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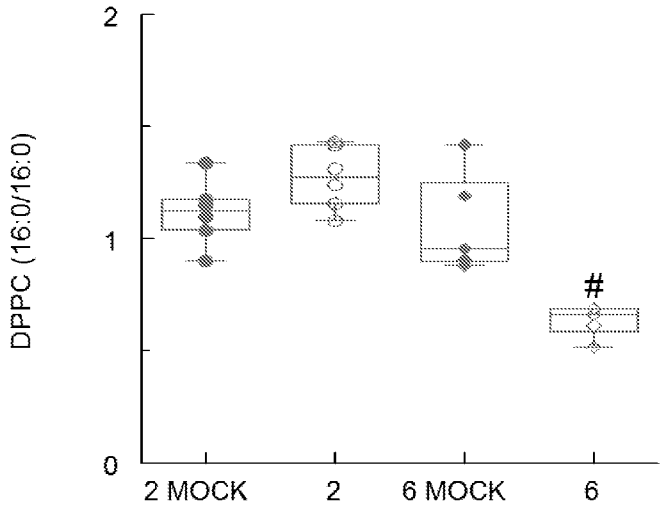

FIGURE 1

(57) Abstract: Compositions and method are therefore disclosed for treating ARDS. In particular, disclosed a composition that contains one, two, or more cytidine diphosphate (CDP)-conjugated precursors selected from the group consisting of CDP-choline, CDP-ethanolamine, and CDP-diacylglycerol (CDP-DAG) in a pharmaceutically acceptable carrier for use in treating ARDS.

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LIPONUCLEOTIDE-BASED THERAPY FOR ARDS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Application No. 62/355,096, filed June 27, 2016, which is hereby incorporated herein by reference in its entirety.

BACKGROUND

Acute respiratory distress syndrome (ARDS, also known as acute lung injury or acute hypoxemic respiratory failure) is a clinical syndrome characterized by acute onset of severely impaired alveolar gas exchange. ARDS can be caused by both direct lung insults (infection, toxic gas inhalation, etc.) or as an indirect result of trauma, sepsis, or other bodily insults. Approximately 200,000 human ARDS cases occur per year in the US. ARDS can also develop in other animals. Once ARDS has developed, the only treatment option is nonspecific supportive management in the ICU. Currently, approximately 40% of human patients with any form of ARDS die and many more are left with severe deficits in lung function and reduced quality of life.

Influenza is the 8th leading cause of attributable annual human mortality in the USA, accounting for approximately 200,000 hospitalizations and greater than 30,000 excess deaths per year. Influenza also has significant pandemic potential. For example, the 1918 “Spanish flu” pandemic resulted in more than 50 million deaths worldwide. Influenza also has potential as a biological warfare and bioterrorism agent. Approximately 20% of patients with severe influenza develop ARDS, which is associated with poor prognosis. There is a great need for new treatments that can prevent, retard, or manage progression of severe influenza to ARDS: this is also true for ARDS from other causes.

Pulmonary surfactant, which is primarily composed of phospholipids, is essential to normal lung function and is synthesized by alveolar type II (ATII) cells. Phospholipids are also vital to many other aspects of cellular and organellar metabolism and function. Phospholipid content of bronchoalveolar lavage fluid (BALF) from ARDS patients is often low, although the mechanisms underlying this effect have not been defined. Direct administration of artificial surfactant (e.g., Survanta) into the lungs is highly effective in treating neonatal respiratory distress syndrome (neonatal RDS) in humans. However, recent trials of surfactant replacement therapy in human ARDS patients were inconclusive or showed no benefit.

SUMMARY

Development of influenza-induced ARDS is shown herein to result from reduced levels of phospholipids and cytidine diphosphate (CDP)-conjugated liponucleotide precursors for phospholipid synthesis in ATII cells. This is accompanied by reduced BALF surfactant phospholipid content. The disclosed data indicate that influenza infection results in decreased synthesis of CDP-conjugated liponucleotide precursors for phospholipid synthesis by ATII cells. This may occur directly as a result of influenza viral infection of and/or replication in said cell, or indirectly as a result of the effect of host factors currently known or to be discovered in the future that are induced in other cells in response to viral infection acting on said cell. Therefore, as disclosed herein, supplementation with the liponucleotides CDP-choline, CDP-ethanolamine, CDP-diacylglycerol (CDP-DAG), or any combination thereof, either prior to or after onset of injury or disease has occurred can bypass the block(s) in phospholipid synthesis resulting from reduced liponucleotide synthesis and thereby improve ATII cell phospholipid synthesis in a cell being susceptible to an injury which causes normal phospholipid production of said cell to become retarded and/or completely inhibited. This supplementation can result in increased ATII cell and surfactant phospholipid levels, thereby promoting improved ATII cell and lung function. This will prevent or retard development of ARDS in influenza-infected subjects, or will reduce severity of ongoing ARDS and will thereby increase influenza survival rates and reduce incidence and severity of long-term clinical sequelae associated with ARDS and mechanical ventilation. These include, but are not limited to, reduced lung function, pulmonary fibrosis, depression, post-traumatic stress disorder, and others known to those skilled in the art. Because similar decreases in BALF surfactant levels have been described for ARDS caused by other insults, this therapy could have general patient outcome benefits in various delivery modalities and the wide applicability for ARDS.

An additional reason for the focus on these lipids is that they are vital to many other aspects of cellular and organellar metabolism and function. ATII cells have high metabolic activity and are therefore heavily dependent on mitochondrial (Mi) function for energy production. Mi function is also important for other lung cells. Mi membranes contain large amounts of phospholipids, which play an important role in maintaining normal Mi structure and function. Hence, alterations in phospholipid synthesis may also impair Mi viability, function and generation of ATP. This will have consequences for ATII cell function. A change in Mi phospholipid composition could also promote mitophagy, Mi-dependent ATII cell apoptosis, and release of Mi DNA,

which can have pro-inflammatory effects and may contribute to development of ARDS. The data disclosed herein show that development of influenza-induced ARDS is associated with dysregulated oxidative phosphorylation and abnormal mitochondrial (Mi) morphology in ATII cells, which can be reversed by treatment with CDP-choline. Therefore, as disclosed herein, supplementation with the liponucleotides CDP-choline, CDP-ethanolamine, CDP-DAG, or any combination thereof, can bypass the block(s) in phospholipid synthesis resulting from reduced liponucleotide synthesis and thereby improve Mi structure and function in an ATII cell and/or other lung cells being susceptible to an injury which causes normal phospholipid production of said cell to become retarded, impaired, and/or completely inhibited.

The plasma membranes and lipid membranes of all other cellular organelles in all lung cells known or to be discovered in the future will all be expected to contain large amounts of phospholipids, which are essential to the normal function of said organelles. Hence, alterations in phospholipid synthesis will impair plasma membrane and organelle membrane integrity and function. This will have consequences for ATII cell and other lung cell function and viability. Therefore, supplementation with the liponucleotides CDP-choline, and/or CDP-ethanolamine, and/or CDP-DAG, with or without chemical modifications, can bypass the block in phospholipid synthesis resulting from reduced liponucleotide synthesis and thereby improve ATII cell and other lung cell plasma membrane and organelle structure and function in a cell being susceptible to an injury which causes normal phospholipid production of said cell to become retarded and or completely inhibited.

Compositions and methods are therefore disclosed for preventing, retarding development of, or treating ARDS. For example, a composition is disclosed that contains one, two, or more cytidine diphosphate (CDP)-conjugated precursors selected from the group consisting of CDP-choline, CDP-ethanolamine, and CDP-DAG in a pharmaceutically acceptable carrier.

DAG is a glyceride consisting of two fatty acid (acyl) chains covalently bonded to a glycerol molecule through ester linkages. Two possible forms exist, 1,2-diacylglycerols and 1,3-diacylglycerols. In some embodiments, the CDP-DAG contains acyl chains derived from short-chain fatty acids (with aliphatic tails containing fewer than 6 carbons), medium-chain fatty acids (with aliphatic tails containing 6-12 carbons), long-chain fatty acids (with aliphatic tails containing 13-21 carbons), or very long-chain fatty acids (with aliphatic tails containing more than 22 carbons). Fatty acids may be of natural origin or generated by chemical synthesis,

according to any methods known to those skilled in the art. In some embodiments, the two acyl chains are in the 1,2 positions. In some embodiments, the two acyl chains are in the 1,3 positions. In some embodiments, both acyl chains are of the same length (contain the same number of carbons). In some embodiments, the two acyl chains are of different lengths. In some embodiments, one or both acyl chains of the DAG component of CDP-DAG are mono-unsaturated (containing one double bond in *cis* and/or *trans* configuration). In some embodiments, one or both acyl chains of the DAG component of CDP-DAG are poly-unsaturated (containing more than one double bond in *cis* and/or *trans* configuration). In some embodiments, one or both acyl chains of the DAG component of CDP-DAG are saturated (containing no double bonds). In some embodiments, one or both acyl chains are chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, the CDP component of CDP-choline is chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, the CDP component of CDP-ethanolamine is chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, the CDP component of CDP-DAG is chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, the choline component of CDP-choline is chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, the ethanolamine component of CDP-ethanolamine is chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, the glycerol component of CDP-DAG is chemically modified. Chemical modifications include, but are not limited to, methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, conjugation to fluorophores, and other modifications known to those skilled in the art.

