COMPOSITIONS AND METHODS FOR TREATING OR PREVENTING PNEUMOCOCCAL INFECTION

Related U.S. Application

This application claims priority from U.S. Provisional Patent Application Number 60/424,497, filed November 7, 2002. The entire content of the prior application is incorporated herein by reference.

Field of the Invention

The invention relates to polypeptides, pneumococcal polysaccharide-polypeptide conjugates, expression vectors encoding pneumococcal polypeptides, methods of inducing an anti-pneumococcal immune response, and methods of treating and preventing pneumococcal infection.

Background of the Invention

Streptococcus pneumoniae (*S. pneumoniae*) is a common cause of bacterial pneumonia, meningitis, otitis media, and bacteremia in children, the elderly, and immunodeficient individuals. *S. pneumoniae* can be subdivided into approximately 90 serotypes, based on the capsular polysaccharide of the organism. However, disease is generally caused by approximately 30 types of *S. pneumoniae* isolates. The World Health Organization estimates that there are one million deaths among children due to pneumococcal meningitis and sepsis each year, with 98% of these deaths occurring in developing countries. The emergence of pneumococcal strains with antimicrobial resistance underscores the need for treating and preventing pneumococcal infection by methods in addition to antimicrobials.

Summary of the Invention

In one aspect, the invention features a composition containing a polypeptide conjugated to a *S. pneumoniae* capsular polysaccharide, wherein the polypeptide contains a fragment of at least 400 contiguous amino acids of a *S. pneumoniae* pneumolysin protein,

wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22) (e.g., at the carboxy terminus), wherein the polypeptide lacks hemolytic activity, and wherein the composition elicits an immune response (e.g., a humoral immune response and/or a cellular immune response) against *S. pneumoniae* when administered to a mammal. The immune response can be a prophylactic and/or therapeutic immune response.

The *S. pneumoniae* pneumolysin protein can have the amino acid sequence of SEQ ID NO:1. In some embodiments, the polypeptide contains amino acids 1-460 of SEQ ID NO:1. In other embodiments, the polypeptide contains amino acids 1-464 of SEQ ID NO:1, amino acids 1-465 of SEQ ID NO:1, amino acids 1-466 of SEQ ID NO:1, amino acids 1-469 of SEQ ID NO:1, or amino acids 1-470 of SEQ ID NO:1.

The polypeptide can optionally lack the amino acid sequence EDKVEND (SEQ ID NO:23) or the amino acid sequence YPQVEDKVEND (SEQ ID NO:24).

In some embodiments, the polypeptide consists of amino acid residues 1-460 of SEQ ID NO:1, amino acid residues 1-464 of SEQ ID NO:1, amino acid residues 1-465 of SEQ ID NO:1, amino acid residues 1-466 of SEQ ID NO:1, amino acid residues 1-469 of SEQ ID NO:1, or amino acid residues 1-470 of SEQ ID NO:1.

In some embodiments, the capsular polysaccharide is selected from the group consisting of serotype 4, 6B, 9V, 14, 18C, 19F, and 23F. In one example, the capsular polysaccharide is serotype 14. In another example, the capsular polysaccharide is serotype 18C. The composition can optionally contain a plurality of different capsular polysaccharides selected from the group consisting of serotype 4, 6B, 9V, 14, 18C, 19F, and 23F.

The immune response elicited by the composition can be directed against a *S. pneumoniae* capsular polysaccharide, against a *S. pneumoniae* pneumolysin protein, or against a *S. pneumoniae* capsular polysaccharide and a *S. pneumoniae* pneumolysin protein.

In another aspect, the invention features a mammalian expression vector containing a promoter operably linked to a nucleotide sequence containing a nucleic acid encoding a polypeptide containing a fragment of at least 400 contiguous amino acids of a *S. pneumoniae* pneumolysin protein, wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22) (e.g., at the carboxy terminus), wherein the polypeptide lacks hemolytic activity, and wherein the polypeptide elicits an immune response (e.g., a humoral immune response

and/or a cellular immune response) against *S. pneumoniae* when the expression vector is administered to a mammal. The immune response can be a prophylactic and/or therapeutic immune response.

The *S. pneumoniae* pneumolysin protein can have the amino acid sequence of SEQ ID NO:1. In some embodiments, the encoded polypeptide contains amino acids 1-460 of SEQ ID NO:1. In other embodiments, the encoded polypeptide contains amino acids 1-464 of SEQ ID NO:1, amino acids 1-465 of SEQ ID NO:1, amino acids 1-466 of SEQ ID NO:1, amino acids 1-469 of SEQ ID NO:1, or amino acids 1-470 of SEQ ID NO:1.

The encoded polypeptide can optionally lack the amino acid sequence EDKVEND (SEQ ID NO:23) or the amino acid sequence YPQVEDKVEND (SEQ ID NO:24).

In some embodiments, the encoded polypeptide consists of amino acid residues 1-460 of SEQ ID NO:1, amino acid residues 1-464 of SEQ ID NO:1, amino acid residues 1-465 of SEQ ID NO:1, amino acid residues 1-466 of SEQ ID NO:1, amino acid residues 1-469 of SEQ ID NO:1, or amino acid residues 1-470 of SEQ ID NO:1.

The immune response elicited by the encoded polypeptide can be directed against a *S. pneumoniae* pneumolysin protein.

In another aspect, the invention features a mammalian expression vector containing a promoter operably linked to a nucleotide sequence containing a nucleic acid encoding a *S. pneumoniae* autolysin polypeptide, wherein the polypeptide elicits an immune response (e.g., a humoral immune response and/or a cellular immune response) against *S. pneumoniae* when the expression vector is administered to a mammal. The immune response can be a prophylactic and/or therapeutic immune response.

In some embodiments, the encoded polypeptide contains the amino acid sequence of SEQ ID NO:14. In other embodiments, the encoded polypeptide consists of the amino acid sequence of SEQ ID NO:14.

In another aspect, the invention features a mammalian expression vector containing a promoter operably linked to a nucleotide sequence containing a nucleic acid encoding a *S. pneumoniae* pneumococcal surface protein A polypeptide, wherein the polypeptide elicits an immune response (e.g., a humoral immune response and/or a cellular immune response) against *S. pneumoniae* when the expression vector is administered to a mammal. The immune response can be a prophylactic and/or therapeutic immune response.

In some embodiments, the encoded polypeptide contains the amino acid sequence of SEQ ID NO:18. In other embodiments, the encoded polypeptide consists of the amino acid sequence of SEQ ID NO:18.

In another aspect, the invention features a polypeptide consisting of an amino acid sequence selected from the group consisting of amino acids 1-460 of SEQ ID NO:1, amino acids 1-464 of SEQ ID NO:1, amino acids 1-466 of SEQ ID NO:1, and amino acids 1-469 of SEQ ID NO:1.

In another aspect, the invention features a method of inducing an immune response in a mammal by administering to a mammal an amount of a composition described herein that is effective to induce an immune response against *S. pneumoniae* in the mammal. The immune response can be a prophylactic and/or therapeutic immune response.

In some embodiments, the immune response is cross-reactive against at least one *Streptococcus pneumoniae* serotype that differs from the serotype of the capsular polysaccharide (e.g., serotype 7, 6B, 18C, or 23F) present in the composition. In some embodiments, the immune response is cross-reactive against at least one non-*Streptococcus pneumoniae* member of the *Streptococcus* genus.

In another aspect, the invention features a method of inducing an immune response in a mammal by administering to a mammal an amount of an expression vector described herein (e.g., a pneumolysin, pseudopneumolysin, autolysin, or pneumococcal surface protein A expression vector) that is effective to induce an immune response against *S. pneumoniae* in the mammal. The immune response can be a prophylactic and/or therapeutic immune response. In some embodiments, the immune response is cross-reactive against at least one non-*Streptococcus pneumoniae* member of the *Streptococcus* genus.

In another aspect, the invention features a method of inducing an immune response in a mammal by: administering to a mammal a mammalian expression vector containing a promoter operably linked to a nucleotide sequence containing a nucleic acid encoding a *Streptococcus pneumoniae* pneumolysin polypeptide or antigenic fragment thereof; and administering to the mammal a purified *S. pneumoniae* pneumolysin polypeptide or antigenic fragment thereof, wherein the combined administrations elicit an immune response against *S. pneumoniae* pneumolysin in the mammal.

In some embodiments, the mammal is administered at least two, three, or more separate doses of the expression vector. The doses can optionally be separate by at least 1, 2, 3, 4, 5, 6, 7, or more days.

In some embodiments, the administration of the *S. pneumoniae* pneumolysin polypeptide or antigenic fragment thereof is at least 1, 2, 3, 4, 5, 6, 7, or more days after the administration of the expression vector.

In another aspect, the invention features a composition containing a polypeptide conjugated to a non-*Streptococcus pneumoniae* bacterial polysaccharide, wherein the polypeptide contains a fragment of at least 400 contiguous amino acids of a *Streptococcus pneumoniae* pneumolysin protein, wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22), wherein the polypeptide lacks hemolytic activity, and wherein the composition elicits an immune response against the non-*Streptococcus pneumoniae* bacterium when administered to a mammal. In some examples, the non-*Streptococcus pneumoniae* bacterium is selected from the group consisting of pneumococcus, haemophilus influenza type b, meningococcal group A, B or C, and group B streptococcus type Ia, Ib, II, III, V or VIII. Such a composition can be used to induce an immune response in a mammal by administering to the mammal an amount of the composition effective to induce an immune response against the non-*Streptococcus pneumoniae* bacterium in the mammal.

In another aspect, the invention features a purified antibody that binds (e.g., selectively binds) to a composition or polypeptide described herein. For example, an antibody may specifically bind to a composition containing a polypeptide conjugated to a *S. pneumoniae* capsular polysaccharide, wherein the polypeptide contains a fragment of at least 400 contiguous amino acids of a *S. pneumoniae* pneumolysin protein, wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22) (e.g., at the carboxy terminus), wherein the polypeptide lacks hemolytic activity, and wherein the composition elicits an immune response (e.g., a humoral immune response and/or a cellular immune response) against *S. pneumoniae* when administered to a mammal). Such an antibody can be, for example, a monoclonal or polyclonal antibody. Cell lines such as hybridomas can be prepared that secrete an antibody described herein. The antibody can be used to treat or prevent *Streptococcus pneumoniae* infection in a mammal by administering to the mammal a therapeutically or prophylactically effective amount of the purified antibody.

An advantage of the invention is that, in some embodiments, a first *S. pneumoniae* serotype polysaccharide-polypeptide conjugate can unexpectedly provide cross-protection against infection with a second *S. pneumoniae* serotype. Such cross-protection can increase the effectiveness of a given conjugate in treating or preventing infection by more than one *S. pneumoniae* serotype. Accordingly, protection against a plurality of *S. pneumoniae* serotypes can be provided without necessarily providing conjugates for every specific serotype.

Another advantage of the invention is that, in some embodiments, the pseudopneumolysin polypeptides lack hemolytic activity. Accordingly, such pseudopneumolysin conjugates and expression vectors have reduced or absent toxicity as compared to compositions containing a naturally occurring pneumolysin having hemolytic activity or a toxoided pneumolysin having partial hemolytic activity.

Another advantage of the invention is that, in some embodiments, expression vectors encoding pneumolysin truncates, as opposed to nucleic acids encoding pneumolysin point mutants, are unlikely to revert so as to encode a toxic protein having hemolytic activity. Because the pneumolysin truncates lack a region of pneumolysin that contributes to the hemolytic activity, any mutations in the nucleotide sequence of the expression vector should be unable to regenerate the toxic activity.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by those of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of a conflict in terminology, the present specification will control. In addition, the described materials and methods are illustrative only and are not intended to be limiting.

Other features and advantages of the invention will be apparent from the following detailed description and the claims.

Brief Description of the Drawings

Fig. 1 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 2 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 3 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 18C polysaccharide-pseudopneumolysin conjugate.

Fig. 4 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 18C polysaccharide-pseudopneumolysin conjugate.

Fig. 5 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 19F polysaccharide-pseudopneumolysin conjugate.

Fig. 6 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 19F polysaccharide-pseudopneumolysin conjugate.

Fig. 7 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 23F polysaccharide-pseudopneumolysin conjugate.

Fig. 8 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 23F polysaccharide-pseudopneumolysin conjugate.

Fig. 9 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 4 polysaccharide-pseudopneumolysin conjugate.

Fig. 10 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 4 polysaccharide-pseudopneumolysin conjugate.

Fig. 11 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 6B polysaccharide-pseudopneumolysin conjugate.

Fig. 12 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 6B polysaccharide-pseudopneumolysin conjugate.

Fig. 13 is a graph depicting anti-pneumolysin IgG antibody production elicited in mice following immunization with a serotype 9V polysaccharide-pseudopneumolysin conjugate.

Fig. 14 is a graph depicting anti-polysaccharide IgG antibody production elicited in mice following immunization with a serotype 9V polysaccharide-pseudopneumolysin conjugate.

Fig. 15 is a graph depicting the antibody response to *S. pneumoniae* serotype 14 polysaccharide after a third injection of *S. pneumoniae* serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 16 is a graph depicting the antibody response in rabbit against pneumolysin using a prime-boost strategy for pseudopneumolysin DNA vaccination.

Fig. 17 is a graph depicting an antibody response after injection with an expression vector encoding pneumococcal surface protein A DNA vaccine.

Fig. 18 is a graph depicting an antibody response after injection with an expression vector encoding autolysin DNA vaccine.

Fig. 19 is a graph depicting bacterial clearance in mice challenged with *S. pneumoniae* serotype 14 after immunization with a type 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 20 is a graph depicting bacterial clearance in mice challenged with *S. pneumoniae* serotype 7 after immunization with a type 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 21 is a graph depicting bacterial clearance in mice challenged with *S. pneumoniae* serotype 6B after immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 22 is a graph depicting bacterial clearance in mice challenged with *S. pneumoniae* serotype 18C after immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 23 is a graph depicting bacterial clearance 1 hour following challenge with *S. pneumoniae* serotype 23F after immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 24 is a graph depicting bacterial clearance 3 hours following challenge with *S. pneumoniae* serotype 23F after immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Fig. 25 is a graph depicting bacterial clearance 5 hours following challenge with *S. pneumoniae* serotype 23F after immunization with a serotype 14 polysaccharide-pseudopneumolysin conjugate.

