ABSTRACT

• **Objective:** To describe the definition, incidence, diagnosis, etiology, and treatment and prevention practices for ventilator-associated pneumonia (VAP) in 4 pediatric post-acute care hospitals.

• **Methods:** Retrospective medical record review for the 1-year period May 2009 through April 2010 of infants and children ages 4 months to 18 years requiring tracheostomy with assisted ventilation admitted to pediatric post-acute care hospitals. A data collection tool was developed to record responses to 30 questions regarding VAP definition, incidence, diagnosis, etiology, and treatment and prevention at each facility. Data were combined for descriptive data analysis.

• **Results:** Most facilities used the CDC definition of VAP. 28 cases of VAP were documented for 21,118 ventilator-days across facilities, accounting for a mean VAP rate of 1.33 over a 1-year period. Diagnostic practices were consistent while prevention practices varied. Antibiotic use was the only reported treatment but differed by type, route of administration, and days of use.

• **Conclusions:** Across pediatric post-acute care facilities, diagnostic procedures and method of treating VAP are consistent. While the incidence of VAP appears low, inconsistency exists in defining, treating, and preventing VAP. Greater use of prevention and treatment bundles should be considered.

Ventilator-associated pneumonia (VAP) is one of the most common health care–associated infections in adults and children who are hospitalized due to critical or chronic illness [1,2]. Pneumonia is considered ventilator-associated if the patient was intubated and ventilated at the time of or within 48 hours before the onset of the pneumonia. In the most recent National Healthcare Safety Network (NHSN) report, of children in critical care units, 100% classified as “pediatric medical” and 68% classified as “medical/surgical” had VAP [3]. Eighty percent of infants in level II/III neonatal ICUs (NICUs) were reportedly diagnosed with VAP [3].

Diagnosis of VAP can be made clinically, radiographically, and/or using laboratory testing. Clinically defined pneumonia is the most frequently reported, regardless of patient age or care location. In pediatric critical care, however, approximately 42% of VAP cases are diagnosed using more rigorous criteria, including laboratory findings. In NICUs, only 17% of VAP cases are diagnosed using clinical and laboratory findings [3].

Certain diagnostic groups, such as children with genetic syndromes, those born before 28 weeks’ gestation [4], those with low birthweight [3,4] and those admitted to the ICU with a postsurgical diagnosis [5], have been found to be at increased risk of developing VAP. Other risk factors for VAP include subglottic/tracheal stenosis, trauma, tracheostomy [6], age less than 1 year [7], use of continuous IV sedation [7], bloodstream infection [4], enteral feeds [5], increased length of stay in intensive care [5], length of time on the ventilator [5], re-intubation [8], aspiration [9], and treatment with opiates [5,8]. The use of histamine-2 blockers has also been associated with a higher incidence of VAP in children [10]. VAP has also been associated with common care practices such as ventilator circuit changes [11] and endotracheal suctioning [8]. This evidence is derived from studies of patients in intensive care units.

Improving the health and safety of patients on mechanical ventilation and prevention of VAP has been promoted as a key area for patient safety in hospitals [3]. In recent years, there has been an increased focus on “bundles,” cohesive sets of evidence-based, well-established clinical practices that, when implemented together, achieve better patient outcomes than when im-

From the Franciscan Hospital for Children, Boston, MA.
implemented individually [12,13]. Common pediatric VAP prevention bundle elements include elevated head of bed positioning, peptic ulcer disease and deep vein thrombosis prophylaxis, daily oral care with chlorhexidine, daily assessment of readiness to extubate, and meticulous, frequent handwashing by all care providers [1,12–14].

Much of what we know about VAP is based on the study of adults and children on mechanical ventilation in hospital ICUs; there is a paucity of literature describing VAP in pediatric post-acute care rehabilitation facilities. Children unable to be weaned from a ventilator are often transferred from NICUs or PICUs to these facilities with a goal of reducing dependence on airway support (pulmonary rehabilitation) and/or to improve or regain physical function after a catastrophic injury, illness, or surgery (physical rehabilitation). Children admitted to inpatient rehabilitation programs have had endotracheal tubes removed and tracheostomies placed. Typical admission diagnoses to pediatric post-acute care settings include children that have been born prematurely, have congenital conditions, status post neurological trauma due to illness or injury, and with a range of post-surgical diagnoses [15,16]. As infants and children in these diagnostic groups have been shown to be at risk for VAP in ICU settings and spend an even greater length of time on a ventilator when admitted to inpatient pulmonary rehabilitation programs [17], it is surprising that no literature exists examining VAP in pediatric post-acute care rehabilitation programs. The purpose of this article is to describe the definition, incidence, etiology, diagnosis, treatment and prevention practices for VAP in pediatric post-acute care rehabilitation hospitals.

