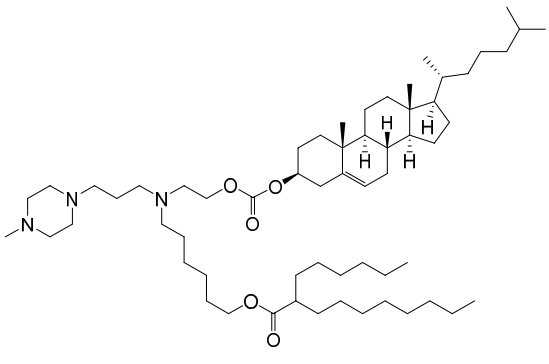
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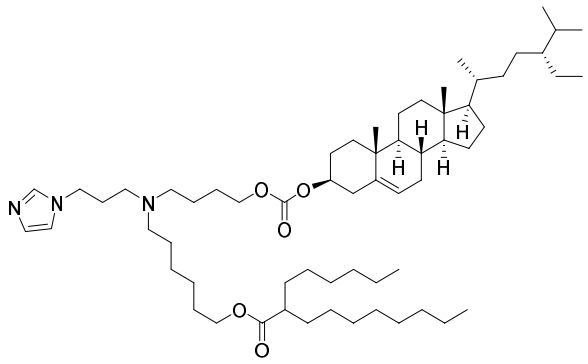
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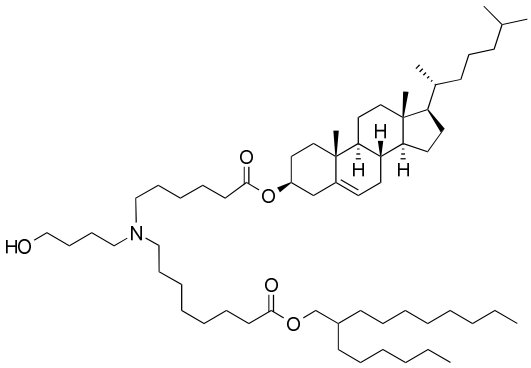
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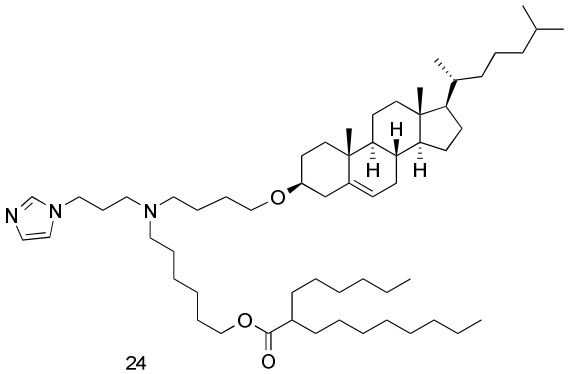
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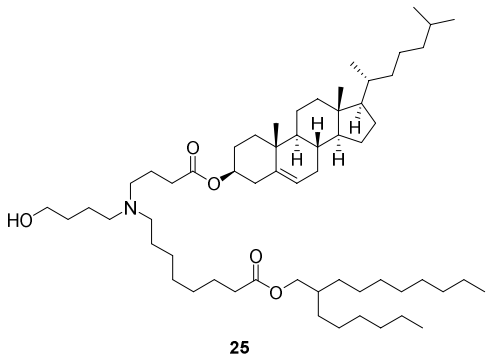
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24 , and



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4. A lipid nanoparticle, comprising the compound according to any one of claims 1-3.

5. The lipid nanoparticle according to claim 4, further comprising a polyethylene glycol lipid and at least one helper lipid, wherein the helper lipid is selected from a neutral lipid, a zwitterionic lipid, and an anionic lipid.