Detailed Description of the Invention

The present invention provides compositions and methods for treating or preventing pneumococcal infection. The polypeptides, polysaccharide-polypeptide conjugates, and expression vectors described herein, when administered to a mammal, induce an anti-pneumococcal immune response in the mammal. These compositions can be used prophylactically to vaccinate an individual and/or to therapeutically induce a therapeutic immune response in an infected individual.

Polysaccharide-Protein Conjugates

A polypeptide can be conjugated to a *S. pneumoniae* capsular polysaccharide by covalent or non-covalent methods. In general, the polypeptide component of the conjugate: contains either a portion of a *S. pneumoniae* pneumolysin protein or a mutated *S. pneumoniae* pneumolysin protein; lacks the amino acid sequence KVEND (SEQ ID NO:22); and lacks hemolytic activity. The polysaccharide-polypeptide conjugate elicits an immune response against *S. pneumoniae* when administered to a mammal. The immune response can be directed against the polypeptide, the polysaccharide, or the combination of the polypeptide and the polysaccharide.

The polypeptide component of the conjugate can be prepared using recombinant DNA technology, purified from natural sources, or synthesized chemically. In general, the polypeptide component differs in amino acid sequence from a naturally occurring

S. pneumoniae pneumolysin protein. The sequence of the *S. pneumoniae* type 19A pneumolysin polypeptide is depicted in SEQ ID NO:1 (see Example 1). Exemplary polypeptide components of a conjugate include, but are not limited to amino acids 1-460, 1-461, 1-462, 1-463, 1-464, 1-465, 1-466, 1-469, and 1-470 of SEQ ID NO:1

Nucleic acids encoding truncated and/or mutated forms of a *S. pneumoniae* pneumolysin protein can be prepared, for example, by polymerase chain reaction (PCR). Nucleic acids encoding such proteins can be chosen for having codons, which are preferred or non-preferred, for a particular expression system. For example, the nucleic acid can be one in which at least one codon, preferably at least 10%, or 20% of the codons have been altered such that the sequence is optimized for expression in *E. coli*, yeast, human, insect, or CHO cells.

Nucleic acids encoding truncated and/or mutated forms of a *S. pneumoniae* pneumolysin protein can be fused to nucleotide sequences encoding (1) other pneumococcal proteins, such as autolysin, surface protein A, neuraminidase, hyaluronate lysate, choline binding protein A, or (2) non-pneumococcal proteins from organisms such as hemophilus influenza b, meningococcus group A, B, or C, or streptococcus group B. The nucleic acids encoding such fused protein are expressed in the expression systems.

Pneumolysin truncates can be useful carriers of polysaccharides, as hosts may lacking pre-existing antibodies to such a carrier polypeptide. Pneumolysin is a virulence factor in pneumococcal infections and there is little antigenic variation of the pneumolysin among pneumococci with different subtypes.

The polysaccharide-protein conjugate, when administered to a mammal such as a human, induces immune response that exceeds in magnitude, type, and/or duration the immune response induced by administration to a mammal of only the polysaccharide component. Accordingly, the polypeptide component must be of a length sufficient to induce such an enhanced immune response. For fragments of a naturally occurring *S. pneumoniae* pneumolysin protein, the fragments are at least 8, 10, 25, 50, 75, 100, 125, 150, 175, 200, 250, 300, 350, 400, 425, 450, 460, 465, 460, 465, or more amino acids in length. For polypeptides, varying in sequence from a naturally occurring *S. pneumoniae* pneumolysin protein, the polypeptide can be at least about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%,

98% or more identical to a naturally occurring *S. pneumoniae* pneumolysin protein, e.g., SEQ ID NO:1

The polypeptide component preferably lacks hemolytic activity present in a naturally occurring *S. pneumoniae* pneumolysin protein. Generally, the polypeptide component exhibits less than 30%, 20%, 10%, 5%, 1%, or less of the hemolytic activity of a naturally occurring *S. pneumoniae* pneumolysin protein. Hemolytic activity can be measured as detailed in Example 3. In general, the hemolytic activity of a polypeptide can be determined by incubating the polypeptide with red blood cells, e.g., sheep erythrocytes, and measuring hemolysis induced by the polypeptide (see, e.g., Owen et al. (1994) FEMS Microbiology Letters 121:217-222 for a description of an exemplary hemolytic assay).

The polysaccharide component of the conjugate can be any *S. pneumoniae* capsular polysaccharide, including but not limited to, any of subtypes 1, 2, 3, 4, 5, 6B, 7F, 8, 9N, 9V, 10A, 11A, 12F, 14, 15B, 17F, 18C, 19A, 19F, 19A, 20, 22F, 23A, 23F, 24F, 27, 33F, or 34. In some embodiments, the capsular polysaccharide is selected from subtypes 4, 6B, 9V, 14, 18C, 19F, or 23F. In some embodiments, the polysaccharide is serotype 14. In other embodiments, the polysaccharide is serotype 18C. One or more of different capsular polysaccharides can be conjugated to a single polypeptide or a plurality of polypeptides. For example, a multivalent conjugate can include at least 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 different capsular polysaccharides. Polysaccharides can be conjugated to polypeptides, for example, via a monomeric linkage (only one end of the polysaccharide is attached to the polypeptide), a looped linkage (a single polypeptide is attached to looped polysaccharides), or cross-linked (multiple polysaccharides attached to multiple polypeptides).

Methods for the purification of polypeptides, e.g., pseudopneumolysin polypeptides described in the examples, and the conjugation of polysaccharides to polypeptides are described in Example 4. Additional details concerning polypeptide or polysaccharide purification and conjugation processes are described in, e.g., U.S. Patent Numbers 4,242,501; 4,686,102; 5,623,057; and 5,565,204.

The conjugates or polypeptides described herein can be administered to a mammal to elicit an immune response (a prophylactic and/or therapeutic immune response) against *S. pneumoniae* in the mammal. A pharmaceutical composition containing a conjugate or polypeptide can be delivered in a pharmaceutically acceptable carrier, buffer, or preservative

which is suitable for a vaccine including, but not limited to physiological saline or other injectable liquids. Additives customary in vaccines may also be present, for example stabilizers such as lactose or sorbitol, and adjuvants to enhance the immunogenic response such as aluminum phosphate, hydroxide, or sulphate and stearyl tyrosine. The vaccine produced may also be used as components of multivalent vaccines which elicit an immune response against a plurality of infectious agents.

The compositions can be administered in any manner known in the art, e.g., orally intramuscularly, intravenously, intraarterially, intrathecally, intradermally, intraperitoneally, intranasally, intrapulmonarily, intraocularly, intravaginally, intrarectally or subcutaneously. They can be introduced into the gastrointestinal tract or the respiratory tract, e.g., by inhalation of a solution or powder containing the conjugates. In some embodiments, the compositions can be administered via a skin patch.

A pharmaceutical composition (e.g., a vaccine) is administered in an amount sufficient to elicit production of antibodies as part of an immunogenic response. Dosage for any given patient depends upon many factors, including the patient's size, general health, sex, body surface area, age, the particular compound to be administered, time and route of administration, and other drugs being administered concurrently. Determination of optimal dosage is well within the abilities of a pharmacologist of ordinary skill.

The ability of a composition to elicit an immune response in a host mammal can be assayed by using methods for measuring immune responses that are well known in the art. For example, the generation of cytotoxic T cells can be demonstrated in a standard ^{51}Cr release assay, by measuring intracellular cytokine expression or secretion, or by using major histocompatibility complex (MHC) tetramers. Standard assays, such as enzyme-linked immunosorbent assay (ELISA) or enzyme-linked immunospot (ELISPOT), can be used to measure cytokine profiles attributable to T cell activation. T cell proliferation can be measured using assays such as ^{3}H-thymidine uptake and other assays known in the art. B cell responses can be measured using art recognized assays such as ELISA. Other methodologies can also be used to evaluate the effects of the conjugates on pathogen-associated lesions or on other pathogen levels generally (e.g., pneumococci clearance in challenged mice treated with the conjugate).

The composition described herein can be used in the manufacture of a medicament for the prevention or treatment of an infection with *S. pneumoniae* or conditions associated with such infection.

Antibodies

Antibodies directed against a polysaccharide, pneumolysin, or a combination thereof may be used in a prophylactic or therapeutic application to confer immunity from a first individual to a second individual (e.g., to augment the second individual's immune response against *S. pneumoniae* or to provide a response if the second individual is an immunocompromised patient). Antibodies directed against a polysaccharide, pneumolysin, or a combination thereof can be generated in an immunocompetent host (e.g., by administering to the immunocompetent host a conjugate described herein), harvested from the host and transfused into a recipient in need of treatment or prophylaxis, thereby conferring resistance to the recipient against not only the pneumolysin toxin, but also against *S. pneumoniae* and any possibly other bacteria which bind antibodies elicited by the conjugate (e.g., the polysaccharide component of the conjugate).

Antibodies elicited by a composition described herein can be formulated as a pharmaceutical composition and be used to confer a prophylactic or therapeutic immune response to an individual. Suitable components and methods of administration for pharmaceutical compositions are described herein. For eliciting passive immunity, the pharmaceutical composition may contain polyclonal antibodies or monoclonal antibodies or their derivatives of fragments. A pharmaceutical composition contains a prophylactically or therapeutically effective amount of an antibody, fragment, or derivative, as determined by standard clinical techniques.

Nucleic Acids Encoding Pneumococcal Polypeptides

Nucleic acids encoding a pneumococcal polypeptide or a fragment or variant of pneumococcal polypeptide can be administered to a mammal (e.g., a human) to generate a prophylactic and/or therapeutic immune response in the mammal. The immune response can be an anti-pneumococcal humoral and/or a cellular immune response.

Polypeptides that can be encoded by the nucleic acid constructs include the polypeptide components of the conjugates described herein, pseudopneumolysin polypeptides described in the examples, as well as autolysin and pneumococcal surface protein A and fragments and variants thereof. In addition, a nucleic acid can encode a combination of two or more such polypeptides, fragments, or variants.

Nucleic acid expression constructs can be prepared by using standard recombinant DNA methods. Regulatory elements can be included in a construct to facilitate expression of the nucleic acid encoding the polypeptide. These elements include sequences for enhancing expression in human or other mammalian cells, e.g., promoters, RNA stabilization sequences 5' and/or 3' to the coding sequence, introns (which can be placed at any location within or adjacent to the encoded sequence), and poly(A) addition sites, as well as an origin of replication and one or more genes encoding selectable markers enabling the constructs to replicate and be selected in prokaryotic and/or eukaryotic hosts. A T7 polymerase promoter or other type of promoter (e.g., a tissue-specific promoter or a cell-specific promoter such as a muscle-specific promoter) is optionally present at the 5' end of the coding sequence, and a sequence encoding a FLAG or other mAb determinant is optionally present at the 3' end of the coding sequence. The construct may also contain other transcriptional and translational signals, such as a Kozak sequence.

The construct may in addition include a sequence encoding a targeting signal that directs the encoded polypeptide to a desired intracellular compartment, the targeting signal being linked to the polypeptide. Targeting signals can direct the encoded polypeptide to endoplasmic reticulum (ER), the golgi, the nucleus, a lysosome, a class II peptide loading compartment, or an endosome, and include signal peptides, ER retention peptides, and lysosome-targeting peptides.

The nucleic acids can be used in any vector that allows for expression in cells of a mammal. The vector can be, e.g., a non-viral vector such as a plasmid or bacterial vector, an integrating viral vector, or a non-integrating viral vector. An example of a suitable vector is the family of pcDNA mammalian expression vectors (Invitrogen), which permit direct and rapid cloning of PCR products.

Various delivery systems can be used to deliver nucleic acids encoding polypeptides into appropriate cells. The nucleic acids encoding the polypeptides can be delivered in a

pharmaceutically acceptable carrier such as saline, or as colloidal suspensions, or as powders, with or without diluents. The nucleic acids can be "naked" or associated with delivery vehicles and delivered using delivery systems known in the art, such as lipids, liposomes, microspheres, microparticles or microcapsules, gold particles, ISCOMS, nanoparticles, polymers, condensing agents, polysaccharides, polyamino acids, dendrimers, saponins, QS21, adsorption enhancing materials, adjuvants, or fatty acids. Nucleic acids can also be delivered to a cell, e.g., a skeletal muscle cell, either *in vitro* or *in vivo*, using electroporation.

The nucleic acids can be administered using standard methods, e.g., those described in Donnelly et al., J. Immunol. Methods 176:145, 1994, and Vitiello et al., J. Clin. Invest. 95:341, 1995, and can be delivered into subjects in any manner known in the art, e.g., orally intramuscularly, intravenously, intraarterially, intrathecally, intradermally, intraperitoneally, intranasally, intrapulmonarily, intraocularly, intravaginally, intrarectally or subcutaneously. They can be introduced into the gastrointestinal tract or the respiratory tract, e.g., by inhalation of a solution or powder containing the nucleic acids. Administration can be local or systemic.

It is expected that a dosage of approximately 100-2000 μg of nucleic acid would be administered to an individual. Where the patient is an adult human, vaccination regimens can include, e.g., intramuscular, intradermal, inhalation, or subcutaneous administrations of 10-1000 μg of a plasmid DNA when delivered in a microparticle, or of about 10-2500 μg, e.g., 100 to 2000, or 500 to 1000 μg, of naked plasmid DNA delivered intramuscularly or intradermally, repeated 3-6 times. As is well known in the medical arts, dosage for any given patient depends upon many factors, including the patient's size, general health, sex, body surface area, age, the particular compound to be administered, time and route of administration, and other drugs being administered concurrently. Determination of optimal dosage is well within the abilities of a pharmacologist of ordinary skill.

Other standard delivery methods, e.g., biolistic transfer or *ex vivo* treatment, can also be used. In *ex vivo* treatment, antigen presenting cells (APCs) such as dendritic cells, peripheral blood mononuclear cells, or bone marrow cells can be obtained from a patient or an appropriate donor and activated *ex vivo* with the nucleic acid, and then implanted or reinfused into the patient.