**METHODS**

A comprehensive literature review was performed to obtain current information related to VAP in children in intensive care and rehabilitation settings. The literature review was also used as an aid to the group in developing the data collection tool (Appendix). The tool consists of 30 questions regarding institution-specific diagnostic, treatment, and prevention practices regarding VAP as well as some other related questions.

Four inpatient pediatric post-acute care rehabilitation hospitals in the eastern United States (Table 1) were included in the study. The hospitals are part of the Specialized Pediatric Applied Research Collaborative (SPARC), a multisite clinical research consortium founded by the Research Center for Children with Special Health Care Needs, housed within Franciscan Hospital. The data collection tool was completed by the project investigator at each site, who was intimately familiar with the institution's VAP practices. To answer the questions about incidence and comorbidities, the investigator conducted a retrospective medical record review for the period May 2009 through April 2010. De-identified data was sent to 1 coordinating facility and combined for analysis. Data analysis consisted of a descriptive analysis and calculation of an overall VAP rate. Institutional review board approval was granted at each site for all facilities.

**RESULTS**

There were no studies reporting on the definition, incidence, diagnostic methods, etiology, treatment, and/or preventive measures regarding VAP in pediatric post-acute care facilities. Methods of invasive ventilation used at the participating facilities included positive pressure ventilation and continuous positive airway pressure. All children received ventilator support via tracheostomy.

**Definition**

Three of the 4 participating facilities used the definition of VAP from the Centers for Disease Control and Prevention that was current at the time of our study [18], while 1 facility used modified criteria (Table 2).

### Table 1. Participating Pediatric Post-Acute Care Hospitals

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Location</th>
<th>Discharges/Year*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blythedale Children's Hospital</td>
<td>Valhalla, New York</td>
<td>400</td>
</tr>
<tr>
<td>Children's Specialized Hospital</td>
<td>New Brunswick, New Jersey</td>
<td>500</td>
</tr>
<tr>
<td>Franciscan Hospital for Children</td>
<td>Boston, Massachusetts</td>
<td>80</td>
</tr>
<tr>
<td>Hospital for Special Care</td>
<td>New Britain, Connecticut</td>
<td>30</td>
</tr>
</tbody>
</table>

*Children with medical complexity, including ventilator use.**
Incidence

Tracking the incidence of VAP was a consistent activity in all 4 facilities as well as tracking the incidence of lower respiratory infections (eg, bronchitis) for infants and children who are ventilator-dependent. Twenty-eight cases of VAP were documented for 21,118 ventilator-days across facilities, accounting for a mean VAP rate of 1.33 over the 1-year period (range, 0.3–3.9). The cases included infants, children, and youth from age 4 months to 18 years with primary diagnoses that included prematurity, cardiac conditions, neurological disorders and/or multiple congenital anomalies. The percentage of VAP cases that occurred in infants and children who were on ventilators less than 24 hours per day ranged from no cases to 75% of cases at 1 facility. The percentage of VAP cases that occurred in infants and children who were on portable ventilators was as low as 10% at 1 facility and as high as 80% at another facility.

Diagnosis and Etiology

All facilities reported that the diagnosis of VAP is made using a clinical assessment with radiographic evaluation for confirmation of the diagnosis. None of the participating facilities perform follow-up radiographs to confirm clearance of the pneumonia. Blood cultures are not consistently performed when VAP is suspected and all such cultures reported were negative. In addition, no infants, children or youth were identified as having respiratory syncytial virus (RSV), H1N1 or influenza pneumonia during this time period. The most commonly reported suspected cause of VAP was aspiration and the most common pathogen recovered from sputum cultures was *Pseudomonas*.

Treatment and Prevention

All participating facilities in this study use antibiotics in the treatment of VAP. Methods of administration include intravenous, intramuscular, inhaled, via nasogastric tube, via gastrostomy tube, gastrojejunostomy, and orally. Antibiotics used for treatment in this study included Augmentin, Bactrim, Zosyn, ciprofloxacin, vancomycin, ceftriaxone, levofloxacin, and/or keflex. Treatment was noted to last from 7 to 14 days.