In some embodiments, a mixture of two or more CDP-choline precursors with or without different chemical modifications of CDP and/or choline can be incorporated.

In some embodiments, a mixture of two or more CDP-ethanolamine precursors with or without different chemical modifications of CDP and/or ethanolamine chains can be incorporated.

In some embodiments, a mixture of two or more CDP-DAG precursors with or without different acylations or chemical modifications of CDP and/or acyl chains can be incorporated.

In some embodiments, the CDP-conjugated precursors are collectively present at a unit dose of at least 0.1 ng/kg, including 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 ng/kg.

In some embodiments, the CDP-choline and/or CDP-ethanolamine and/or CDP-DAG are present in equal concentrations or ratios. In some embodiments, at least two of the CDP-conjugated precursors are present in equal concentrations or ratios, which can be higher or lower than the third CDP-conjugated precursor, which may be absent. In some cases, one of the CDP-conjugated precursors is present at a concentration or ratio that is at least 2, 3, 4, 5, 6, 7, 8, 9, or 10 fold higher than one or both of the other CDP-conjugated precursors.

The disclosed compositions can further contain other active and inactive ingredients. For example, in some embodiments, the composition can contain additional lipid moieties, nucleotides, organic acids, amino acids, or sugars.

Also disclosed is a method for preventing development of ARDS in a subject that involves administering to the subject an effective amount of a composition comprising a CDP-conjugated precursor selected from the group consisting of CDP-

choline, CDP-ethanolamine, CDP-DAG, and combinations thereof as prophylaxis prior to infection with one or more influenza virus strains.

Also disclosed is a method for preventing development of ARDS in a subject that involves administering to the subject an effective amount of a composition comprising a CDP-conjugated precursor selected from the group consisting of CDP-choline, CDP-ethanolamine, CDP-DAG, and combinations thereof after the subject has been infected with one or more influenza virus strains but before said subject has developed ARDS.

Also disclosed is a method for treating ARDS in a subject that involves administering to the subject with ARDS an effective amount of a composition comprising a CDP-conjugated precursor selected from the group consisting of CDP-choline, CDP-ethanolamine, CDP-DAG, and combinations thereof.

The disclosed methods can be used to prevent, retard development of, or treat any form of ARDS, which can be caused by both direct lung insults (infection, toxic gas inhalation, cancer, acid aspiration, chest trauma, etc.) or as an indirect result of trauma to other body regions, sepsis, ischemia/reperfusion, surgery, or other causes (see Table 1). In some cases, the ARDS is caused by influenza or by other respiratory viral, bacterial, or fungal infections.

In some cases, the subject has a PaO_2/FiO_2 ratio of about 550 - 750 mmHg (≤ 100 kPa) which would be considered normal clinically. Alternatively, the subject has an arterial O_2 saturation of greater than 92%. In other cases, the subject has normal lung compliance and no evidence of non-cardiogenic pulmonary edema by radiography, CT scan, magnetic resonance imaging, or other imaging modalities present and future. In some cases, sound medical judgment may dictate that the subject requires prophylactic treatment as a result of having co-morbidities associated with increased risk of influenza infection and/or development of ARDS including, but not limited to, type I diabetes mellitus, type II diabetes mellitus, obesity, pregnancy, epilepsy, pre-existing pulmonary disease, pre-existing cardiovascular disease, pre-existing renal disease, or any other co-morbidity currently known to be or identified in the future as being associated with increased risk of developing ARDS. In other cases, the subject may be clinically normal but require prophylactic treatment as a result of increased risk of exposure to influenza viruses, influenza-infected subjects, or other known causes of ARDS, in order to preserve availability of essential personnel.

In some cases, the subject has a PaO_2/FiO_2 ratio of about 201 - 300 mmHg (≤ 39.9 kPa), 101 - 200 mmHg (≤ 26.6 kPa), or ≤ 100 mmHg (≤ 13.3 kPa). In some

cases, the subject has a PaO_2/FiO_2 ratio of less than 300 mmHg, less than 200 mmHg, or less than 100 mmHg. These 3 categories correspond to mild, moderate and severe ARDS, as currently defined clinically by the Berlin criteria. In other cases, the subject may have a PaO_2/FiO_2 ratio of about 300 - 550 mmHg (≤ 73.3 kPa), which would be considered moderately abnormal clinically. Alternatively, the subject has an arterial O_2 saturation of less than 92%. In other cases, the subject has a reduced lung compliance or evidence of non-cardiogenic pulmonary edema by radiography, CT scan, magnetic resonance imaging, or other imaging modalities present and future. The subject may exhibit alterations in other measures that may have been or will be found to be associated with ARDS presence and severity in either clinical or experimental situations, including, but not limited to, impaired alveolar fluid clearance, elevated pro-inflammatory cytokines, chemokines, and other inflammatory mediators in lung and/or blood, decreased anti-inflammatory cytokines, chemokines, and other inflammatory mediators in lung and/or blood, increased leukocytes in lung and/or blood, and increased cell death in lung tissue.

The disclosed composition can be administered, for example, intravenously, orally, intramuscular, intraperitoneally, by intrapulmonary instillation, or by inhalation (e.g., aerosolized dry powder or nebulized droplet). Compositions delivered by different routes may contain different formulations.

In some embodiments, the method further involves treating the subject with surfactant therapy. In some embodiments, the method further involves treating the subject with tracheal intubation, tracheotomy, tracheostomy, mechanical ventilation, with or without positive end-expiratory pressure (PEEP), prone or supine positioning, supplemental oxygen, nitric oxide, extracorporeal membrane oxygenation, beta-adrenergic agonists or antagonists, corticosteroids and other anti-inflammatory agents, antibiotics, antiviral drugs, antifungal drugs, cytokines, stem cells from any source, intravenous fluids, whole blood or blood components, parenteral or enteral nutritional formulations, vasodilators, vasoconstrictors, diuretics, insulin or other synthetic or natural hormones, or any combination thereof, or any other treatments found to be beneficial in future experimental and/or clinical situations.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

Figure 1 is a plot showing effect of infection on ATII cell DPPC (16:0/16:0) surfactant. # = P<0.001.

Figure 2 is a plot showing effect of infection on ATII cell DPPG (16:0/16:0) surfactant. * = P<0.05, # = P<0.001.

Figure 3 is a plot showing effect of infection on ATII cell PE (16:0/18:2) surfactant. # = P<0.001.

Figure 4 is a plot showing effect of infection on BALF phospholipid glycerol. # = P<0.001.

Figure 5 is a schematic showing DPPC synthesis by the CDP-choline (Kennedy) pathway.

Figure 6 is a plot showing effect of infection on ATII cell DAG (18:1/18:2). * = P<0.05, # = P<0.001.

Figure 7 is a plot showing effect of infection on ATII cell choline-P (18:1/18:2).

Figure 8 is a plot showing effect of infection on ATII cell CDP-choline.

Figure 9 is a schematic showing therapeutic approach.

Figure 10 is a graph showing effect of CDP-choline treatment (▲) on mouse O_2 SATS as a function of time (days after infection). # = P<0.001.

Figure 11 is a graph showing effect of CDP-choline treatment (▲) on mouse activity (rmp/mouse) as a function of time (days after infection). * = P<0.05, # = P<0.001.

Figure 12 is a bar graph showing effect of day 5 only CDP-choline treatment on mouse O_2 SATS. * = P<0.05, # = P<0.001.

Figure 13 is a bar graph showing effect of formulation treatment on mouse O_2 SATS. # = P<0.001.

Figure 14 is a group of three transmission electron micrographs showing effects of CDP-choline treatment on ultrastructure of ATII cell lamellar bodies (composed of surfactant lipids and proteins).

Figure 15 is a group of 3 transmission electron micrographs showing effects of influenza infection on ultrastructure of ATII cell mitochondria (Mi).

DETAILED DESCRIPTION

The term “subject” refers to any individual who is the target of administration or treatment. The subject can be a vertebrate, for example, a mammal or bird. Thus, the subject can be a human or veterinary patient. The term “patient” refers to a subject under the treatment of a clinician, e.g., physician or veterinarian, as well as

other allied health professionals, including nurses, physician's assistants, and pharmacists.

The term "therapeutically effective" refers to the amount of the composition used is of sufficient quantity to ameliorate one or more causes, symptoms, and/or clinical signs of a disease or disorder. Such amelioration only requires a reduction or alteration, not necessarily elimination.

The term "pharmaceutically acceptable" refers to those compounds, materials, compositions, and/or dosage forms which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and animals without excessive toxicity, irritation, allergic response, or other problems or complications commensurate with a reasonable benefit/risk ratio.

