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(71) Applicant *(for all designated States except US)*: **THE UAB RESEARCH FOUNDATION** [US/US]; 1530 3rd Avenue South, AB 770G, Birmingham, AL 35294 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **BRILES, David E.** [US/US]; 760 Linwood Road, Birmingham, AL 35222 (US). **HOLLINGSHEAD, Susan K.** [US/US]; 1008 32nd Street South, Birmingham, AL 35205 (US).

(74) Agents: **MCKEON, Tina Williams** et al.; Fish & Richardson P.C., P.O. Box 1022, 3300 Dain Rauscher Plaza, Minneapolis, MN 55440-1022 (US).

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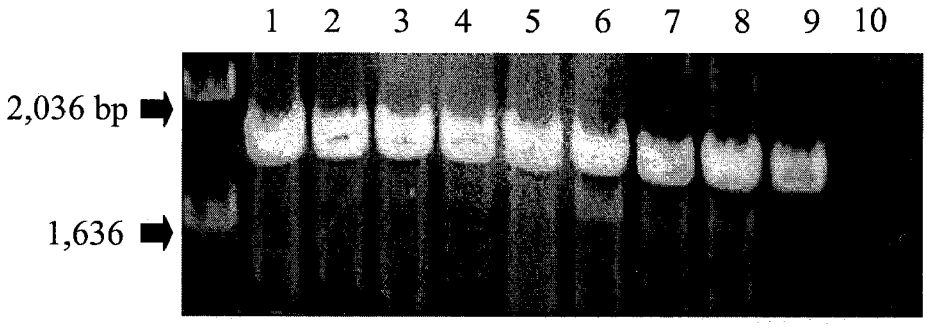

(57) Abstract: Compositions and methods for eliciting an immune response against Streptococcus pneumoniae are described. More particularly, the present disclosure relates to immunogenic PcpA polypeptides, including fragments of PcpA and variants thereof, and nucleic acids that encode the polypeptides. The present disclosure further relates to methods of making and using the immunogenic polypeptides. Further provided is a method of diagnosing pneumococcal infection (e.g., pneumonia) in a subject by obtaining a biological sample from the subject and detecting one or more pneumococcal antigens that are selectively expressed during invasion (e.g., PcpA or fragments thereof).

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DIAGNOSING PNEUMOCOCCAL PNEUMONIA

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to U.S. Serial No. 60/822,715, filed August 17, 2006; U.S. Serial No. 60/827,348, filed September 28, 2006; and U.S. Serial No. 60/917,178, filed May 10, 2007, which are incorporated by reference herein in their entireties.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

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BACKGROUND

Streptococcus pneumoniae is a rather ubiquitous human pathogen, which can infect several organs including lungs, the central nervous system (CNS), the middle ear, and the nasal tract. Infection results in various symptoms such as bronchitis, pneumonia, meningitis, sinus infection, and sepsis. *S. pneumoniae* is a major cause of bacterial meningitis in humans and is associated with significant mortality and morbidity despite antibiotic treatment (Quagliarello et al., (1992) N. Eng. J. Med. 327: 864-872).

There are two currently available pneumococcal vaccines. One is a vaccine for adults composed of 23 different capsular polysaccharides, which together represent the capsular types of about 90% of strains causing pneumococcal infection. This vaccine, however, is not immunogenic in children, an age group with high susceptibility to pneumococcal infection. In adults the vaccine has been shown to be about 60% efficacious against bacteremic pneumonia, but it is less efficacious in adults at higher risk of pneumococcal infection because of age or underlying medical conditions (Fedson, and Musher. 2004. "Pneumococcal Polysaccharide Vaccine," pp. 529-588. In *Vaccines*. S. A. Plotkin and W. A. Orenstein (eds.), W. B. Saunders and Co., Philadelphia, PA; Shapiro et al., *N. Engl. J. Med.* 325:1453-1460 (1991)). This vaccine has not been shown to be effective against non-bacteremic pneumococcal pneumonia, the most common form of infection.

The second available vaccine is a 7-valent conjugate vaccine that is efficacious against bacteremic pneumococcal infections in children less than 2 years of age. It has also demonstrated efficacy against pneumonia (Black et al., *Pediatr. Infect. Dis.* 21:810-5 (2002); Black et al., *Arch. Pediatr.* 11(7):843-53 (2004)). The production of this vaccine is complicated because of the need to produce 7 different conjugates, which leads to the vaccine being expensive (about $200/child). Moreover, the vaccine does not do a good job of covering infections in the developing world where non-vaccine types of *Streptococcus pneumoniae* are very common (Di Fabio et al., *Pediatr. Infect. Dis. J.* 20:959-967 (2001); Mulholland, *Trop. Med. Int. Health* 10:497-500 (2005)). This vaccine does not work as well against otitis media and colonization as it does against invasive disease. It has also been shown that the use of the 7-valent conjugate vaccine has led to an increase in colonization and disease with strains of capsule types not represented by the 7 polysaccharides included in the vaccine (Bogaert et al., *Lancet Infect. Dis.* 4:144-154 (2004); Eskola et al., *N. Engl. J. Med.* 344:403-409 (2001); Mbelle et al., *J. Infect. Dis.* 180:1171-1176 (1999)). Therefore, a need remains for effective treatments for *Streptococcus pneumoniae*. There are also limited diagnostic assays available for *Streptococcus pneumonoiae*.

The standard procedure for diagnosing pneumonia is based on clinical presentation, pulmonary consolidation seen by X-ray and a positive blood culture for *Streptococcus pneumoniae*. Unfortunately this method misses between 75 and 85 percent of patients with pneumococcal pneumonia because many subject have no pneumococci in their blood. An antigen detection assay that detects a cell wall polysaccharide is more sensitive but unfortunately leads to many false positives because pneumococci can be present in the nasal passages of subjects without being present in their lungs or blood.

SUMMARY

Compositions and methods for diagnosing *Streptococcus pneumoniae* are described. More particularly, the present disclosure relates to antigenic PcpA polypeptides, including fragments of PcpA and variants thereof, and nucleic acids that encode the polypeptides. The present disclosure further relates to methods of making and using the antigenic polypeptides of any pneumococcal antigen that is produced

during invasive disease but not during nasal colonization. Further provided is a method of diagnosing pneumococcal infection (e.g., pneumonia) in a subject by obtaining a biological sample from the subject and detecting one or more pneumococcal antigens that are selectively expressed during invasion (e.g., PcpA or fragments thereof). These compositions and methods offer improved efficacy and efficiency and reduced cost as compared to presently available compositions and methods designed to diagnose pneumococcal infection.

DESCRIPTION OF DRAWINGS

Figure1 shows PCR confirmation of *pcpA*. PCR analysis of genomic DNA of various *S. pneumoniae* strains. Primer pair (BGP1 (SEQ ID NO:45) and BGP2 (SEQ ID NO:46)) were used to amplify the nucleic acid encoding the N-terminal portion of PcpA (including the LRR region). Lane1, TIGR4; Lane 2, L82013; Lane 3, D1091B; Lane 4, BG12730; Lane 5, TJ0893; Lane 6, R6; Lane 7, BG10752; Lane 8, V175; Lane 9, EF3030; Lane 10, negative control (no template DNA).

Figure 2 shows Western blot analysis of PcpA presence under low Mn2+ conditions. Bacteria were cultured in low Mn2+ medium until mid-log phase and total cellular protein samples prepared. Samples were separated by SDS-PAGE, transferred to nitrocellulose and probe with a rPcpA polyclonal antiserum. Lane 1, JEN11 (*pcpA*- mutant); Lane 2, JEN7 (*pcpA* constitutive mutant); Lane 3, D1091B; Lane 4, EF5668; Lane 5, BG10752; Lane 6, V175; Lane 7, L82013; Lane 8, BG12730; Lane 9, TJ0893.

Figure 3 shows that protection against lung infection but not against nasal colonization conferred by rPcpA immunization compared to adjuvant alone was statistically significant in a murine model of pneumonia. CBA/N mice were subcutaneously immunized with rPcpA adsorbed to aluminum hydroxide or aluminum hydroxide alone. Mice were challenged intranasally under light anesthesia, with $5x10^6$ CFUs of EF3030. Mice were sacrificed 7 days post-infection and bacterial counts determined from lung homogenates (Figure 3A) and nasal washes (Figure 3B). Horizontal line denotes median Log10CFUs. (**:p=0.0019, Mann-Whitney).

Figure 4 shows that protection conferred against other *S. pneumoniae* capsular serotypes by rPcpA immunization versus adjuvant alone was statistically significant in

a murine model of pneumonia. Mice were challenged with strains (Figure 4A) TJ0893, serotype 14 (**:p=0.0209); (Figure 4B) L82016, serotype 6B (**:p=0.0193); or (Figure 4C) EF9303, serotype 23F (**:p=0.0388, Mann-Whitney). Horizontal line denotes median Log10CFUs.

Figure 5 shows the lack of an effect of *pcpA* inactivation on intranasal colonization of *S. pneumoniae*. Mice were challenged intranasally with 10^6 CFUs of EF3030 or its derivative JEN18. Mice were sacrificed 7 days post-infection and bacterial counts determined from nasal washes. Horizontal line denotes median Log10CFUs/Nose.

Figure 6 shows that protection conferred by rPcpA immunization versus adjuvant alone was statistically significant in a murine model of fatal sepsis. CBA/N mice were subcutaneously immunized with rPcpA adsorbed to aluminum hydroxide or aluminum hydroxide alone. Mice were challenged intravenously with 300 CFUs of TIGR4 and survival time was monitored for 21 days. Horizontal line denotes median survival time. (**:*P*=0.0067, Mann-Whitney). Surviving mice were euthanized and, upon examination, none had detectable *S. pneumoniae* in their blood.

Figure 7 shows virulence of TIGR4 and its *pcpA* inactivated derivative JEN11 in a murine model of sepsis. Mice were challenged intravenously with 300 CFUs of TIGR4 or JEN11 and survival time was monitored for 21 days. Horizontal line denotes median survival time. (**:*P*=0.0299, Mann-Whitney).

Figure 8 shows that protection was conferred by rPcpA mucosal immunization compared to adjuvant alone in a murine model of pneumonia. CBA/N mice were intranasally immunized with rPcpA and cholera toxin B subunit (CTB) or CTB alone. Mice were challenged intranasally under light anesthesia, with $5x10^6$ CFUs of EF3030. Mice were sacrificed 7 days post-infection and bacterial counts in the homogenized lungs were determined. Horizontal line denotes median Log10CFUs. (*:*P*=0.0001, Mann-Whitney).

Figure 9 shows adherence of *pcpA*+ and *pcpA*- TIGR4 strains (TIGR4 and JEN11, respectively) to human lung epithelial cells. A549 human lung epithelial cell monolayers were incubated for 150 minutes with 10^6 CFU of *pcpA*+ and *pcpA*- TIGR4 strains that had been grown under high manganese (High Mn^{2+}) or low manganese (Low Mn^{2+}) growth conditions. The epithelial cells were washed and

lysed. Numbers of adherent pneumococci in each lysate were determined by quantitative plating on blood agar plates. Log10 CFU recovered refers to the number of pneumococci associated with the lung epithelial cells at the end of the experiment. (**:*P*=0.0022, Mann-Whitney).

Figure 10 shows *pcpA*+ and *pcpA*- TIGR4 strains did not adhere to human nasal epithelial cells. Detroit562 human nasal epithelial cell monolayers were incubated for 150 minutes with 10^6 CFU of *pcpA*+ and *pcpA*- TIGR4 strains that had been grown under high manganese (High Mn^{2+}) or low manganese (Low Mn^{2+}) growth conditions. The cells were then washed and lysed. Numbers of pneumococci in the lysate were determined by quantitative plating on blood agar plates. Log10 CFU recovered refers to the number of pneumococci at the end of the experiment.

Figure 11 shows inhibition of adherence of pneumococci to A549 cells by an antibody to PcpA. A549 human lung epithelial cell monolayers were incubated with 10^6 CFU of *pcpA*+ and *pcpA*- TIGR4 strains grown in high manganese (High Mn^{2+}) or low manganese (Low Mn^{2+}) without antibody, with 1/100 dilution, or with 1/50 dilution of PcpA antibody. The cells were washed and lysed. Numbers of pneumococci in the lysate were determined by quantitative plating on blood agar plates.

Figure 12 shows protection against sepsis using rabbit sera to PcpA. Rabbit serum was prepared by immunizing a rabbit with 100 μg rPcpA in complete Freund's adjuvant followed two and four weeks later by 100 μg rPcpA in complete Freund's adjuvant. Sera was collected two weeks after the final boost and was shown to contain antibody to PcpA by dot blot assay. Pre-immune sera was also collected before the start of the immunizations. Mice were tested in groups of two for the ability of dilutions of the rabbit anti-sera to protect against fatal pneumococcal infection. Three groups of mice received 0.1 mL of 1/10, 1/100 or 1/1000 dilutions of the immune sera intraperitoneally one hour prior to i.v. challenge with TIGR4. Two mice received 1/10 pre-immune (non-immune) rabbit serum and two mice received the diluent, PBS, only. Mice were observed for 500 hours or until time of death. The two mice receiving 1/10 immune sera lived throughout the experiment. All other mice died between 40 and 60 hours post challenge.

Figure 13 shows protection against lung infection with PcpA and pneumolysin (Ply). Mice were immunized three times with 5 μg of rPcpA, 5 μg of pneumolysin (Ply), or 5 μg of rPcpA plus 5 μg Ply. The first two injections were with alum and the third injection was with protein alone. The Ply used was wild-type Ply. Mice were anethesized with isoflurane (MinRAD, Buffalo, NY) and challenged i.n. with $5x10^6$ CFU of capsular type 19F strain EF3030 in 40 μL volume. This procedure results in lung infection and nasal colonization. Seven days later mice were sacrificed and homogenized lungs were plated. The CFU observed indicated that immunization with either PcpA or Ply resulted in similar levels of protection. Mice immunized with PcpA and Ply resulted in over 100-fold more protection than control mice and 10 times more protection than Ply or PcpA alone.

DETAILED DESCRIPTION

Immunogenic fragments and variants of PcpA are described herein along with methods of making and using the fragments and variants. PcpA, which was initially identified as a choline binding protein (CBP) of *Streptococcus pneumoniae*, differs from the CBP proteins PspA and PspC (Sanchez-Beato et al., *FEMS Microbiol. Lett.* 164:207-214 (1998)), and mutations in *pcpA* have been shown to cause (1) reduced virulence in the lung, in bacteremia, and in the nasopharynx of mice in competition models in which a mutant strain and a wild type strain are allowed to compete (Hava and Camilli, *Mol. Microbiol.* 45:1389-1406 (2002)); (2) reduced virulence and bacterial load in a non-competition comparison of lung sepsis (Johnston et al., *Infect. Immun.* 74:1171-1180 (2006)); (3) reduced ability of the invasive strain TIGR4 (capsular type 4) *S. pneumoniae* to cause sepsis in CBA/CaHN-Btkxid/J mice; and (4) reduced lung colonization in competition with wild type strains. The present disclosure provides the first evidence that PcpA is immunogenic and, in particular, that fragments and variants of PcpA are immunogenic. The present disclosure also provides the first evidence that PcpA is import for invasion of *S. pneumoniae* into the lung (i.e., lung infection) but not for colonization of *S. pneumoniae* in nasal passages.

Immunogenic polypeptides comprise the full-length PcpA amino acid sequence (in the presence or absence of the signal sequence), fragments thereof, and variants thereof. Full-length PcpA includes GenBank Accession No. CAB04758 from

Streptococcus pneumoniae strain B6, GenBank Accession No. NP_346554 from *S. pneumoniae* strain TIGR4 and GenBank Accession No. NP_359536 from *S. pneumoniae* strain R6.

Optionally, immunogenic polypeptides of PcpA comprise one or more leucine rich regions (LRRs). These LLRs are present in naturally occurring PcpA or have about 60 to about 99% sequence identity, including, for example, 80%, 85%, 90% or 95% sequence identity to the naturally occurring LRRs. LRRs in the mature PcpA protein (i.e., the protein lacking the signal peptide) can be found within SEQ ID NOs:1, 2, or 41.

An immunogenic polypeptide of PcpA optionally lacks the choline binding anchor sequence typically present in the naturally occurring mature PcpA protein. The naturally occurring sequence of the choline binding anchor is SEQ ID NO:47 of the mature PcpA protein. More particularly, an immunogenic polypeptide comprises an N-terminal region of naturally occurring PcpA with one or more amino acid substitutions and about 60 to about 99% sequence identity or any identity in between, e.g., 80, 85, 90 and 95% identity, to the naturally occurring PcpA. The N-terminal region may comprise the amino acid sequence of SEQ ID NOs:1, 2, 3, 4, or 41, in the presence or absence of one or more conservative amino acid substitutions and in the presence or absence of the signal sequence. The N-terminal region may comprise an amino acid sequence having about 60 to about 99% sequence identity (or any identity in between 80 to 99% identity) to SEQ ID NOs:1, 2, 3, 4, or 41.

Immunogenic fragments of SEQ ID NOs:1, 2, 3, 4, or 41 comprise 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190 and 191 amino acid residues of SEQ ID NOs:1, 2, 3, 4, or 41 or any number of amino acid residues between 5 and 191. Examples of such fragments include, by way of example, amino acids comprising LEKIEDRAFD (SEQ ID NO:5), FSELEEIELP (SEQ ID NO:6), ASLEYIGTSA (SEQ ID NO:7), FSFSQKLKKL (SEQ ID NO:8), TFSSSSKLEL (SEQ ID NO:9), ISHEAFANLS (SEQ ID NO:10), NLEKLTLPKS (SEQ ID NO:11), VKTLGSNLFR (SEQ ID NO:12), LTTSLNMLML (SEQ ID NO:13), LTTSLKHVDV (SEQ ID NO:14), RGMIVASVDG (SEQ ID NO:15), EEGNESFASVDG (SEQ ID NO:16), VSFQSKTQLI (SEQ ID NO:17), VLFSKDKTQLI (SEQ ID NO:18), YYPSQKNDES (SEQ ID NO:19),

YKTPKETKEL (SEQ ID NO:20), ASYSFNKNSY (SEQ ID NO:21), LKKLELNEGL (SEQ ID NO:22), QKIGTFAFAD (SEQ ID NO:23), EKIGTFAFAD(SEQ ID NO:24), ATKLEEISLP(SEQ ID NO:25), AIKLEEISLP(SEQ ID NO:26), NSLETIERLA (SEQ ID NO:27), FYGNLELKELIL (SEQ ID NO:28).

