Introduction and Rationale

Community-acquired pneumonia (CAP) continues to be a one of the leading causes of morbidity and mortality worldwide [1-3]. The prevalence of *Streptococcus pneumoniae* in CAP, especially non-bacteremic pneumococcal CAP, is likely underestimated due to a lack of sensitive diagnostic assays [4]. A traditional etiologic approach to subjects with CAP requiring hospitalization includes obtaining blood and/or sputum cultures. Although cultures are highly specific, their sensitivity is low [5]. Despite difficulty in identifying etiologic agents associated with CAP, *S. pneumoniae* was estimated to cause nearly 600,000 cases of pneumonia among United States (U.S.) adults >18 years of age in 2004, of which approximately 50% occurred in subjects aged >65 years and older [6].

In 2000, a 7-valent pneumococcal conjugate vaccine (PCV7) was introduced into the U.S. infant immunization program. This vaccine was replaced in 2010 with a 13-valent pneumococcal conjugate vaccine (PCV13). This vaccination program has had a well-documented and significant public health impact among those vaccinated [1, 7-12], and unvaccinated children and adults have benefited from indirect (herd) protection derived from the program [13, 14]. However, most of this indirect effect has been reported for invasive pneumococcal disease; the impact in non-invasive pneumonia is not entirely understood.

One screening method for detecting infection by *S. pneumoniae* is the BinaxNOW® kit provided by Alere™. This commonly used rapid assay tests for the presence of pneumococcal C-polysaccharide (C-PS) antigens in the urine using an immunochromatographic membrane test kit. The sensitivity of this assay is documented by the manufacturer as 86% for bacteremic pneumococcal pneumonia [15]. While the BinaxNOW® assay detects C-PS antigen, which is present in all *S. pneumoniae* strains; it does not distinguish among different pneumococcal serotypes.

More recently, a Luminex technology-based multiplex urinary antigen detection (UAD) assay has demonstrated the ability to simultaneously detect 13 different *S. pneumoniae* serotype-specific capsular polysaccharides in human urine [16]. These
polysaccharides correspond to the 13 serotypes in PCV13 (1, 3, 4, 5, 6A, 6B, 7F, 9V, 14, 18C, 19A, 19F, and 23F). A notable advantage of this UAD assay is its ability to combine multiple distinct beads, each conjugated to a different serotype-specific monoclonal antibody, in a single well with the urine to be tested. This allows the detection of all 13 polysaccharides simultaneously using only a small sample volume. The UAD assay has demonstrated greater sensitivity than culture or BinaxNOW® urinary antigen detection and excellent specificity in a convenience sample obtained from 776 subjects with radiographically confirmed CAP [16], and in a separate prospective study of adults with radiographically-confirmed pneumonia [17]. In a study conducted in 2010, the use of the UAD assay helped to demonstrate PCV7 associated serotypes were still prevalent among adults aged ≥50 years with CAP, representing 26.6% of all S. pneumoniae serotypes detected [19]. Nevertheless, the burden of both non-invasive and invasive pneumococcal disease in adults with pneumonia after the introduction of PCV13 remains unclear.

To provide more contemporary information about the proportion of radiographically-confirmed CAP in adults (≥18 years old) caused by S. pneumoniae, a large epidemiological study was undertaken. Pneumococcal serotypes were identified using the serotype-specific UAD assay and standard culture methods. Serotype distribution was estimated for the total population and incidence was calculated at selected sites. In this report we describe the methodology of the study design, including the specifics of subject selection and study procedures.

Objectives

The primary objective of this study was to estimate the proportion of pneumonia cases caused by PCV13 S. pneumoniae serotypes among adults ≥18 years of age hospitalized with radiographically-confirmed pneumonia. Secondary objectives included: 1. Description of the full distribution of detected S. pneumoniae serotypes; 2. Estimation of the incidence rate of CAP overall and CAP caused by S. pneumoniae (SP+ CAP) for sites where a population denominator could be established; and 3. Description of the differences in detection of S. pneumoniae by culture, BinaxNOW® and UAD assay.

Study Design

This prospective, multicenter, surveillance study was conducted at 21 hospitals in 10 geographically dispersed U.S. cities between October 7th, 2013 and September 30th, 2016. The institutional review board (IRB)/independent ethics committee (IEC) at each participating site reviewed and approved the protocol and informed consent form before any subjects provided consent.