The nucleic acids can be administered alone or in combination with other therapies known in the art, e.g., antimicrobial agents. In addition, the nucleic acids can be administered in combination with other treatments designed to enhance immune responses, e.g., by co-administration with adjuvants, cytokines (or nucleic acids encoding cytokines), or CpG oligonucleotides, as is well known in the art.

The ability of a nucleic acid to elicit an immune response in a host mammal can be assayed by using methods for measuring immune responses that are well known in the art. For example, the generation of cytotoxic T cells can be demonstrated in a standard ^{51}Cr release assay, by measuring intracellular cytokine expression or secretion, or by using MHC tetramers. Standard assays, such as ELISA or ELISPOT, can be used to measure cytokine profiles attributable to T cell activation. T cell proliferation can be measured using assays such as ^{3}H-thymidine uptake and other assays known in the art. B cell responses can be measured using art recognized assays such as ELISA. Other methodologies can also be used to evaluate the effects of the nucleic acids on pathogen-associated lesions or on other pathogen levels generally (e.g., pneumococci clearance in challenged mice treated with the conjugate).

The nucleic acids described herein can be used in the manufacture of a medicament for the prevention or treatment of an infection with *S. pneumoniae* or conditions associated with such infection.

The invention will be further described in the following examples, which do not limit the scope of the invention described in the claims.

Examples

Example 1: Construction of Pseudopneumolysin Expression Vectors

Vectors for expressing truncated forms of a pneumolysin polypeptide are described in Examples 1A-1E. The encoded truncated polypeptides, termed "pseudopneumolysin" polypeptides, can be used for conjugation to pneumococcal polysaccharides for the preparation of conjugate vaccines. In addition, a nucleic acid encoding a pseudopneumolysin

polypeptide can be administered to an individual to generate an immune response against the encoded polypeptide.

PCR was performed using *S. pneumoniae* type 19A chromosomal DNA as a template to amplify various fragments of the pneumolysin gene. The sense primer used for the PCR reaction annealed to the coding sequence of the pneumolysin gene just upstream of the translation initiation codon and incorporated a specific restriction enzyme site. The senses primer, designated LYSN-1 (5'-GACTAGATCTCCATATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:2), is complementary to nucleotides 1 to 24 at the 5' end of the pneumolysin gene. The antisense primer, designated LYSN-3 (5'-CAGTGGATCCTTACTAGTCATTTTCTACCTTATC-3'; SEQ ID NO:3), is complementary to pneumolysin nucleotides 1396 to 1413 at the 3' end of the pneumolysin gene. The primers amplify a 1413 base pair DNA encoding 471 amino acids of full length pneumolysin protein. The following is the amino acid sequence of the *S. pneumoniae* type 19A pneumolysin polypeptide:

MANKAVNDFILAMNYDKKKLLTHQGESIENRFIKEGNQLPDEFVVIERKKRSLSTNT
SDISVTATNDSRLYPGALLVVDETLLENNPTLLAVDRAPMTYSIDLPGLASSDSFLQV
EDPSNSSVRGAVNDLLAKWHQDYGQVNNVPARMQYEKITAHSMEQLKVKFGSDFE
KTGNSLDIDFNSVHSGEKQIQIVNFKQIYYTVSVDAVKNPGDVFQDTVTVEDLKQRG
ISAERPLVYISSVAYGRQVYLKLETTSKSDEVEAAFEALIKGVKVAPQTEWKQILDNT
EVKAVILGGDPSSGARVVTGKVDMVEDLIQEGSRFTADHPGLPISYTTSFLRDNVVA
TFQNSTDYVETKVTAYRNGDLLLDHSGAYVAQYYITWNELSYDHQGKEVLTPKAW
DRNGQDLTAHFTTSIPLKGNVRNLSVKIRECTGLAWEWWRTVYEKTDLPLVRKRTIS
IWGTTLYPQVEDKVEND (SEQ ID NO:1).

PCR was generally performed as follows: 1 cycle at 94°C for 4 minutes; 30 cycles at 94°C for 1 minute, at 55° C for 1 minutes, and at 72°C for 1.5 minutes; and 1 cycle at 72°C for 10 minutes. The PCR-synthesized DNA fragment was digested with NdeI and BamHI restriction enzymes and ligated into the pET11b expression vector (to generate pSA-14). The recombinant DNA was introduced into *E. coli* DE3 cells by transformation. Ampicillin-resistant transformants were selected. The presence of the insert was confirmed by digestion with NdeI and BamHI restriction enzymes.

The amplified DNA fragments lack nucleotides at the 3' end compared to wild type genomic sequence. Many of the pseudopneumolysin polypeptides encoded by these modified nucleic acids were found to be non-hemolytic and non-cytotoxic, but retain immunogenicity.

A. Construction of pSA-1 Expression Vector

The pSA-1 expression vector encodes a polypeptide consisting of amino acids 1-460 of the pneumolysin protein of SEQ ID NO:1. PCR was performed on *S. pneumoniae* type 19A chromosomal DNA using LSYN-1 (5'-GACTAGATCTCCATATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:2) and LSYN-4 (5'-GACTGGATCCTTACTAGAGAGTTGTTCCCCAAATAG-3'; SEQ ID NO:5) primers to amplify a 1380 base pair DNA.

The PCR-synthesized DNA fragment was digested with NdeI and BamHI and ligated into the NdeI and BamHI sites of the pET11b expression vector to generate pSA-1. The recombinant DNA was introduced into *E. coli* DE3 cells by transformation. Ampicillin-resistant transformants were selected. The presence of the insert was confirmed by digestion with restriction enzymes, NdeI and BamHI and further confirmed by DNA sequencing.

The encoded 460 amino acid polypeptide, which lacks the 11 amino acids present at the carboxy terminus of the wild type pneumolysin protein, has the following sequence: MANKAVNDFILAMNYDKKKLLTHQGESIENRFIKEGNQLPDEFVVIERKKRSLSTNT SDISVTATNDSRLYPGALLVVDETLLENNPTLLAVDRAPMTYSIDLPGLASSDSFLQV EDPSNSSVRGAVNDLLAKWHQDYGQVNNVPARMQYEKITAHSMEQLKVKFGSDFE KTGNSLDIDFNSVHSGEKQIQIVNFKQIYYTVSVDAVKNPGDVFQDTVTVEDLKQRG ISAERPLVYISSVAYGRQVYLKLETTSKSDEVEAAFEALIKGVKVAPQTEWKQILDNT EVKAVILGGDPSSGARVVTGKVDMVEDLIQEGSRFTADHPGLPISYTTSFLRDNVVA TFQNSTDYVETKVTAYRNGDLLLDHSGAYVAQYYITWNELSYDHQGKEVLTPKAW DRNGQDLTAHFTTSIPLKGNVRNLSVKIRECTGLAWEWWRTVYEKTDLPLVRKRTIS IWGTTL (amino acids 1-460 of SEQ ID NO:1).

B. Construction of pSA-49 Expression Vector

The pSA-49 expression vector encodes a polypeptide consisting of amino acids 1-464 of the pneumolysin protein of SEQ ID NO:1. PCR was performed on *S. pneumoniae* type 19A chromosomal DNA using LSYN-1 (5'-GACTAGATCTCCATATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:2) and LSYN-54 (5'-CTGAGGATCCTTACTATACCTGAGGATAGAGAGTTGTTC-3'; SEQ ID NO:25) primers to amplify a 1392 base pair DNA.

The PCR-synthesized DNA fragment was digested with NdeI and BamHI and ligated into the NdeI and BamHI sites of the pET11b expression vector to generate pSA-49. The recombinant DNA was introduced into *E. coli* DE3 cells by transformation. Ampicillin-resistant transformants were selected. The presence of the insert was confirmed by digestion with restriction enzymes, NdeI and BamHI and further confirmed by DNA sequencing.

The encoded 464 amino acid polypeptide, which lacks the 7 amino acids present at the carboxy terminus of the wild type pneumolysin protein, has the following sequence: MANKAVNDFILAMNYDKKKLLTHQGESIENRFIKEGNQLPDEFVVIERKKRSLSTNT SDISVTATNDSRLYPGALLVVDETLLENNPTLLAVDRAPMTYSIDLPGLASSDSFLQV EDPSNSSVRGAVNDLLAKWHQDYGQVNNVPARMQYEKITAHSMEQLKVKFGSDFE KTGNSLDIDFNSVHSGEKQIQIVNFKQIYYTVSVDAVKNPGDVFQDTVTVEDLKQRG ISAERPLVYISSVAYGRQVYLKLETTSKSDEVEAAFEALIKGVKVAPQTEWKQILDNT EVKAVILGGDPSSGARVVTGKVDMVEDLIQEGSRFTADHPGLPISYTTSFLRDNVVA TFQNSTDYVETKVTAYRNGDLLLDHSGAYVAQYYITWNELSYDHQGKEVLTPKAW DRNGQDLTAHFTTSIPLKGNVRNLSVKIRECTGLAWEWWRTVYEKTDLPLVRKRTIS IWGTTLYPQV (amino acids 1-464 of SEQ ID NO:1).

C. Construction of pSA-11 Expression Vector

The pSA-11 expression vector encodes a polypeptide consisting of amino acids 1-466 of the pneumolysin protein of SEQ ID NO:1. PCR was performed on *S. pneumoniae* type 19A chromosomal DNA using LSYN-1 (5'-GACTAGATCTCCATATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:2) and LSYN-17 (5'-GACTGGATCCTTACTAATCTTCTACCTGAGGATAG-3'; SEQ ID NO:6) primers to amplify a 1398 base pair DNA.

The PCR-synthesized DNA fragment shown was digested with NdeI and BamHI and ligated into the NdeI and BamHI sites of the pET11b expression vector to generate pSA-11. The recombinant DNA was introduced into *E. coli* DE3 cells by transformation. Ampicillin-resistant transformants were selected. The presence of the insert was confirmed by digestion with restriction enzymes, NdeI and BamHI and further confirmed by DNA sequencing.

The encoded 466 amino acid polypeptide, which lacks the 5 amino acids present at the carboxy terminus of the wild type pneumolysin protein, has the following sequence:
MANKAVNDFILAMNYDKKKLLTHQGESIENRFIKEGNQLPDEFVVIERKKRSLSTNT
SDISVTATNDSRLYPGALLVVDETLLENNPTLLAVDRAPMTYSIDLPGLASSDSFLQV
EDPSNSSVRGAVNDLLAKWHQDYGQVNNVPARMQYEKITAHSMEQLKVKFGSDFE
KTGNSLDIDFNSVHSGEKQIQIVNFKQIYYTVSVDAVKNPGDVFQDTVTVEDLKQRG
ISAERPLVYISSVAYGRQVYLKLETTSKSDEVEAAFEALIKGVKVAPQTEWKQILDNT
EVKAVILGGDPSSGARVVTGKVDMVEDLIQEGSRFTADHPGLPISYTTSFLRDNVVA
TFQNSTDYVETKVTAYRNGDLLLDHSGAYVAQYYITWNELSYDHQGKEVLTPKAW
DRNGQDLTAHFTTSIPLKGNVRNLSVKIRECTGLAWEWWRTVYEKTDLPLVRKRTIS
IWGTTLYPQVED (amino acids 1-466 of SEQ ID NO:1).

D. Construction of pSA-32 Expression Vector

The pSA-32 expression vector encodes a polypeptide consisting of amino acids 1-469 of the pneumolysin protein of SEQ ID NO:1. PCR was performed on *S. pneumoniae* type 19A chromosomal DNA using LSYN-1 (5'-GACTAGATCTCCATATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:2) and LSYN-37 (5'-GACTGGATCCTTACTATTCTACCTTATCTTCTACCTGAG-3'; SEQ ID NO:7) primers to amplify a 1407 base pair DNA.

The PCR-synthesized DNA fragment was digested with NdeI and BamHI and ligated into the NdeI and BamHI sites of the pET11b expression vector to generate pSA-32. The recombinant DNA was introduced into *E. coli* DE3 cells by transformation. Ampicillin-resistant transformants were selected. The presence of the insert was confirmed by digestion with restriction enzymes, NdeI and BamHI and further confirmed by DNA sequencing.

The encoded 469 amino acid polypeptide, which lacks the 2 amino acids present at the carboxy terminus of the wild type pneumolysin protein, has the following sequence:

MANKAVNDFILAMNYDKKKLLTHQGESIENRFIKEGNQLPDEFVVIERKKRSLSTNT
SDISVTATNDSRLYPGALLVVDETLLENNPTLLAVDRAPMTYSIDLPGLASSDSFLQV
EDPSNSSVRGAVNDLLAKWHQDYGQVNNVPARMQYEKITAHSMEQLKVKFGSDFE
KTGNSLDIDFNSVHSGEKQIQIVNFKQIYYTVSVDAVKNPGDVFQDTVTVEDLKQRG
ISAERPLVYISSVAYGRQVYLKLETTSKSDEVEAAFEALIKGVKVAPQTEWKQILDNT
EVKAVILGGDPSSGARVVTGKVDMVEDLIQEGSRFTADHPGLPISYTTSFLRDNVVA
TFQNSTDYVETKVTAYRNGDLLLDHSGAYVAQYYITWNELSYDHQGKEVLTPKAW
DRNGQDLTAHFTTSIPLKGNVRNLSVKIRECTGLAWEWWRTVYEKTDLPLVRKRTIS
IWGTTLYPQVEDKVE (amino acids 1-469 of SEQ ID NO:1).

E. Construction of pSA-31 Expression Vector

The pSA-31 expression vector encodes a polypeptide consisting of amino acids 1-470 of the pneumolysin protein of SEQ ID NO:1. PCR was performed on *S. pneumoniae* type 19A chromosomal DNA using LSYN-1 (5'-GACTAGATCTCCATATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:2) and LSYN-38 (5'-GACTGGATCCTTACTAATTTTCTACCTTATCTTCTACCTGAG-3'; SEQ ID NO:8) primers to amplify a 1410 base pair DNA.