Optionally, immunogenic polypeptides of PcpA lack the LRRs. Examples of immunogenic polypeptides lacking the LRR include SEQ ID NO:29, SEQ ID NO:30, and SEQ ID NO:31 or any immunogenic fragment of either SEQ ID NOs:29, 30 or 31 comprising 5 or more amino acid residues. SEQ ID NOs:30 and 31 comprise the residues C-terminal to the leucine-rich region of PcpA.

Variants of the immunogenic polypeptides described herein may comprise one or more conservative amino acid substitutions. Variants of the immunogenic polypeptides include amino acid sequence having about 60 to about 99% sequence identity (or any identity in between 60 and 99% identity) to SEQ ID NOs:1 to 31, and 41 or any fragment thereof. Variants are selected for their immunogenic capacity using methods taught herein.

The immunogenic polypeptides of PcpA described herein include fragments of PcpA and variants of such fragments. Variants of PcpA fragments may comprise amino acid sequence modifications. For example, amino acid sequence modifications include substitutional, insertional or deletional changes. Substitutions, deletions, insertions or any combination thereof may be combined in a single variant so long as the variant is an immunogenic polypeptide. Insertions include amino and/or carboxyl terminal fusions as well as intrasequence insertions of single or multiple amino acid residues. Insertions ordinarily will be smaller insertions than those of amino or carboxyl terminal fusions, for example, on the order of one to four residues. Deletions are characterized by the removal of one or more amino acid residues from the protein sequence. Typically, no more than about from 2 to 6 residues are deleted at any one site within the protein molecule. These variants ordinarily are prepared by site specific mutagenesis of nucleotides in the DNA encoding the protein, thereby producing DNA encoding the variant, and thereafter expressing the DNA in recombinant cell culture. Techniques for making substitution mutations at predetermined sites in DNA having a known sequence are well known and include, but are not limited to, M13 primer mutagenesis and PCR mutagenesis. Amino acid

substitutions are typically of single residues but can occur at a number of different locations at once. Substitutional variants are those in which at least one residue has been removed and a different residue inserted in its place. Such substitutions generally are made in accordance with the following Table 1 and are referred to as conservative substitutions. However, others are well known to those of skill in the art.

Table 1. Conservative Amino Acid Substitutions

Original Residue	Exemplary Substitutions	Original Residue	Exemplary Substitutions
Arg	Lys	Leu	Ile, Val
Asn	Gln	Lys	Arg, Gln
Asp	Glu	Met	Leu, Ile
Cys	Ser	Phe	Met, Leu, Tyr
Gln	Asn	Ser	Thr
Glu	Asp	Thr	Ser
Gly	Pro	Trp	Tyr
His	Gln	Tyr	Trp, Phe
Ile	Leu, Val	Val	Ile, Leu

Variants as used herein may also include naturally occurring *pcpA* alleles from alternate strains that exhibit polymorphisms at one or more sites within the homologous *pcpA* gene. Variants can be produced by conventional molecular biology techniques. The variants are described herein relative to sequence identity as compared to the naturally occurring *pcpA*. Those of skill in the art readily understand how to determine the sequence identity of two polypeptides or nucleic acids. For example, the sequence identity can be calculated after aligning the two sequences so that the identity is at its highest level. Alignments are dependent to some extent upon the use of the specific algorithm in alignment programs. This could include, for example, the local homology algorithm of Smith and Waterman *Adv. Appl. Math.* 2: 482 (1981), the homology alignment algorithm of Needleman and Wunsch, *J. MoL Biol.* 48: 443 (1970), by the search for similarity method of Pearson and Lipman, *PNAS USA* 85: 2444 (1988), by computerized implementations of these algorithms (GAP, BESTFIT, FASTA, and TFASTA in the Wisconsin Genetics Software Package,

Genetics Computer Group, 575 Science Dr., Madison, WI), BLAST and BLAST 2.0 and algorithms described by Altschul et al., *Nucleic Acids Res.* 25:3389-3402, 1977; Altschul, et al., *J. Mol. Biol.* 215:403-410, 1990; Zuker, M. *Science* 244:48-52, 1989; Jaeger et al. *PNAS USA* 86:7706-7710, 1989 and Jaeger et al. *Methods Enzymol.* 183:281-306, 1989. Each of these references is incorporated by reference at least for the material related to alignment and calculation of identity. It is understood that any of the methods typically can be used and that in certain instances the results of these various methods may differ. Where sequence identity is provided as, for example, 95%, then such identity must be detectable with at least one of the accepted methods of calculation.

The immunogenic polypeptides described herein can include one or more amino acid analogs or non-naturally occurring stereoisomers. These amino acid analogs and stereoisomers can readily be incorporated into polypeptide chains by charging tRNA molecules with the amino acid of choice and engineering genetic constructs that utilize, for example, amber codons, to insert the analog amino acid into a peptide chain in a site specific way (Thorson et al., *Methods in Molec. Biol.* 77:43-73 (1991), Zoller, *Current Opinion in Biotechnology*, 3:348-354 (1992); Ibba, *Biotechnology & Genetic Engineering Reviews* 13:197-216 (1995), Cahill et al., *TIBS*, 14(10):400-403 (1989); Benner, *TIB Tech*, 12:158-163 (1994); Ibba and Hennecke, *Bio/technology*, 12:678-682 (1994) all of which are herein incorporated by reference at least for material related to amino acid analogs). Immunogenic fragments can be produced that resemble peptides but which are not connected via a natural peptide linkage. For example, linkages for amino acids or amino acid analogs can include CH2NH--, --CH2S--, --CH2--CH2--, --CH=CH-- (cis and trans), --COCH2--, --CH(OH)CH2--, and --CHH2SO-- (These and others can be found in Spatola, A. F. "Peptide backbone modifications: A structure-activity analysis of peptides containing amide bond surrogates, conformational constraints, and related backbone modifications." In *Chemistry and Biochemistry of Amino Acids, Peptides, and Proteins*, pp. 267-357. Weinstein, B. editor, Marcel Dekker, New York, N.Y. (1983); Morley, *Trends in Pharm. Sci.* 1(2):463-468 (1980); Hudson, et al., *Int J Pept Prot Res* 14:177-185 (1979) (--CH2NH--, CH2CH2--); Spatola et al. *Life Sci* 38:1243-1249 (1986) (--CH H2--S); Hann, *Journal of the Chemical Society: Perkin Transactions 1*

pp.307-314 (1982) (--CH--CH--, cis and trans); Almquist et al., *J. Med. Chem.* 23:1392-1398 (1980) (--COCH2--); Jennings-White et al., *Tetrahedron Lett* 23:2533 (1982) (--COCH2--); European Publication No. EP0045665 to Szelke, et al. (1982) (--CH(OH)CH2--); Holladay et al., *Tetrahedron. Lett* 24:4401-4404 (1983) (--C(OH)CH2--); and Hruby *Life Sci* 31:189-199 (1982) (--CH2--S--); each of which is incorporated herein by reference at least for the material regarding linkages).

Amino acid analogs and stereoisomers often have enhanced or desirable properties, such as, more economical production, greater chemical stability, enhanced pharmacological properties (half-life, absorption, potency, efficacy, etc.), altered specificity (e.g., a broad-spectrum of biological activities), and others. For example, D-amino acids can be used to generate more stable peptides, because D amino acids are not recognized by naturally occurring peptidases. Systematic substitution of one or more amino acids of a consensus sequence with a D-amino acid of the same type (e.g., D-lysine in place of L-lysine) can be used to generate more stable peptides. Cysteine residues can be used to cyclize or attach two or more peptides together. This can be beneficial to constrain peptides into particular conformations. (Rizo and Gierasch *Ann. Rev. Biochem.* 61:387 (1992), incorporated herein by reference).

A composition comprising an immunogenic polypeptide of PcpA and a pharmaceutically acceptable carrier are described herein. Optionally, the composition further comprises an adjuvant. Compositions comprising the immunogenic polypeptide may contain combinations of other immunogenic polypeptides, including, for example, an immunogenic *Staphylococcus* polypeptide or immunogenic fragments of PspA, NanA, PsaA, pneumolysin, PspC, PotD or any combination thereof.

Optionally, the compositions described herein are suitable for administration to a mucosal surface. The composition can be a nasal spray, a nebulizer solution, or an aerosol inhalant, for example. Thus the composition may be present in a container and the container may be a nasal sprayer, a nebulizer, or an inhaler.

By pharmaceutically acceptable carrier is meant a material that is not biologically or otherwise undesirable, i.e., the material may be administered to a subject, along with the immunogenic fragment of PcpA, without causing any undesirable biological effects or interacting in a deleterious manner with any of the other components of the pharmaceutical composition in which it is contained. The

carrier would naturally be selected to minimize any degradation of the active ingredient and to minimize any adverse side effects in the subject, as would be well known to one of skill in the art.

Suitable carriers and their formulations are described in *Remington: The Science and Practice of Pharmacy, 21st Edition*, David B. Troy, ed., Lippicott Williams & Wilkins (2005). Typically, an appropriate amount of a pharmaceutically-acceptable salt is used in the formulation to render the formulation isotonic. Examples of the pharmaceutically-acceptable carriers include, but are not limited to, sterile water, saline, buffered solutions like Ringer's solution, and dextrose solution. The pH of the solution is generally from about 5 to about 8 or from about 7 to about 7.5. Other carriers include sustained release preparations such as semipermeable matrices of solid hydrophobic polymers containing the immunogenic PcpA polypeptides. Matrices are in the form of shaped articles, e.g., films, liposomes or microparticles. It will be apparent to those persons skilled in the art that certain carriers may be more preferable depending upon, for instance, the route of administration and concentration of composition being administered. Carriers are those suitable for administration of the PcpA immunogenic fragments to humans or other subjects.

Pharmaceutical compositions may include carriers, thickeners, diluents, buffers, preservatives, surface active agents, adjuvants, immunostimulants, in addition to the immunogenic polypeptide. Pharmaceutical compositions may also include one or more active ingredients such as antimicrobial agents, anti-inflammatory agents and anesthetics.

Adjuvants include metallic salts, such as aluminium salts, and are well known in the art as providing a safe excipient with adjuvant activity. The mechanism of action of these adjuvants are thought to include the formation of an antigen depot such that antigen may stay at the site of injection for up to 3 weeks after administration, and also the formation of antigen/metallic salt complexes which are more easily taken up by antigen presenting cells. In addition to aluminium, other metallic salts have been used to adsorb antigens, including salts of zinc, calcium, cerium, chromium, iron, and berilium. The hydroxide and phosphate salts of aluminium are the most common. Formulations or compositions containing aluminium salts, antigen, and an

additional immunostimulant are known in the art. An example of an immunostimulant is 3-de-O-acylated monophosphoryl lipid A (3D-MPL).

The adjuvant and/or immunostimulant can be administered concomitantly with the polypeptide composition, immediately prior to, or after administration of the composition. Optionally, the composition further comprises the adjuvant. Adjuvant formulations include, for example, an agent that targets mucosal inductive sites. The adjuvant may optionally be selected from the group including, but not limited to, cytokines, chemokines, growth factors, angiogenic factors, apoptosis inhibitors, and combinations thereof. When a cytokine is chosen as an adjuvant, the cytokine may be selected from the group including, but not limited to, interleukins including IL-1, IL-3, IL-2, IL-5, IL-6,IL-12, IL-15 and IL-18; transforming growth factor-beta (TGF-β); granulocyte macrophage colony stimulating factor (GM-CSF); interferon-gamma(IFN-γ); or any other cytokine that has adjuvant activity. Portions of cytokines, or mutants or mimics of cytokines (or combinations thereof), having adjuvant activity or other biological activity can also be used in the compositions and methods of the present invention.

When a chemokine is chosen as an adjuvant, the chemokine may optionally be selected from a group including, but not limited to, Lymphotactin, RANTES, LARC, PARC, MDC, TAR C, SLC and FKN. When an apoptosis inhibitor is chosen as an adjuvant, the apoptosis inhibitor may optionally be selected from the group including, but not limited to, inhibitors of caspase-8, and combinations thereof. When an angiogenic factor is chosen as an adjuvant, the angiogenic factor may optionally be selected from the group including, but not limited to, a basic fibroblast growth factor (FGF), a vascular endothelial growth factor (VEGF), a hyaluronan (HA) fragment, and combinations thereof.

Other examples of substantially non-toxic, biologically active adjuvants include hormones, enzymes, growth factors, or biologically active portions thereof. Such hormones, enzymes, growth factors, or biologically active portions thereof can be of human, bovine, porcine, ovine, canine, feline, equine, or avian origin, for example, and can be tumor necrosis factor (TNF), prolactin, epidermal growth factor (EGF), granulocyte colony stimulating factor (GCSF), insulin-like growth factor

(IGF-1), somatotropin (growth hormone) or insulin, or any other hormone or growth factor whose receptor is expressed on cells of the immune system.

Adjuvants also include bacterial toxins, e.g., the cholera toxin (CT), the *E. coli* heat-labile toxin (LT), the *Clostridium difficile* toxin A and the pertussis toxin (PT), or combinations, subunits, toxoids, chimera, or mutants thereof. For example, a purified preparation of native cholera toxin subunit B (CTB) can be used. Fragments, homologs, derivatives, and fusions to any of these toxins are also suitable, provided that they retain adjuvant activity. Suitable mutants or variants of adjuvants are described, e.g., in WO 95/17211 (Arg-7- Lys CT mutant), WO 96/6627 (Arg-192-Gly LT mutant), and WO 95/34323 (Arg-9-Lys and Glu-129-Gly PT mutant). Additional LT mutants that can be used in the methods and compositions include, e. g., Ser-63-Lys, Ala-69-Gly,Glu-110-Asp, andGlu-112-Asp mutants. Other adjuvants, such as RH3-ligand; CpG-motif oligonucleotide; a bacterial monophosphoryl lipid A(MPLA) of, e. g., *E. coli*, *Salmonella minnesota, Salmonella typhimurium*, or *Shigella exseri*; saponins (e. g., QS21), or polylactide glycolide (PLGA) microspheres, can also be used. Possible other adjuvants are defensins and CpG motifs.

Provided are methods of making and using the immunogenic polypeptides described herein and compositions useful in such methods. The polypeptides can be generated using standard molecular biology techniques and expression systems. (See, for example, *Molecular Cloning: A Laboratory Manual, Third Edition* by Sambrook et al., Cold Spring Harbor Press, 2001). For example, a fragment of the *pcpA* gene that encodes an immunogenic polypeptide may be isolated and the polynucleotide encoding the immunogenic polypeptide may be cloned into any commercially available expression vector (such as pBR322 and pUC vectors (New England Biolabs, Inc., Ipswich, MA)) or expression/purification vectors (such as GST fusion vectors (Pfizer, Inc., Piscataway, N.J.)) and then expressed in a suitable prokaryotic, viral or eukaryotic host. Purification may then be achieved by conventional means or, in the case of a commercial expression/purification system, in accordance with a manufacturer's instructions.

Provided herein are nucleic acids comprising a sequence that encodes any one of SEQ ID NOs:1 to 31, and 41. Provided herein is a nucleic acid comprising SEQ ID NOs:32 and 33, which encode full length PcpA proteins or fragments thereof. Also

provided are degenerate variants and fragments of these degenerate variants of SEQ ID NOs:32 and 33.

Nucleic acids that encode SEQ ID NOs:1 and 2 or fragments thereof are described, including SEQ ID NO:34 and SEQ ID NO:35, respectively, or degenerate variants or fragments thereof.

Nucleic acids that encode SEQ ID NOs:3 and 4 or fragments thereof include, but are not limited to, SEQ ID NOs:36 and 37, respectively, or degenerate variants or fragments thereof.

Nucleic acids that encode SEQ ID NO:41 or fragments thereof are described, including SEQ ID NO:42 or degenerate variants or fragments thereof.

Exemplary nucleic acids that encode SEQ ID NO:29 or fragments thereof include SEQ ID NO:38 or degenerate variants or fragments thereof.

More specifically, provided herein is a nucleic acid comprising any one of the sequences designated as SEQ ID NOs:32 to 38, and 42 or degenerate variants thereof.

Also provided are isolated nucleic acids comprising a sequence that hybridizes under highly stringent conditions to all or any portion of a hybridization probe having a nucleotide sequence that comprises SEQ ID NOs:32 to 38, and 42 or the complement of SEQ ID NOs:32 to 38, and 42 or any fragment of the sequence or complement thereof. The hybridizing portion of the hybridizing nucleic acid is typically at least 15 (e.g., 15, 20, 25, 30, 40, or more) nucleotides in length. The hybridizing portion is at least 80% (e.g., 85%, 90% or 95%) identical to the a portion of the sequence to which it hybridizes. Hybridizing nucleic acids are useful, for example, as cloning probes, primers (e.g., PCR primer), or a diagnostic probe. Nucleic acid duplex or hybrid stability is expressed as the melting temperature or Tm, which is the temperature at which a probe dissociates from a target DNA. This melting temperature is used to define the required stringency conditions. If sequences are identified that are related and substantially identical to the probe, rather than identical, then it is useful to first establish the lowest temperature at which only homologous hybridization occurs with a particular concentration of salt (e.g., SSC or SSPE). Assuming that a 1% mismatching results in a 1°C decrease in Tm, the temperature of the final wash in the hybridization reaction is reduced accordingly (for example, if sequences having more than 95% identity are sought, the final wash

temperature is decreased by 5°C). In practice, the change in Tm can be between 0.5 and 1.5°C per 1% mismatch. Highly stringent conditions involve hybridizing at 68°C in 5X SSC/5X Denhardt's solution/1.0% SDS, and washing in 0.2X SSC/0.1% SDS at room temperature. Moderately stringent conditions include washing in 3X SSC at 42°C. Salt concentrations and temperatures can be varied to achieve the optimal level of identity between the probe and the target nucleic acid. Additional guidance regarding such conditions is readily available in the art, for example, in *Molecular Cloning: A Laboratory Manual, Third Edition* by Sambrook et al., Cold Spring Harbor Press, 2001.