Inclusion criteria

Subjects 18 years of age and older who presented to a study hospital were eligible for enrollment if they met the following criteria: 1) the presence of 2 or more of the following a) fever (oral temperature > 38°C/100.4°F or tympanic temperature >38.5°C/101.2°F) or hypothermia (<35.5°C) within 24 hours of enrollment b) chills or rigor c) pleuritic chest pain d) cough e) sputum production f) dyspnea g) tachypnea h) malaise i) abnormal auscultatory findings; 2) radiographic finding consistent with pneumonia (chest radiograph or chest computed tomography scan obtained no more than 72 hours prior to study enrollment); and 3) able and willing to provide urine samples for diagnostic evaluation.

Exclusion criteria

Subjects were excluded from the study if they: 1) were transferred from another inpatient healthcare facility after already being hospitalized for 48 hours or more; 2) had a diagnosis of hospital acquired pneumonia (ie, developed signs and symptoms of pneumonia after being hospitalized for 48 hours or more); and 3) were previously enrolled in this study within the past 30 days.

Enrollment Sites

This study enrolled subjects from 21 hospitals in 10 US cities (Akron, OH, Chicago, IL, Detroit, MI, Louisville, KY, Nashville, TN, Norfolk, VA, Houston, TX, Las Vegas, NV, San Diego, CA and Worcester, MA) (Table 1). Pneumonia incidence was calculated at sites which were able to establish a population denominator: Louisville, KY (nine hospitals), Nashville, TN (one hospital) and Chicago, IL (one hospital).

Table 1. Details of 21 enrolling hospital centers

<table>
<thead>
<tr>
<th>Institution Name</th>
<th>City</th>
<th>State</th>
<th>Setting</th>
<th>Number of Adult Beds</th>
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<tr>
<td>Norton General Hospital</td>
<td>Norton</td>
<td>VA</td>
<td>Not-for-profit community based teaching hospital</td>
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<tr>
<td>Sharp Grossmont Medical Center</td>
<td>La Mesa</td>
<td>CA</td>
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<td>Chicago</td>
<td>IL</td>
<td>Urban Academic/teaching Non-Profit Hospital</td>
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<tr>
<td>University of Louisville Hospital</td>
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<td>Urban Academic/teaching Non-Profit Hospital</td>
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<td>Rubley Rex VA Medical Center</td>
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<td>Teaching Hospital</td>
<td>109</td>
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<tr>
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<td>Detroit Receiving Hospital</td>
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<td>MI</td>
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<td>Vanderbilt University Medical Center</td>
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<tr>
<td>University of Texas Medical School at Houston</td>
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<td>TX</td>
<td>Out for profit University-affiliated tertiary care center</td>
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</tr>
</tbody>
</table>

Incidence surveillance sites

Louisville

The surveillance area for Louisville is Jefferson County, located in the northwest region of the state of Kentucky. All nine hospitals providing adult hospitalization for pneumonia were included in this study. The adult census population of Louisville was used as the denominator for incidence rate calculations, while the numerator was derived from the number of Louisville residents hospitalized for CAP. The annual population incidence rate per 100,000 adults was estimated for this catchment area. Although all eligible cases were identified, approximately 20% of patients did not consent to participate in the study (Table 2).
This 20% of unconsented CAP patients will be factored into the numerator for this site. The comprehensive management group in Louisville included over 60 team members performing functions that spanned all aspects of study management. The overall accountability remained with the Principal Investigator, however daily operations were led by the coordinating center manager. Study related activities were stratified into four categories: 1) compliance/administration, 2) data science/infrastructure, 3) clinical operations and 4) laboratory/biorepository operations. The compliance and administration group managed budgets, payments, invoicing, IRB approvals, issues of informed consent, and compliance with all federal, state, local and university study conduct requirements. The data science and infrastructure group was responsible for maintaining security of the data during collection, transmission, and storage, management of data quality monitoring meetings, development and implementation of the Data Security Plan, and implementing real-time reporting of enrollment across the coordinating center. The clinical operations team was responsible for the development of Standard Operating Procedures (SOPs) for clinical operations, the manual of operations, development of data collection forms and training in their use, study team management and training, ensuring adequate supply of materials needed for daily operations, establishing tools for assessment of coordinators as well as testing procedures and processes. Laboratory and biorepository operations developed the process for specimen collection, analysis, and tracking and documented receipt, shipment, and storage of study specimens.