The PCR-synthesized DNA fragment was digested with NdeI and BamHI and ligated into the NdeI and BamHI sites of the pET11b expression vector to generate pSA-31. The recombinant DNA was introduced into *E. coli* DE3 cells by transformation. Ampicillin-resistant transformants were selected. The presence of the insert was confirmed by digestion with restriction enzymes, NdeI and BamHI and further confirmed by DNA sequencing.

The encoded 470 amino acid polypeptide, which lacks the 1 amino acid present at the carboxy terminus of the wild type pneumolysin protein, has the following sequence:

MANKAVNDFILAMNYDKKKLLTHQGESIENRFIKEGNQLPDEFVVIERKKRSLSTNT
SDISVTATNDSRLYPGALLVVDETLLENNPTLLAVDRAPMTYSIDLPGLASSDSFLQV
EDPSNSSVRGAVNDLLAKWHQDYGQVNNVPARMQYEKITAHSMEQLKVKFGSDFE
KTGNSLDIDFNSVHSGEKQIQIVNFKQIYYTVSVDAVKNPGDVFQDTVTVEDLKQRG
ISAERPLVYISSVAYGRQVYLKLETTSKSDEVEAAFEALIKGVKVAPQTEWKQILDNT
EVKAVILGGDPSSGARVVTGKVDMVEDLIQEGSRFTADHPGLPISYTTSFLRDNVVA
TFQNSTDYVETKVTAYRNGDLLLDHSGAYVAQYYITWNELSYDHQGKEVLTPKAW

DRNGQDLTAHFTTSIPLKGNVRNLSVKIRECTGLAWEWWRTVYEKTDLPLVRKRTIS IWGTTLYPQVEDKVEN (amino acids 1-470 of SEQ ID NO:1).

Example 2: Expression, Purification, and Characterization of Recombinant Pseudopneumolysin Polypeptides

PCR products were cloned into pET expression vectors, as described in Example 1. Recombinant DNA was transformed into *E. coli* and transformants were selected on plates containing antibiotics. Inserted DNA sequences were confirmed by DNA sequencing. Recombinant *E. coli* was grown at 37°C overnight and isopropylthio-β-D-galactoside (IPTG) was added to the culture as an inducer and the cells were grown continuously for three hours. The expressed recombinant polypeptide was evaluated by SDS-polyacrylamide gel electrophoresis (SDS-PAGE) stained with Coomassie blue. Recombinant polypeptides were purified using affinity chromatography and hemolytic activity was tested with a hemolysis assay using sheep or human red blood cells (as detailed in Example 3).

Example 3: Determination of Hemolytic Activity of Pseudopneumolysin Polypeptides

Hemolytic activity of the encoded polypeptides was determined according to the following protocol.

1) Prepare 2% suspension of human or sheep red blood cells. 0.2 mL of fresh blood cells is added into 10 mL of PBS (pH 7.2). Spin the suspension at 3000 rpm for 30 seconds and re-suspend the pellet in 10 mL of PBS three times.

2) Add 1 μg of polypeptide in 0.5 mL PBS (pH7.2) and mix with 0.5 mL of washed 2% of RBC suspension.

3) Incubate the mixture at 37°C for 1 hour and then centrifuge at 10,000 rpm for 2 min in an Eppendorf microcentrifuge.

4) Measure optical density (OD) at 541 nm. Hemolysis activity was measured as the percentage of OD absorption compared to full length pneumolysin polypeptide.

As shown in Table 1, truncates of pneumolysin lacking the C-terminal 7, 6, 2, or 1 amino acids lacked hemolytic activity. A truncate lacking the C-terminal 5 amino acids demonstrated a partial loss of hemolytic activity.

Table1: Hemolytic Activity of Full Length Pneumolysin and Pseudopneumolysin

Construct	Portion of pneumolysin (a)	% Hemolytic activity(b)
pSA-14	1-471 (full length pneumolysin)	100
pSA-49	1-464 (-7 aa pseudopneumolysin)	0
pSA-48	1-465 (-6 aa pseudopneumolysin)	0.2
pSA-11	1-466 (-5 aa pseudopneumolysin)	17
pSA-34	1-467 (-4 aa pseudopneumolysin)	100
pSA-33	1-468 (-3 aa pseudopneumolysin)	100
pSA-32	1-469 (-2 aa pseudopneumolysin)	0
pSA-31	1-470 (-1 aa pseudopneumolysin)	1.8

(a) Numbers represent amino acids (aa) from the native pneumolysin polypeptide absent in the C-terminal truncate.

(b) The hemolytic activities of the C-terminal truncates are expressed as a percentage of the full length construct, pSA-14.

Example 4: Preparation of Polysaccharide-Protein Conjugates

A. Oxidization of Polysaccharide

Pneumococcal capsular polysaccharides, such as 4, 6B, 9V, 14, 18, 19F, and 23F, were purchased from American Type Culture Collection (Manassas, VA). 10 mg of polysaccharide was dissolved in 1 mL of distilled water at 4°C overnight. One mL of 0.2 M PBS (pH 7.2) was added the next day. Polysaccharide was oxidized by reaction with 2 mM sodium periodate (MW: 213.9, Sigma) in the dark for 10 minutes at room temperature. Excess sodium periodate was destroyed by reaction with ethylene glycol (MW: 62.07) at a final concentration of 25 mM. The reaction mixture containing the polysaccharide was dialyzed extensively three times in 1000 mL 0.1 M PBS (pH 7.2).

B. Preparation of Immuno-Affinity Column

(i) Purification of full length His-tagged pneumolysin

E. coli (pET24b containing C-His-tagged pneumolysin) was grown in 4 mL LB medium containing 40 μL of 20% glucose and 4 μL of 50 mg/mL kanamycin and incubated at 37°C overnight with consistent shaking of 160 rpm. Three mL overnight culture was transferred into 100 mL LB medium containing 1 mL of 20% glucose and 100μL of 50 mg/mL kanamycin and incubated at 37°C with consistent shaking of 160 rpm until OD_{600} reached 0.4-0.5. 400 μL of 1 M IPTG was added to 100 mL of culture with a final concentration of 4 mM of IPTG. Cells were harvested, 3 hours after inducing gene expression, by centrifugation at 4000 rpm for 5 minutes. Full length His-tagged pneumolysin was purified according to the protocol of ProBond Purification System provided by Invitrogen (Carlsbad, CA).

(ii) Production of polyclonal antibodies against His-tagged pneumolysin

New Zealand white rabbits were injected with 4 equal doses of 25 μg each, at 4 different sites of emulsified His-tagged pneumolysin and TiterMax adjuvant (400 μL of 1 mg/mL His-tagged pneumolysin and 400 μL TiterMax adjuvant); one in each thigh muscle (i.m.) and one subcutaneously (s.c.) on each side of the spine over the longitudinal mucles of the back. After 14 days, 5 mL of blood was collected from the rabbits via ear veins.

If antibody titers from serum reached 1:3000 dilution levels, the animals were terminal bled out. If antibody titers were below 1:3000, a second dose of antigen was injected, and the animals were tested one week later (7 days after second dose). The cycles were continued until adequate titers were achieved.

(iii) Rabbit IgG purification using Affi-Gel protein A agarose

Serum from a rabbit immunized with His-tagged pneumolysin was applied to Affi-Gel protein A column equilibrated with 10 mM sodium phosphate and 150 mM NaCl (pH 8.2). After washing with 10 bed volumes, immunoglobulins were eluted with 2 to 5 volumes of 100 mM Na citrate (pH 3.0). The eluted IgG was collected, pooled and measured OD at 280. Three ml of purified IgG was further applied to 10 DG column and the first three ml eluted from the column was discarded. The column was added 3.5 mL of either coupling

buffer (150 mM NaCl and 100 mM Na acetate pH 5.5) or 0.1M 3-(N-morpholino) propane-sulfonic acid) (MOPS) buffer. 3.5 ml eluant IgG was collected, pooled, and further coupled to either Affi-Gel Hz or Affi-Gel10.

(iv) Preparation of immunoaffinity column using IgG random coupling to Affi-Ge10

Affi-Gel 10 is N-hydroxysuccinimide esters of a derivatized crosslinked agarose gel bead support and couples all ligands via primary amines. For coupling with IgG, Affi-Gel 10 was transferred to 15 mL tube and washed three times with cold DDH_2O and two times with cold 0.1 M MOPS buffer (pH 7.0). Purified IgG was added to 15 mL tube containing pre-washed Affi-Gel 10 and rotated-over-end at 4°C for four hr. The remaining active esters of Affi-Gel 10 was blocked by adding 100 mM Tris HCl pH 8.0 for another 0.5 hr at 4°C. The gel was transferred to 1.5 x 9.0 cm column. The column eluant was collected and measured OD at 280. The Affi-Gel 10 immunoaffinity column was washed with two bed volumes of 0.5M NaCl and 25 mM Tris HCl (pH 8.0). The column eluant was collected again and measured OD at 280. Based on the concentration of total IgG and uncoupled IgG , the coupling efficiency was calculated.

(v) Examination of immunoaffininty columns

For testing the immunoaffininty columns, the fractions with pseudopneumolysin from DEAE-Sepharose chromatography was added into 25 mM TrisHCl (pH8.0), 0.5 M NaCl and 0.5% Triton X-100. The sample was applied to 6.5 ml Affi-Gel 10 column (1.5 x12 cm) equilibrated with 0.5 M NaCl and 25 mM Tris HCl (pH8.0) at flow rate of 1 mL/2 min. The flow through fraction was collected. The column was washed with 15 mL of 0.5 M NaCl and 25 mM Tris HCl (pH8.0) two to three times. The column was washed again with 5 mL of 4 M urea. The bound pseudopneumolysin protein was eluted with 7 mL of 4 M urea twice. Protein samples from first 7 mL of 4 M urea fractions were analyzed by 9 % SDS- PAGE and visualized by staining with Coomassie brilliant blue R-20.

C. Preparation of Recombinant Pseudopneumolysin Protein

Bacteria transformed with expression vector pSA-49 (which encodes a polypeptide lacking the 7 amino acids at the C-terminus of pneumolysin; see Example 1) were grown in a

50 mL tube containing 30 mL LB medium with 100 μg/ml ampicillin at 37°C overnight. The following morning, 400 mL of LB medium with 100 μg/mL ampicillin and 0.2 % glucose in a 1 liter flask was inoculated with 13 ml of overnight culture and incubated with shaking at 37°C. At a cell density corresponding to an A600 of 0.5, the expression of the pseudopneumolysin protein was induced by addition of 2 or 4 mM IPTG for 3 hours.

Bacteria were centrifuged in a 500 mL centrifuge tube at 6,500 rpm for 10 minutes. The bacterial pellet was resuspended in 40 mL Tris HCl buffer (pH 8.0) with 100 μg/mL lysozyme, incubated on ice for 15 minutes, and sonicated 3 times with 10-second bursts on ice. The lysate was frozen at -80°C for 10 min and thawed at 37°C for 5 min. The cell lysate was treated by sonication-freezing-thawing two more times. Insoluble cell debris was removed by centrifugation at 6,000 rpm for 20 minutes. The supernatant lysate was further passed through 0.8 μM filter. The flow through proteins were examined by 9% SDS PAGE analysis and visualized by Coomassie brilliant blue R-250 staining. The crude lysate was further purified by DEAE-Sepharose chromatography.

Twenty mL crude bacterial lysate was loaded on a column (5 x 12 cm) with DEAE-Sepharose equilibrated with 25 mM Tris-HCl (pH 8.0). After the first flow through was collected, 10 mL of 25 mM Tri-HCl was added to the column. 10 mL of flow through was collected and pooled with the first flow through fraction (fraction 1). Next, 35 mL of 25 mM Tris-HCl (pH 8.0) was applied and the flow through was collected (fraction 2). Another 35 mL of 25 mM Tris-HCl (pH 8.0) was applied and the flow through was collected again (fraction 3). The bound bacterial proteins were eluted with 4 M NaCl and 25 mM Tris HCl (fraction 4). The protein concentration in each fraction was measured by reading OD at 280 nm. Protein samples were analyzed by 9% SDS-polyacrylamide gel electrophoresis (SDS-PAGE) and visualized by stained with Coomassie blue R-20. The flow through fractions (1 and 2) containing pseudopneumolysin were further purified by immunoaffinity chromatography.

After DEAE-Sepharose chromatography, the fractions with pseudopneumolysin were added to 25 mM Tris HCl (pH 8.0), 0.5 M NaCl and 0.5% Triton X-100. The sample was applied to 6.5 mL Affi-Gel 10 column coupled rabbit anti- pneumolysin IgG (1.5 x 12 cm) equilibrated with 0.5 M NaCl and 25 mM Tris HCl (pH 8.0) at flow rate of 1 mL/2 min. The flow through fraction was collected. The column was washed with 15 mL of 0.5 M NaCl

and 25 mM Tris HCl (pH 8.0) three times. The column was washed again with 5 mL of 4 M urea. The bound pseudopneumolysin protein was eluted with 7 mL of 4 M urea twice. Protein samples from unbound and bound fractions were analyzed by SDS-PAGE and visualized by staining with Coomassie brilliant blue R-20.

After immunoaffinity chromatography, 4 M urea eluted fraction containing pseudopneumolysin was further purified by 10 DG chromatography to remove urea. A 3.0 mL sample was applied to 10 DG column (1.5 x 12 cm) equilibrated with 1 x PBS buffer. The first 3.0 mL of flow through was discarded. The column was added a 3.9 mL of 1 x PBS buffer. The 3.9 mL fraction collected from the column was measured OD at 280 and the protein fractions were collected. The purity of protein was evaluated by 9% SDS-polyacrylamide gel electrophoresis.