Thus, it is understood that the nucleic acids that can encode the aforementioned peptide sequences, variants and fragments thereof are disclosed. This would include all degenerate sequences related to a specific protein sequence, i.e., all nucleic acids having a sequence that encodes one particular protein sequence as well as all nucleic acids, including degenerate nucleic acids, encoding the disclosed variants and derivatives of the protein sequences. Thus, while each particular nucleic acid sequence may not be written out herein, it is understood that each and every sequence is in fact disclosed and described herein through the disclosed protein sequence.

Also disclosed are vectors comprising the nucleic acids described herein. Thus, provided is a vector that comprises a nucleic acid that encodes an immunogenic polypeptide (e.g., SEQ ID NOs:1 to 31, or 41 or fragments or variants thereof). The vector can comprise any of the nucleic acid sequences SEQ ID NOs:32 to 38, and 42 or degenerate variants or fragments thereof. Optionally, the nucleic acid of the vector is operably linked to an expression control sequence (e.g., a promoter or enhancer or both). Suitable expression vectors are well known to those of skill in the art and commercially available from a variety of sources such as Novagen, Inc., Madison, WI; Invitrogen Corporation, Carlsbad, CA; and Promega Corporation, Madison, WI.

A cultured cell comprising the vector is also provided. The cultured cell can be a cultured cell transfected with the vector or a progeny of the cell, wherein the cell expresses the immunogenic polypeptide. Suitable cell lines are known to those of skill in the art and are commercially available, for example, through the American Type Culture Collection (ATCC).

The transfected cells can be used in a method of producing an immunogenic polypeptide. The method comprises culturing a cell comprising the vector under conditions that allow expression of the immunogenic polypeptide, optionally under the control of an expression sequence. The immunogenic polypeptide can be isolated from the cell or the culture medium using standard protein purification methods.

The immunogenic polypeptides can be made using standard enzymatic cleavage of larger polypeptides or proteins or can be generated by linking two or more peptides or polypeptides together by protein chemistry techniques. For example, peptides or polypeptides can be chemically synthesized using currently available laboratory equipment using either Fmoc (9-fluorenylmethyloxycarbonyl) or Boc (tert -butyloxycarbonoyl) chemistry. (Applied Biosystems, Inc., Foster City, CA). By peptide condensation reactions, native chemical ligation, solid phase chemistry, or enzymatic ligation, two fragments can be covalently joined via a peptide bond at their carboxyl and amino termini to form an immunogenic PcpA polypeptide. (*Synthetic Peptides: A User Guide.*, Grant, ed., W.H. Freeman and Co., New York, N.Y. (1992); *Principles of Peptide Synthesis.*, Bodansky and Trost, eds. Springer-Verlag Inc., New York, N.Y. (1993); Abrahmsen L et al., *Biochemistry*, 30:4151 (1991); Dawson et al. *Science*, 266:776-779 (1994); *Solid Phase Peptide Synthesis*, 2nd Edition, Stewart, ed., Pierce Chemical Company, Rockford, IL, (1984), all of which are incorporated herein by reference for the methods described therein).

The immunogenic polypeptides and compositions comprising one or more polypeptides may be used to generate antibodies. Thus, a method of generating antibodies specific to PcpA in a subject comprises administering to the subject a immunogenic PcpA fragment described herein. Also provided herein are antibodies that bind the PcpA polypeptides as well as antibody fragments that bind the PcpA polypeptides.

Antibodies may be polyclonal or monoclonal, may be fully human or humanized, and include naturally occurring antibodies and single-chain antibodies. Antibodies can be made *in vivo* by administering to a subject an immunogenic PcpA polypeptide. Antibody production includes making monoclonal antibodies using hybridoma methods. Hybridoma methods are well known in the art and are described by Kohler and Milstein, *Nature*, 256:495 (1975) and Harlow and Lane. *Antibodies, A*

Laboratory Manual. Cold Spring Harbor Publications, New York, (1988), which are incorporated by reference in their entirety for the methods described therein.

Methods for the production of single-chain antibodies are well known to those of skill in the art. See, for example, U.S. Pat. No. 5,359,046, (incorporated herein by reference in its entirety for such methods). A single chain antibody is created by fusing together the variable domains of the heavy and light chains using a short peptide linker, thereby reconstituting an antigen binding site on a single molecule. Single-chain antibody variable fragments (scFvs) in which the C-terminus of one variable domain is tethered to the N-terminus of the other variable domain via a 15 to 25 amino acid peptide or linker have been developed without significantly disrupting antigen binding or specificity of the binding. The linker is chosen to permit the heavy chain and light chain to bind together in their proper conformational orientation. See, for example, Huston, J. S., et al., *Methods in Enzym.* 203:46-121 (1991), which is incorporated herein by reference for its material regarding linkers.

Fully human and humanized antibodies to the PcpA polypeptides may be used in the methods described herein. Humanized antibodies include human immunoglobulins (recipient antibody) in which residues from a complementary determining region (CDR) of the recipient are replaced by residues from a CDR of a non-human species (donor antibody) such as mouse, rat or rabbit having the desired specificity, affinity and capacity. In some instances, Fv framework residues of the human immunoglobulin are replaced by corresponding non-human residues. Transgenic animals (e.g., mice) that are capable, upon immunization, of producing a full repertoire of human antibodies (i.e., fully human antibodies) may be employed. The homozygous deletion of the antibody heavy chain joining region (J(H)) gene in chimeric and germ-line mutant mice results in complete inhibition of endogenous antibody production. Transfer of the human germ-line immunoglobulin gene array in such germ-line mutant mice results in the production of human antibodies upon antigen challenge (see, e.g., Jakobovits et al., *PNAS USA*, 90:2551-255 (1993); Jakobovits et al., *Nature*, 362:255-258 (1993); Bruggemann et al., *Year in Immuno.*, 7:33 (1993)). Human antibodies can also be produced in phage display libraries (Hoogenboom et al., *J. Mol. Biol.*, 227:381 (1991); Marks et al., *J. Mol. Biol.*, 222:581 (1991)). The techniques of Cote et al. and Boerner et al. also describe

methods for the preparation of human monoclonal antibodies (Cole, et al., "The EBV-hybridoma technique and its application to human lung cancer." In, *Monoclonal Antibodies and Cancer Therapy*, Volume 27, Reisfeld and Sell, eds., pp. 77-96, Alan R. Liss, Inc., New York, N.Y., (1985); Boerner et al., *J. Immunol.*, 147(1):86-95 (1991)). These references are incorporated by reference in their entirety for the methods described therein.

Antibody fragment as used herein includes F(ab')2, Fab', and Fab fragments, including hybrid fragments. Such fragments of the antibodies retain the ability to bind a specific PcpA polypeptide. Methods can be used to construct (ab) expression libraries (see e.g., Huse, et al., 1989 *Science* 246: 1275-1281) to allow rapid and effective identification of monoclonal F(ab) fragments with the desired specificity for a PcpA polypeptide. Antibody fragments that contain the idiotypes to the polypeptide may be produced by techniques known in the art including, but not limited to: (i) an F(ab')2 fragment produced by pepsin digestion of an antibody molecule; (ii) an Fab fragment generated by reducing the disulfide bridges of an F(ab')2 fragment; (iii) an F(ab) fragment generated by the treatment of the antibody molecule with papain and a reducing agent and (iv) F(v) fragments.

Described herein is a method of reducing the risk of a pneumococcal infection in a subject comprising administering to the subject the immunogenic fragment of PcpA or a composition thereof. Pneumococcal infections include, for example, meningitis, otitis media, pneumonia, sepsis, or hemolytic uremia. Thus, the risk of any one or more of these infections are reduced by the methods described herein. The method can further comprise the step of administering a second immunogenic fragment. The second immunogenic fragment can be from PspA, NanA, PsaA, pneumolysin, PspC, or any combination thereof. The second immunogenic fragment can be administered at the same time, before or after the immunogenic fragment of PcpA.

The compositions comprising a PcpA polypeptide or fragments thereof may be administered orally, parenterally (e.g., intravenously), intramuscularly, intraperitoneally, transdermally or topically, including intranasal administration or administration to any part of the respiratory system. As used herein, administration to the respiratory system means delivery of the compositions into the nose and nasal

passages through one or both of the nares or through the mouth, including delivery by a spraying mechanism or droplet mechanism, through aerosolization or intubation.

The exact amount of the compositions and PcpA polypeptides or fragments required will vary from subject to subject, depending on the species, age, weight and general condition of the subject, the polypeptide used, and its mode of administration. Thus, it is not possible to specify an exact amount for every composition. However, an appropriate amount can be determined by one of ordinary skill in the art given the description herein. Furthermore, multiple doses of the PcpA polypeptide or fragment may be used including, for example, in a prime and boost regimen.

Combinations of PspA and pneumolysin are more efficacious that either protein alone at eliciting protective immunity against pneumonia and sepsis (Briles et al., *J. Infect. Immun.* 188:339-48 (2003); Ogunniyi et al., *Infect. Immun.* 68:3028-33 (2000)). Thus, the compositions comprising PcpA or immunogenic fragments can optionally comprise a second immunogenic fragment of PcpA, PspA, NanA, PsaA, pneumolysin, PspC, PhtE, PhtB or any combination thereof. These references are incorporated herein by reference in their entireties for methods of combining and methods of administration for the proteins taught therein.

Any of the aforementioned treatments can be used in any combination with the compositions described herein. Combinations may be administered either concomitantly (e.g., as an admixture), separately but simultaneously (e.g., via separate intravenous lines into the same subject), or sequentially (e.g., one of the compounds or agents is given first followed by the second). Thus, the term combination is used to refer to either concomitant, simultaneous, or sequential administration of two or more agents.

Also provided are methods of diagnosing pneumococcal pneumonia in a subject. Bacteremia is the "gold standard" for diagnosis of pneumococcal pneumonia, however less than 1 in 4 patients with pneumococcal pneumonia are thought to be bacteremic and are therefore not informative in vaccine trials or diagnosis. If a higher percentage of pneumococcal pneumonia patients could be accurately diagnosed, the size of the trials, treatment and thus their costs would be proportionately reduced. Antigen detection assays based on the detection of C-polysaccharide are plagued with two competing problems. One is that they are not

sensitive enough to detect most of the patients with non-bacteremic pneumonia. The other problem is that they are sensitive enough to detect some individuals who are colonized but not infected with *S. pneumoniae*. Thus, making these assays more sensitive is not likely to greatly improve diagnosis of the non-bacteremic patients. The use of C-polysaccharide as a target antigen is especially problematic because it is made in higher levels by colonizing *S. pneumoniae* than invading *S. pneumoniae*.

To determine efficacy of pneumococcal vaccines to accurately diagnose, and to monitor treatment, it is necessary to know which subjects have pneumococcal pneumonia and which ones do not. The standard procedure for diagnosing pneumonia is by X-ray or other diagnostic tests and a positive blood culture for *Streptococcus pneumoniae*. Subjects satisfying these criteria are assumed to have pneumococcal pneumonia. Unfortunately this method misses between 75 and 85 percent of patients with pneumococcal pneumonia, because it has been estimated that only 15-25% of patients with pneumonia also have bacteremia (Fedson, et al., Vaccine 17:Suppl. 1:S11-18 (1999); Ostergaard and Andersen, Chest 104:1400-1407 (1993)).

One approach to solve this problem has been to use antigen detection assays that detect a cell wall polysaccharide in the urine. This assay is much more sensitive but unfortunately has false positives in 12% of adults and up to 60% of children. This is because the assay target is sometimes present in the urine because of nasal colonization with pneumococci in patients without pneumococcal disease in their lungs or blood.

Methods of detecting PcpA expression to diagnose pneumococcal pneumonia are provided. The major reservoir of pneumococci in the world resides in human nasal carriage. Acquisition of infection is generally from a carrier and infection is always preceded by nasal carriage. The colonization of the nasopharynx is considered a prerequisite for the spread of pneumococci to the lower respiratory tract, the nasal sinuses, and the middle ear. Expression of PcpA by *Streptococcus pneumoniae* is repressed by the regulator PsaR in response to high manganese (Mn2+) in the nasopharynx (Johnston, et al., *Infect. Immun.* 74:1171-1180 (2006)). Thus PcpA is only made and present on the surface of the pneumococcus when the organism has transitioned from its position in the nasopharynx into the lung where the manganese

concentration is low. This is also true for other pneumococcal antigens including, but not limited to, surface antigen A (PsaA), PsaB, PsaC, rrgA (a gram positive anchor family protein), rrgB (a gram positive anchor family protein), rrgC, srtB, pyruvate formate acetyltransferase (pfl), septation ring formation regulator EzrA, SecA subunit (a preprotein translocase), StpK (a serine/threonine protein kinase), galactose-1-phosphate uridylytransferase (galT), ORF00431 sortase B, ORF00767, prtA (also known as ppmA and is a serine protease, subtilysin family protein) and psrP (a cell wall surface anchor family protein). The nucleic and amino acid sequences for these proteins are known and can be found at www.genbank.org and www.tigr.org.

Thus, provided are methods to detect a pneumococcal antigen that is only produced in the lung and blood but not in the nasal cavity. PcpA is only produced in areas of low Mn2+ concentration ($\leq$0.1 μM) such as the lung and blood (Johnston, et al., *Infect. Immun.* 74:1171-1180 (2006)). Therefore PcpA is only made by pneumococci in the lung and blood but not by pneumococci on mucosal surfaces. Thus, colonization of pneumococci on mucosal surfaces would not be detected by the methods described herein and would therefore not lead to a false positive. By detecting pneumococcal antigens only produced in areas of low Mn2+ concentrations, only subjects with pneumonia would be diagnosed. Thus the present disclosure provides an advantageous method for diagnosing a subject with pneumonia or other pneumococcal infections like meningitis.

Thus provided are methods of diagnosing pneumococcal pneumonia in a subject comprising obtaining a biological sample from a subject and detecting in the biological sample the presence of one or more pneumococcal antigens selectively expressed during invasive disease, wherein the presence of the antigen indicates pneumococcal pneumonia in the subject. Also provided are methods of pneumococcal pneumonia in a subject comprising obtaining a biological sample from a subject and detecting in the biological sample the presence of one or more pneumococcal antigens expressed in the presence of high concentrations of Mn2+, wherein the presence of the antigen indicates pneumococcal pneumonia in the subject. The subject may or may not be bacteremic. Preferably, the antigen is not expressed or is not expressed in high quantities during colonization.

As used herein a biological sample which is subjected to testing is a sample derived from a subject such as a human and includes, but is not limited to, any biological fluid, preferably a bodily fluid. Examples of bodily fluids include, but are not limited to, whole blood, serum, urine, saliva, tissue infiltrate, pleural effusions, lung lavage fluid, bronchoalveolar lavage fluid, and the like. The biological fluid may be a cell culture medium or supernatant of cultured cells. For example, the sample can be a blood sample or a serum sample. Optionally, the biological sample is not from the nasal cavity of the subject.

The provided methods can also comprise the step of detecting in the biological sample the presence of C-polysaccharide. A ratio of PcpA to C-polysaccharide in the biological sample can also be determined.

Optionally, the ratio in bodily fluid of an antigen such as PcpA that is expressed only during invasive disease with an antigen such as neuraminidase A (NanA) that is expressed only during colonization is determined. This can be important since in virtually all colonization there may be a little bit of invasion and in virtually all pneumococcal pnemonia there is invariable also colonization. The ratio of the concentration of an invasive antigen such as PcpA to the concentration of a colonization antigen such as NanA will be low in subjects with colonization. For subjects with pneumococcal pneumonia this ratio should be high. By way of example only without meaning to be limiting, a ratio of 2:1, PcpA:NanA would indicate pneumococcal pneumonia in the subject while a ratio of 1:2, PcpA:NanA would indicate the subject does not have pneumococcal pneumonia. Examples of other antigens that may be markers of invasion include SmrC and PhoU, which have been found by others to be required for both pneumonia and sepsis but to play only a minimal role in colonization. An example of an antigen expressed primarily during colonization includes, but it not limited to, NanA, which is critical for colonization but plays little role in invasive disease. (Lau et al Mol. Micro. 40:555-571 (2001), Hava et al Mol Micro 50:1103-1110 (2003), Hava et al Mol. Micro 45:1389-1406 (2002), Orihuela, et al J. Infect. Dis. 190:1661-1669 (2004)).

As used herein pneumococcal antigens selectively expressed during invasive disease refers to an antigen that is expressed in areas of low Mn2+ concentration. Such antigens have little to no expression during colonization of pneumococci on

mucosal surfaces. The phrase pneumococcal antigens selectively expressed during invasive disease also refers to levels of a pneumococcal antigen, such as PcpA, that are at least 1.5 times higher in a biological sample from a subject being tested than in a control sample. As used throughout, higher, increases, enhances or elevates as compared to a control refer to increases above a control. For example, a control level can be the level of expression or activity in a control sample in the absence of a stimulus. A control sample as used herein includes a sample from a subject without pneumococcal pneumonia. Antigens that are selectively expressed in invasive disease or expressed in the presence of low concentrations of Mn2+ include, but are not limited to, PcpA, PsaA, PsaB, PsaC, rrgA, rrgB, rrgC, srtB, pfl, septation ring formation regulator EzrA, SecA subunit, StpK, galT, ORF00431, ORF00767, prtA and psrP. Optionally, one of the pneumococcal antigens detected in the provided methods is PcpA.