Chicago and Nashville

The surveillance centers for Nashville and Chicago are located at Vanderbilt University Medical Center and Northwestern Memorial Hospital, respectively. Each represents only one of multiple hospitals in the Nashville and Chicago regions, respectively. Both are large urban hospitals serving adult general medical and surgical patients. For the Nashville site, patients were enrolled from 9 counties around Nashville area (Cheatham, Davidson, Dickson, Montgomery, Robertson, Rutherford, Sumner, Trousdale, and Williamson). Eight other hospitals in the area treat adult pneumonia. Thus, the cases enrolled at this site did not represent all cases in this catchment area (nine counties); however estimations of incidence were performed by applying market share estimation. The Tennessee Hospital Discharge Data System (HDDS) database was used to determine the percentage (market share) of CAP hospitalizations contributed by Vanderbilt University hospital among the total hospitals within the nine counties. All hospitals in Tennessee are required to report discharge diagnoses for each hospitalization, emergency department visit and outpatient clinic visit to the HDDS system.

The incidence from the Chicago site was also calculated using the market share method. COMPdata-Illinois Health and Hospital Association provided the market share for Northwestern Memorial Hospital pneumonia hospitalizations among Cook County residents [16]. Approximately 32% of CAP patients did not provide consent for enrollment in the study. This will be factored into the incidence calculation for this site.

### Table 2. Estimated catchment area denominator and market share for incidence calculations

<table>
<thead>
<tr>
<th>Year of data</th>
<th>Nashville</th>
<th>Louisville</th>
<th>Chicago</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market share ages 18-64 years</td>
<td>3.63%</td>
<td>4.57%</td>
<td>6.38%</td>
</tr>
<tr>
<td>Market share ages 65+</td>
<td>14.30%</td>
<td>13.39%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Adjusted for an estimated 32% non-consented rate.

Adjust for a 20% non-consented rate.

**Subjects**

Subjects with suspected pneumonia who provided written informed consent were screened for inclusion in the study. Subjects were actively identified during normal day to day procedures at participating centers. Subject recruitment included at a minimum a daily review of the emergency department and admission records for potential subjects, as well as doctor-to-doctor communication regarding the study. Subjects identified outside of normal daily procedures were also contacted, evaluated and recruited on the following calendar day. Sites used for the estimation of incidence employed several approaches to ensure complete identification of all patients meeting study criteria. In Louisville, the Clinical Research Coordinating Center at the University of Louisville Division of Infectious Diseases operationalized the project across all nine participating hospitals. Adult patients presenting to participating hospitals with the following conditions were assessed via electronic medical records (EMR) for inclusion in the study: respiratory failure, congestive heart failure, aspiration, stroke, urinary tract infection, confusion, and altered mental status. Initial radiographic findings were reviewed for patients meeting any of the criteria. Patients with findings consistent with pneumonia were approached for inclusion in the study.

Eligible patients presenting in Nashville were identified electronically utilizing the EMR system at Vanderbilt University Medical Center (StarPanel®). The system was programmed to alert the study team of chest x-ray and CT findings potentially consistent with pneumonia. Research team members stationed in the emergency department were then dispatched to further evaluate patients for inclusion. In Chicago, individual research coordinators screened hospital admission records daily for patients meeting inclusion criteria. Identified patients were subsequently contacted for further evaluation for study inclusion.

### Study Procedures

Results of chest imaging (X-ray or CT scan) performed per the standard of care were recorded. Images obtained within 72 hours prior to the signing of informed consent could be used in addition to those obtained at the time of hospitalization. Upon confirmation of eligibility, further information was collected, including demographic information, pneumonia severity index (PSI) and medical history (including chronic obstructive pulmonary disease [COPD], asthma, congestive heart failure [CHF], coronary artery disease, chronic kidney disease, diabetes and liver disease, immunosuppressive therapy, autoimmune disease, HIV/AIDS, solid and hematologic tumors and organ.
transplantation). Self-reported vaccination status was collected for influenza (within the previous year) and pneumococcal vaccine exposure (within the previous five years).

Urine was collected via micturation as soon as possible following the signing of the informed consent. Urine samples were frozen and stored for subsequent UAD and BinaxNOW® testing. If a blood culture was not obtained as standard of care, it was performed by the study team within 24 hours of study enrollment. Available results of blood and respiratory cultures (sputum, tracheal aspirate, bronchial washing, pleural fluid, etc.), including antibiotic susceptibility testing, were recorded.  

*S. pneumoniae* isolates obtained from the sites were sent to a central laboratory for confirmation of the pathogen and serotype identification.