D. Preparation of Polysaccharide-Protein Conjugates

Two milligrams of *S. pneumoniae* polysaccharide 18C was conjugated to the pseudopneumolysin protein (described in section C above) by direct conjugation using a reductive amination assay. 10 mg of pseudopneumolysin in 0.1 M PBS was added to the oxidized polysaccharide reaction mix and incubated at room temperature with gentle stirring for 30 min. Sodium cyanoborohydride was added at the final concentration of 20 mM (e.g., 750 µL of 100 mM cyanoborohydride was added into 3 ml of oxidized polysaccharide and pseudopneumolysin mixture). The mixture was incubated at room temperature with gentle stirring for 5 days. The conjugate was precipitated at 9,000 rpm for 10 minutes and then dissolved in 1-2 mL 0.1 M PBS, pH 7.2. The mixture was chromatographed on Sepharose CL-4B column (1.5 x 100 cm) equilibrated with 1 x PBS, pH 7.2. The fractions containing both protein and polysaccharide were pooled and concentrated by an Amicon Centricon-30 (molecular weight cutoff 30,000) and then assayed for protein and polysaccharide content.

Example 5: Antibody Response of Mice to the Polysaccharide-Protein Conjugates

The *S. pneumoniae* 14, 18C, 19F, 23F, 4, 6B and 9V polysaccharide-pseudopneumolysin protein conjugates prepared as described in Example 4 were tested for their ability to raise antibodies against polysaccharide and pneumolysin in mice. The conjugates, 0.3, 1, 3 µg /dose of polysaccharide mixed with aluminum hydroxide adjuvant

(0.1 mg/dose), were injected intraperitoneally to groups of female NIH Swiss mice. In some experiments, a second group of mice received 1 μg of polysaccharide, and/or a third group of mice received 1 μg of pseudopneumolysin. Mice received two boosters at two weeks of intervals. At seven days after the final injection, the serum levels of anti-polysaccharide antibodies and anti-pneumolysin antibodies were measured. Table 2 is a summary of the specific conjugates administered and the immune responses measured in the experiments depicted in each of Figs. 1-14.

Table 2: Summary of Conjugates Administered and Antibodies Detected in Mice Immunization Experiments

Figure Number	Serotype of *S. pneumoniae* polysaccharide component of conjugate	Antibody Response Measured
1	14	anti-pneumolysin IgG antibody
2	14	anti-serotype14 polysaccharide IgG antibody
3	18C	anti-pneumolysin IgG antibody
4	18C	anti-serotype 18C polysaccharide IgG antibody
5	19F	anti-pneumolysin IgG antibody
6	19F	anti-serotype 19F polysaccharide IgG antibody
7	23F	anti-pneumolysin IgG antibody
8	23F	anti-serotype 23F polysaccharide IgG antibody
9	4	anti-pneumolysin IgG antibody
10	4	anti-serotype 4 polysaccharide IgG antibody
11	6B	anti-pneumolysin IgG antibody
12	6B	anti-serotype 6B polysaccharide IgG antibody
13	9V	anti-pneumolysin IgG antibody
14	9V	anti-serotype 9V polysaccharide IgG antibody

The following abbreviations are used in the legends of Figs. 1-14: Phosphate Buffered Saline ("PBS"); Conjugates ("C"); Aluminum Hydroxide Adjuvant ("A"); and Pseudopneumolysin ("PPN").

Mice immunized with the polysaccharide-pseudopneumolysin conjugate showed an induction of antibodies that reacted by ELISA with His-tagged wild-type pneumolysin. For all groups receiving the conjugate and adjuvant, the anti-pneumolysin and anti-polysaccharide antibody levels were significantly greater than the PBS and adjuvant control ($p<0.001$, t-test). The serum of the conjugate-administered mice exhibited unexpectedly high titers of anti-pneumolysin and anti-polysaccharide antibodies, at serum dilution factors of 76800 and 9600 respectively, as compared to mice administered the PBS alone. The highest anti-pneumolysin and anti-polysaccharide antibody levels were observed in mice that received 3.0 μg of the polysaccharide-pseudopneumolysin conjugate (Figs. 1-14). Anti-pneumolysin antibody levels were higher in the groups that received the polysaccharide-pseudopneumolysin conjugate with adjuvant, as compared to the pseudopneumolysin with the adjuvant group (Fig. 3) or the pseudopneumolysin without adjuvant group (Fig. 6).

Tables 3 and 4 show that mice that received 3.0 μg of the conjugate had the highest percentage of responders. These results indicate that the effectiveness of pneumococcal vaccine can be improved by the conjugate of polysaccharide to a pseudopneumolysin protein. In addition to the antibody response, cross protective immunity and bacterial clearance were examined in mice administered the conjugate vaccines (see Example 8).

Table 3: Percentage of Mice With Positive Response Against 18C Polysaccharide

Groups of Mice	Percentage of Positive Responders
Aluminum Hydroxide Adjuvant	0 %
1 μg Pseudopneumolysin (PPN)	0 %
1 μg 18C Polysaccharide(PS) + Adjuvant	0 %
0.3 μg 18C (PS)-PPN Conjugate + Adjuvant	60 %

1.0 μg 18C (PS)-PPN Conjugate + Adjuvant	75 %
3.0 μg 18C (PS)-PPN Conjugate +Adjuvant	100 %
1.0 μg 18 C (PS)-PPN Conjugate without Adjuvant	20 %

Note: The positive responder was determined using 1:100 dilution of serum samples from all the mice. An A405 nm optical reading greater than 0.05 indicated a positive response.

Table 4: Percentage of Mice With Positive Response Against 14 Polysaccharide

Groups of Mice	Percentage of Positive Responders
Aluminum Hydroxide Adjuvant	0 %
1 μg Pseudopneumolysin (PPN)	0 %
1 μg 14 Polysaccharide(PS) + Adjuvant	0 %
0.3 μg 14 (PS)-PPN Conjugate + Adjuvant	100 %
1.0 μg 14 (PS)-PPN Conjugate + Adjuvant	100 %
3.0 μg 14 (PS)-PPN Conjugate +Adjuvant	100 %
1.0 μg 14 (PS)-PPN Conjugate without Adjuvant	20 %

Note: Positive responses were determined using 1:300 dilution of serum samples from all the mice. An A405 nm optical reading greater than 0.12 indicated a positive response.

Fig. 15 is a graph depicting the antibody response in mice to serotype 14 polysaccharide 7 days after the third injection of the serotype 14 polysaccharide-pseudopneumolysin conjugate. In Fig. 15, G1, G2, and G3 are groups of mice injected with 0.3 μg, 1.0 μg and 3.0 μg per mouse of the conjugate vaccine, respectively. G4 represents mice that were injected with 1.0 μg of the serotype 14 polysaccharide alone. G5 and G6 are groups of mice injected with 1.0 and 3.0 μg pseudopneumolysin alone, respectively. G7 is the group of mice injected with 1.0 μg of the serotype 14 polysaccharide-pseudopneumolysin conjugate vaccine without adjuvant. Little or no antibody responses against the polysaccharide were observed in mice of G4, G5, and G6.

Example 6: Construction of Expression Vectors for Pseudopneumolysin, Pneumococcal Autolysin, and Pneumococcal Surface Protein DNA vaccines

A. pVAX1 Vector for the Construction of a DNA Vaccine

pVAX1 vector (Invitrogen) was specifically designed for use in the development of DNA vaccines. Its construction is consistent with the Food and Drug Administration's document, "Points to Consider on Plasmid DNA Vaccines for Preventive Infectious Disease Indications" published on December 22, 1996.

B. Cloning and Expression of Pseudopneumolysin

PCR was carried out using Ready-to-go PCR beads (Amersham Pharmacia Biotech Inc. Piscataway, NJ) containing primers and template pneumococcal 19A chromosomal DNA. PCR was performed as follows: 94°C, 4 minutes for 1 cycle; 94°C, 1 minute; 55°C, 1 minute; 72°C, 1.5 minutes for 30 cycles; and 72°C, 10 minutes for 1 cycle.

The amplified PCR product was digested with restriction enzymes and ligated into sites of the pVAX1 vector to generate pSA-8, pSA-45, pSA-12, pSA-42, and pSA-41. The recombinant DNA was introduced into *E. coli* DH5α cells by transformation and checked by digestion with restriction enzymes. The inserted gene was analyzed by DNA sequencing. *In vitro* transcription and translation were carried out with TnT kit according to the manufacture's protocol (Promega, Madison, WI) to confirm the expression of the inserted gene.

The pSA-8 expression vector encodes a polypeptide consisting of amino acids 1-460 of the pneumolysin protein of SEQ ID NO:1. The insert was generated as described above using LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) and LSYN-4 primer (5'-GACTGGATCCTTACTAGAGAGTTGTTCCCCAAATAG-3'; SEQ ID NO:5) to amplify the 1380 base pair DNA. The 1380 base pair PCR product was then restricted with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 vector to generate pSA-8.

The pSA-45 expression vector encodes a polypeptide consisting of amino acids 1-464 of the pneumolysin protein of SEQ ID NO:1. The insert was generated using LSYN-15

(5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) and LSYN-105 (GACTGGATCCCTATACCTGAGGATAGAGAGTTG; SEQ ID NO:27) to amplify the 1392 base pair PCR product was then restricted with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 vector to generate pSA-45.

The pSA-12 expression vector encodes a polypeptide consisting of amino acids 1-466 of the pneumolysin protein of SEQ ID NO:1. The insert was generated as described above using LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) and LSYN-17 primer (5'-GACTGGATCCTTACTAATCTTCTACCTGAGGATAG-3'; SEQ ID NO:6) to amplify the 1398 base pair DNA. The 1398 base pair PCR product was then restricted with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 vector to generate pSA-12.

The pSA-42 expression vector encodes a polypeptide consisting of amino acids 1-469 of the pneumolysin protein of SEQ ID NO:1. The insert was generated as described above using LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) and LSYN-37 primer (5'-GACTGGATCCTTACTATTCTACCTTATCTTCTACCTGAG-3'; SEQ ID NO:7) to amplify the 1407 base pair DNA. The 1407 base pair PCR product was then restricted with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 vector to generate pSA-42.

The pSA-41 expression vector encodes a polypeptide consisting of amino acids 1-470 of the pneumolysin protein of SEQ ID NO:1. The insert was generated as described above using LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) and LSYN-38 primer (5'-GACTGGATCCTTACTAATTTTCTACCTTATCTTCTACCTGAG-3'; SEQ ID NO:8) to amplify the 1410 base pair DNA. The 1410 base pair PCR product was then restricted with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 vector to generate pSA-41.

Nucleic acids containing the unmethylated cytosine-guanine ("CpG") dinucleotide in a particular sequence context or motif can be potent stimulators of several types of immune cells *in vitro*. Synthetic oligonucleotides containing CpG motifs can directly activate the

innate immune system by stimulating B-cells to proliferate and secrete immunoglobulin, IL-6 and IL-10, NK cells to produce IFN-γ, and monocytes and dendritic cells to produce IL-6, IL-12, IL-18 TNT-α and IFN-α. A DNA motif consisting of an unmethylated CpG dinucleotide flanked by two 5' purines and two 3' pyrimidines stimulates B cells to produce IL-6 and IL-12, and stimulates CD4+ T cells to produce IL-6 and IFN-gamma.

Structure-function analysis of pneumolysin has demonstrated that a domain (located at amino acids 427 to 437) at the C terminus of the polypeptide, which includes a cysteine residue, is critical for cytotoxicity. This cysteine motif is highly conserved among other members of the thiol-activated cytolysin family. Several single amino acid substitutions within this domain reduce the cytotoxicity of pneumolysin significantly. The following nucleic acid construct substitutes the cysteine motif with a CpG motif by introducing GAGCGTT at nucleotide position of 1272 and 1274 of pneumolysin (via site directed mutagenesis). The mutated nucleic acid containing the GAGCGTT immunostimulatory sequence is as follows:

ATGGCAAATAAAGCAGTAAATGACTTTATACTAGCTATGAATTACGATAAAAAG
AAACTCTTGACCCATCAGGGAGAAAGTATTGAAAATCGTTTCATCAAAGAGGGT
AATCAGCTACCCGATGAGTTTGTTGTTATCGAAAGAAAGAAGCGGAGCTTGTCG
ACAAATACAAGTGATATTTCTGTAACAGCTACCAACGACAGTCGCCTCTATCCTG
GAGCACTTCTCGTAGTGGATGAGACCTTGTTAGAGAATAATCCCACTCTTCTTGC
GGTCGATCGTGCTCCGATGACTTATAGTATTGATTTGCCTGGTTTGGCAAGTAGC
GATAGCTTTCTCCAAGTGGAAGACCCCAGCAATTCAAGTGTTCGCGGAGCGGTA
AACGATTTGTTGGCTAAGTGGCATCAAGATTATGGTCAGGTCAATAATGTCCCAG
CTAGAATGCAGTATGAAAAAATCACGGCTCACAGCATGGAACAACTCAAGGTCA
AGTTTGGTTCTGACTTTGAAAAGACAGGGAATTCTCTTGATATTGATTTTAACTCT
GTCCATTCAGGCGAAAAGCAGATTCAGATTGTTAATTTTAAGCAGATTTATTATA
CAGTCAGCGTAGATGCTGTTAAAAATCCAGGAGATGTGTTTCAAGATACTGTAA
CGGTAGAGGATTTAAAACAGAGAGGAATTTCTGCAGAGCGTCCTTTGGTCTATAT
TTCGAGTGTTGCTTATGGGCGCCAAGTCTATCTCAAGTTGGAAACCACGAGTAAG
AGTGATGAAGTAGAGGCTGCTTTTGAAGCTTTGATAAAAGGAGTCAAGGTAGCT
CCTCAGACAGAGTGGAAACAGATTTTGGACAATACAGAAGTGAAGGCGGTTATT
TTAGGGGGCGACCCAAGTTCGGGTGCCCGAGTTGTAACAGGCAAGGTGGATATG

GTAGAGGACTTGATTCAAGAAGGCAGTCGCTTTACAGCAGATCATCCAGGCTTG
CCGATTTCCTATACAACTTCTTTTTTACGTGACAATGTAGTTGCGACCTTTCAAAA
TAGTACAGACTATGTTGAGACTAAGGTTACAGCTTACAGAAACGGAGATTTACT
GCTGGATCATAGTGGTGCCTATGTTGCCCAATATTATATTACTTGGAATGAATTA
TCCTATGATCATCAAGGTAAGGAAGTCTTGACTCCTAAGGCTTGGGACAGAAAT
GGGCAGGATTTAACGGCTCACTTTACCACTAGTATTCCTTTAAAAGGGAATGTTC
GTAATCTCTCTGTCAAAATTAGAGAGCGTTCCGGGCTTGCCTGGGAATGGTGGCG
TACGGTTTATGAAAAAACCGATTTGCCACTAGTGCGTAAGCGGACGATTTCTATT
TGGGGAACAACTCTCTATCCTCAGGTAGAAGATAAGGTAGAAAATGAC (SEQ ID
NO:9).