Assay techniques that can be used to determine levels of expression in a sample are well-known to those of skill in the art. Such assay methods include radioimmunoassays, reverse transcriptase PCR (RT-PCR) assays, immunohistochemistry assays, in situ hybridization assays, competitive-binding assays, Western Blot analyses, ELISA assays and proteomic approaches, two-dimensional gel electrophoresis (2D electrophoresis) and non-gel based approaches such as mass spectrometry or protein interaction profiling. Assays also include, but are not limited to, competitive and non-competitive assay systems using techniques such as radioimmunoassays, enzyme immunoassays (EIA), enzyme linked immunosorbent assay (ELISA), sandwich immunoassays, precipitin reactions, gel diffusion reactions, immunodiffusion assays, agglutination assays, complement-fixation assays, immunoradiometric assays, fluorescent immunoassays, protein A immunoassays, and immunoelectrophoresis assays. For examples of immunoassay methods, see U.S. Patent No. 4,845,026 and U.S. Patent No. 5,006,459.

For diagnostic methods, an antigen binding partner, for example, an antibody, can be labeled with a detectable moiety and used to detect the antigen in a sample. The antibody can be directly labeled or indirectly labeled (e.g., by a secondary or tertiary antibody that is labeled with a detectable moiety). Numerous labels are available including, but not limited to radioisotopes, fluorescent labels, and enzyme-

substrate labels. Radioisotopes include, for example, ^{35}S, ^{14}C, ^{125}I, ^{3}H, and ^{131}I. Fluorescent labels include, for example, rare earth chelates (europium chelates), fluorescein and its derivatives, rhodamine and its derivatives, dansyl, Lissamine, phycoerythrin and Texas Red. The labels can be conjugated to the antigen binding partner using the techniques disclosed in Current Protocols in Immunology, Volumes 1 and 2, Coligen et al., Ed., Wiley-Interscience, New York, N.Y., Pubs., (1991), for example.

When using enzyme-substrate labels, the enzyme preferably catalyses a chemical alteration of the chromogenic substrate which can be measured using various techniques. For example, the enzyme may catalyze a color change in a substrate, which can be measured spectrophotometrically. Alternatively, the enzyme may alter the fluorescence or chemiluminescence of the substrate. The chemiluminescent substrate becomes electronically excited by a chemical reaction and may then emit light which can be measured (using a chemiluminometer, for example) or donates energy to a fluorescent acceptor. Examples of enzymatic labels include luciferases (e.g., firefly luciferase and bacterial luciferase), luciferin, 2,3-dihydrophthalazinediones, malate dehydrogenase, urease, peroxidase such as horseradish peroxidase (HRPO), alkaline phosphatase, β-galactosidase, glucoamylase, lysozyme, saccharide oxidases (e.g., glucose oxidase, galactose oxidase, and glucose-6-phosphate dehydrogenase), heterocyclic oxidases (such as uricase and xanthine oxidase), lactoperoxidase, microperoxidase, and the like. Techniques for conjugating enzymes are described in O'Sullivan et al., Methods for the Preparation of Enzyme-Antibody Conjugates for use in Enzyme Immunoassay, in Methods in Enzym. (ed J. Langone & H. Van Vunakis), Academic press, New York, 73: 147-166 (1981). Examples of enzyme-substrate combinations include, for example, horseradish peroxidase (HRPO) with hydrogen peroxidase as a substrate, alkaline phosphatase (AP) with para-Nitrophenyl phosphate as chromogenic substrate, and β-D-galactosidase (β-D-Gal) with a chromogenic substrate (e.g. p-nitrophenyl-β-D-galactosidase) or fluorogenic substrate 4-methylumbelliferyl-β-D-galactosidase.

In an ELISA assay, an antibody is prepared, if not readily available from a commercial source, specific to an antigen. In addition, a reporter antibody generally is prepared which binds specifically to the antigen. The reporter antibody is attached

to a detectable reagent such as a radioactive, fluorescent or enzymatic reagent, for example horseradish peroxidase enzyme or alkaline phosphatase. To carry out the ELISA, antibody specific to antigen is incubated on a solid support, e.g., a polystyrene dish, that binds the antibody. Any free protein binding sites on the dish are then covered by incubating with a non-specific protein such as bovine serum albumin. Next, the sample to be analyzed is incubated in the dish, during which time the antigen binds to the specific antibody attached to the polystyrene dish. Unbound sample is washed out with buffer. A reporter antibody specifically directed to the antigen and linked to a detectable reagent such as horseradish peroxidase is placed in the dish resulting in binding of the reporter antibody to any antibody bound to the antigen. Unattached reporter antibody is then washed out. Reagents for peroxidase activity, including a colorimetric substrate are then added to the dish. Immobilized peroxidase, linked to antibodies, produces a colored reaction product. The amount of color developed in a given time period is proportional to the amount of antigen present in the sample. Quantitative results typically are obtained by reference to a standard curve.

A competition assay can also be employed wherein antibodies specific to antigen are attached to a solid support and labeled antigen and a sample derived from the subject or control are passed over the solid support. The amount of label detected which is attached to the solid support can be correlated to a quantity of antigen in the sample.

Of the proteomic approaches, 2D electrophoresis is a technique well known to those in the art. Isolation of individual proteins from a sample such as serum is accomplished using sequential separation of proteins by different characteristics usually on polyacrylamide gels. First, proteins are separated by size using an electric current. The current acts uniformly on all proteins, so smaller proteins move farther on the gel than larger proteins. The second dimension applies a current perpendicular to the first and separates proteins not on the basis of size but on the specific electric charge carried by each protein. Since no two proteins with different sequences are identical on the basis of both size and charge, the result of a 2D separation is a square gel in which each protein occupies a unique spot. Analysis of the spots with chemical

or antibody probes, or subsequent protein microsequencing can reveal the relative abundance of a given protein and the identity of the proteins in the sample.

Optionally, a genetic sample from the biological sample can be obtained. The genetic sample comprises a nucleic acid, preferably RNA and/or DNA. For example, in determining the expression of genes mRNA can be obtained from the biological sample, and the mRNA may be reverse transcribed into cDNA for further analysis. Alternatively, the mRNA itself is used in determining the expression of genes.

A genetic sample may be obtained from the biological sample using any techniques known in the art (Ausubel et al. Current Protocols in Molecular Biology (John Wiley & Sons, Inc., New York, 1999); Molecular Cloning: A Laboratory Manual, 2nd Ed., ed. by Sambrook, Fritsch, and Maniatis (Cold Spring Harbor Laboratory Press: 1989); Nucleic Acid Hybridization (B. D. Hames & S. J. Higgins eds. 1984)). The nucleic acid may be purified from whole cells using DNA or RNA purification techniques. The genetic sample may also be amplified using PCR or *in vivo* techniques requiring subcloning. The genetic sample can be obtained by isolating mRNA from the cells of the biological sample and reverse transcribing the RNA into DNA in order to create cDNA (Khan et al. Biochem. Biophys. Acta 1423:17 28, 1999).

Once a genetic sample has been obtained, it can be analyzed for the presence or absence of one or more particular genes encoding pneumococcal antigens such as, for example, PcpA. Thus, pneumococcal antigens that can be assayed include, but are not limited to, PcpA, PsaA, PsaB, PsaC, rrgA, rrgB, rrgC, srtB, pfl, septation ring formation regulator EzrA, SecA subunit, StpK, galT, ORF00431, ORF00767, prtA and psrP or any combination thereof. The analysis may be performed using any techniques known in the art including, but not limited to, sequencing, PCR, RT-PCR, quantitative PCR, restriction fragment length polymorphism, hybridization techniques, Northern blot, microarray technology, DNA microarray technology, and the like. In determining the expression level of a gene or genes in a genetic sample, the level of expression may be normalized by comparison to the expression of another gene such as a well known, well characterized gene or a housekeeping gene. For example, reverse-transcriptase PCR (RT-PCR) can be used to detect the presence of a specific mRNA population in a complex mixture of thousands of other mRNA

species. In RT-PCR, an mRNA species is first reverse transcribed to complementary DNA (cDNA) with use of the enzyme reverse transcriptase; the cDNA is then amplified as in a standard PCR reaction. RT-PCR can thus reveal by amplification the presence of a single species of mRNA.

Hybridization to clones or oligonucleotides arrayed on a solid support (i.e., gridding) can be used to both detect the expression of and quantitate the level of expression of that gene. In this approach, a cDNA encoding an antigen is fixed to a substrate. The substrate may be of any suitable type including but not limited to glass, nitrocellulose, nylon or plastic. At least a portion of the DNA encoding the antigen is attached to the substrate and then incubated with the analyte, which may be RNA or a complementary DNA (cDNA) copy of the RNA, isolated from the sample of interest. Hybridization between the substrate bound DNA and the analyte can be detected and quantitated by several means including but not limited to radioactive labeling or fluorescence labeling of the analyte or a secondary molecule designed to detect the hybrid. Quantitation of the level of gene expression can be done by comparison of the intensity of the signal from the analyte compared with that determined from known standards. The standards can be obtained by *in vitro* transcription of the target gene, quantitating the yield, and then using that material to generate a standard curve.

It must be noted that, as used in the specification and the appended claims, the singular forms a, an and the include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to an antigenic fragment includes mixtures of antigenic fragments, reference to a pharmaceutical carrier or adjuvant includes mixtures of two or more such carriers or adjuvants.

As used herein, a subject is meant an individual. Thus, the subject can include domesticated animals, such as cats and dogs, livestock (e.g., cattle, horses, pigs, sheep, and goats), laboratory animals (e.g., mice, rabbits, rats, guinea pigs) and birds. In one aspect, the subject is a mammal such as a primate or a human.

Optional or optionally means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where the event or circumstance occurs and instances where it does not. For example, the phrase optionally the composition can comprise a combination means that the

composition may comprise a combination of different molecules or may not include a combination such that the description includes both the combination and the absence of the combination (i.e., individual members of the combination).

Ranges may be expressed herein as from about one particular value, and/or to about another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent about, it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

When the terms prevent, preventing, and prevention are used herein in connection with a given treatment for a given condition (e.g., preventing pneumococcal infection), they mean that the treated patient either does not develop a clinically observable level of the condition at all, or develops it more slowly and/or to a lesser degree than he/she would have absent the treatment. These terms are not limited solely to a situation in which the patient experiences no aspect of the condition whatsoever. For example, a treatment will be said to have prevented the condition if it is given during exposure of a patient to a stimulus that would have been expected to produce a given manifestation of the condition, and results in the patient's experiencing fewer and/or milder symptoms of the condition than otherwise expected. A treatment can prevent infection by resulting in the patient's displaying only mild overt symptoms of the infection; it does not imply that there must have been no penetration of any cell by the infecting microorganism.

Similarly, reduce, reducing, and reduction as used herein in connection with the risk of infection with a given treatment (e.g., reducing the risk of a pneumococcal infection) refers to a subject developing an infection more slowly or to a lesser degree as compared to a control or basal level of developing an infection in the absence of a treatment (e.g., administration of an immunogenic polypeptide). A reduction in the risk of infection may result the patient's displaying only mild overt symptoms of the infection or delayed symptoms of infection; it does not imply that there must have been no penetration of any cell by the infecting microorganism.

It is to be understood that the disclosed method and compositions are not limited to specific synthetic methods, specific analytical techniques, or to particular reagents unless otherwise specified, and, as such, may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made. Furthermore, when one characteristic or step is described it can be combined with any other characteristic or step herein even if the combination is not explicitly stated. Accordingly, other embodiments are within the scope of the claims.

EXAMPLES

Example 1: PcpA Elicits Protection Against Lung Infection and Fatal Sepsis.

Materials and Methods.

Bacterial strains, medium, and growth conditions. *S. pneumoniae* strains TIGR4 and EF3030, and their derivatives, were used in this study. Pneumococci were grown at 37°C in Todd-Hewitt broth with 0.5% yeast extract (THY) or on blood agar plates unless otherwise indicated. When appropriate, erythromycin was added to the medium at a concentration of 0.3 μg/ml. Clinical isolates of *S. pneumoniae* (Table 2) and isolates of major clonal groups (Table 3) were used.

Table 2. Clinical Isolates of *Streptococcus pneumoniae*

Strain	Capsular type	PspA family	Origin	Reference
R6	Non-encapsulated variant of D39 (type 2)	1	New York	(Belanger et al., *J. Bacteriol.* 186:8164-71 (2004); Ottolenghi and Hotchkiss, *Science* 132:1257-8 (1960)
TIGR4*	4	2	Norway	Ren et al., *Infect. Immun.* 71:75-85 (2003); Roach et al., *PNAS* 102:9577-82 (2005)
BG12730*	6	2/3	Gambia	Shaper et al., *Infect. Immun.* 72:5031-40 (2004)
BG10752*	9	1	Alabama	This Study
TJ0893*	14	2	Mississippi	Wu et al., *J. Infect. Dis.* 175:839-46 (1997)
V175*	18	2	Tennessee	Robinson et al., *J. Infect. Dis.* 183:1501-7 (2001)
L82013*	19	2	Alaska	Briles et al., *Infect. Immun.* 188:339-48 (2003)
EF3030*	19F	1	Sweden	Briles et al., *Infect. Immun.* 188:339-48 (2003); Briles et al., *Infect. Immun.* 73:6945-51 (2005); Johnston et al., *Infect. Immun.* 74:1171-80 (2006)
EF9303*	23F	Unknown	Sweden	Wu et al., *Microb. Pathog.* 23:127-37 (1997)
L82016*	6B	1	U.S.A.	Briles et al., *Infect. Immun.* 60:111-6 (1992); Briles et al., *Infect. Immun.* 188:339-48 (2003)
D-1091B*	23	1	Unknown	This Study

(*) clinical strains that are not separated by more than 10 passages from the original patient isolate. R6 was derived from strain D39, which was a patient isolate in the 1920's.

Table 3. *Streptococcus pneumoniae* of major clonal groups

Strain	Capsular type	Origin	Characteristics	Reference
MA-14	14	UK	Worldwide Erm^r clone; MLST sequence type 9	(1)
MB-23F	23F	UK	Unknown disease; MLST sequence type 81	(1)
MC-6B	6B	Spain	Unknown disease; MLST sequence type 90	(3, 4)
MD-6B	6B	Alaska	Unknown disease; MLST sequence type 138	(2)
ME-19	19	Tennessee	Carriage clone; MLST sequence type 236	(2)
MF-6A	6A	Tennessee	Carriage clone; Unknown MLST sequence type	(2)
MG-1	1	UK	Major invasive clone; MLST sequence type 227	(1)
MI-7F	7F	Norway	Major invasive clone; MLST sequence type 191	(1)
MJ-35	35	Tennessee	Carriage clone; MLST sequence type 65	(2)
MK-22	22	Tennessee	Major invasive clone; Unknown MLST sequence type	(2)
ML-11	11	Tennessee	Carriage clone; MLST sequence type 62	(2)
MM-14	14	Tennessee	Major invasive clone; MLST sequence type 124	(2)
MN-23F	23	Tennessee	Carriage clone; MLST sequence type 37	(2)

1. Enright, M. C., and B. G. Spratt. 1998. A multilocus sequence typing scheme for *Streptococcus pneumoniae*: identification of clones associated with serious invasive disease. Microbiology 144:3049-60.
2. Robinson, D. A., K. M. Edwards, K. B. Waites, D. E. Briles, M. J. Crain, and S. K. Hollingshead. 2001. Clones of *Streptococcus pneumoniae* Isolated from Nasopharyngeal Carriage and Invasive Disease in Young Children in Central Tennessee. J Infect Dis 183:1501-7.
3. Hakenbeck, R., T. Briese, L. Chalkley, H. Ellerbrok, R. Kalliokoski, C. Latorre, M. Leinonen, and C. Martin. 1991. Antigenic variation of penicillin-binding proteins from penicillin-resistant clinical strains of *Streptococcus pneumoniae*. J Infect Dis 164:313-319.
4. Hakenbeck, R., T. Briese, L. Chalkley, H. Ellerbrok, R. Kalliokoski, C. Latorre, M. Leinonen, and C. Martin. 1991. Variability of penicillin-binding proteins from penicillin-sensitive *Streptococcus pneumoniae*. J Infect Dis 164:307-312.

The clinical strains used in these studies were isolated within the last 25 years. To examine the possible diversity of PcpA, isolates were selected from the group of strains utilized in the *Streptococcus pneumonia* Genome Diversity Project (http://genome.microbio.uab.edu/strep/info).

During strain construction, plasmids were maintained in *Escherichia coli* TOP10 cells (Invitrogen, Carlsbad, CA) grown in Luria-Bertani (LB) broth or LB plates with 1.5% agar. Ampicillin (50 μg/ml) for pCR2.1, pCR4 and pET-20b-based plasmids or erythromycin (400 μg/ml) for pJY4164-based plasmids was added to the growth medium.

THY medium was used for growth of bacteria in high manganese medium. For growth in low manganese conditions, a manganese depleted form of THY was prepared. THY medium was prepared according to the manufacturer's directions, with Chelex-100 (2% w/v) (Sigma Aldrich, St. Louis, Mo) added prior to autoclaving. After autoclaving, the THY/Chelex mixture was stirred overnight at room temperature, followed by filter sterilization. $ZnCl_2$, $MgCl_2$, $CaCl_2$, and $FeSO_4$ were added to concentrations of 1mM each, and $MnSO_4$ was add to a concentration of 0.1 μM prior to use. Growth was monitored by optical density at 600 nm.