**Assessments**

Subjects had a final diagnosis recorded based on available data, including both study and standard of care exams, procedures and tests through hospital discharge or hospitalization day 10, which ever occurred first. Principal investigators confirmed whether the subject had clinical and radiographically confirmed pneumonia and recorded the subjects’ vital status. A final assessment was conducted to determine subject vital status at 30 days post-enrollment, either by phone call or follow-up as standard of care.

**Urine assays**

The BinaxNOW® antigen test is a rapid assay for the qualitative detection of *S. pneumoniae* antigen in the urine of patients with pneumonia [20]. The UAD is a validated limit assay with defined positivity cut-off limits and is based on the ability of individual serotype-specific monoclonal antibodies to detect the polysaccharides of the 13 serotypes covered by PCV13 in urine.

**Statistics**

**Sample Size Determination**

The primary objective of this study was to estimate the proportion of adults hospitalized with CAP infected with a PCV13 *S. pneumoniae* serotype. Sample size determination was based on the 95% confidence interval around this proportion. With a sample size of 216 subjects at each site and an expected proportion of 0.10, an approximate 95% confidence interval will be ±0.04 at a given site.

**Analyses**

The primary study analysis population was comprised of subjects meeting all inclusion criteria, with a final diagnosis of CAP, and no evidence of pneumococcal vaccination within 30 days prior to enrollment. A subject with SP+CAP was defined as a patient meeting criteria for CAP and with *S. pneumoniae* identified by UAD, BinaxNOW®, or cultures. The primary endpoint of this study was the proportion of subjects with clinically (confirmed diagnosis of CAP at final assessment) and radiographically-confirmed CAP who had any of the *S. pneumoniae* serotypes from the PCV13 vaccine based on the UAD assay or culture. This proportion was summarized for all sites with 95% confidence interval using the exact method. The proportion of subjects with PCV13 vaccine type (VT) and non-vaccine type (non-VT) *S. pneumoniae* was summarized by site and geographic region in the full analysis population. To examine the differences in detection by the different methods, the proportion of subjects with detection of *S. pneumoniae* by culture, BinaxNOW®, and UAD assay were summarized by method (among patients with tests performed). Serotype distribution of *S. pneumoniae* isolates was described by determining the proportion of subjects for each of the *S. pneumoniae* serotypes. Antibiotic resistance rates of *S. pneumoniae* isolates were also determined.

**Incidence**

For sites with well-defined catchment areas, annual pneumonia incidence rates per 100,000 at risk population were estimated. All incidence rates were computed separately, as well as an annualized rate of the two study years combined. The numerators for each of the incidence rate calculations were the respective numbers of cases during the designated time periods as operationalized in the case definitions; the denominators were the corresponding estimated population figures provided by the US census bureau. Ninety-five percent confidence intervals, based on the Poisson distribution were computed for all incidence rates. Incidence rates were also computed for key-sub-groups (e.g., age and gender).

**Discussion**

This is the largest surveillance study for *S. pneumoniae* CAP among hospitalized adults in the U.S. with the ability to measure non-invasive pneumococcal disease and identify causal serotypes. The results of this prospective study will provide epidemiologic information concerning the current burden of CAP due to *S. pneumoniae*, including the current distribution of pneumococcal serotypes and their incidence based on population surveillance. Previous analyses of *S. pneumoniae* incidence [2, 21] in CAP have been performed in the U.S.; however, they were conducted before widespread use of PCV13 in children, and before the increasing use of PCV13 among adults seen in recent years. Current data on *S. pneumoniae* serotype distribution in CAP are also limited, as few studies have measured both non-invasive and invasive disease utilizing non-culture methods to identify *S. pneumoniae* in adults.

Importantly, the population surveillance conducted in the Louisville sites provides virtually complete capture of the population at risk for CAP in this area, and therefore yields an incidence rate representative of 100% of the market share in the Louisville area. Market share methodologies for the estimates of incidence in Chicago and Nashville hospital sites (~5-15% market share at one hospital in each location) may yield incidence rates affected by potential differences in patient population at each hospital in the catchment area and an inability to capture the entire population at risk.

In conclusion, the novel methodology of this study allows for a more accurate estimation of the current incidence of PCV13-isolates among hospitalized patients with CAP in the United States via the use of the UAD assay. In addition, information on non-PCV13 serotypes is being gathered via culture methods, along with each subject’s PCV13 vaccination status. This may have implications both for evaluation of PCV13 vaccine effectiveness and non-vaccine serotypes likely to be of increasing importance in the near future.


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**References**