In another embodiment, the immunostimulatory DNA sequence GAGCGTT was introduced (via site directed mutagenesis) at nucleotide position 1272 to 1274 of a pseudopneumolysin having 33 nucleotides deleted at the C-terminal. The pseudopneumolysin DNA with the immunostimulatory sequence is as follows:

ATGGCAAATAAAGCAGTAAATGACTTTATACTAGCTATGAATTACGATAAAAAG
AAACTCTTGACCCATCAGGGAGAAAGTATTGAAAATCGTTTCATCAAAGAGGGT
AATCAGCTACCCGATGAGTTTGTTGTTATCGAAAGAAAGAAGCGGAGCTTGTCG
ACAAATACAAGTGATATTTCTGTAACAGCTACCAACGACAGTCGCCTCTATCCTG
GAGCACTTCTCGTAGTGGATGAGACCTTGTTAGAGAATAATCCCACTCTTCTTGC
GGTCGATCGTGCTCCGATGACTTATAGTATTGATTTGCCTGGTTTGGCAAGTAGC
GATAGCTTTCTCCAAGTGGAAGACCCCAGCAATTCAAGTGTTCGCGGAGCGGTA
AACGATTTGTTGGCTAAGTGGCATCAAGATTATGGTCAGGTCAATAATGTCCCAG
CTAGAATGCAGTATGAAAAAATCACGGCTCACAGCATGGAACAACTCAAGGTCA
AGTTTGGTTCTGACTTTGAAAAGACAGGGAATTCTCTTGATATTGATTTTAACTCT
GTCCATTCAGGCGAAAAGCAGATTCAGATTGTTAATTTTAAGCAGATTTATTATA
CAGTCAGCGTAGATGCTGTTAAAAATCCAGGAGATGTGTTTCAAGATACTGTAA
CGGTAGAGGATTTAAAACAGAGAGGAATTTCTGCAGAGCGTCCTTTGGTCTATAT
TTCGAGTGTTGCTTATGGGCGCCAAGTCTATCTCAAGTTGGAAACCACGAGTAAG
AGTGATGAAGTAGAGGCTGCTTTTGAAGCTTTGATAAAAGGAGTCAAGGTAGCT
CCTCAGACAGAGTGGAAACAGATTTTGGACAATACAGAAGTGAAGGCGGTTATT
TTAGGGGGCGACCCAAGTTCGGGTGCCCGAGTTGTAACAGGCAAGGTGGATATG

GTAGAGGACTTGATTCAAGAAGGCAGTCGCTTTACAGCAGATCATCCAGGCTTG
CCGATTTCCTATACAACTTCTTTTTTACGTGACAATGTAGTTGCGACCTTTCAAAA
TAGTACAGACTATGTTGAGACTAAGGTTACAGCTTACAGAAACGGAGATTTACT
GCTGGATCATAGTGGTGCCTATGTTGCCCAATATTATATTACTTGGAATGAATTA
TCCTATGATCATCAAGGTAAGGAAGTCTTGACTCCTAAGGCTTGGGACAGAAAT
GGGCAGGATTTAACGGCTCACTTTACCACTAGTATTCCTTTAAAAGGGAATGTTC
GTAATCTCTCTGTCAAAATTAGAGAGCGTTCCGGGCTTGCCTGGGAATGGTGGCG
TACGGTTTATGAAAAAACCGATTTGCCACTAGTGCGTAAGCGGACGATTTCTATT
TGGGGAACAACTCTC (SEQ ID NO:10).

D. Cloning and Expression of Pneumococcal Autolysin Gene

The pSA-59 expression vector encodes a 316 amino acid autolysin (Aly) polypeptide. The Type 19A Aly gene was amplified by PCR using Ready-to-go PCR beads containing primers and template from pneumococcal 19A chromosomal DNA. PCR was performed as follows: 94°C, 4 minutes for 1 cycle; 94°C, 1 minute; 50°C, 1 minute; 72°C, 1 minute, 15 seconds for 30 cycles; and 72°C, 10 minutes for 1 cycle. The insert was generated using LSYN-74 primer (5'-GACTAAGCTTGCCACCATGGAAATTAATGTGAGTAAATTAAG-3'; SEQ ID NO:11) and LSYN-89 primer (5'-CTGACTCGAGTTATTTTACTGTAATCAAGCCATC-3'; SEQ ID NO:12) to amplify the 948 base pair DNA.

PCR-synthesized DNA was digested with HindIII and XhoI and ligated at HindIII and XhoI sites of pVAX1 to generate pSA-59 (Aly). The recombinant DNA was introduced into E. coli DH5α cells by transformation checked by digestion with restriction enzymes, HindIII and XhoI. The Aly insert were confirmed by DNA sequencing. *In vitro* transcription and translation was carried out with TnT kit (Promega, Madison, WI) according to manufacture's protocol to confirm the expression of pSA-59.

The nucleic acid sequence of the pSA-59 Aly insert is as follows:
ATGGAAATTAATGTGAGTAAATTAAGAACAGATTTGCCTCAAGTTGGCGTGCAA
CCATATAGGCAAGTACACGCACACTCAACTGGGAATCCGCATTCAACCGTACAG
AATGAAGCGGATTATCATTGGCGGAAAGACCCAGAATTAGGTTTTTTCTCGCACA
TTGTTGGGAACGGATGCATCATGCAGGTAGGACCTGTTAATAATGGTGCCTGGG

ACGTTGGGGGCGGTTGGAATGCTGAGACCTATGCAGCGGTTGAACTGATTGAAA
GCCATTCAACTAAAGAAGAGTTCATGACGGACTACCGCCTTTATATCGAACTCTT
ACGCAATCTAGCAGATGAAGCAGGTTTGCCGAAAACGCTTGATACAGGGAGTTT
AGCTGGAATTAAAACGCACGAGTATTGCACGAATAACCAACCAAACAACCACTC
AGACCATGTGGATCCATACCCTTACTTGGCAAAATGGGGCATTAGCCGTGAGCA
GTTTAAGCATGATATTGAGAACGGCTTGACGATTGAAACAGGCTGGCAGAAGAA
TGACACTGGCTACTGGTACGTACATTCAGACGGCTCTTATCCAAAAGACAAGTTT
GAGAAAATCAATGGCACTTGGTACTACTTTGACAGTTCAGGCTATATGCTTGCAG
ACCGCTGGAGGAAGCACACAGACGGCAATTGGTACTACTTTGACCAATCAGGCG
AAATGGCTACAGGCTGGAAGAAAATCGCTGAGAAGTGGTACTATTTCAACGAAG
AAGGTGCCATGAAGACAGGCTGGGTCAAGTACAAGGACACTTGGTACTACTTAG
ACGCTAAAGAAGGCGCAATGGTATCAAATGCCTTTATCCAGTCAGCGGACGGAA
CAGGCTGGTACTACCTCAAACCAGACGGAACACTGGCAGACAAGCCAGAATTCA
CAGTAGAGCCAGATGGCTTGATTACAGTAAAA (SEQ ID NO:13).

The amino acid sequence encoded by the pSA-59 Aly insert is as follows:

MEINVSKLRTDLPQVGVQPYRQVHAHSTGNPHSTVQNEADYHWRKDPELGFFSHIV
GNGCIMQVGPVNNGAWDVGGGWNAETYAAVELIESHSTKEEFMTDYRLYIELLRN
LADEAGLPKTLDTGSLAGIKTHEYCTNNQPNNHSDHVDPYPYLAKWGISREQFKHDI
ENGLTIETGWQKNDTGYWYVHSDGSYPKDKFEKINGTWYYFDSSGYMLADRWRK
HTDGNWYYFDQSGEMATGWKKIAEKWYYFNEEGAMKTGWVKYKDTWYYLDAK
EGAMVSNAFIQSADGTGWYYLKPDGTLADKPEFTVEPDGLITVK (SEQ ID NO:14).

E. Cloning and Expression of N-terminal Pneumococcal Surface Protein A (PspA) Gene

The pSA-60 expression vector encodes a 459 amino acid PspA polypeptide. The type 19A PspA gene was amplified by PCR using Ready-to-go PCR beads containing primers and template from pneumococcal 19A chromosomal DNA. PCR was performed as follows: 94°C, 4 minutes for 1 cycle; 94°C, 1 minute; 50°C, 1 minute; 72°C, 1 minute, 15 seconds for 30 cycles; and 72°C, 10 minute for 1 cycle. The insert was generated using LSYN-90 (5'-GACTAAGCTTGCCACCATGGAA GAAGCTCCCGTAGCTAGTCAG-3'; SEQ ID NO:15) with LSYN-78 primer (5'-GACTCTCGAGCTATCCATCAGGGCCTAACTCATTAAG-3'; SEQ ID NO:16) to

amplify the 1377 base pair DNA. PCR-synthesized DNA was digested with HindIII and XhoI and ligated at HindIII and XhoI sites of pVAX1 to generate pSA-60 (PspA). The recombinant DNA was introduced into E. coli DH5α cells by transformation checked by digestion with restriction enzymes, HindIII and XhoI. The PspA insert was confirmed by DNA sequencing. In vitro transcription and translation was carried out with TnT kit (Promega, Madison, WI) according to manufacture's protocol to confirm the expression of pSA-60.

The nucleic acid sequence of the pSA-60 PspA insert is as follows:

ATGGAAGAAGCTCCCGTAGCTAGTCAGTCTAAAGCTGAGAAAGACTATGATGCA
GCAGTGAAAAAATCTGAAGCTGCTAAGAAGGCTTACGAAGAAGCTAAAAAGAA
AGCAGAAGACGCTCAGAAAAAATATGATGAGGATCAGAAGAAAACTGAGGCAA
AAGCGGATAAGGAAGCAAAAGCATCTGCGGAAATAGATAAAGCCACGTTTGCTG
TACAAAGTGCGTATGTAAAATTTTTAAATGTCCAATCTAATCGTCAAATTTCGGA
GAATGAACGAAAAAAACAATTAGCAGAAATAGATAAAGAGATAGAGAATGCTA
AACAAAATTTACAGAATAAACAGGAAGAATTTAATAAGGTTAGAGCAGAAGTA
ATTCCTGAAGCAAAGGGGTTAGCTGTTACTAAACAAAAAGCGGAAGAAGCTAAA
AAAGAAGCAGAAGTAGCTAAGAGAAAATATGATTATGCAACTCTAAAGGTAGC
ACTAGCGAAGAAAGAAGTAGAGGCTAAGGAACTTGAAATTGAAAAACTTCAAT
ATGAAATTTCTACTTTGGAACAAGAAGTTGCTATTGCTCAACATCAAGTAGATAA
TTTGAAAAAACTTCTTGCTGGTGCGGATCCTGATGATGGCACAAAAGTTATAGAA
GCTAAATTAAACAAAGGAGAAGCTGAGCTAAACGCTAAACAAGCTGAGTTAGCA
AAAAAACAAACAGAACTTGAAAAACTTCTTGACAGCCTTGATCCTGAAGGTAAG
ACTCAGGATGAATTAGATAAAGAAGCTGCTGAAGCTGAGTTGGATAAAAAAGCT
GATGAACTTCAAAATAAAGTTGCTGATTTAGAAAAAGGAATTGCTCCTTATCAA
ATCAAAGTCGCTGAATTAAATAAAGAAATTGCTAGACTTCAAAGCGATTTAAAA
GATGCTGAAGAAAATAATGTAGAAGACTATATTAAAGAAGGTTTAGAGCAAGCT
ATCGCTGATAAAAAAGCTGAATTAGCTACAACTCAACAAAACATAGATAAAACT
CAAAAAGATTTAGAGGATGCTGAATTAGAACTTGAAAAAGTATTAGCTACATTA
GACCCTGAAGGTAAAACTCAAGATGAATTAGATAAAGAAGCTGCAGAAGATGCT
AATATTGAAGCTCTTCAAAACAAAGTTGCTGATCTAGAAAACAAGGTTGCTGAA
TTAGATAAAGAAGTTACTAGACTTCAAAGCGATTTAAAAGATGCTGAAGAAAAC

AATGTAGAAGACTACGTTAAAGAAGGCTTAGATAAAGCTCTTACTGATAAAAAA
GTTGAATTAAATAATACTCAAAAAGCATTAGATACTGCTCAAAAAGCATTAGAT
ACTGCTCTTAATGAGTTAGGCCCTGATGGA (SEQ ID NO:17).

The amino acid sequence encoded by the pSA-60 PspA insert is as follows:

MEEAPVASQSKAEKDYDAAVKKSEAAKKAYEEAKKKAEDAQKKYDEDQKKTEAK
ADKEAKASAEIDKATFAVQSAYVKFLNVQSNRQISENERKKQLAEIDKEIENAKQNL
QNKQEEFNKVRAEVIPEAKGLAVTKQKAEEAKKEAEVAKRKYDYATLKVALAKKE
VEAKELEIEKLQYEISTLEQEVAIAQHQVDNLKKLLAGADPDDGTKVIEAKLNKGEA
ELNAKQAELAKKQTELEKLLDSLDPEGKTQDELDKEAAEAELDKKADELQNKVAD
LEKGIAPYQIKVAELNKEIARLQSDLKDAEENNVEDYIKEGLEQAIADKKAELATTQ
QNIDKTQKDLEDAELELEKVLATLDPEGKTQDELDKEAAEDANIEALQNKVADLEN
KVAELDKEVTRLQSDLKDAEENNVEDYVKEGLDKALTDKKVELNNTQKALDTAQK
ALDTALNELGPDG (SEQ ID NO:18).