The term "carrier" means a compound, composition, substance, or structure that, when in combination with a compound or composition, aids or facilitates preparation, storage, administration, delivery, effectiveness, selectivity, or any other feature of the compound or composition for its intended use or purpose. For example, a carrier can be selected to minimize any degradation of the active ingredient and to minimize any adverse side effects in the subject.

The term "treatment" refers to the medical management of a patient with the intent to cure, ameliorate, stabilize, or prevent a disease, pathological condition, or disorder. This term includes active treatment, that is, treatment directed specifically toward the improvement of a disease, pathological condition, or disorder, and also includes causal treatment, that is, treatment directed toward removal of the cause of the associated disease, pathological condition, or disorder. In addition, this term includes palliative treatment, that is, treatment designed for the relief of symptoms and/or clinical signs rather than the curing of the disease, pathological condition, or disorder; preventative treatment, that is, treatment directed to minimizing or partially or completely inhibiting the development of the associated disease, pathological condition, or disorder; and supportive treatment, that is, treatment employed to supplement another specific therapy directed toward the improvement of the associated disease, pathological condition, or disorder.

The disclosed methods can be used to prevent or treat any form of ARDS, which can be caused by both direct lung insults (infection, toxic gas inhalation, cancer, acid aspiration, chest trauma, etc.) or as an indirect result of trauma to other body regions, sepsis, ischemia/reperfusion, or surgery. In some cases, the ARDS is caused by influenza or by other respiratory viral, bacterial, or fungal infections.

In some embodiments, the disclosed methods can be used to treat cardiogenic pulmonary edema, pulmonary trauma and/or hemorrhage, pulmonary ischemia, or pulmonary embolism. Additional primary ARDS indications and non-ARDS uses are described in Table 1.

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Table 1.

Indication	Cause of ARDS*	Cause of non-ARDS lung injury or dysfunction
Pneumonia/pneumonitis associated with infectious diseases (bacterial, viral, fungal)	YES	YES
Sepsis, septicemia, SIRS (infectious and non-infectious)	YES	YES
Exposure to toxic vapors (natural and synthetic), irritant gases, products of combustion, chemical warfare agents, or pollutants by inhalation or any other any route	YES	YES
Aspiration of gastric contents, acids, alkalis, or other irritants	YES	YES
Pancreatitis	YES	YES
Near drowning resulting in aspiration of fresh or salt water into lungs	YES	YES
Burns	YES	YES
Chest or other trauma	YES	YES
Diffuse alveolar or other pulmonary hemorrhage	YES	YES
Extrapulmonary hemorrhage and/or hypovolemic shock	YES	YES
Lung transplantation	YES	YES
Cardiopulmonary bypass	YES	YES
Transfusion-related acute lung injury (TRALI) resulting from massive blood transfusion	YES	YES
Bone marrow transplantation	YES	YES
Pulmonary embolism (fat, air, other), ischemia, atelectasis	YES	YES
Mechanical ventilation and ventilator-induced lung injury	YES	YES
Hyperoxia	YES	YES
Cardiogenic pulmonary edema resulting from acute myocardial infarction, cardiac arrhythmia, or other causes of acute or chronic heart failure	YES	YES
Neoplasia (primary and/or metastatic lung cancer and injurious effects of cancers in other organs on lung function)	YES	YES
Neonatal respiratory distress syndrome	YES	YES
Multi-organ dysfunction syndrome (MODS)	YES	YES
Iatrogenic and side-effects of pharmacologics, antineoplastic drugs, radiographic contrast media, nutritional supplements, alternative medicines, and other biologics administered by inhalation or any other route	YES	YES

Drug overdose (e.g., aspirin, cocaine, opioids, phenothiazenes, trcicyclics, and the like)	YES	YES
Asthma, anaphylactic shock, autoimmunity, allergy, immune suppression, or other intra- and extra-pulmonary conditions resulting from genetic or acquired abnormalities in host immune function	YES	YES
Neurogenic pulmonary edema due to stroke, seizure, head trauma, anoxia, and other neurologic injuries or defects	YES	YES
Idiopathic acute interstitial pneumonia (Hamman-Rich syndrome) and other idiopathic causes of lung injury	YES	YES
Other causes of ARDS known or yet to be discovered	YES	YES
* According to Berlin definition plus any subsequent modifications to the current clinical definition of ARDS		

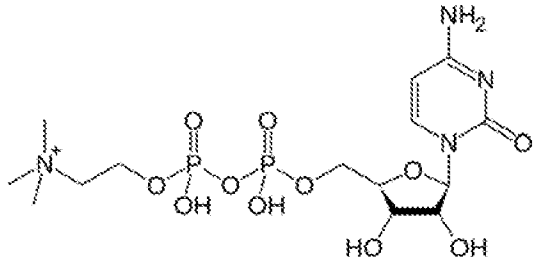
The ARDS-associated cancer of the disclosed methods can be any cell in a subject undergoing unregulated growth, invasion, or metastasis that directly or indirectly results in a form of ARDS. In some cases cancer is a primary or secondary cancer in the lungs. In some case, the cancer is not present in the lung, but the cancer, or treatment of the cancer, causes injury to the lungs.

In some aspects, the cancer can be any neoplasm or tumor for which radiotherapy is currently used. Alternatively, the cancer can be a neoplasm or tumor that is not sufficiently sensitive to radiotherapy using standard methods. Thus, the cancer can be a sarcoma, lymphoma, leukemia, carcinoma, blastoma, or germ cell tumor. A representative but non-limiting list of cancers that the disclosed compositions can be used to treat include lymphoma, B cell lymphoma, T cell lymphoma, mycosis fungoides, Hodgkin's Disease, myeloid leukemia, bladder cancer, brain cancer, nervous system cancer, head and neck cancer, squamous cell carcinoma of head and neck, kidney cancer, lung cancers such as small cell lung cancer and non-small cell lung cancer, neuroblastoma/glioblastoma, ovarian cancer, pancreatic cancer, prostate cancer, skin cancer, liver cancer, melanoma, squamous cell carcinomas of the mouth, throat, larynx, and lung, colon cancer, cervical cancer, cervical carcinoma, breast cancer, epithelial cancer, renal cancer, genitourinary cancer, pulmonary cancer, esophageal carcinoma, head and neck carcinoma, large bowel cancer, hematopoietic cancers; testicular cancer; colon and rectal cancers, prostatic cancer, and pancreatic cancer.

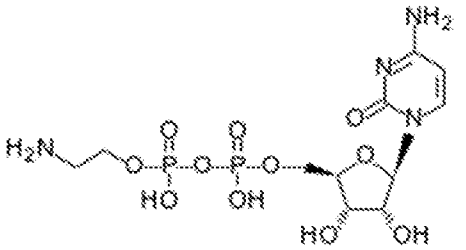
Cytidine diphosphate-choline (CDP-choline) is a naturally occurring compound that is synthesized from cytidine-5'-triphosphate and phosphocholine with accompanying production of inorganic pyrophosphate in a reversible reaction

catalyzed by the enzyme CTP:phosphocholine cytidylyltransferase-α (*pcyt1a*). CDP-ethanolamine is synthesized from cytidine-5'-triphosphate and phosphoethanolamine with accompanying production of inorganic pyrophosphate in a reversible reaction catalyzed by the enzyme CTP-phosphoethanolamine cytidyltransferase (*pcyt2*).

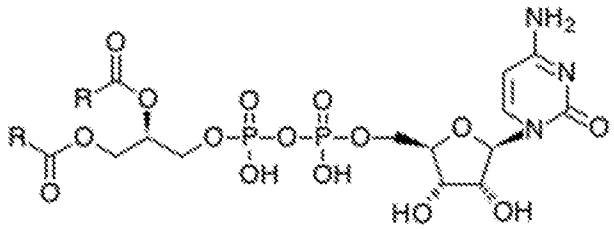
The molecular structure of CDP-choline is provided below.



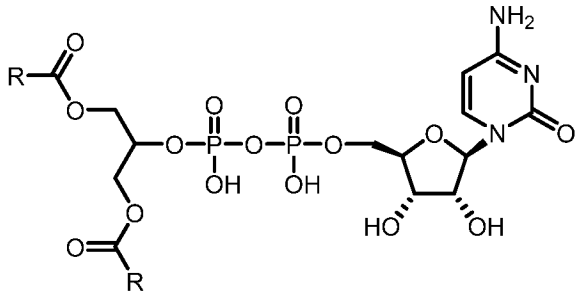
The molecular structure of CDP-ethanolamine is provided below.



Molecular structures of CDP-DAG are provided below.



, and



In these structures, R denotes points of attachment of various length acyl chains to the glycerol moiety of CDP-DAG.

The compositions disclosed can be used therapeutically in combination with a pharmaceutically acceptable carrier. By “pharmaceutically acceptable” is meant a material that is not biologically or otherwise undesirable, i.e., the material may be administered to a subject, along with the nucleic acid or vector, without causing any undesirable biological effects or interacting in a deleterious manner with any of the other components of the pharmaceutical composition in which it is contained. The carrier would naturally be selected to minimize any degradation of the active ingredient and to minimize any adverse side effects in the subject, as would be well known to one of skill in the art.