Strain construction. The *E. coli* strains, plasmids, and primers used in this study are listed (Table 4). Mutagenesis was used to inactivate *pcpA* in the parental strains TIGR4 and EF3030. The construction of mutant strains was previously carried out and described (Johnston, et al., *Infect. Immun.* 74:1171-80 (2006)).

TABLE 4. Additional bacterial strains, and plasmids used in this study

Strain, plasmid, or primer	Relevant characteristics or sequence and gene	Reference
Strains		
S. pneumoniae		
JEN7	TIGR4 *psaR*::Erm (*pcpA* constituative mutant)	Johnston, et al., Infect. Immun. 74:1171-80 (2006)
Jen11	TIGR4 *pcpA*::Erm	Johnston, et al., Infect. Immun. 74:1171-80 (2006)
E. coli		
TOP10	General cloning strain	Invitrogen, Carlsbad, CA
Rosetta (DE3) pLysS	Expression strain	Novagen, Madison, WI
Plasmids		
pCR2.1	3.9 kb, Amp^r, Kan^r	Invitrogen, Carlsbad, CA
pCR4	3.9 kb, Amp^r, Kan^r	Invitrogen, Carlsbad, CA
pET-20b	3.7 kb, Amp^r, C-term his-tag	Novagen, Madison, WI
pDG-1	pCR4 with *pcpA* fragmnet; Amp^r	This study
pJM-1	pET-20b with *pcpA fragment;* Amp^r	This study
pJJ035	pCR2.1 with 412 bp internal *pcpA* fragment; Amp^r	This study
Primers[a]		
DTG-16	cgcggatccATATGTCCCTAATGAACC (SEQ ID NO:39); *pcpA* **F**	This study
DTG-12	gcgctcgagTTCCTTTAATGAATCTAAGACGC CACTTAGGAAGAAGGAC (SEQ ID NO:40); *pcpA* **R**	This study
JWJ28	AAC TGT TCA AGT GGG TAA TGG (SEQ ID NO:43); *pcpA* **F**	Johnston, et al., Infect. Immun. 74:1171-80 (2006)
JWJ29	TGA ACT TGA GGA AAA GGT TAG C (SEQ ID NO:44); *pcpA* **R**	Johnston, et al., Infect. Immun. 74:1171-80 (2006)
BGP1	ATGAAAAAACTACAATATTATCATTAAC TACAGCTGCG (SEQ ID NO:45); *pcpA* **F**	This study
BGP2	CCATAAACCTTTGTCTTTAACCCAACCA ACTAC (SEQ ID NO:46); *pcpA* **R**	This study

[a] Primers were based on the complete genome sequence of *S. pneumoniae* TIGR4 (2). Lowercase denotes mismatches used to create restriction endonuclease sites. All sequences are expressed 5' to 3'.

Recombinant PcpA expression and purification. The strains, plasmids, and primers used in this study are listed in Table 2. Primers DTG-16 (5'-CGCGGATCCATATGTCCCTAATGAACC-3' (SEQ ID NO:39)) and DTG-12 (5'-GCGCTCGAGTTCCTTTAATGAATCTAAGACGCCACTTAGGAAGAAGGA C-3' (SEQ ID NO:40)) were designed to amplify a 1126 bp fragment of *pcpA* in strain TIGR4. The primers contain engineered restriction endonuclease sites, BamHI and XhoI respectively. Reactions were carried out for 30 cycles in a total volume of 50 µl in a cocktail containing 3.0 mM $MgCl_2$, 125 µM dNTPs, 50 picomole of each primer, and 2.5 units of Taq DNA Polymerase. The cycle was 94°C, 1 min.; 55°C, 1 min; 72°C, 5 minutes. This amplified gene fragment was initially cloned into pTOPO4 (Invitrogen, Inc., Carlsbad, CA) by a T-tailed method forming plasmid pLMG.

This fragment was cloned into pCR4 with the TOPO TA cloning kit (Invitrogen, Carlsbad, CA). Purified plasmids were screened by endonuclease digestion with BamHI and XhoI (Promega, Madison, WI). Agarose gel electrophoresis, PCR analysis, and DNA sequencing were all used to confirm insertion of the *pcpA* fragment in the resulting plasmid, pDG-1. The insert from pDG-1 was subcloned into the pET-20b expression vector (Novagen, Madison, WI). The resulting plasmid, pJM-1, was transformed into the *E. coli* strain RosettaBlue (DE3) pLysS (Novagen, Madison, WI) for protein production. This strain contains a chromosomal copy of the T7 promoter under control of the inducible UV5 promoter. Upon IPTG induction a truncated protein, containing amino acids 19-391, was expressed. The over-expressed truncated protein was purified using the Novagen HIS-BIND® Purification Kit (Novagen, Madison, WI), which utilized a C-carboxy terminal histidine tag to facilitate purification. Subsequent SDS-PAGE analysis with Comassie Blue staining yielded a single band of approximately 41-kDa.

Below is the complete sequence of the rPcpA protein that has been cloned and expressed. Underlined portions are from the cloning vector.

MDIGINSDPYVPNEPILADTPSSEVIKETKVGSIIQQNNIKYKVLTVEGNI GTVQVGNGVTPVEFEAGQDGKPFTIPTKITVGDKVFTVTEVASQAFSYYPDET GRIVYYPSSITIPSSIKKIQKKGFHGSKAKTIIFDKGSQLEKIEDRAFDFSELEEIE LPASLEYIGTSAFSFSQKLKKLTFSSSSKLELISHEAFANLSNLEKLTLPKSVKT

LGSNLFRLTTSLKHVDVEEGNESFASVDGVLFSKDKTQLIYYPSQKNDESYKT PKETKELASYSFNKNSYLKKLELNEGLEKIGTFAFADAIKLEEISLPNSLETIER LAFYGNLELKELILPNNVKNFGKHVMNGLPKLKSLTIGNNINSLPSFFLSGVLD SLKELEHHHHHH (SEQ ID NO:41)

Anti-PcpA polyclonal antibody production. Purified rPcpA was used to immunize a New Zealand White Rabbit (Myrtle's Rabbity, Thompson Station, TN) rabbit subcutaneously to obtain anti-PcpA polyclonal serum. The rabbit was injected subcutaneously with 100 μg of rPcpA in 1 ml of Freund's complete adjuvant, 2ml total volume. A second boost, with 100 μg of rPcpA in Freund's incomplete adjuvant, was given 2 weeks later and a third boost of 100 μg of PcpA in Freund's incomplete adjuvant was given 2 weeks after the second boost. Two weeks following the final boost the rabbit was bled by cardiac puncture, under anesthesia. The blood was allowed to clot, and serum was obtained by centrifugation and stored at -80°C.

PCR confirmation of pcpA in S. pneumoniae strains. The presence or absence of *pcpA* in various *S. pneumoniae* strains was checked using PCR primer pair BGP-1 and BGP-2. The primer pair was designed to amplify a 1416 bp N-terminal fragment of *pcpA* in strain TIGR4. The PCR products were then separated on a T.A.E. agarose gel, stained with ethidium bromide, and examined for the correct size amplified band.

S. pneumoniae cell fractionation. Protoplasts were produced with the method described by Yother and White (Yother and White, *J. Bacteriol.* 176:2976-85 (1994)), with slight modification. Log-phase cells, grown in MTHY, were pelleted and washed in PBS. The cells were then resuspended in 0.5 ml of 2% choline chloride and the tube inverted several times. The cells were then pelleted and the supernatant drawn off and stored at -20°C (choline elution fraction). Cells were pelleted and washed once with 300μl of protoplast buffer (20% sucrose, 5 mM Tris [pH 7.4], 2.5 mM $MgSO_4$). The pellet was then resuspended in 1ml protoplast buffer, and Mutanolysin (Sigma Aldrich, St. Louis, MO) was then added at 5 U per ml of culture pelleted. The suspension was incubated overnight at room temperature. Cells were pelleted by centrifugation at 6000rpm for 10min, supernatant is stored at -20°C (Cell Wall Fraction). The protoplast were then washed in 1ml of protoplast buffer. The

formation of protoplasts was confirmed by microscopic examination. The protoplast were pelleted and lysed in 0.3 - 1ml of dH_2O, this is stored at -20°C (Cell Membrane/Cytosolic Fraction). Samples of each fraction are examined for the presence of PcpA by Western blot analysis.

Antibody staining of S. pneumoniae. Mid-log-phase cells, OD_{600}0.6, grown in high or low manganese medium, were pelleted, washed with PBS, resuspended in PBS with 1% bovine serum albumin (PBSB), and incubated at room temperature 20 min. Cells were pelleted and resuspended in PBSB or anti-PcpA serum diluted 1:100 in PBSB and incubated at 37°C for 30 min. Incubation was followed by two washes with PBS. Cells were then incubated with goat anti-rabbit immunoglobulin G (heavy and light chains)-fluorescein isothiocyanate (Southern Biotechnology Associates, Inc., Birmingham, AL) diluted in PBSB at 4°C for 30 min. The cells were then washed twice with PBS and resuspended in 4% formaldehyde in PBS containing 0.01 mM of the lipophylic membrane dye TMA-DPH (Invitrogen, Carlsbad, CA). Bacterial cells were then inspected by epifluorescence using the Olympus IX 70 microscope.

Western blot. Bacterial cultures were grown in THY and MTHY to mid-log phase, OD_{600}0.6. Equivalent amounts of each strain were washed twice with phosphate-buffered saline (PBS), resuspended in PBS with sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) sample buffer, and boiled for 5 min. Samples and a pre-stained protein standard (Invitrogen, Carlsbad, CA) were loaded onto a NuPAGE10% Bis-Tris gel (Invitorgen, Carlsbad, CA) and separated by electrophoresis in morpholineethanesulfonic acid (MES)-SDS running buffer (Invitrogen, Carlsbad, CA) in accordance to the manufacturer's instructions. Proteins were then transferred to a nitrocellulose membrane with the Trans-Blot SD semidry transfer cell (Bio-Rad, Hercules, CA). The blot was probed with anti-PcpA polyclonal antibody diluted 1:1000 in PBSB. Goat anti-rabbit immunoglobulin G (heavy and light chains)-alkaline phosphatase and streptavidin-alkaline phosphatase (Southern Biotechnology Associates, Inc., Birmingham, AL) were used as the secondary antibody. Colorimetric detection was performed with Sigma Fast nitrobluetetrazolium-5-bromo-4-chloro-3-indolylphosphate (NBT-BCIP) tablets (Sigma Aldrich, Switzerland).

Systemic immunization of mice. 6-8 week old CBA/CaHNBtkxid/J (CBA/N) mice (JacksonLabs, Bar Harbor, Maine) were initially injected subcutaneously with 10 μg of rPcpA with 2 μg of Aluminum hydroxide as an adjuvant, 200 μl total volume. A second boost with 10 μg of rPcpA with Aluminum hydroxide was given 2 weeks later. A third boost containing 10 μg of rPcpA without Aluminum hydroxide was given 2 weeks following. The mice were then allowed to rest 2 weeks prior to challenge with *S. pneumoniae*. Mice were bled 24 hrs prior to infection.

Murine model of sepsis. The virulence of pneumococci was examined in a systemic model of infection previously described (Coats, et al., *Vaccine* 23:4257-62 (2005); Ren et al., *Infect. Immun.* 71:75-85 (2003)). 6-8 week old CBA/N mice were injected intravenously with 300 CFUs of bacteria diluted in lactated ringers. Mice were monitored for 21 days. When they become unresponsive to touch and their body temperature decreased to below normal they were scored as moribund and the date and time were recorded. All moribund mice were euthanized with CO_2 narcosis.

Murine model of pneumonia. Lung infections were performed as previously described (Balachandran et al., *Infect. Immun.* 70:2526-34 (2002); Briles et al., *J. Infect. Dis.* 188:339-48 (2003); Takashima et al., *Infect. Immun.* 65:257-260 (1997)). 6-8 week old CBA/N mice were anesthetized with Isoflurane (MinRAD, Buffalo, NY), and suspensions of 40 μl of lactated ringers solution containing 5 x 10^6 bacteria were introduced into the nares of the mice to induce aspiration pneumonia. After 7 days the mice were sacrificed. The nasal cavities of sacrificed mice were washed with 50 μl of lactated ringers, as previously described (Wu et al., *J. Infect. Dis.* 175:839-46 (1997)). The nasal wash was serially diluted and plated onto blood agar with gentamicin (4 μg/ml). The lungs were harvested and placed into 2 ml of lactated ringers in a stomacher bag, homogenized, serially diluted, and plated onto blood agar with gentamicin in serial 3-fold dilutions.

Murine model of nasopharyngeal colonization: Intranasal inoculations were performed as previously described (Balachandran et al., *Infect. Immun.* 70:2526-34 (2002); Wu et al., J. Infect. Dis. 175:839-46 (1997)). 6-8 week old CBA/N mice were infected intranasally with 10^6 bacteria in 10 μl of lactated Ringer's solution without anesthesia. Infected mice were then sacrificed, and their nasal cavities were washed

with 50 µl of Ringer's solution. The nasal washes were serially diluted and plated on blood agar with gentamicin. Visible counts from blood agar plates were determined after overnight incubation at 37°C in candle jars.

Statistical analysis. Statistically analysis was carried out using Instat (GraphPad Software Inc., San Diego, Ca). Comparisons of time to moribund or numbers of recovered CFU between the control and experimental groups were conducted using the Mann-Whitney two sample rank test. *P*-values less than 0.05 were considered to be statistically significant.

Results

pcpA is present in clinically relevant strains of S. pneumoniae. The presence of *pcpA* was examined by PCR, with primers (BGP1 and BGP2) spanning the LRR region of the *pcpA*. Each of the 23 strains examined (Tables 2 and 3) yielded a roughly 1500-bp fragment. Eight of these strains are clinical strains isolated within the last 25 years that are representative strains of the seven common capsular types covered by the 7-valent conjugate vaccine (Fig. 1). The remaining 12 strains are a set of *S. pneumoniae* that were selected from a set of strains assembled as part of the Genome Diversity Project (http://genome.microbio.uab.edu/strep/info/) which includes a set of strains chosen to span the breadth of diversity in *S. pneumoniae.* These 12 strains were selected as highly divergent based on MLST data. Four strains were from patients with serious invasive disease, five were from asymptomatic carriage, for 2 strains disease/colonization was not know, and one strain was from a worldwide antibiotic resistant clone. These strains represent 12 different capsule types from different world regions.

To test for expression of PcpA in all strains they were grown in low ($\leq$0.1 µM) manganese. Total cellular protein samples were prepared from mid-log phase cells cultured in the low manganese medium. All strains listed in (Tables 2 and 3) were examined, but only those representing capsular types included in the heptavalent vaccine are depicted (Fig. 2). Total cellular protein samples were separated by SDS-PAGE and transferred to nitrocellulose. The blot was probed with anti-PcpA polyclonal antiserum, identifying a band of approximately 62-kDa in each of these wild-type strains of capsulare serotypes 4, 6, 9, 14, 18, 19, 23 (Fig. 2). This 62-kDa band was absent in the *pcpA*-inactivated mutant JEN11 but was present in seven

representative strains. Total cellular protein samples were also prepared from strains grown in high manganese medium for the same strains, but no bands were identified with the anti-PcpA antiserum. The PCR analysis in combination with the Western blot data, demonstrated that *pcpA* is present in all *S. pneumoniae* strains listed in Tables 2 and 3.

PcpA is exposed on the surface of S. pneumoniae under low manganese conditions. Studies have shown that through the action of the regulator PsaR, manganese controls the transcription of the *pcpA* gene (Johnston et al., *Infect. Immun.* 74:1171-80 (2006)). As described herein, manganese dependent regulation directly affects the presence of PcpA on surface of *S. pneumoniae* and surface PcpA is accessible to antibody even on encapsulated pneumococci.

Cell fractionation was performed to determine if PcpA was associated with the cell wall or cell membrane/cytosol of *S. pneumonia.* Western blot analysis of these cellular fractions revealed that PcpA was present predominantly in the cell wall of *S. pneumoniae*, in bacteria grown in low manganese medium. A small fraction of the PcpA was associated with the cell membrane/cytosol, and probably represents PcpA yet to be exported to the surface of the bacteria.

In addition to the cell fractionation, log-phase cells from wild type *S. pneumoniae* strain TIGR4 were grown in high or low manganese medium, stained with anti-PcpA polyclonal antiserum followed by fluorescein isothiocyanate (FITC)-conjugated anti-rabbit immunoglobulin. Specifically, TIGR4 was cultured in high or low Mn2+ medium until mid-log phase. Bacteria were incubated with anti-PcpA rabbit serum, followed by incubation with FITC-conjugated anti-rabbit Ig antibodies. Cells were then fixed in 4% formaldehyde containing the membrane dye TMA-DPH. The labeled bacteria were then examined by immunofluorescence microscopy. The antibodies to PcpA were able to mediate staining of the bacteria grown in low manganese, but not those grown in high manganese.

These results indicate that PcpA is surface exposed on wild-type *S. pneumoniae* cultured under low manganese conditions *in vitro*. This indicates that PcpA is expressed and surfaced exposed on bacteria infecting low manganese sites inside the host, such as the lungs and blood. This exposure of PcpA facilitates PcpA-ligand interactions between the bacterium and the host epithelium during infection.

These results also indicate that regulation of PcpA production by manganese concentration is generalizable to most pneumococci.