6. The lipid nanoparticle according to claim 5,

(a) wherein the polyethylene glycol lipid is selected from 2-[(polyethylene glycol)-2000]-N,N-ditetradecylacetamide (ALC-0159), 1,2-dimyristoyl-sn-glycero-methoxypolyethylene glycol (PEG-DMG), 1,2-distearoyl-sn-glycero-3-phosphoethanolamine-N-[amino(polyethylene glycol)] (PEG-DSPE), PEG-disterol glycerol (PEG-DSG), PEG-dipalmitoyl, PEG-dioleyl, PEG-distearyl, PEG-diacylglycerol amide (PEG-DAG), PEG-dipalmitoyl phosphatidylethanolamine (PEG-DPPE), and PEG-1,2-dimyristoyloxypropyl-3-amine (PEG-c-DMA);

the helper lipid is selected from 1,2-distearoyl-sn-glycero-3-phosphocholine (DSPC), 1,2-dipalmitoyl-sn-glycero-3-phosphocholine (DPPC), 1,2-dioleoyl-sn-glycero-3-phosphoethanolamine (DOPE), 1,2-dipalmitoyl-sn-glycero-3-phosphoethanolamine (DPPE), 1,2-dimyristoyl-sn-glycero-3-phosphoethanolamine (DMPE), 2-dioleoyl-sn-glycero-3-phospho-(1'-rac-glycerol) (DOPG), palmitoyloleoylphosphatidylcholine (POPC), 1-palmitoyl-2-oleoylphosphatidylethanolamine (POPE), phosphocholine (DOPC), dimyristoylphosphatidylcholine (DMPC), phosphatidylcholine (PLPC), 1,2-distearoyl-sn-glycero-3-phosphocholine (DAPC), phosphatidylethanolamine (PE), egg phosphatidylcholine (EPC), dilauroylphosphatidylcholine (DLPC), dimyristoylphosphatidylcholine (DMPC), 1-myristoyl-2-palmitoylphosphatidylcholine (MPPC), 1-palmitoyl-2-myristoylphosphatidylcholine (PMPC), 1-palmitoyl-2-stearoylphosphatidylcholine (PSPC), 1,2-diarachidoyl-sn-

glycero-3-phosphocholine (DBPC), 1-stearoyl-2-palmitoylphosphatidylcholine (SPPC), 1,2-eicosenoyl-sn-glycero-3-phosphocholine (DEPC), lysophosphatidylcholine, dilinoleoylphosphatidylcholine distearoylphosphatidylethanolamine (DSPE), and lysophosphatidylethanolamine; or

(b) wherein the molar ratio of the compound according to any one of claims 1-3 to the helper lipid to the polyethylene glycol lipid is (20-80):(20-80):(0.5-20); preferably, the molar ratio of the compound according to any one of claims 1-3 to the helper lipid to the polyethylene glycol lipid is (30-80):(30-80):(0.5-20).

7. The lipid nanoparticle according to claim 4, wherein the lipid nanoparticle has a diameter of 15-300 nm.

8. Use of the compound according to claims 1-3 and/or the lipid nanoparticle according to claims 4-7 in preparing a bioactive substance delivery system.

9. The use according to claim 8, wherein the bioactive substance is a DNA or an RNA, wherein the RNA is selected from an antisense RNA, an saRNA, an mRNA, an lncRNA, an miRNA, an siRNA, a piRNA, a gRNA, a tsRNA, a circRNA, and a self-amplifying mRNA;

preferably, the bioactive substance delivery system is an mRNA vaccine;

preferably, the mRNA vaccine is a vaccine for preventing a cancer, a virus infection, a bacterial infection, or a fungal infection;

preferably, the virus is selected from norovirus, Ebola virus, coronavirus, cytomegalovirus, Dengue virus, Zika virus, coxsackievirus, enterovirus, hepatitis virus, herpes simplex virus, human papilloma virus, influenza virus, Marburg virus, measles virus, poliovirus, rabies virus, rotavirus, and/or measles virus.

10. The lipid nanoparticle according to any one of claims 4-7, further comprising a bioactive substance.

11. The lipid nanoparticle according to claim 10, wherein the bioactive substance is a DNA or an RNA, wherein the RNA is preferably selected from an antisense RNA, an saRNA, an mRNA, an lncRNA, an miRNA, an siRNA, a piRNA, a gRNA, a tsRNA, a circRNA, and a self-amplifying mRNA.

12. The lipid nanoparticle according to claim 10 or 11, wherein the lipid nanoparticle has a nitrogen-to-phosphorus ratio of (1-15):1.

13. A medicament, comprising the lipid nanoparticle according to any one of claims 10-12 and a pharmaceutically acceptable excipient.

14. The medicament according to claim 13,

(a) wherein the medicament is a liquid formulation or a lyophilized powder formulation; or

(b) wherein the medicament is a formulation for oral administration, intramuscular injection, subcutaneous injection, intravenous injection, aerosol inhalation, and/or dry powder inhalation.