Example 7: Immunogenicity of DNA Vaccines

Plasmid vector pSA-7 encodes a full length pneumolysin protein. Type 19A Ply gene was amplified by PCR using Ready-to-go PCR beads containing primers and template from Pneumococcal 19A chromosomal DNA. PCR was performed at 94°C 4 min for 1 cycle, 94°C 1 min, 55°C 1 min, and 72°C 1.5 min for 30 cycles, and 72°C 10 min for 1 cycle. LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) complementary to Ply nucleotides 1 to 24 at 5' end was used with LSYN-3 primer (5'-CAGTGGATCCTTACTAGTCATTTTCTACCTTATC-3'; SEQ ID NO:3) complementary to Ply nucleotides 1396 to 1413 at 3' end to amplify the 1413 base pair DNA encoding the 471 amino acid full-length, wild type Ply protein. The PCR-synthesized DNA fragment was treated with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 expression vector to generate pSA-7. The recombinant DNA was introduced into *E. coli* DE5α cells by transformation and checked by digestion with restriction enzymes, NheI and BamHI. The inserted type 19A wild type Ply gene was confirmed by DNA sequencing.

Plasmid vector pSA-10 encodes a C-terminal truncated pneumolysin protein (lacking 114 amino acids at the C-terminus of Ply). Type 19A Ply gene was amplified by PCR using

Ready-to-go PCR beads containing primers and template from Pneumococcal 19A chromosomal DNA. PCR was performed at 94°C 4 min for 1 cycle, 94°C 1 min, 55°C 1 min, and 72°C 1.5 min for 30 cycles, and 72°C 10 min for 1 cycle. LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4) complementary to Ply nucleotides 1 to 24 at 5' end was used with LSYN-6 primer (5'-CTGAGGATCCTTACTAAGCTGTAACCTTAGTCTC-3'; SEQ ID NO:19) complementary to Ply nucleotides 1054 to1071 at the 3'end to amplify a 1071 base pair DNA encoding a 357 amino acid polypeptide. The PCR-synthesized DNA fragment was treated with NheI and BamHI and ligated into NheI and BamHI sites of pVAX1 expression vector to generate pSA-10. The recombinant DNA was introduced into *E. coli* DE5α cells by transformation and checked by digestion with restriction enzymes, NheI and BamHI. The inserted type 19A pseudopneumolysin gene was confirmed by DNA sequencing.

Plasmid vector pSA-26 encodes a full length pneumolysin carrying a CpG motif. PCR Primers LSYN-34 and LSYN-33, containing two complementary oligonucleotides carrying CpG motif at the 3' termini, were used to prime PCR1 and PCR2. The second primers LSYN-15 and LSYN-3 are complementary to sequences lying N and C-terminal of pneumolysin, respectively. In separate amplification, the first PCR products, PCR1 (1.2 kb) and PCR2 (150 bp) were generated by PCR using Ready-to-go PCR beads containing primers LSYN-15 and -34 (PCR1) and LSYN-33 and -3 (PCR2) and template pSA7 containing full-length pneumolysin gene. The first PCR products were mixed and denatured and used as templates to generate second PCR product, which was primed by the second set primers LSYN-15 and -3. The second PCR product was cut with NheI and BamHI, and cloned at NheI and BamHI of pVAX1 to generate pSA-26. PCR was performed at 94°C 4 min for 1 cycle, 94°C 1 min, 55°C 1 min, and 72°C 1 min for 30 cycles, and 72°C 8 min for 1 cycle.

The sequence of primers LSYN-3, LSYN-15, LSYN-33 and LSYN-34 are as follows: LSYN-3 primer (5'-CAGTGGATCCTTACTAGTCATTTTCTACCTTATC-3'; SEQ ID NO:3); LSYN-15 primer (5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4); LSYN-33 primer (5'-CAAAATTAGAGAACGTTCCGGGCTTGCCTGGGAATGG-3';

SEQ ID NO:20), LSYN-34 primer
(5'-GCCCGGAACGTTCTCTAATTTTGACAGAGAGATTACG-3'; SEQ ID NO:21).

The recombinant DNA was introduced into *E. coli* DE5α cells by transformation and checked by digestion with restriction enzymes, NheI and BamHI. The inserted type 19A wild type Ply gene carrying a CpG motif was confirmed by DNA sequencing.

Plasmid vector pSA-27 contains a CpG motif and encodes a C-terminal truncation of pneumolysin (11 amino acids deleted). Primers LSYN-34 and LSYN-33, containing two complementary oligonucleotides carrying CpG motif at the 3' termini, were used to prime PCR1 and PCR2. The second primers LSYN-15 and LSYN-3 are complementary to sequences lying N and C-terminal of pneumolysin, respectively. In separate amplification, the first PCR products, PCR1 (1.2 kb) and PCR2 (150 bp) were generated by PCR using Ready-to-go PCR beads containing primers LSYN-15 and -34 (PCR1) and LSYN-33 and -3 (PCR2) and template pSA-7 containing full-length pneumolysin gene.

The first PCR products were mixed and denatured and used as templates to generate a second PCR product, which was primed by the second set primers LSYN-15 and -4. The second PCR product was cut with NheI and BamHI, and cloned at NheI and BamHI of pVAX1 to generate pSA-27. PCR was performed at 94°C 4 min for 1 cycle, 94°C 1 min, 55°C 1 min, and 72°C 1 min for 30 cycles, and 72°C 8 min for 1 cycle. The oligonucleotides of primers LSYN-3, LSYN-4, LSYN-15, LSYN-33 and LSYN-34 are as follows: LSYN-3 primer (5'-CAGTGGATCCTTACTAGTCATTTTCTACCTTATC-3'; SEQ ID NO:3); LSYN-4 primer (5'-GACTGGATCCTTACTAGAGAGTTGTTCCCCAAATAG-3'; SEQ ID NO:5) LSYN-15 primer
(5'-GACTGCTAGCCACCATGGCAAATAAAGCAGTAAATGAC-3'; SEQ ID NO:4); LSYN-33 primer (5'-CAAAATTAGAGAACGTTCCGGGCTTGCCTGGGAATGG-3'; SEQ ID NO:20); LSYN-34 primer (5'-
GCCCGGAACGTTCTCTAATTTTGACAGAGAGATTACG-3'; SEQ ID NO:21). The recombinant DNA was introduced into *E. coli* DE5α cells by transformation and checked by digestion with restriction enzymes, NheI and BamHI. The inserted type 19A pseudopneumolysin gene carrying CpG motif was confirmed by DNA sequencing.

A vaccination program which entails priming with a DNA vector and boosting with a protein has resulted in the generation of a high level of specific immunity and, in some cases,

afforded protection against infectious agents that currently pose great problems for vaccine development. In these experiments, rabbits were primed three times with a pneumolysin DNA vector and boosted with a pneumolysin protein without adjuvant.

Fig. 16 is a graph depicting an anti-pneumolysin antibody response in rabbits using a prime-boost strategy for pseudopneumolysin DNA vaccination, as described above. Lanes 1, 2, and 3 represent immune responses 7 days after a first (1), second (2), and third (3) intramuscular pseudopneumolysin DNA vaccination. Lane 4 represents the response 10 days after protein boost (200 μg pneumolysin). Lane 5 depicts the antibody response 10 days after injection of 200 μg pneumolysin protein together with TiterMax adjuvant. The results demonstrate that three injections of DNA plus a boost with protein can result in a higher antibody response compared to a traditional protein vaccination method using an adjuvant.

DNA vaccines pSA-59, and pSA-60, and one vector control plasmid DNA, in the amount of 100 μg each in a total volume of 0.1 mL in 1 x PBS, were each injected intramuscularly into both quadriceps muscle or hind limbs of Balb/C mice. Mice were injected with 4 doses of 100 μg DNA vaccines with 2 week intervals between the injections. At 7 days after the final injection, the serum levels of IgG antibodies were measured by ELISA. The mice that received 4 injections DNA vaccines produced 9600 fold more IgG Ab than did the control group. These results indicate that plasmid DNA can express autolysin or pneumococcal surface protein A antigens *in vivo* and stimulate the immune system to produce high levels of specific IgG antibodies in mice.

Fig. 17 is a graph of the antibody response to pneumococcal surface protein A 7 days after the fourth injection with the PspA DNA vaccine. Fig. 18 is a graph of the antibody response to pneumococcal autolysin 7 days after the fourth injection with the autolysin DNA vaccine.

Example 8: Protective Immunity and Cross-Protection Against Challenge With Heterologous Serotypes of Virulent Pneumococci

Mice were injected intraperitonealy with three doses of 2.5 μg serotype 14 polysaccharide-pseudopneumolysin (-7 amino acids) conjugate at 2 week intervals. In control groups, the conjugate was substituted with PBS. Eight days after the third injections, the immunized mice were challenged intraperitonealy with 1 x 10^5 to 1 x 10^6 CFU (colony

forming unit) pneumococci / 0.1 mL . The exact number of CFU per milliliter injected was determined by plate count on sheep blood agar plate. At 1, 3, and 5 hours after challenge, 5 μL and 20 μL of blood samples of each mouse were plated onto sheep blood agar plate and incubated at 37°C overnight. Significant differences were detected for bacterial clearance from blood samples of conjugate vaccinated mice relative to controls following challenge.

Fig. 19 shows bacterial clearance from the blood of mice immunized with a serotype 14 polysaccharide-pseudopneumolysin conjugate when challenged with type 14 pneumococci. There were significant differences ($P<0.01$) of CFUs between the conjugate and PBS treated groups 1, 3, and 5 hours after challenge.

Fig. 20 shows bacterial clearance from the blood of mice immunized with a serotype 14 polysaccharide-pseudopneumolysin conjugate when challenged with type 7 pneumococci. There were significant differences ($P<0.01$) of CFUs between the conjugate and PBS treated groups at 1, 3, and 5 hours after challenge. These data also indicate that mice immunized with the conjugate were provided cross-protection against challenge with a heterologous pneumococcal serotype.

Fig. 21 shows bacterial clearance from the blood of mice immunized with a serotype 14 polysaccharide-pseudopneumolysin conjugate when challenged with type 6B pneumococci. There were significant differences ($P<0.05$) of CFUs between the conjugate and PBS treated groups at 1, 3, and 5 hours after challenge. These data also indicate that mice immunized with the conjugate were provided cross-protection against challenge with a heterologous pneumococcal serotype.

Fig. 22 shows bacterial clearance from the blood of mice immunized with a serotype 14 polysaccharide-pseudopneumolysin conjugate when challenged with type 18C pneumococci. There were significant differences ($P<0.01$) of CFUs between the conjugate and PBS treated groups at 1, 3, and 5 hours after challenge. These data also indicate that mice immunized with the conjugate were provided cross-protection against challenge with a heterologous pneumococcal serotype.

Figs. 23-25 show bacterial clearance from the blood of mice immunized with a serotype 14 polysaccharide-pseudopneumolysin conjugate when challenged with type 23F pneumococci. There were significant differences ($P<0.01$) of CFUs between the groups of conjugate and PBS at 1 hour (Fig. 23), 3 hours (Fig. 24) and 5 hours (Fig. 25) after challenge.

These data also indicate that mice immunized with the conjugate were provided cross-protection against challenge with a heterologous pneumococcal serotype.

Example 9. Opsonophagocytic Assay

A. Opsonophagocytic Assay

The functional activity of an antibody against serotype 14 pneumococcal polysaccharide was measured by an opsonophagocytic assay using human polymorphonuclear leukocytes (PMNL). Antisera were serially diluted (two-fold) and 20 μL of each serum sample was combined with 20 μL of bacterial suspension, containing approximately 200 CFU in brain heart infusion medium and incubated at 37°C for 15 minutes. After incubation, 10 μL of baby rabbit complement and 40 μL of PMNL (4×10^5 cells) were added. The mixture was incubated at 37°C in a 5% CO_2 atmosphere for 60 minutes. To obtain viable cell counts, a 20 μL aliquot from each sample was inoculated on triplicate blood agar plates and kept at 37°C overnight. Complement control included all test reagents except antibodies to pneumococci. Opsonophagocytic titers were reported as the reciprocal of the highest serum dilution with > 50 % killing of bacteria compared with growth in the complement.

B. Phagocytes

Fresh PMNL were isolated from peripheral blood of a healthy adult volunteer by dextran sedimentation and ficoll (ICN Biomedical Company, #16-922-54 Lymphocyte Separation Medium) separation of mononuclear cells and PMNL. Red blood cells were lysed with ACK lysis buffer (BioFluids, Catalog number p304-100). The final concentration of cells was adjusted to 1×10^7 cells/mL in BME (Life Technologies GIBCO BRL, Basal Medium Eagle). 40 μL of PMNL $2\text{-}4 \times 10^5$ cells was used for each sample.

C. Mouse Serum and Bacteria

Mouse antisera against 14 polysaccharide were serially diluted in brain-heart infusion medium (two-fold, from 1:2 to 1:256) and 20 μL of each serum sample was mixed with 20 ul of bacterial suspension (200 CFU of *S. pneumoniae* serotype 14) at 37°C for 15 minutes.

Serotype 14 *S. pneumoniae* was cultured in brain-heart infusion medium at 37°C for 10 hours. 10 fold serial dilutions were made to determine the number of bacteria used for this experiment. 100 ul of sample was applied to a plate. 10 CFU was found on the plate using the sample with a $1:10^7$ dilution and 91 CFU was found on the plate using the sample with a $1:10^6$ dilution. Therefore, the concentration of the bacteria used for the experiment was determined to be about 1×10^9 CFU/mL. Serotype 14 *S. pneumoniae* 1×10^9 CFU/mL was diluted to 1×10^4 CFU/mL. 200 CFU/20 µL was used for each sample.

D. Complement and PMNL

After incubation, 10 µL of baby rabbit complement (aliquots of fresh collected young rabbit serum and stored at –80°C before using) and 40 µL of PMNL 2.8×10^5 cells was added. The mixture was incubated at 37°C in a 5% CO_2 atmosphere for 60 minutes.

E. CFU Counts

To obtain viable cell counts, a 20 µL aliquot of two dilutions, 1:10 and 1:100 from each sample, was inoculated on triplicate blood agar plates and kept at 37°C overnight. Complement control included all test reagents except antibodies to pneumococci.