Immunization with rPcpA elicits antibody and provides protection against lung and systemic infection, but does not significantly affect nasopharyngeal colonization. Mice were immunized with rPcpA with aluminum hydroxide or received aluminum hydroxide alone, prior to use in infection studies. Total Ig(H+L) was quantified for both groups of mice by ELISA. The geometric mean level of antibody specific PcpA in the serum of the immunized mice was 0.465 (± 0.119) μg/ml, versus a mean of 0.002 (± 0.002) μg/ml for mice receiving the adjuvant alone, (± SEM). This indicates the route of immunization was successful at eliciting an immune response to rPcpA.

To see if the immunization protected mice from pneumonia, the immunized and alum-only mice were lightly anesthetized and inoculated in the nares with 5×10^6 CFU of strain EF3030. This procedure resulted in focal pneumonia without bacteremia. Protection in this model can thus be associated with pneumonia per se and not sepsis in general. Seven days post infection all mice were sacrificed. Bacterial counts were determined from homogenized lung tissue and nasal wash. Based on the median CFU recovered, there were less than 1/100 as many pneumococci recovered from the lung homogenates of mice immunized with rPcpA versus those receiving adjuvant alone (Fig. 3A)(P=0.002). These results indicate that immunization with rPcpA is able to elicit protection against pulmonary infection with *S. pneumoniae*. There was no significant difference in the bacterial counts recovered from nasal washes of mice immunized with rPcpA versus those receiving adjuvant alone (Fig. 3B).

Next it was determined whether subcutaneous immunization would confer protection against focal lung infection with other strains of *S. pneumoniae* (TJ0893, serotype 14; EF9303, serotype 23F; and L82016, serotype 6B). Subcutaneous immunization with rPcpA elicited significant protection against each strain compared to mice receiving immunizations of just the adjuvant alone (Fig 5).

Expression of PcpA is not required for optimal nasal colonization. Since immunization did not affect the number of bacteria recovered from the nasal washes of mice used for the pneumonia model, the effect of *pcpA* inactivation was examined

in a model of nasopharyngeal carriage. This model allowed a direct view of any effects of PcpA on nasal carriage, as opposed to the indirect observations gathered from the nasal washes of mice in the pneumonia model. Mice were inoculated without prior anesthesia with 10^6 CFU of either strain EF3030 or its *pcpA*-inactivated mutant JEN18. Seven days post infection the mice were sacrificed and nasal washes were collected and plated to detect pneumococci. There was no significant difference in the number of bacteria recovered from the nasal washes of mice inoculated with either EF3030 or JEN18 (Fig. 5).

The failure of either the presence of an intact *pcpA* gene or subcutaneous immunization with rPcpA to have an effect on numbers of pneumococci recovered in the nasal washes of mice is consistent with the fact that the manganese concentration in the nasopharynx ($\geq$36μM) is high enough to suppress *pcpA* transcription. Under these conditions *pcpA* transcription would be repressed, by *psaR,* in the nasopharynx. Thus, immunity to PcpA would be expected to have little effect on bacteria in this host site.

PcpA and immunity to PcpA effects virulence in the murine model of systemic infection. To evaluate the ability of immunity to PcpA to protect against sepsis, CBA/N mice were subcutaneously immunized with PcpA in aluminum hydroxide or aluminum hydroxide alone as a control and challenged intravenously with capsular type 4, TIGR4 *S. pneumoniae*. This strain was used rather than EF3030 since this strain can readily cause bacteremia and sepsis in mice. The immunized animals were injected IV with 300 CFU of TIGR4 strain *S. pneumoniae*. Survival was monitored for 21 days. Mice receiving rPcpA immunizations had a median time to become moribund that was extended by 43.5 hours compared to mice receiving adjuvant alone (Fig. 6). Twenty six percent of mice immunized with rPcpA lived, whereas no mice immunized with aluminum hydroxide alone lived; this difference in survival was statistically significant (P=0.007).

Effect of inactivation of pcpA on the ability of pneumococci to cause mice to become moribund following intravenous inoculation. Inactivation of *pcpA* results in reduced virulence in the murine model of pneumonia and in a lung-sepsis model. As described herein, the effect of *pcpA* inactivation on systemic infection following intravenous challenge was examined by infecting naive mice with 300 CFU of either

TIGR4 or its *pcpA* inactivated mutant JEN11. The median time to become moribund for mice infected with the *pcpA*⁻ mutant was extended by 31.5 hours (P=0.0299) compared to those infected with wild-type bacteria (Fig. 7). This demonstrates that there is a role for PcpA in the ability of *S. pneumoniae* to cause systemic diseases.

Example 2. Mucosal immunization with PcpA protects against lung infection.

As shown in Figure 8, mucosal immunization with PcpA protects against pulmonary infection with strain EF3030. CBA/N mice were immunized intranasally with 5 μg of PcpA plus cholera toxin B sub-unit (CTB) as the adjuvant. Post-immunization mice were bled and then challenged intranasally with $5x10^6$ CFU of strain EF3030. Figure 8 shows logCFU of bacteria in lung homogenate at 7 days post-infection.

Mucosal immunization protection was observed to be slightly better than with SC immunization. These data and Example 1 indicate that protection against pneumonia and sepsis can be conferred using at least mucosal or subcutaneous routes of administration. Mucosal immunization with PcpA does not protect against nasal colonization with this strain. This is expected since PcpA is not expressed during colonization.

Example 3. Antibody elicited by subcutaneous or intranasal immunization with PcpA.

Sera obtained from mice immunized with PcpA were examined for the level of antibody to PcpA. CBA/N mice were immunized either subcutaneously (SC) with aluminum hydroxide or cholera toxin B subunit (CTB) as the adjuvant on days 0 and 14, and with PcpA alone on day 21. On day 35 mice were bled and the antibody levels in the serum were determined by using as a standard the OD observed with a known concentrations of PspA antibodies reacting with PspA-coated microtitration plates. As controls, additional groups of mice were immunized with diluent and adjuvant alone. A 1.3-fold higher IgG antibody response was observed with SC rather than intranasal (IN) immunization (Table 5).

Table 5. Antibodies to PcpA in mice immunized with PcpA

		Ig(H+L)	IgG1	IgG2a	IgG2b	IgA
rPcpA Route of Admin.	**Group**	**Mean μg/ml (± SEM)**				
S.C.	rPcpA + Adjuvant (n=10)	0.465(0.159)	1.768(0.378)	0.123(0.041)	0.125(0.048)	<0.001
S.C.	Adjuvant alone (n=10)	0.002(0.002)	0.007(0.007)	<0.001	0.002(0.001)	<0.001
I.N.	rPcpA + Adjuvant (n=10)	0.356(0.159)	0.151(0.085)	0.118(0.057)	0.093(0.033)	<0.001
I.N.	Adjuvant alone (n=10)	<0.001	<0.001	<0.001	<0.001	<0.001

As is common with this type of assay, the amounts of the subclasses did not add up to the amount of total Ig. This is an indication that anti-IgG serum does not recognize all IgG subclasses equally.

Example 4. PcpA is necessary for adherence to lung cells.

PcpA is necessary for adherence to the A549 cell line of transformed lung epithelial cells (Fig. 9) but not to the Detroit562 line of transformed human nasal epithelial cell (Fig. 10). It was observed that adherence to the A549 lung epithelial cells also required that the pneumococci be grown in low Mn^{2+} so that they would produce PcpA. The pneumococci for these studies were grown in Todd-Hewitt and Yeast medium (high Mn^{2+}) or Todd-Hewitt and Yeast Medium that had been passed over Chelex-100 (Sigma) and reconstituted with 0.1 μm $MnSO_4$ and 1 mM $ZnCl_2$, $MgCl_2$, $CaCl_2$, and $FeSO_4$. (low Mn^{2+}) (Briles et al., *J. Infect. Dis.* 188:339-48 (2003)). The Detroit 562 or A549 cells monolayers were incubated for 150 minutes with 10^6 CFU of TIGR4 (*pcpA*+) or JEN11 (*pcpA*- TIGR4 strain). The epithelial cells with adherent bacteria were washed and lysed with 0.5% Tween 20. The numbers of pneumococci in the lysate were determined by quantitative plating on blood agar plates.

Adherence of pneumococci to A549 cells is inhibited with antibody to PcpA (Fig. 11). These data demonstrate PcpA-dependent adherence of pneumococci to lung epithelial cells.

Example 5. Passive protection model.

Based on the ability of active immunization with PcpA to elicit protection against lung infection, it was determined whether antibody to PcpA would be able to passively protect mice from lung infection. However, passive protection has not yet been observed in a pneumonia model. In a second passive immunization study, passive protection against IV sepsis with the TIGR4 strain was determined using immune rabbit sera to PcpA. It was observed that the highest concentration of sera tested (1/10) was able to protect two of mice from death (Fig. 12). A non-immune serum was not able to protect at the same concentration. These data suggest that passive immunization can protect against TIGR4 strain, which can be a difficult strain to protect against (Roche et al., *Infect. Immun.* 71:4498-505 (2003)).

Example 6. Protection by PcpA and Pneumolysin.

Pneumolysin (Ply) is another protein that can elicit some protection against lung infection (Briles et al., *J. Infect. Dis.* 188:339-48 (2003)). Since pneumolysin and PcpA are both candidates for use in protein-based pneumococcal vaccines, it was determined whether the two proteins produce better protection against lung infection when both are used as immunogens than when either one is used alone. Mice were immunized three times with 5 μg of PcpA, 5 μg pneumolysin, or 5 μg of PcpA plus 5 μg of pneumolysin. The first two injections were with alum and the third injections were with protein alone. The pneumolysin used here was wild-type pneumolysin. Figure 13 shows that pneumolysin elicits similar protection against lung infection to that elicited by PcpA. The combination of PcpA and pneumolysin was significantly more protective than pneumolysin alone. These data indicate that protection can be conferred using both PcpA and pneumolysin.

Example 7: Cross-protection against other pneumococci.

To determine whether PcpA elicits cross protection, strains in addition to those described in Examples 1-2 can be tested using the methods described above. For

studies of sepsis, strains such as WU2, A66, BG7322, EF6796, D39 in addition to TIGR4 are tested. These strains are of capsular types 3, 3, 6B, 6A, and 2. To examine lung infection, strains that work well in a mouse model of focal lung infection are used. These strains include EF9309, TG0893, L82016, BG7322 and EF6796. These are capsular types 23F, 14, 6B, 6B, and 6A.

Example 8. Presence of PcpA in mice.

CD1 outbred mice or CBA mice are infected with pneumococci in colonization, pneumonia and fatal sepsis models. Biological samples from lung wash, nasal wash, blood, and urine are obtained. Samples from mice with colonization and pneumonia are collected 6 days after inoculation. Samples from mice with sepsis following IN inoculation will be collected at 2 or 3 days post infection. EF3030 (type 19F), TJ0893, type 14, and EF9393 (type 23) are used for focal pneumonia. These strains cause focal pneumonia when $5x10^5$ CFU are administered IN in 40 µl of Ringer's injection solution while mice are anesthetized. If the same number of CFU is given IN in 10µl of Ringers without anesthesia mice are colonized but never achieve more than a couple hundred CFU in their lungs. To achieve pneumonia followed by sepsis mice will be given strains L82016 (type 6B) and TIGR4 (type 4). All of these strains can also be used in colonization models.

Mouse urine is collected by picking the mice up and holding the animal over a collection tube. The mice are also anesthetized with isoflurane (Attane; Minrad Inc), and bled by heart puncture, and serum was collected. The mice are then euthanized with an overdose of CO_2 and tested with a tail pinch to make sure they are unconscious. Next the trachea is severed and 0.5 ml of Ringers solution are pushed though the trachea and out the nose to obtain a nasal wash. The lungs are likewise lavaged with 0.5 ml of Ringers to obtain a lung wash. The washed nasal tissue and lung tissue from each mouse is homogenized in 0.5 ml volumes.

Each sample obtained from each mouse is quantitated by plating on blood agar plates to confirm disease in the mouse and to determine the numbers of live pneumococci, if any, in the particular fluid sample or tissue extract.

Each sample is assayed for PcpA content in serial dilution using ELISA capture assay. The PcpA is detected on whole pneumococci, pneumococcal

fragments, or as a free protein released during autolysis of pneumococci *in vivo*. PcpA is observed in the lung wash or lung homogenate of mice with focal or septic lung infections but not from colonized mice even though the numbers of CFU seen in colonization with these strains is similar in colonization as well as focal pneumonia. Little to no PcpA is observed in a nasal wash of mice that are colonized or mice with lung infection.

Example 9. Presence of PcpA in humans.

Biological samples from a subject are assayed in a capture ELISA. AP-conjugated antibody used to detect the antibody in the top level of the sandwich is pre-absorbed so that it does not cross-react with the antibody used to capture the PcpA on the microtiter plate surface. One way to do this is to use the same species of antibody to detect the second layer of anti-PcpA as was used for the first layer. For example, if the plate is coated with rabbit anti-PcpA as a capture reagent and a mouse anti-PcpA is used to detect the bound PcpA, then if a commercial rabbit anti-mouse reagent is used to detect the mouse antibody to PcpA, there should be no reactivity of this antibody with the rabbit Ig used to initially coat the plates. Another approach can be to use a AP-conjugated IgG-specific MAb to develop the assay.

A positive control for this assay is a recombinant rPcpA of known concentration. After the concentration of the rPcpA is determined, it is diluted in 1% BSA, aliquoted and stored frozen at -80°C. A second positive control is a lysate of pneumococci grown in low Mn2+ conditions so that it contains PcpA. This lysate is aliquoted and stored at -80°C. Since the standard contains a known concentration of PcpA, based on protein assay, the exact sensitivity of the assay is known and nanogram concentrations of PcpA is determined in each fluid examined. Negative controls in the assay include a) the use of normal rabbit serum instead of the capture serum, b) the use of normal mouse serum in place of the detection serum, c) the absence of any PcpA containing solution (samples from non-infected mice or humans), and d) the absence of the anti-mouse Ig AP-conjugated rabbit antibodies. PcpA is detected on whole pneumococci, pneumococcal fragments, or as a free protein released during autolysis of pneumococci *in vivo*. PcpA observed in the

biological samples indicates the subject has pneumonia. Little to no PcpA is observed in a nasal wash of subjects that are colonized.

Example 10 Use of Ratio of a colonization antigen and an invasive antigens to diagnose pneumonia.

Pneumonia can be diagnosed by determining the ratio of the concentration of an invasive antigen such as, for example, PcpA to the concentration of a colonization antigen such as, for example, NanA. The detection of NanA is done with a capture ELISA using antibodies to NanA. High ratios of PcpA:NanA are associated with pneumonia while low ratios of PcpA:NanA are associated with the absence of pneumonia. For example, a ratio of 2:1, PcpA:NanA, indicates pneumococcal pneumonia in the subject while a ratio of 1:2, PcpA:NanA, indicates the subject does not have pneumococcal pneumonia. This approach may help eliminate any false positives due to antigens produced during minimal invasion that is sometimes associated with colonization (Briles et al. Infect. Immun. 73:6945-6951 (2005)).

Publications cited herein and the material for which they are cited are hereby specifically incorporated by reference in their entireties.

WHAT IS CLAIMED IS:

1. A method of diagnosing pneumococcal pneumonia in a subject comprising:

a) obtaining a biological sample from a subject; and

b) detecting in the biological sample the presence of one or more pneumococcal antigens selectively expressed during invasive disease, wherein the presence of the antigen indicates pneumococcal pneumonia in the subject.

2. A method of diagnosing pneumococcal pneumonia in a subject comprising:

a) obtaining a biological sample from a subject; and

b) detecting in the biological sample the presence of one or more pneumococcal antigens expressed in the presence of low concentrations of Mn2+, wherein the presence of the antigen indicates pneumococcal pneumonia in the subject.

3. The method of claim 1 or 2, wherein the biological sample is a biological fluid.
4. The method of claim 3, wherein the biological fluid is selected from the group consisting of blood, serum, sputum, lung lavage and urine.
5. The method of claim 1 or 2, wherein the biological sample is not from the nasal cavity of the subject.
6. The method of claim 1 or 2, wherein the subject is not bacteremic.
7. The method of claim 1 or 2, further comprising the step of detecting in the biological sample the presence of C-polysaccharide.
8. The method of claim 7, further comprising determining the ratio of PcpA to C-polysaccharide in the biological sample.
9. The method of claim 8, wherein a ratio of X indicates pneumococcal pneumonia in the subject.
10. The method of claim 1 or 2, wherein the antigen is not expressed during colonization.
11. The method of claim 1, wherein the antigen is expressed in the presence of low concentrations of Mn2+.
12. The method of claim 1 or 2, wherein the detecting step is carried out using an immunological method.
13. The method of claim 1 or 2, wherein the detecting step is carried out using ELISA.

14. The method of any one of claims 1 to 13, wherein the antigen is PcpA.
15. The method of any one of claims 1 to 13, wherein the antigen is selected from the group consisting of PcpA, PsaA, PsaB, PsaC, rrgA, rrgB, rrgC and srtB.
16. The method of any one of claims 1 to 13, wherein the antigen is selected from the group consisting of pfl, septation ring formation regulator EzrA, SecA subunit, StpK, galT, ORF00431, ORF00767, prtA and psrP.