Pharmaceutical carriers are known to those skilled in the art. These most typically would be standard carriers for administration of drugs to humans or animals, including solutions such as sterile water, saline, and buffered solutions at physiological pH. The compositions can be administered intramuscularly or subcutaneously. Other compounds will be administered according to standard procedures used by those skilled in the art.

Pharmaceutical compositions may include carriers, thickeners, diluents, buffers, preservatives, surface active agents and the like in addition to the molecule of choice. Pharmaceutical compositions may also include one or more active ingredients, such as antimicrobial agents, anti-inflammatory agents, anesthetics, vaccine antigens, adjuvants, and DAMPs,

Preparations for enteral and/or parenteral administration include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils such as olive oil, and injectable organic esters such as ethyl oleate. Aqueous carriers include water, alcoholic/aqueous solutions, emulsions or suspensions, including saline and buffered media. Enteral and parenteral vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's, glucose, or fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Mucosal vehicles include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's, glucose, fixed oils, propylene glycol, and the like. Preservatives and other additives may also be present such as, for example, antimicrobials, anti-oxidants, chelating agents, and inert gases.

Some of the compositions may potentially be administered as a pharmaceutically acceptable acid- or base- addition salt, formed by reaction with

inorganic acids such as hydrochloric acid, hydrobromic acid, perchloric acid, nitric acid, thiocyanic acid, sulfuric acid, and phosphoric acid, and organic acids such as formic acid, acetic acid, propionic acid, glycolic acid, lactic acid, pyruvic acid, oxalic acid, malonic acid, succinic acid, maleic acid, and fumaric acid, or by reaction with an inorganic base such as sodium hydroxide, ammonium hydroxide, potassium hydroxide, and organic bases such as mono-, di-, trialkyl and aryl amines and substituted ethanolamines.

The herein disclosed compositions, including pharmaceutical composition, may be administered in a number of ways depending on whether the desired treatment is prophylactic, for prevention of development of ARDS in influenza-infected and/or other at-risk persons, or for acute treatment of persons with ARDS. For example, the disclosed compositions can be administered orally in powder or tablet form for prophylaxis and prevention of ARDS or given intravenously, intraperitoneally, intramuscularly, subcutaneously, intracavity, or transdermally for treatment of ARDS. Pharmaceutical grade compositions may be administered orally as a compounded tablet including active ingredients at appropriate doses, excipients, and coatings for easing swallowing, and/or controlling release rate of active ingredients, and for shelf life extension.Pharmaceutical grade compositions may be administered orally as a liquid suspension or emulsion. Pharmaceutical grade compositions may be administered parenterally (e.g., intravenously with appropriate carriers, and stabilizers), by intramuscular injection, by intraperitoneal injection, transdermally, extracorporeally, ophthalmically, vaginally, rectally, intranasally, topically or the like, including topical intranasal administration or administration by inhalant.

In one embodiment, the disclosed compositions are administered in a dose equivalent to parenteral administration of about 0.1 ng to about 100 g per kg of body weight, about 10 ng to about 50 g per kg of body weight, about 100 ng to about 1 g per kg of body weight, from about 1µg to about 100 mg per kg of body weight, from about 1 µg to about 50 mg per kg of body weight, from about 1 mg to about 500 mg per kg of body weight; and from about 1 mg to about 50 mg per kg of body weight. Alternatively, the amount of the disclosed compositions administered to achieve a therapeutic effective dose is about 0.1 ng, 1 ng, 10 ng, 100 ng, 1 µg, 10 µg, 100 µg, 1 mg, 2 mg, 3 mg, 4 mg, 5 mg, 6 mg, 7 mg, 8 mg, 9 mg, 10 mg, 11 mg, 12 mg, 13 mg, 14 mg, 15 mg, 16 mg, 17 mg, 18 mg, 19 mg, 20 mg, 30 mg, 40 mg, 50 mg, 60 mg, 70 mg, 80 mg, 90 mg, 100 mg, 500 mg per kg of body weight or greater.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

EXAMPLES

Example 1:

Figure 1 is a plot showing effect of infection on ATII cell DPPC (16:0/16:0) surfactant. # = P<0.001.

Figure 2 is a plot showing effect of infection on ATII cell DPPG (16:0/16:0) surfactant. * = P<0.05, # = P<0.001.

Figure 3 is a plot showing effect of infection on ATII cell PE (16:0/18:2) surfactant. # = P<0.001.

Figure 4 is a plot showing effect of infection on BALF phospholipid glycerol. # = P<0.001.

Figure 5 is a schematic showing DPPC synthesis by the CDP-choline (Kennedy) pathway.

Figure 6 is a plot showing effect of infection on ATII cell DAG (18:1/18:2). * = P<0.05, # = P<0.001.

Figure 7 is a plot showing effect of infection on ATII cell choline-P (18:1/18:2).

Figure 8 is a plot showing effect of infection on ATII cell CDP-choline.

Figure 9 is a schematic showing therapeutic approach.

Figure 10 is a graph showing effect of CDP-choline treatment (▲) on mouse O_2 SATS as a function of time (days after infection). # = P<0.001.

Figure 111 is a graph showing effect of CDP-choline treatment (▲) on mouse activity (rmp/mouse) as a function of time (days after infection). * = P<0.05, # = P<0.001.

Figure 12 is a bar graph showing effect of day 5 only CDP-choline treatment on mouse O_2 SATS. * = P<0.05, # = P<0.001.

CDP-choline improved oxygenation. S_aO2 increased from approximately 85% to approximately 96%. This is equivalent to an increase in P_aO_2 from approximately 65 mmHg to approximately 85 mmHg. It is also equivalent to an increase in O_2 carrying capacity of blood (C_aO_2) from approximately 88% to approximately 97% of normal. Patients with an S_aO_2 of 96% or a P_aO_2 of 96% would not require additional treatment

CDP-choline improved cardiac function and resulted in better lung function and reduced pulmonary edema. Effects of single dose treatment late in infection are as good as those of daily treatment throughout course of infection.

Example 2:

Table 2 shows the effect of CDP-conjugated precursor combinations.

Example 3:

Figure 14 is a group of three transmission electron micrographs showing effects of CDP-choline treatment on ultrastructure of ATII cell lamellar bodies (composed of surfactant lipids and proteins). Relative to mock-infected controls, lamellar bodies in ATII cells from influenza A/WSN/33 (H1N1)-infected mice are smaller and have disordered lamellae. CDP-choline treatment improves lamellar body morphology. Mi in ATII cells from CDP-choline-treated mice are also more electron-dense and have more normal cristae.

Example 4:

Figure 15 is a group of 3 transmission electron micrographs showing effects of influenza infection on ultrastructure of ATII cell mitochondria (Mi). Relative to mock-infected controls (left), Mi in ATII cells from A/WSN/33 (H1N1)-infected mice (center) are fewer in number, less electron dense, and have disordered membranes and cristae. Mi in ATII cells from A/WSN/33 (H1N1)-infected mice treated with CDP-choline display normal morphology.

Example 5:

Table 3 shows the effect of influenza infection and oral liponulceotide treatment on lung function.

Table 4 shows the effect of influenza infection and CDP-choline treatment on ATII cell ultrastructure.

Table 5 shows the effect of influenza infection and CDP-choline treatment on lung inflammation.

Table 6 shows the effect of influenza infection and CDP-choline treatment on mitochondrial function.

Table 2. Effect of influenza infection and i.p. liponucleotide treatment on lung function.

	S_aO_2 (%)	HR (bpm)	WET:DRY	R_{BASAL}	C_{ST}
UNINFECTED	99.0 ± 0.2	710 ± 10	4.2 ± 0.1	0.74 ± 0.03	0.1 ± 0.007
DAY 6 MOCK CDP-CHO	99.0 ± 0.2	730 ± 10	-----	0.99 ± 0.03	0.05 ± 0.002
DAY 6 UNTREATED	86.5 ± 1.1	490 ± 10	7.1 ± 0.2	2.28 ± 0.17	0.04 ± 0.002
DAY 6 CDP-CHO	93.5 ± 1.0#	570 ± 10*	6.2 ± 0.4*	1.96 ± 0.12	0.05 ± 0.002#
DAY 6 CDP-ETH	91.1 ± 1.5	540 ± 20*	6.5 ± 0.4	-----	-----
DAY 6 CDP-DAG	95.2 ± 1.6*	600 ± 10**	5.8 ± 0.1**	-----	-----
DAY 6 CDP-CHO + CDP-ETH	97.5 ± 0.9#	620 ± 10*	6.9 ± 0.2	-----	-----
DAY 6 CDP-CHO + CDP-DAG	97.7 ± 0.9#	600 ± 70	5.5 ± 0.2#	1.54 ± 0.11*	0.04 ± 0.02
DAY 6 CDP-ETH + CDP-DAG	78.7 ± 3.3	470 ± 40	6.7 ± 0.2	-----	-----
DAY 6 CDP-CHO + CDP-ETH + CDP-DAG	94.9 ± 1.1*	620 ± 50*	6.5 ± 0.9	-----	-----
DAY 6 CDP-CHO ON DAY 5 ONLY	92.9 ± 1.5*	550 ± 10	6.2 ± 0.2	1.63 ± 0.22*	0.05 ± 0.006*

MOCK: Inoculated with virus diluent (0.1% FBS in normal saline)
CDP-CHO: CDP-choline (100 □g/mouse in 50 □l saline i.p., daily from 1-5 days post-infection or on day 5 only, as indicated)
CDP-ETH: CDP-ethanolamine (100 □g/mouse)
CDP-DAG: CDP-diacylglycerol (10 □g/mouse)
*: P<0.05, **: P<0.005, #: P<0.001, vs. DAY 6 UNTREATED

Table 3.