F. Opsonophagocytic Activity

Opsonophagocytic titers are reported as the reciprocal of the highest serum dilution with > 50% killing of bacteria compared with growth in the complement control.

Table 5: Opsonization Activity of Mouse Antibody Against Serotype 14 Polysaccharide

	Serum dilution							
Mouse #	1:2	1:4	1:8	1:16	1:32	1:64	1:128	1:256	Control
Vaccine									
1, CFU		12	20	22	25	28	32	45	81
% of killing		85%	76%	73%	69%	65%	60%	44%	
2, CFU		17	18	17	17	32	50	51	81
% of killing		79%	78%	79%	79%	60%	38%	37%	
3, CFU		19	27	31	31	32	44	56	81
% of killing		77%	67%	62%	62%	60%	46%	31%	

4, CFU	15	22	23	19	33	36	40	81
% of killing	81%	73%	72%	77%	59%	56%	51%	
5, CFU	22	26	34	27	33	43	51	81
% of killing	73%	68%	58%	67%	59%	47%	37%	
6, CFU	22	17	19	28	43	51	57	81
% of killing	73%	79%	77%	65%	47%	37%	30%	
7, CFU	22	29	29	26	28	29	57	81
% of killing	73%	64%	64%	68%	65%	64%	30%	
8, CFU	31	23	31	35	48	63	63	81
% of killing	62%	72%	62%	57%	41%	22%	22%	

The titer of mouse serum for opsonization activity
#1, 128 #2, 64 #3, 64 #4, 256 #5, 128 #6, 32 #7, 128 #8, 32.

Table 6: Antibody (Ab) Responses Against Serotype 14 Polysaccharide (PS) and Pseudopneumolysin (PPN)

Mouse#	Ab against PS		Ab against PPN	
	Titer	OD_{405} (1:300)	Titer	OD_{405} (1:300)
1	76800	0.735	9600	0.454
2	76800	0.520	9600	0.360
3	76800	0.738	9600	0.285
4	19200	0.677	9600	0.266
5	19200	0.684	9600	0.381
6	4800	0.518	4800	0.261
7	76800	0.815	9600	0.348
8	4800	0.585	1200	0.125

As shown in Tables 5 and 6, mice (e.g., mice numbers 1, 2, 3, 4, 5, and 7) with higher antibody responses against serotype 14 polysaccharide and pseudopneumolysin showed higher opsonization activity, whereas mice (e.g., mice numbers 6 and 8) with lower antibody titers against serotype 14 polysaccharide and pseudopneumolysin showed lower opsonization activity. No opsonization activity was detected in mice injected with PBS.

Other Embodiments

It is to be understood that, while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention. Other aspects, advantages, and modifications of the invention are within the scope of the claims set forth below.

What is claimed is:

1. A composition comprising an isolated polypeptide conjugated to a *Streptococcus pneumoniae* capsular polysaccharide, wherein the polypeptide comprises a fragment of at least 400 contiguous amino acids of a *Streptococcus pneumoniae* pneumolysin protein, wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22), wherein the polypeptide lacks hemolytic activity, wherein the *Streptococcus pneumoniae* pneumolysin protein contains the amino acid sequence of SEQ ID NO:1, and wherein the composition elicits an immune response against *Streptococcus pneumoniae* when administered to a mammal.

2. The composition of claim 1, wherein the polypeptide comprises amino acids 1-460 of SEQ ID NO:1.

3. The composition of claim 1, wherein the polypeptide comprises amino acids 1-464 of SEQ ID NO:1.

4. The composition of claim 1, wherein the polypeptide comprises amino acids 1-465 of SEQ ID NO:1.

5. The composition of claim 1, wherein the polypeptide comprises amino acids 1-466 of SEQ ID NO:1.

6. The composition of claim 1, wherein the polypeptide comprises amino acids 1-469 of SEQ ID NO:1.

7. The composition of claim 1, wherein the polypeptide comprises amino acids 1-470 of SEQ ID NO:1.

8. The composition of claim 1, wherein the polypeptide lacks the amino acid sequence EDKVEND (SEQ ID NO:23).

9. The composition of claim 1, wherein the polypeptide lacks the amino acid sequence YPQVEDKVEND (SEQ ID NO:24).

10. The composition of claim 1, wherein the polypeptide consists of amino acid residues 1-460 of SEQ ID NO:1.

11. The composition of claim 1, wherein the polypeptide consists of amino acid residues 1-464 of SEQ ID NO:1.

12. The composition of claim 1, wherein the polypeptide consists of amino acid residues 1-465 of SEQ ID NO:1.

13. The composition of claim 1, wherein the polypeptide consists of amino acid residues 1-466 of SEQ ID NO:1.

14. The composition of claim 1, wherein the polypeptide consists of amino acid residues 1-469 of SEQ ID NO:1.

15. The composition of claim 1, wherein the polypeptide consists of amino acid residues 1-470 of SEQ ID NO:1.

16. The composition of claim 1, wherein the capsular polysaccharide is selected from the group consisting of serotype 4, 6B, 9V, 14, 18C, 19F, and 23F.

17. The composition of claim 1, wherein the capsular polysaccharide is serotype 14.

18. The composition of claim 1, wherein the capsular polysaccharide is serotype 18C.

19. The composition of claim 1, wherein the composition comprises a plurality of different capsular polysaccharides selected from the group consisting of serotype 4, 6B, 9V, 14, 18C, 19F, and 23F.

20. The composition of claim 1, wherein the immune response comprises a humoral immune response.

21. The composition of claim 1, wherein the immune response comprises a cellular immune response.

22. The composition of claim 1, wherein the immune response is directed against a *Streptococcus pneumoniae* capsular polysaccharide.

23. The composition of claim 1, wherein the immune response is directed against a *Streptococcus pneumoniae* pneumolysin protein.

24. The composition of claim 1, wherein the immune response is directed against a *Streptococcus pneumoniae* capsular polysaccharide and a *Streptococcus pneumoniae* pneumolysin protein.

25. A mammalian expression vector comprising a promoter operably linked to a nucleotide sequence comprising a nucleic acid encoding a polypeptide comprising a fragment of at least 400 contiguous amino acids of a *Streptococcus pneumoniae* pneumolysin protein, wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22), wherein the polypeptide lacks hemolytic activity, wherein the *Streptococcus pneumoniae* pneumolysin protein comprises the amino acid sequence of SEQ ID NO:1, and wherein the polypeptide elicits an immune response against *Streptococcus pneumoniae* when the expression vector is administered to a mammal.

26. The mammalian expression vector of claim 25, wherein the polypeptide comprises amino acids 1-460 of SEQ ID NO:1.

27. The mammalian expression vector of claim 25, wherein the polypeptide comprises amino acids 1-464 of SEQ ID NO:1.

28. The mammalian expression vector of claim 25, wherein the polypeptide comprises amino acids 1-465 of SEQ ID NO:1.

29. The mammalian expression vector of claim 25, wherein the polypeptide comprises amino acids 1-466 of SEQ ID NO:1.

30. The mammalian expression vector of claim 25, wherein the polypeptide comprises amino acids 1-469 of SEQ ID NO:1.

31. The mammalian expression vector of claim 25, wherein the polypeptide comprises amino acids 1-470 of SEQ ID NO:1.

32. The mammalian expression vector of claim 25, wherein the polypeptide lacks the amino acid sequence EDKVEND (SEQ ID NO:23).

33. The mammalian expression vector of claim 25, wherein the polypeptide lacks the amino acid sequence YPQVEDKVEND (SEQ ID NO:24).

34. The expression vector of claim 25, wherein the polypeptide consists of amino acid residues 1-460 of SEQ ID NO:1.

35. The mammalian expression vector of claim 25, wherein the polypeptide consists of amino acid residues 1-464 of SEQ ID NO:1.

36. The mammalian expression vector of claim 25, wherein the polypeptide consists of amino acid residues 1-465 of SEQ ID NO:1.

37. The mammalian expression vector of claim 25, wherein the polypeptide consists of amino acid residues 1-466 of SEQ ID NO:1.

38. The mammalian expression vector of claim 25, wherein the polypeptide consists of amino acid residues 1-469 of SEQ ID NO:1.

39. The mammalian expression vector of claim 25, wherein the polypeptide consists of amino acid residues 1-470 of SEQ ID NO:1.

40. The mammalian expression vector of claim 25, wherein the immune response comprises a humoral immune response.

41. The mammalian expression vector of claim 25, wherein the immune response comprises a cellular immune response.

42. The mammalian expression vector of claim 25, wherein the immune response is directed against a *Streptococcus pneumoniae* pneumolysin protein

43. A mammalian expression vector comprising a promoter operably linked to a nucleotide sequence comprising a nucleic acid encoding a *Streptococcus pneumoniae* autolysin polypeptide, wherein the polypeptide comprises the amino acid sequence of SEQ ID NO:14 and elicits an immune response against *Streptococcus pneumoniae* when the expression vector is administered to a mammal.

44. The mammalian expression vector of claim 43, wherein the polypeptide consists of the amino acid sequence of SEQ ID NO:14.

45. The mammalian expression vector of claim 43, wherein the immune response comprises a humoral immune response.

46. The mammalian expression vector of claim 43, wherein the immune response comprises a cellular immune response.

47. A mammalian expression vector comprising a promoter operably linked to a nucleotide sequence comprising a nucleic acid encoding a *Streptococcus pneumoniae* pneumococcal surface protein A polypeptide, wherein the polypeptide comprises the amino acid sequence of SEQ ID NO:18 and elicits an immune response against *Streptococcus pneumoniae* when the expression vector is administered to a mammal.

48. The mammalian expression vector of claim 47, wherein the polypeptide consists of the amino acid sequence of SEQ ID NO:18.

49. The mammalian expression vector of claim 47, wherein the immune response comprises a humoral immune response.

50. The mammalian expression vector of claim 47, wherein the immune response comprises a cellular immune response.

51. An isolated polypeptide consisting of an amino acid sequence selected from the group consisting of amino acids 1-460 of SEQ ID NO:1, amino acids 1-464 of SEQ ID NO:1, amino acids 1-466 of SEQ ID NO:1, and amino acids 1-469 of SEQ ID NO:1.

52. A composition of claim 1 for use in inducing an immune response against *Streptococcus pneumoniae* in the mammal.

53. The composition of claim 52, wherein the immune response is a prophylactic immune response.

54. The composition of claim 52, wherein the immune response is a therapeutic immune response.

55. The composition of claim 52, wherein the immune response is cross-reactive against at least one *Streptococcus pneumoniae* serotype that differs from the serotype of the capsular polysaccharide present in the composition.

56. The composition of claim 55, wherein the capsular polysaccharide is serotype 7.

57. The composition of claim 55, wherein the capsular polysaccharide is serotype 6B.

58. The composition of claim 55, wherein the capsular polysaccharide is serotype 18C.

59. The composition of claim 55, wherein the capsular polysaccharide is serotype 23F.

60. The composition of claim 52, wherein the immune response is cross-reactive against at least one non-*Streptococcus pneumoniae* member of the *Streptococcus* genus.

61. A mammalian expression vector of claim 25 for use in inducing an immune response against *Streptococcus pneumoniae* in the mammal.

62. The mammalian expression vector of claim 61, wherein the immune response is cross-reactive against at least one non-*Streptococcus pneumoniae* member of the *Streptococcus* genus.

63. A mammalian expression vector of claim 43 for use in inducing an immune response against *Streptococcus pneumoniae* in the mammal.

64. The mammalian expression vector of claim 63, wherein the immune response is cross-reactive against at least one non-*Streptococcus pneumoniae* member of the *Streptococcus* genus.

65. A mammalian expression vector of claim 47 for use in inducing an immune response against *Streptococcus pneumoniae* in the mammal.

66. The mammalian expression vector of claim 65, wherein the immune response is cross-reactive against at least one non-*Streptococcus pneumoniae* member of the *Streptococcus* genus.

67. A mammalian expression vector comprising a promoter operably linked to a nucleotide sequence comprising a nucleic acid encoding a *Streptococcus pneumoniae* pneumolysin polypeptide or antigenic fragment thereof; and

a purified pneumolysin polypeptide or antigenic fragment thereof, for use in combination in eliciting an immune response against *Streptococcus pneumoniae* pneumolysin in the mammal,

wherein the *Streptococcus pneumoniae* pneumolysin protein contains the amino acid sequence of SEQ ID NO:1.

68. The mammalian expression vector and a purified pneumolysin polypeptide of claim 67, wherein at least two separate doses of the expression vector are used.

69. The mammalian expression vector and a purified pneumolysin polypeptide of claim 67, wherein the pneumolysin polypeptide or antigenic fragment thereof is administered at least one week after the administration of the expression vector.

70. A composition comprising an isolated polypeptide conjugated to a non-*Streptococcus pneumoniae* bacterial polysaccharide, wherein the polypeptide comprises a fragment of at least 400 contiguous amino acids of a *Streptococcus pneumoniae* pneumolysin protein, wherein the polypeptide lacks the amino acid sequence KVEND (SEQ ID NO:22), wherein the polypeptide lacks hemolytic activity, wherein the *Streptococcus pneumoniae* pneumolysin protein contains the amino acid sequence of SEQ ID NO:1, and wherein the composition elicits an immune response against the non-*Streptococcus pneumoniae* bacterium when administered to a mammal.

71. The composition of claim 70, wherein the non-*Streptococcus pneumoniae* bacterium is selected from the group consisting of pneumococcus, haemophilus influenza type b, meningococcal group A, B or C, and group B streptococcus type Ia, Ib, II, III, V or VIII.

72. A composition of claim 70 for use in inducing an immune response against the non-*Streptococcus pneumoniae* bacterium in the mammal.

73. The composition of claim 72, wherein the non-*Streptococcus pneumoniae* bacterium is selected from the group consisting of pneumococcus, haemophilus influenza type b, meningococcal group A, B or C, and group B streptococcus type Ia, Ib, II, III, V or VIII.

74. A purified antibody that binds to the composition of claim 1.

75. A purified antibody of claim 74 for use in the treatment of or preventing *Streptococcus pneumoniae* infection in a mammal.