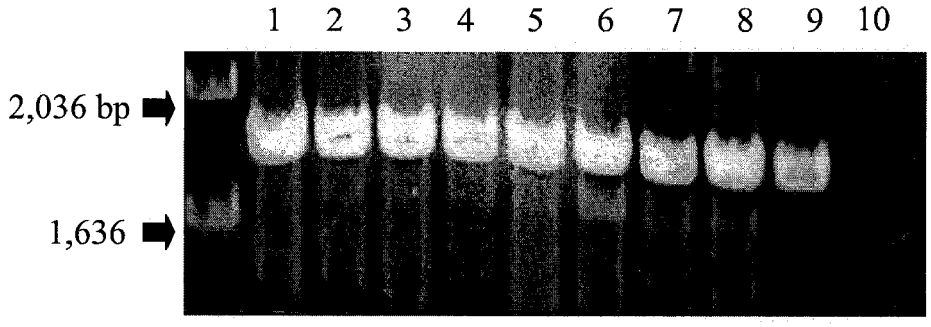


FIG. 1

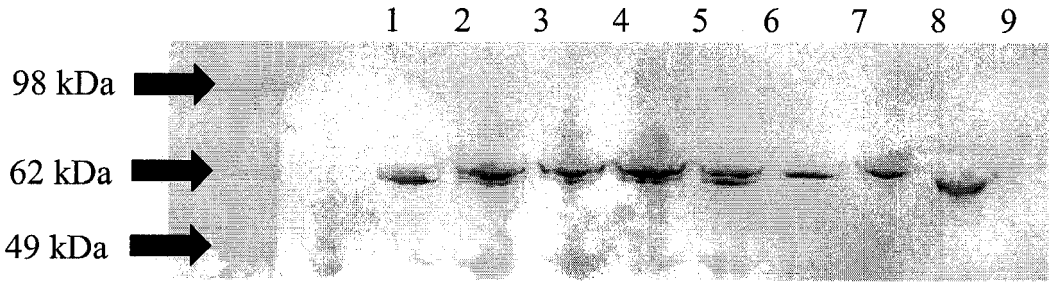
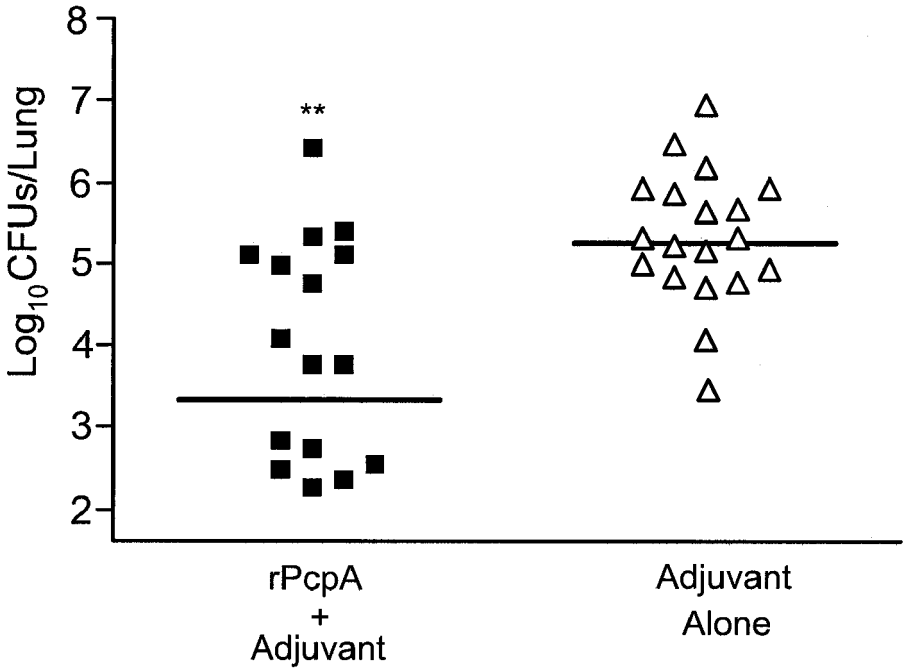


FIG. 2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6
5
4
3
2
Log10CFUs/Lung
**
rPcpA
+
Adjuvant
Adjuvant
Alone

FIG. 3A

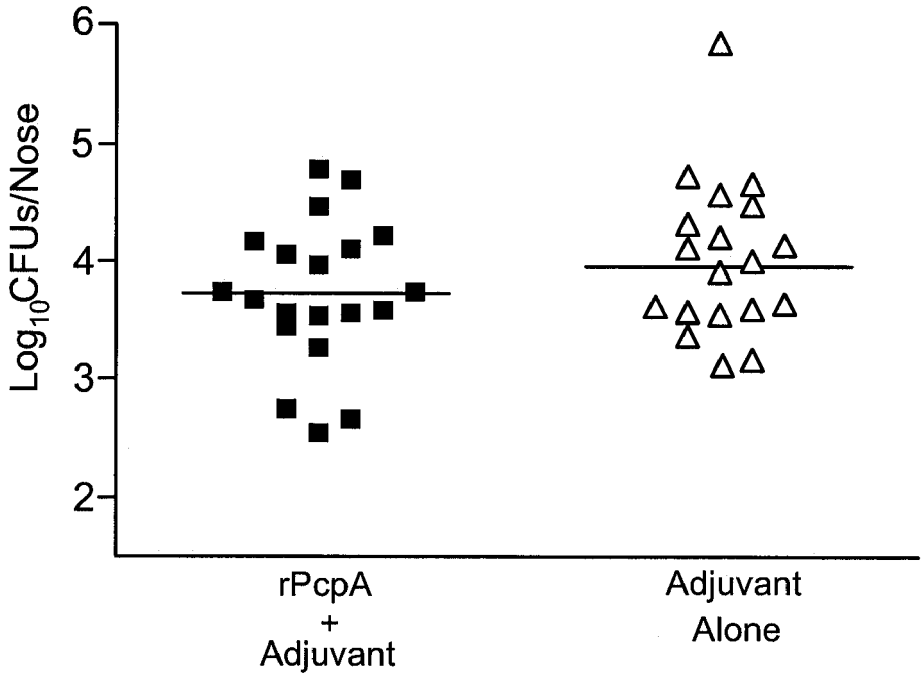

6
5
4
3
2
Log10CFUs/Nose
rPcpA
+
Adjuvant
Adjuvant
Alone

FIG. 3B

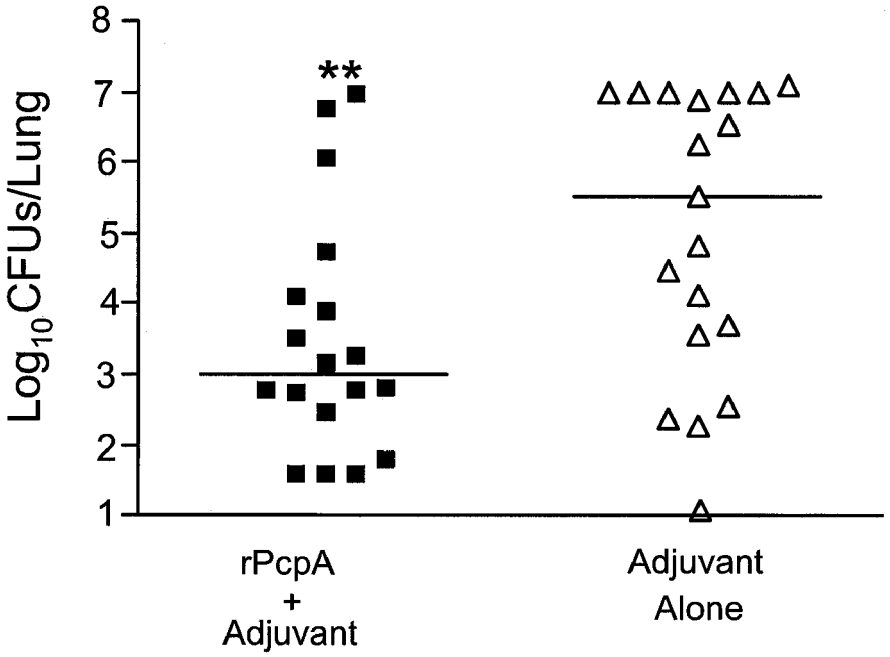
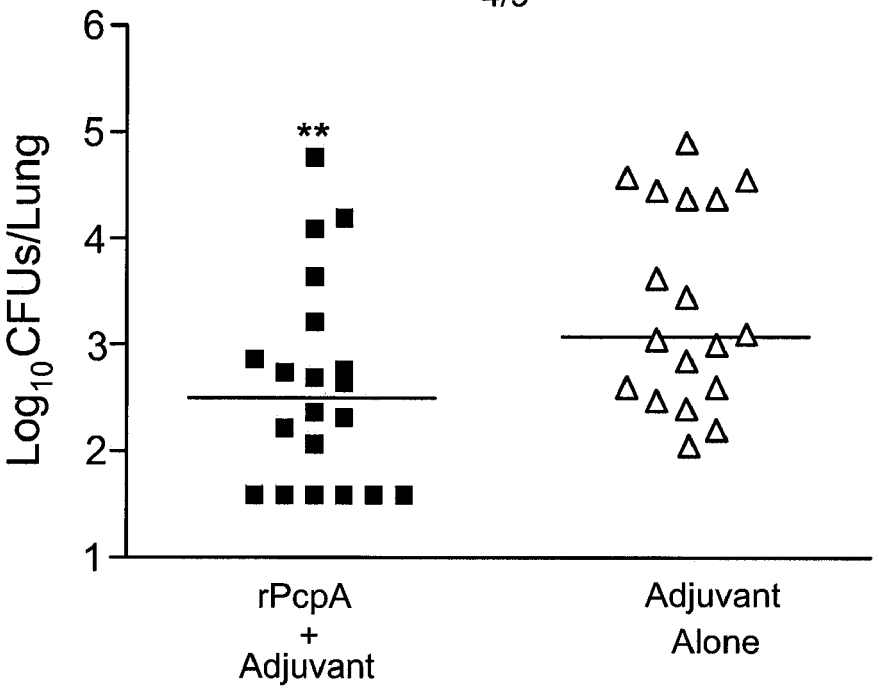


FIG. 4A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4
3
2
1
Log10CFUs/Lung
**
rPcpA
+
Adjuvant
Adjuvant
Alone

FIG. 4B

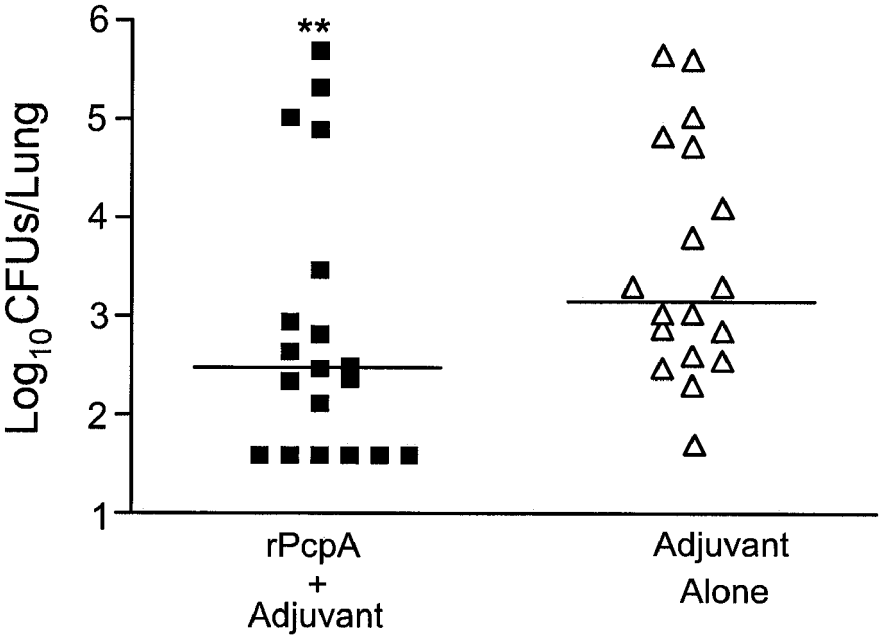

6
5
4
3
2
1
Log10CFUs/Lung
**
rPcpA
+
Adjuvant
Adjuvant
Alone

FIG. 4C

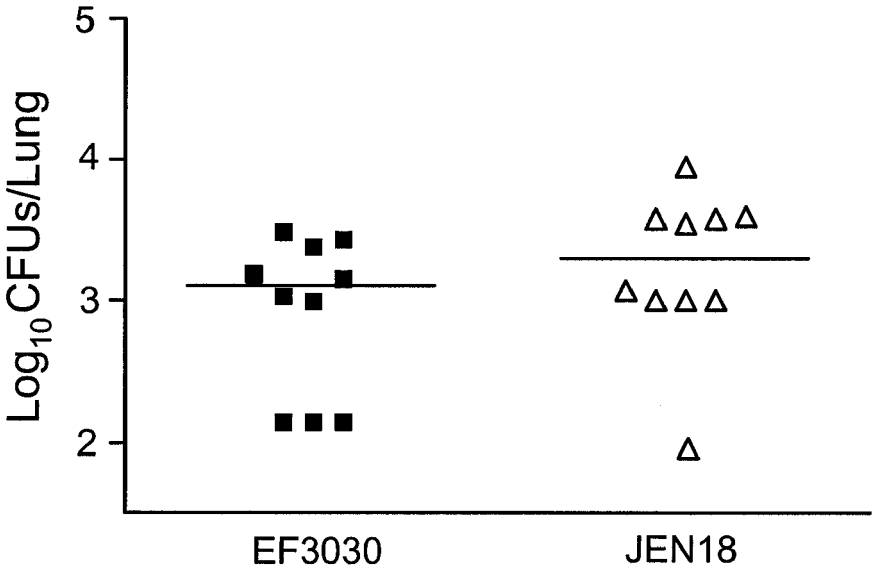

5
4
3
2
Log10CFUs/Lung
EF3030
JEN18

FIG. 5

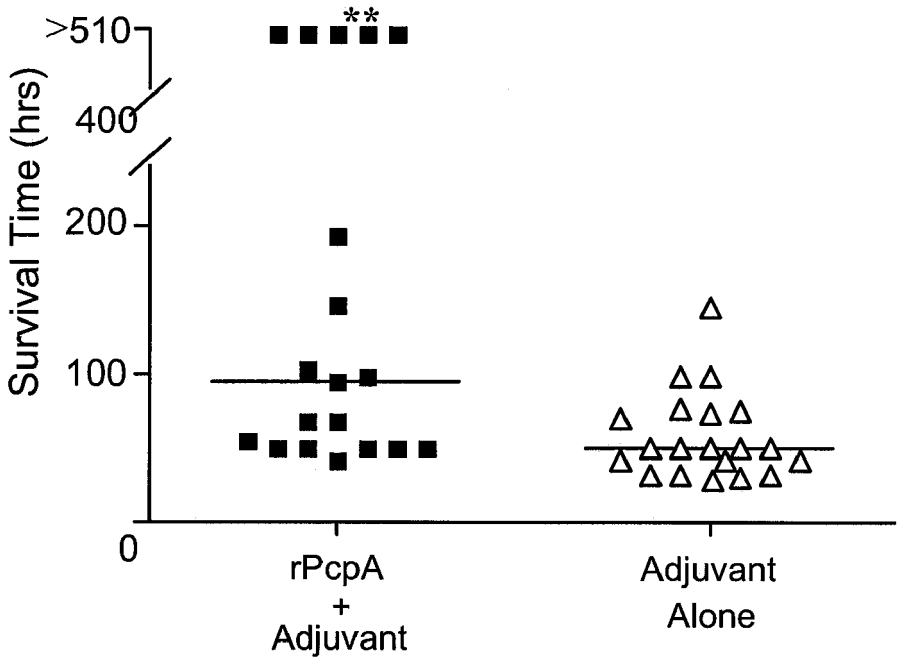

**
>510
400
200
100
0
Survival Time (hrs)
rPcpA
+
Adjuvant
Adjuvant
Alone

FIG. 6

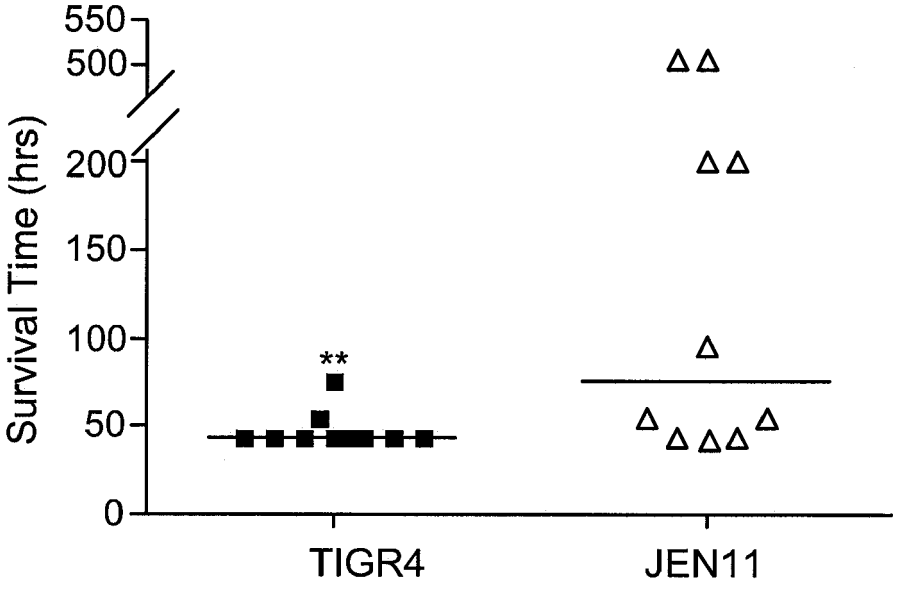
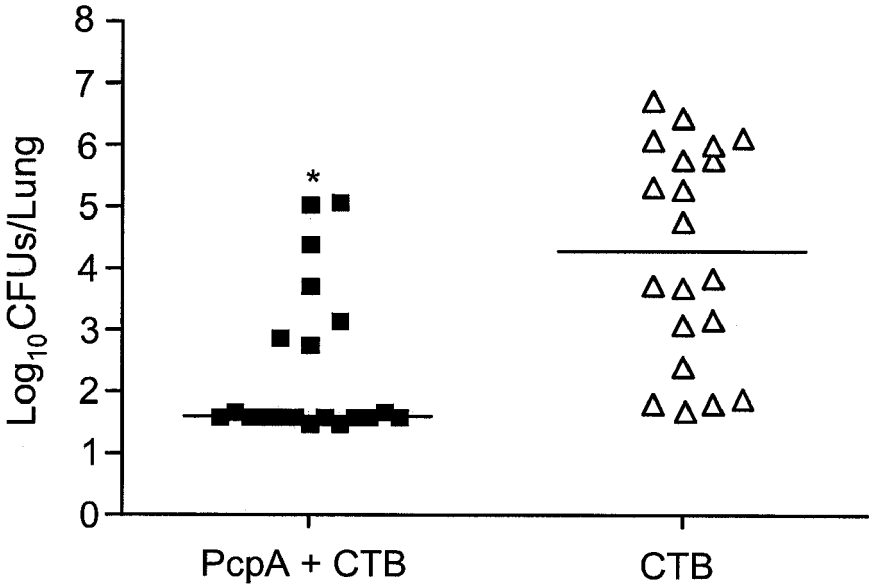