	S_aO_2 (%)	HR (bpm)
UNINFECTED	99.0 ± 0.2	710 ± 10
DAY 6 UNTREATED	86.5 ± 1.1	490 ± 10
DAY 6 SALINE VEHICLE-TREATED	87.1 ± 2.8	460 ± 20
DAY 6 CDP-CHO + CDP-DAG	91.9 ± 2.6(*)	570 ± 40*

CDP-CHO + CDP-DAG: CDP-choline (100 µg/mouse) + CDP-diacylglycerol (10 µg/mouse) by oral gavage, daily from 1-5 days post-infection
(*): P=0.0516, *: P<0.05, vs. DAY 6 UNTREATED

Table 4.			
	DAY 6 MOCK	DAY 6 UNTREATED	DAY 6 FLU + CDP-CHO
ATII CELL AREA (□m^2)	30.37 ± 2.98	72.04 ± 3.63	53.64 ± 5.63*
LAMELLAR BODIES/CELL	14.27 ± 1.32	12.05 ± 0.93	8.1 ± 1.16*
LAMELLAR BODY AREA (□m^2)	0.47 ± 0.06	0.59 ± 0.44	0.41 ± 0.04*
MITOCHONDRIAL/CELL	16 ± 2.31	17.75 ± 2.85	14.5 ± 1.78*
MITOCHONDRIAL AREA (□m^2)	0.43 ± 0.02	0.2 ± 0.01	0.34 ± 0.01*
CDP-CHO: CDP-choline (100 □g/mouse in 50 µl saline i.p., daily from 1-5 days post-infection) *: P<0.05, vs. day 6 untreated			

Table 5.			
	DAY 6 MOCK	DAY 6 UNTREATED	DAY 6 FLU + CDP-CHO
BALF ALVEOLAR MACS (x 10^6/ml)	---	2.67 ± 0.51	1.08 ± 0.21*
BALF NEUTROPHILS (x 10^6/ml)	---	1.69 ± 0.16	0.45 ± 0.07**
BALF PC	---	0.79 ± 0.12	1.61 ± 0.45*
VIRAL TITER (log PFU/g)	0	5.32 ± 0.07	5.32 ± 0.07
CDP-CHO: CDP-choline (100 □g/mouse in 50 µl saline i.p., daily from 1-5 days post-infection) *: P<0.05, **: P<0.005, #: P<0.001, vs. day 6 untreated			

Table 6.			
	DAY 6 MOCK	DAY 6 UNTREATED	DAY 6 FLU + CDP-CHO
MITOCHONDRIAL ATP PRODUCTION	40.54 ± 4.91	20.36 ± 1.3	36.91 ± 6.82#
MITOCHONDRIAL MEMBRANE POTENTIAL (Ψ_m; $DiIC_1(5)$ MCF)	12.29 ± 0.42	6.89 ± 0.38	10.14 ± 2.3*
CDP-CHO: CDP-choline (100 µg/mouse in 50 µl saline i.p., daily from 1-5 days post-infection) *: P<0.05, **: P<0.005, #: P<0.001, vs. day 6 untreated			

Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of skill in the art to which the disclosed invention belongs. Publications cited herein and the materials for which they are cited are specifically incorporated by reference.

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

WHAT IS CLAIMED IS:

1. A composition comprising two or more cytidine diphosphate (CDP)-conjugated precursors selected from the group consisting of CDP-choline, CDP-ethanolamine, and CDP-diacylglycerol (CDP-DAG), in a pharmaceutically acceptable carrier.
2. The composition of claim 1, comprising CDP-choline and CDP-DAG in a pharmaceutically acceptable carrier.
3. The composition of claim 1, consisting essentially of CDP-choline and CDP-DAG in a pharmaceutically acceptable carrier.
4. The composition of claim 2 or 3, wherein the CDP-choline and CDP-DAG are present in equal concentrations.
5. The composition of claim 1, comprising CDP-choline, CDP-ethanolamine, and CDP-DAG in a pharmaceutically acceptable carrier.
6. The composition of claim 5, wherein the CDP-choline, CDP-ethanolamine, and CDP-DAG are present in equal concentrations.
7. The composition of any one of claims 1 to 6, wherein the CDP-conjugated precursors are collectively present at a concentration of at least 0.1 ng per kg of body weight.
8. The composition of any one of claims 1 to 7, wherein the CDP-conjugated precursors comprise one or more chemical modification selected from the group consisting of methylation, esterification, amidation, nitration, nitrosylation, oxidation, sulfation, acetylation, alcoholysis, acidolysis, biotinylation, and fluorophore conjugation.
9. A method for treating an acute respiratory distress syndrome (ARDS) in a subject, comprising administering to the subject an effective amount of a composition comprising one or more cytidine diphosphate (CDP)-conjugated precursors selected from the group consisting of CDP-choline, CDP-ethanolamine, CDP-diacylglycerol (CDP-DAG), and combinations thereof.
10. The method of claim 9, wherein the composition comprises the composition of any one of claim 1 to 8.
11. The method of claim 9 or 10, wherein the composition is administered intravenously, orally, or by inhalation.
12. The method of any one of claims 9 to 11, wherein the ARDS is caused a direct lung insult.

13. The method of claim 12, wherein the direct lung insult is selected from the group consisting of a viral, bacterial, or fungal infection; toxic gas inhalation; a lung cancer; chemotherapy; acid aspiration; and chest trauma.

14. The method of claim 13, wherein the infection comprises influenza.

15. The method of any one of claims 9 to 14, wherein the ARDS is caused an indirect result of trauma to other body regions.

16. The method of claim 15, wherein the trauma is selected from the group consisting of sepsis, ischemia/reperfusion, and surgery.

17. The method of any one of claims 9 to 16, further comprising treating the subject with surfactant therapy.

18. The method of any one of claims 9 to 17, wherein the composition is administered to the subject prior to infection with one or more influenza virus strains.

19. The method of any one of claims 9 to 17, wherein the composition is administered after the subject has been infected with one or more influenza virus strains but before said subject has developed ARDS.

20. The method of any one of claims 9 to 17, wherein the composition is administered after the subject has developed ARDS.