550
500
200
150
100
50
0
Survival Time (hrs)
**
TIGR4
JEN11

FIG. 7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7
6
5
4
3
2
1
0
Log10CFUs/Lung
*
PcpA + CTB
CTB

FIG. 8

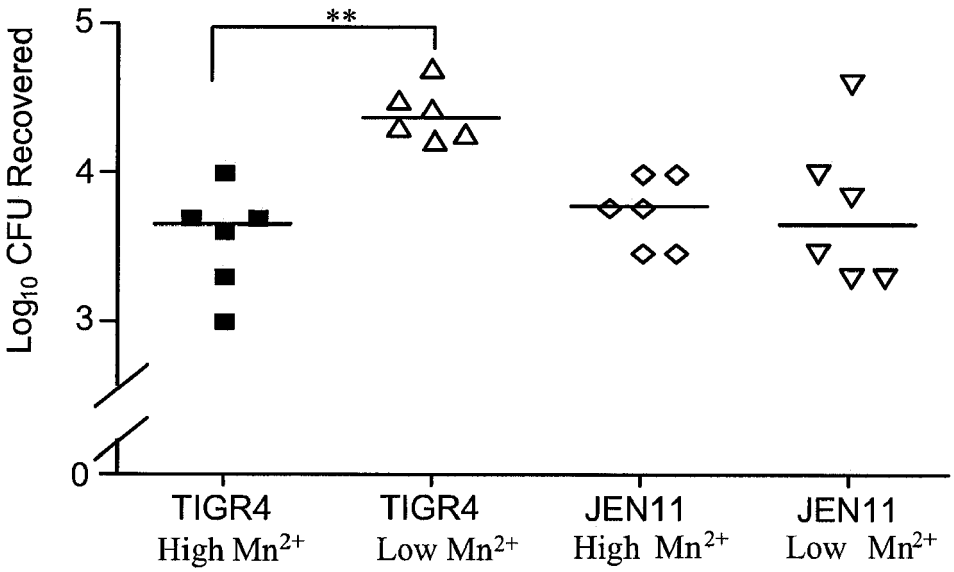
**
5
4
3
0
Log10 CFU Recovered
TIGR4
High Mn2+
TIGR4
Low Mn2+
JEN11
High Mn2+
JEN11
Low Mn2+

FIG. 9

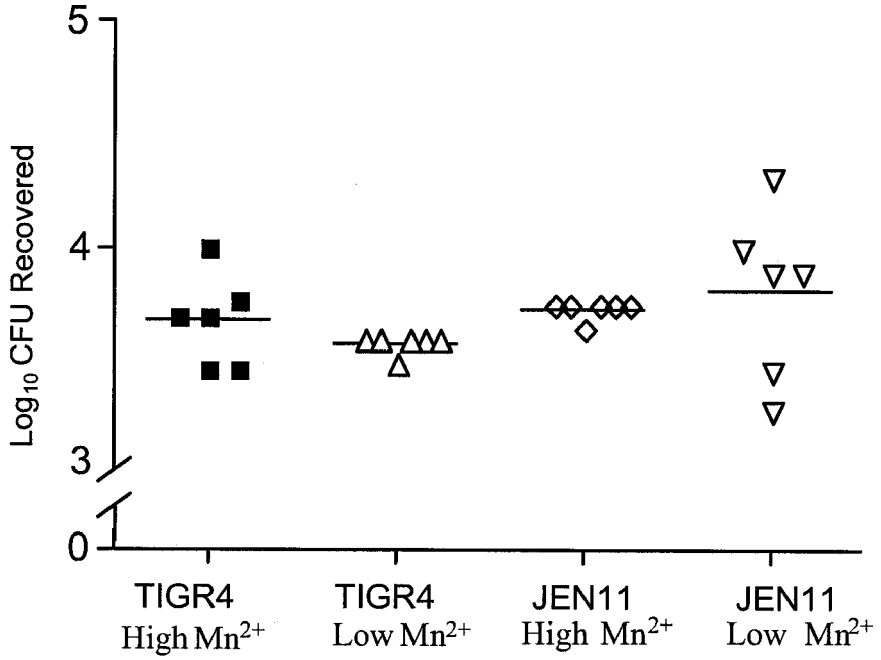
5
4
3
0
Log10 CFU Recovered
TIGR4
High Mn2+
TIGR4
Low Mn2+
JEN11
High Mn2+
JEN11
Low Mn2+

FIG. 10

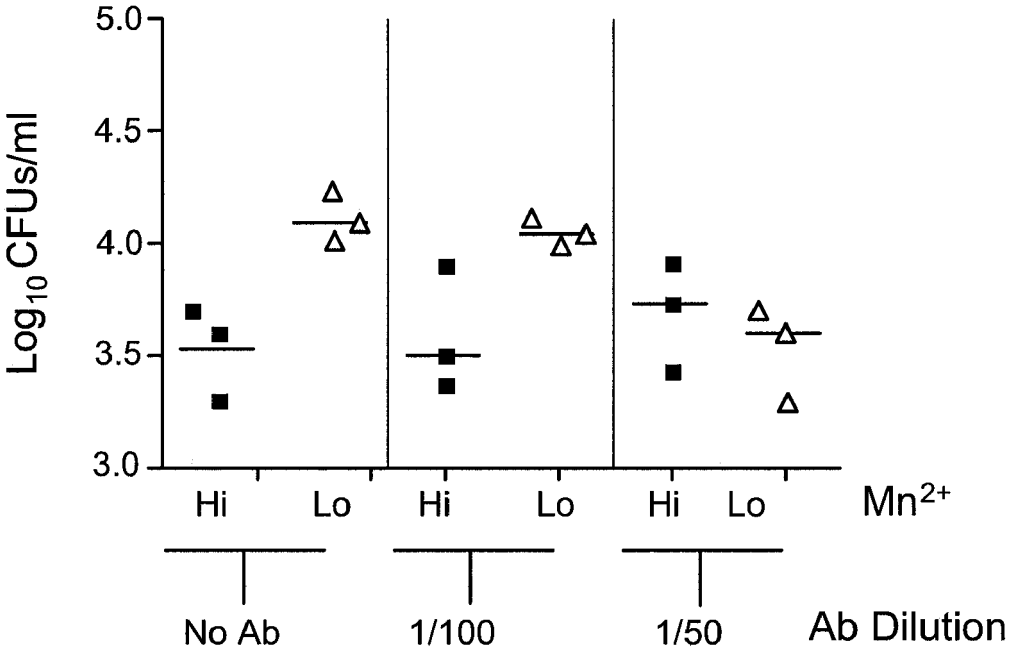
5.0
4.5
4.0
3.5
3.0
Log10CFUs/ml
Hi
Lo
Hi
Lo
Hi
Lo
Mn2+
No Ab
1/100
1/50
Ab Dilution

FIG. 11

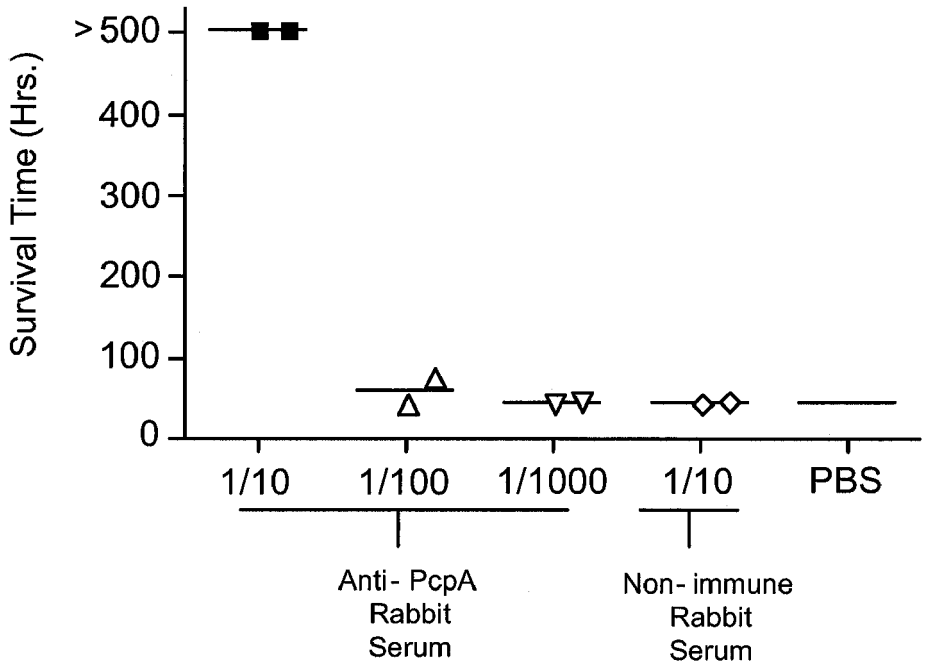
> 500
400
300
200
100
0
Survival Time (Hrs.)
1/10
1/100
1/1000
1/10
PBS
Anti- PcpA Rabbit Serum
Non- immune Rabbit Serum

FIG. 12

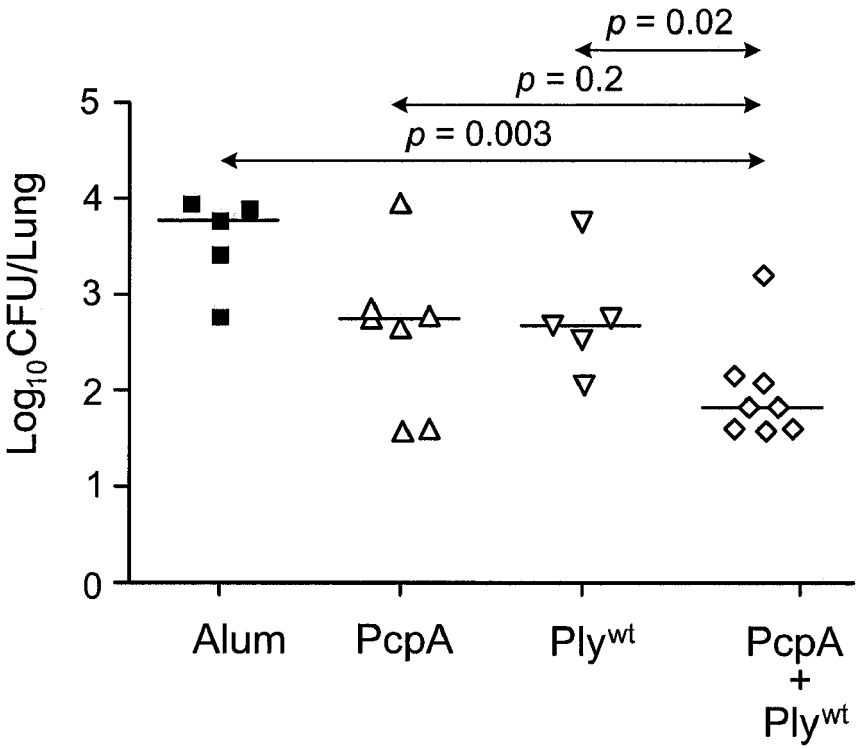
p = 0.02
p = 0.2
p = 0.003
Log10CFU/Lung
5
4
3
2
1
0
Alum
PcpA
Plywt
PcpA + Plywt

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/076172

A. CLASSIFICATION OF SUBJECT MATTER

G01N 33/53(2006.01)i, G01N 33/49(2006.01)i, G01N 33/487(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 8 G01N 33/53, G01N 33/49, G01N 33/487

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and application for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKIPASS (KIPO internal), Delphion, NCBI PubMed (pneumonia, pneumococc*, diagnos*, antigen, PepA, C-polysaccharide and similar terms)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US 6,500, 613 B1 (DAVID E. BRILES, et al.) 31. December 2002. See the whole document especially column 1.	1 ------ 2-13
X --- A	US 6,217,884 B1 (JACQUELYN S. SAMPSON, et. al.) 17. April 2001. See the whole document especially abstract.	1 ------ 2-13
X --- A	US 6, 245, 335 B1 (H. ROBERT MASURE, et al.) 12. June 2001. See the whole document especially columns 10-12.	1 ------ 2-13
X --- A	US 6, 784, 164 B2 (H. ROBERT MASURE, et al.) 31. August 2004. See the whole document especially columns 5-8.	1 ------ 2-13

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
28 DECEMBER 2007 (28.12.2007)	**28 DECEMBER 2007 (28.12.2007)**
Name and mailing address of the ISA/KR Korean Intellectual Property Office 920 Dunsan-dong, Seo-gu, Daejeon 302-701, Republic of Korea Facsimile No. 82-42-472-7140	Authorized officer AHN, Kyu Jeong Telephone No. 82-42-481-8158

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/076172

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- A	US 6, 592, 876 B1 (DAVID E. BRILES, et al.) 15. July 2003. See the whole document especially column 1.	1 ---- 2-13
X ----- A	S. H. GILLESPIE, et al. 'Detection of C-polysaccharide in serum of patients with Streptococcus pneumoniae bacteraemia.' In J. Clin. Pathol. (1995) Vol.48:803-806. See the whole document especially abstract.	1 ---- 2-13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/076172

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

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

1. ☒ Claims Nos.: 1-16
because they relate to subject matter not required to be searched by this Authority, namely:
Although the subject matter of claims 1-13 directed to a diagnosing method and is subject matter which the International Searching Authority is not required to search under PCT Article 17(2)(a)(I) and Rule 39(iv), the search has been carried out. The subject matter of claims 14-16 directed to a diagnosing method and is subject matter which the International Searching Authority is not required to search under PCT Article 17(2)(a)(I) and Rule 39(iv).

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

3. ☒ Claims Nos.: 14-16
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

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

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

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

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

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/076172

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US06500613B1	31.12.2002	US2004077847A1	22.04.2004
		US2004077847AA	22.04.2004
		US6500613BA	31.12.2002
		US7078042BB	18.07.2006
US06217884B1	17.04.2001	US2003105307A1	05.06.2003
		US2003105307AA	05.06.2003
		US2003204074AA	30.10.2003
		US6217884BA	17.04.2001
		US6773880BB	10.08.2004
		US7045132BB	16.05.2006
US06245335B1	12.06.2001	US2003175293A1	18.09.2003
		US2003175293AA	18.09.2003
		US6245335BA	12.06.2001
		US6784164BB	31.08.2004
US06784164B2	31.08.2004	US2003175293A1	18.09.2003
		US2003175293AA	18.09.2003
		US2005048590A1	03.03.2005
		US2005048590AA	03.03.2005
		US6784164BB	31.08.2004

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/076172

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US06592876B1	15.07.2003	AT322279E	15.04.2006
		AU199672392B2	01.04.1997
		AU199923626A1	01.07.1999
		AU236269A1	01.07.1999
		AU703434B2	25.03.1999
		AU7239296A1	01.04.1997
		CA2232033AA	20.03.1997
		DE69636017C0	18.05.2006
		EP00946188B1	05.04.2006
		EP01477185A2	17.11.2004
		EP946188A1	06.10.1999
		EP946188A4	02.05.2003
		EP946188B1	05.04.2006
		FI980561A	13.05.1998
		FI980561A0	13.03.1998
		JP11513371T2	16.11.1999
		JP11513371	16.11.1999
		N0981169A	15.05.1998
		N0981169A0	16.03.1998
		US2004077847A1	22.04.2004
		US2004077847AA	22.04.2004
		US6500613BA	31.12.2002
		US6592876BA	15.07.2003
		US7078042BB	18.07.2006
		W09709994A1	20.03.1997

专利名称(译)	诊断肺炎球菌肺炎		
公开(公告)号	EP2059807A1	公开(公告)日	2009-05-20
申请号	EP2007814201	申请日	2007-08-17
[标]申请(专利权)人(译)	UAB研究基金会		
申请(专利权)人(译)	UAB的研究基金会		
当前申请(专利权)人(译)	UAB的研究基金会		
[标]发明人	BRILES DAVID E HOLLINGSHEAD SUSAN K		
发明人	BRILES, DAVID E. HOLLINGSHEAD, SUSAN K.		
IPC分类号	G01N33/53 G01N33/49 G01N33/487 C07K14/315 A61K39/09		
CPC分类号	A61K2039/575 C07K14/3156 A61P11/00 A61P13/00 A61P13/12 A61P25/00 A61P27/16 A61P31/00 A61P31/04 G01N33/56944 G01N2400/10		
优先权	60/822715 2006-08-17 US 60/827348 2006-09-28 US 60/917178 2007-05-10 US		
其他公开文献	EP2059807A4 EP2059807B1		
外部链接	Espacenet		

摘要(译)

描述了用于引发针对肺炎链球菌的免疫应答的组合物和方法。更具体地，本公开涉及免疫原性PcpA多肽，包括PcpA的片段及其变体，以及编码所述多肽的核酸。本公开进一步涉及制备和使用免疫原性多肽的方法。还提供了通过从受试者获得生物样品并检测在侵入期间选择性表达的一种或多种肺炎球菌抗原（例如，PcpA或其片段）来诊断受试者中肺炎球菌感染（例如肺炎）的方法。