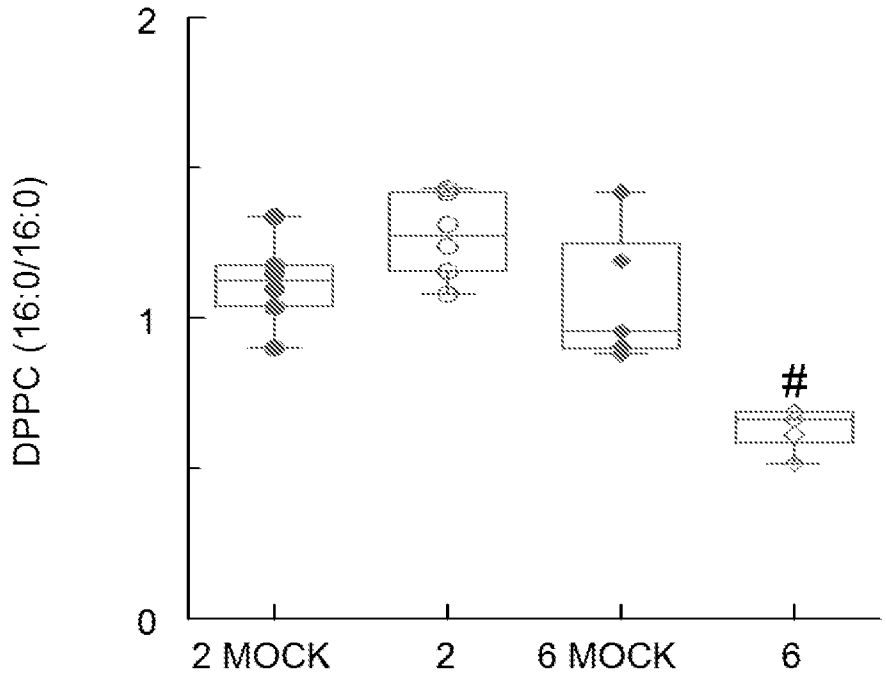


FIGURE 1

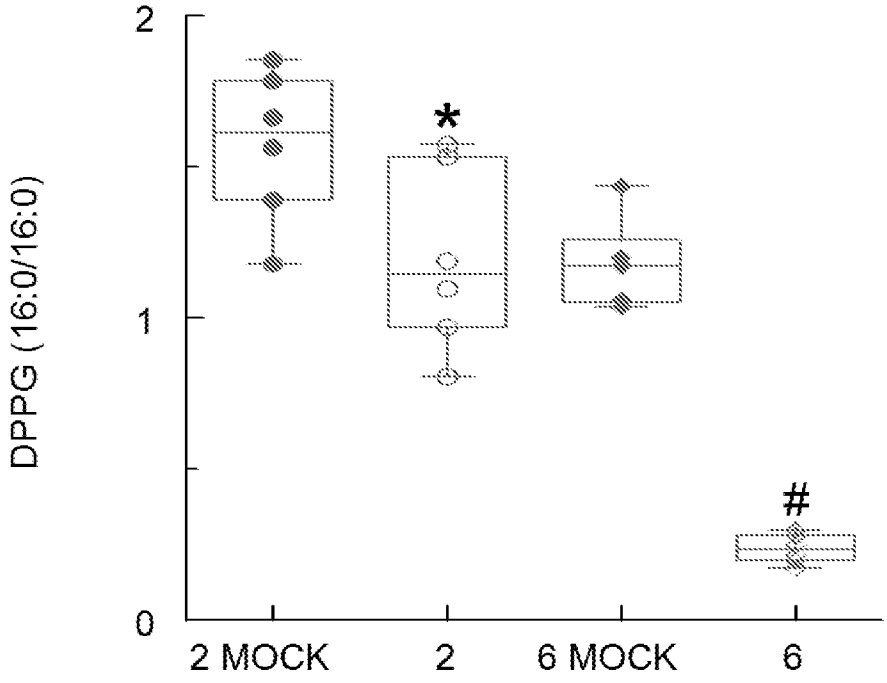


FIGURE 2

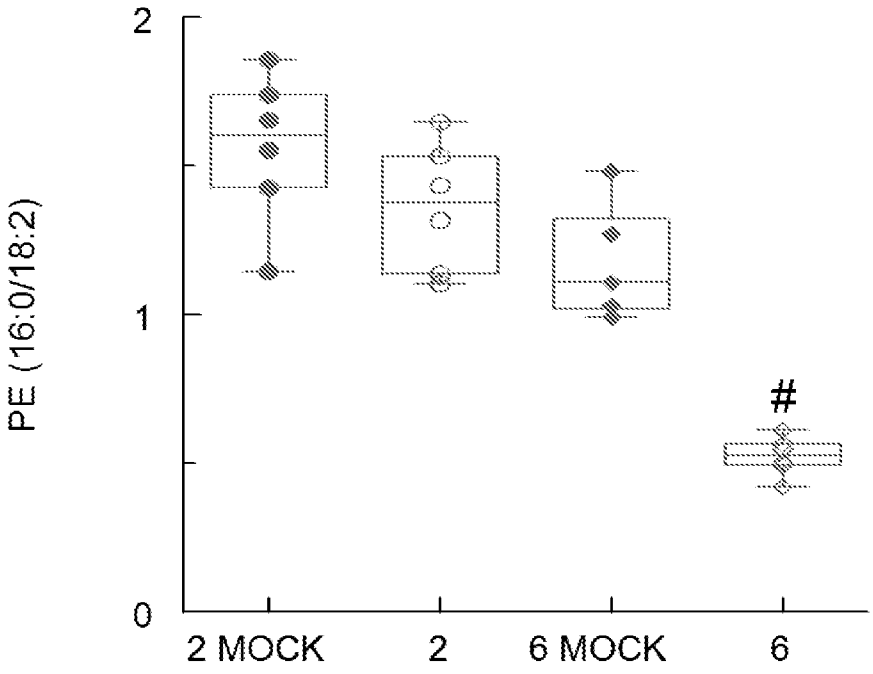


FIGURE 3

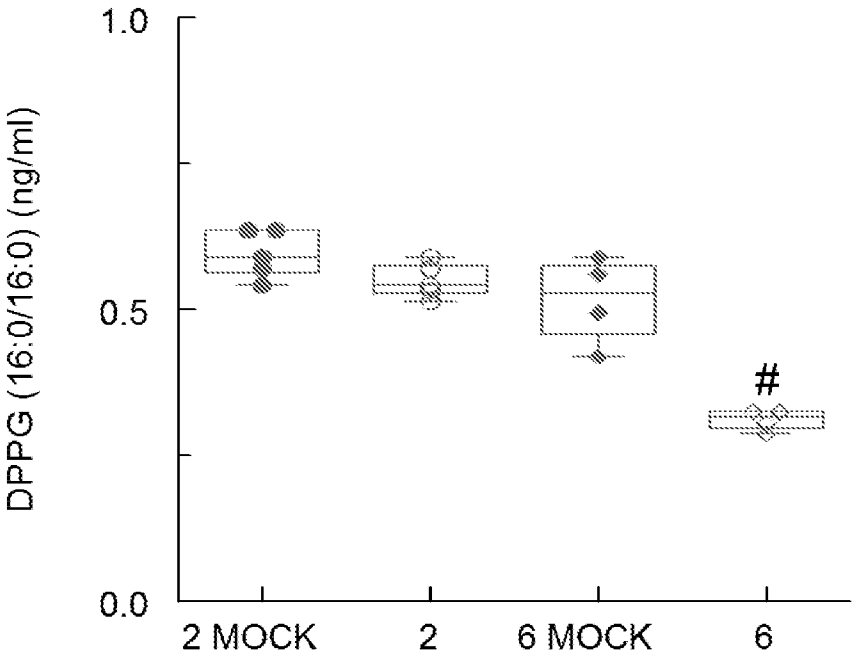


FIGURE 4

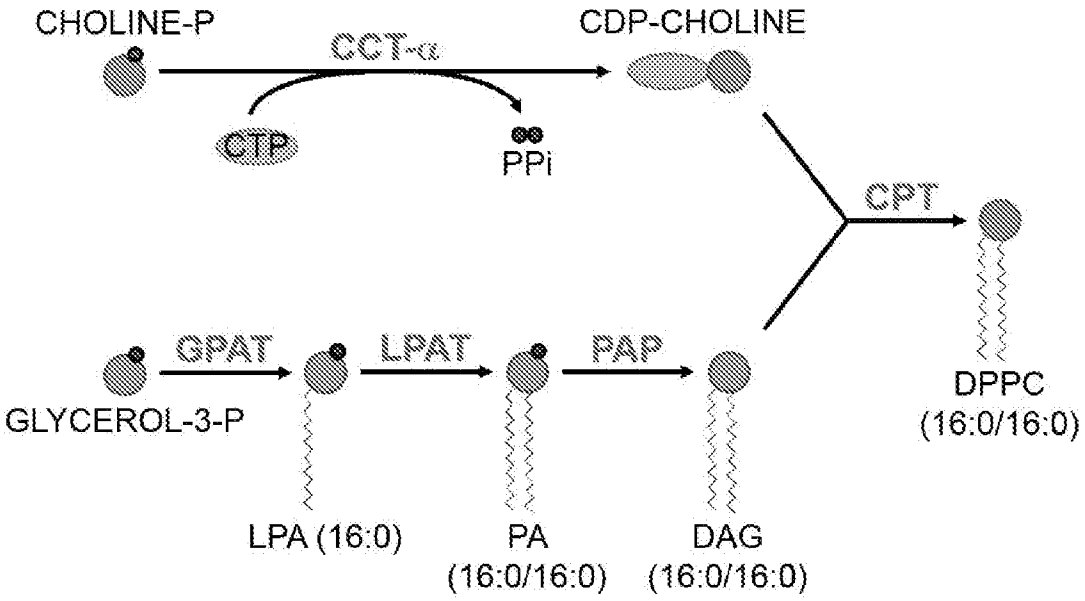


FIGURE 5

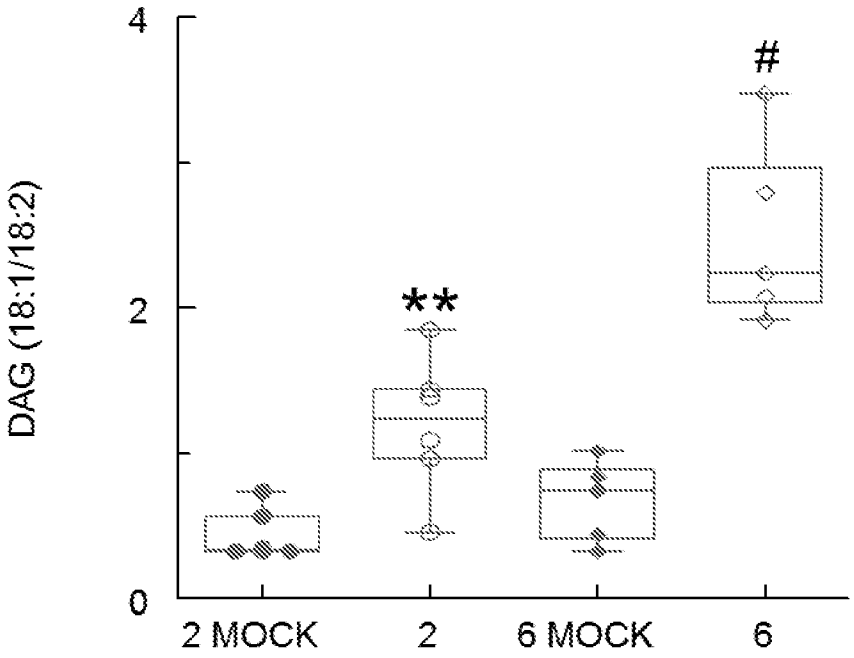


FIGURE 6

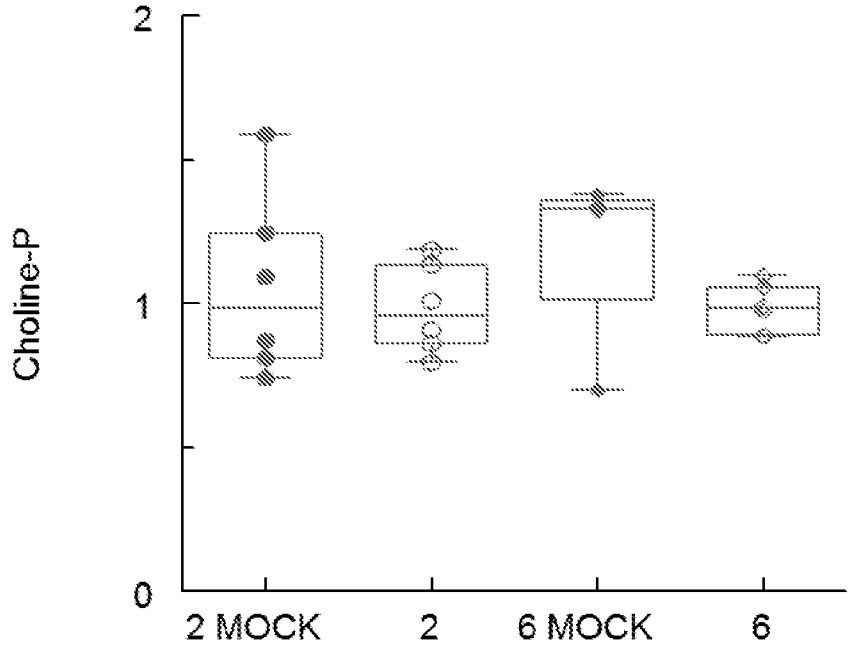


FIGURE 7

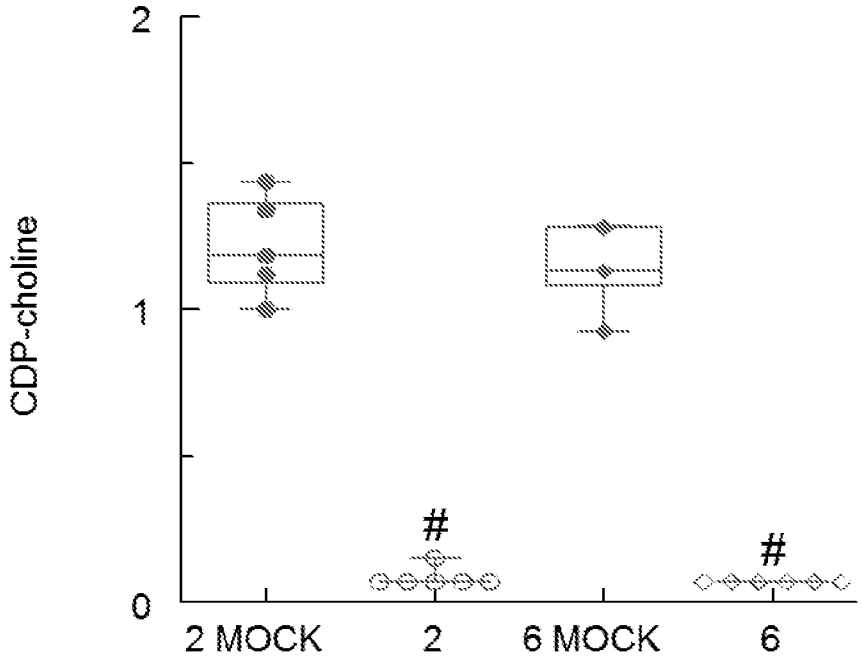


FIGURE 8

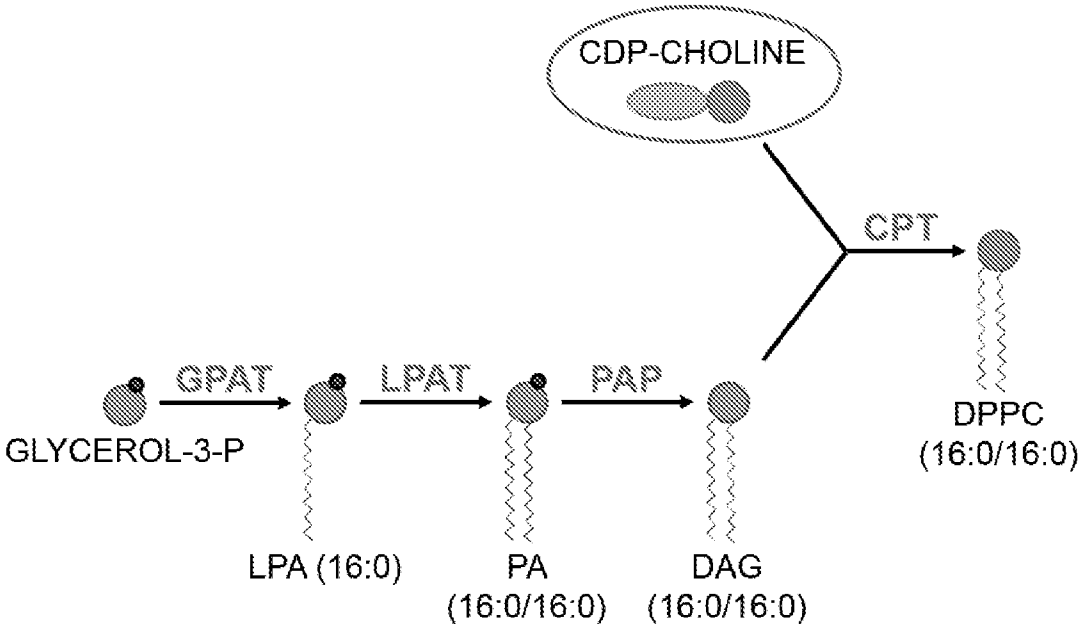


FIGURE 9

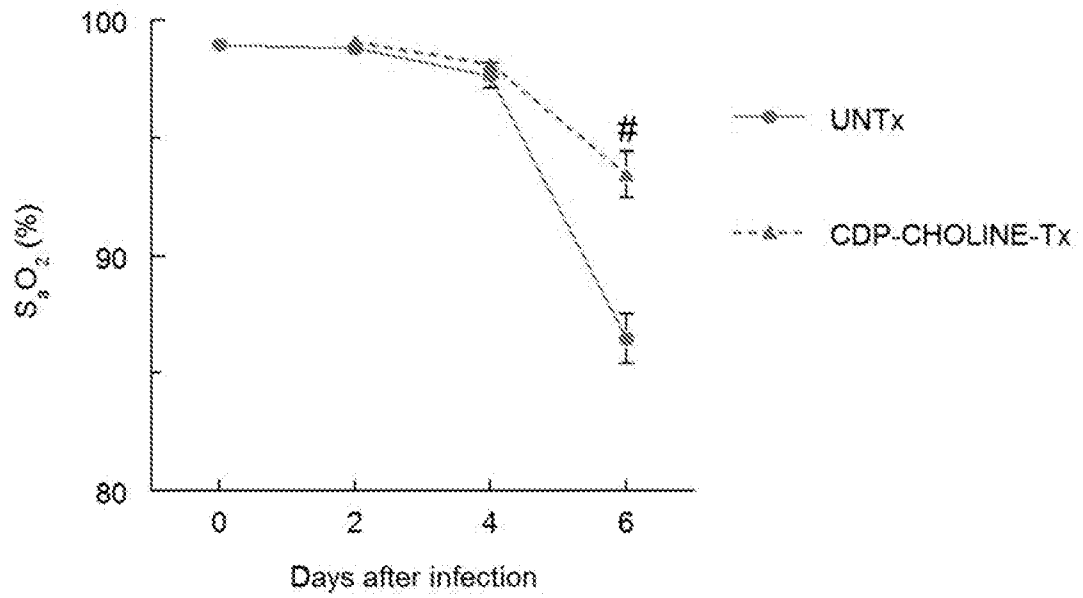


FIGURE 10

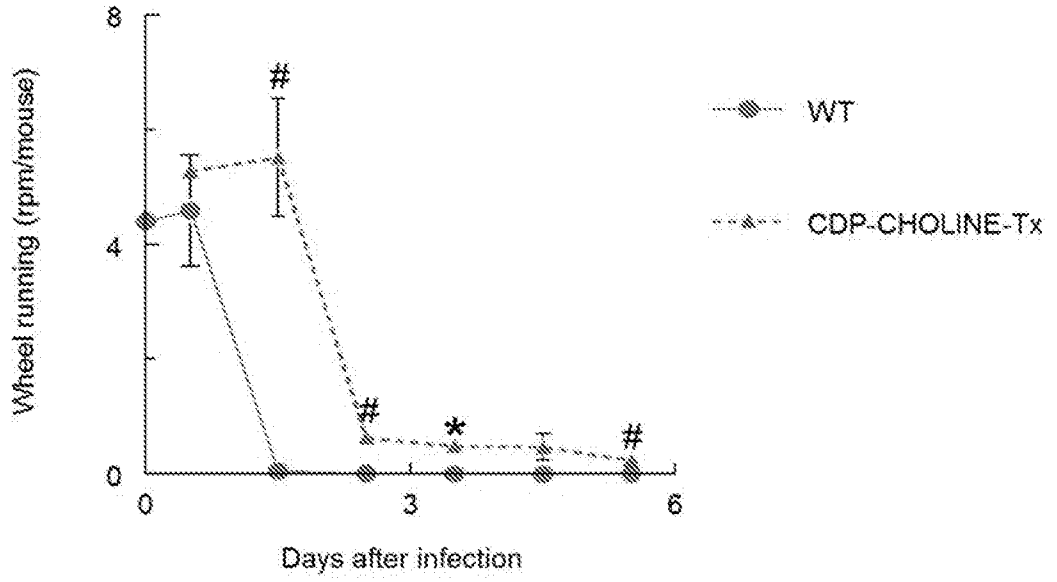


FIGURE 11

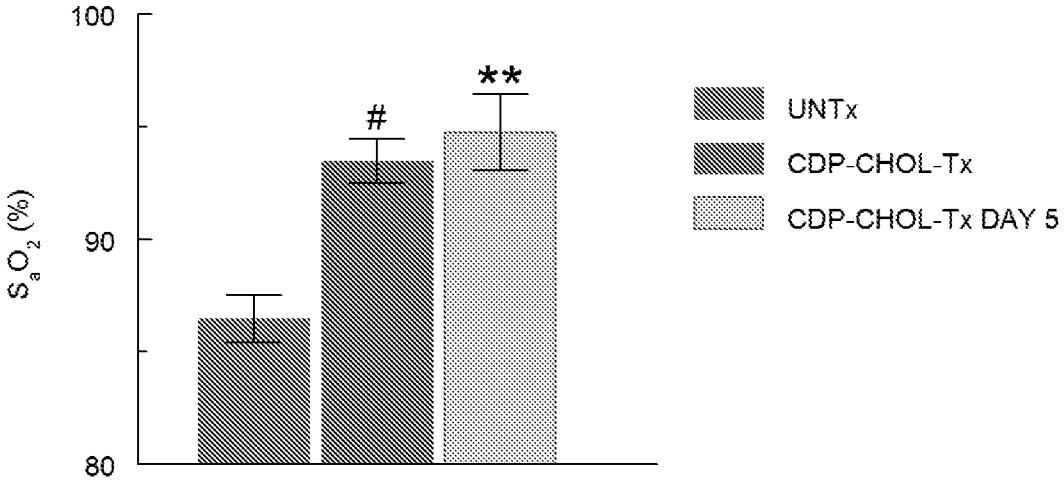


FIGURE 12

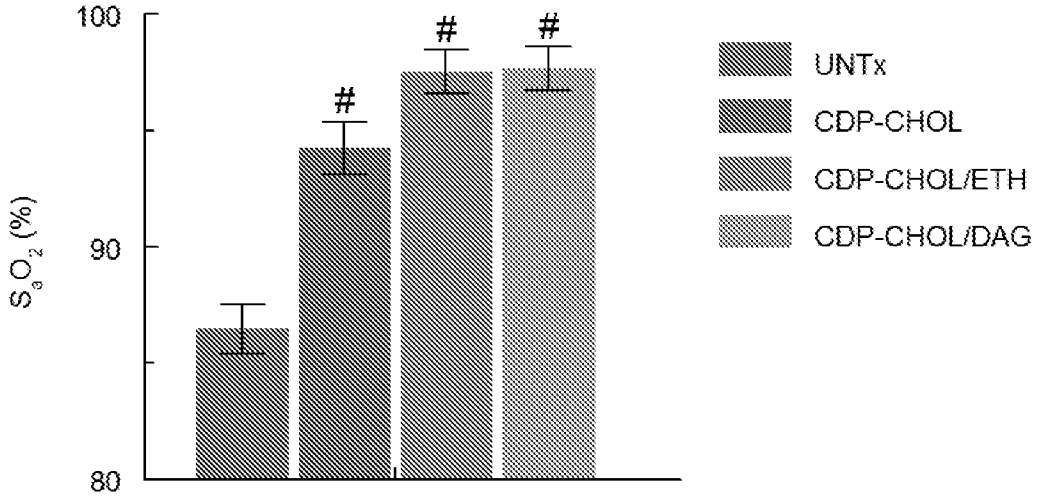


FIGURE 13

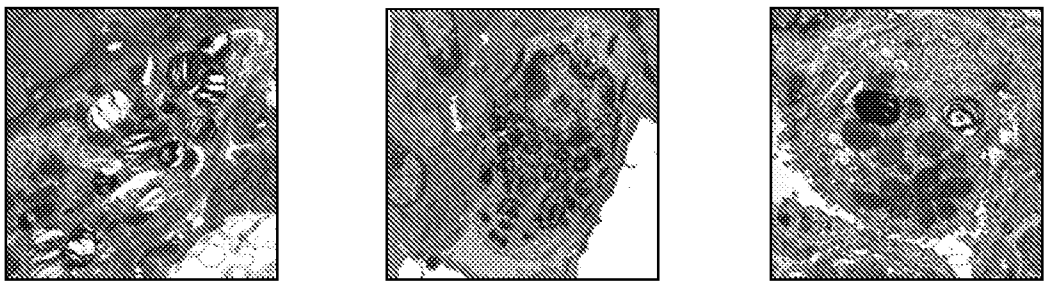


FIGURE 14

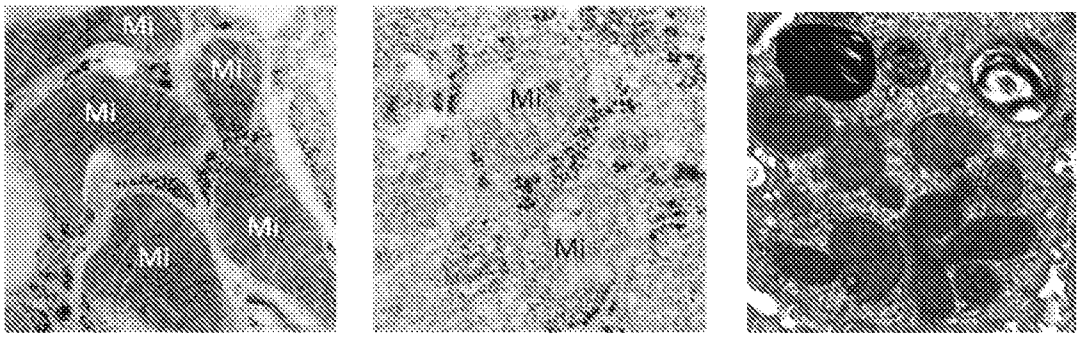


FIGURE 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/39545

A. CLASSIFICATION OF SUBJECT MATTER
IPC - A61K 31/513, 31/70 (2017.01)
CPC - A61K 31/513, 31/70

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,386,078 A (HORROCKS, LA et al.) 31 May 1983; abstract; column 4, lines 20-37; column 6, lines 12-24	1-3, 4/2-3, 5-6
Y	US 2003/0139350 A1 (LARSEN, E et al.) 24 July 2003; abstract; paragraphs [0011], [0033], [0039]	1-3, 4/2-3, 5-6
Y	US 2004/0063674 A1 (LEVY, SB et al.) 01 April 2004; claims 1-3, 20, 35, 37-38	9
Y	US 6,258,795 B1 (VON BORSTEL, RW et al.) 10 July 2001; abstract; column 1, lines 61-65; column 10 , lines 34-43; column 13, lines 48-59	9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
28 August 2017 (28.08.2017)	15 SEP 2017
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/39545

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

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

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

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

3. ☒ Claims Nos.: 7-8, 10-20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

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

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

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

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

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.