All facilities reported using “head-of-bed elevation” and oral care practices for prevention of VAP. Frequent ventilator circuit changes were noted as a prevention practice in 3 of the 4 reporting facilities but frequency varied by facility, ranging from once per month to once every 2 weeks as well as on an “as needed” basis. Draining of ventilator circuits was noted as a prevention procedure in 3 of the 4 participating facilities but frequency varied from “as needed” to “every 4 hours,” “once per shift,” and “daily.” One facility reported use of humidifiers rather than draining of circuits. All facilities reported that if aspiration is a concern, radiographic swallow studies, such as a modified barium swallow, are performed. No facilities used a ventilator bundle, none provided annual

### Table 2. Definition of Ventilator-Associated Pneumonia

<table>
<thead>
<tr>
<th>CDC Definition [3]</th>
<th>Modified Definition (1 facility)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Mechanical ventilation ≥ 48 hours</td>
<td>Mechanical ventilation ≥ 48 hours AND at least 3 of the following:</td>
</tr>
<tr>
<td>B) Worsening gas exchange AND at least 3 of the following:</td>
<td>1) Fever to 38°C (or 100.4°F) rectal or hypothermia &lt; 36°C (or 96.4°F) rectal with no other recognized cause</td>
</tr>
<tr>
<td>• Temperature instability with no other cause</td>
<td>2) New or worsening cough, dyspnea or tachypnea; crackles or bronchial breath sounds</td>
</tr>
<tr>
<td>• Leukopenia (&lt; 4000) or leukocytosis (≥ 15,000)</td>
<td>3) New-onset purulent sputum or change in character of sputum or increased secretions or increased need for suctioning</td>
</tr>
<tr>
<td>• Change in sputum character</td>
<td>4) Worsening gas exchange (O2 desaturations)</td>
</tr>
<tr>
<td>• Increased work of breathing</td>
<td>5) Increasing supplemental O2 requirement or increased need for ventilation and current chest radiograph with at least 1 of the following (compared to admission or most recent radiograph): new infiltrate or progression of infiltrate; new consolidation; and cavitation (new or progressive)</td>
</tr>
<tr>
<td>• Wheezing or rales</td>
<td></td>
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<tr>
<td>• Bradycardia (&lt; 100 bpm) or tachycardia (&gt; 170 bpm)</td>
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<tr>
<td>C) 2 or more serial chest x-rays with at least 1 of the following:</td>
<td></td>
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<tr>
<td>• New, progressive and persistent infiltrate</td>
<td></td>
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<tr>
<td>• Consolidation</td>
<td></td>
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<tr>
<td>• Cavitation</td>
<td></td>
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<tr>
<td>• Pneumatoceles</td>
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inservice about VAP for clinical staff, and none routinely vaccinated for RSV or influenza.

Participation in rehabilitation therapies is an important component of post-acute care pediatric rehabilitation. In this cohort, children received individual rehabilitation therapy while being treated for VAP, but only 2 of the 4 facilities allowed participation in group therapy outside of the child’s hospital room if the child was asymptomatic but still receiving treatment.

DISCUSSION

Pediatric pulmonary post-acute care rehabilitation programs admit medically complex infants and children with acute and long-term care needs, including children in need of ventilator weaning. Infants and children in NICUs and PICUs and adults requiring pulmonary rehabilitation have been shown to have high rates of hospital-based infections, including VAP [1,4,6,19,20]. Little is known about infants and children in pulmonary rehabilitation and VAP. Thus, the purpose of this descriptive pilot study was to describe the incidence, diagnosis, etiology, treatment and prevention practices for VAP in post-acute care pediatric rehabilitation hospitals.

As there are no previously published reports of VAP in post-acute care inpatient pediatric pulmonary rehabilitation programs, there is no comparison data available. VAP rates in adult long-term acute care appear to be lower than the rates reported in acute care hospitals [19]. In a study of adult patients using mechanical ventilation at home, an increased rate of infection was associated with longer daily durations of support and was more likely to occur during the first 500 days of home ventilation [21]. For adults with spinal cord injury and dependence on mechanical ventilation, hypoalbuminemia, administration of antacids and length of need for mechanical ventilation were all risk factors for VAP [22].

The VAP rate for the 4 pediatric post-acute care facilities in this study was comparable with the rate in reports examining NICU care [4,23] but lower than those for PICUs [4,23]. VAP has been associated with extreme prematurity in neonatal intensive care [3,4] and prolonged time on the ventilator [5]. Many children in our cohort had a diagnosis of prematurity and were dependent on mechanical ventilation for a prolonged period but further examination of data for post-acute care facilities is needed to determine if these are contributing factors to the development of VAP. The NHSN indicates that with the changing composition of health care facilities and the changing proportion of data contributed by various types of facilities, the impact of the reported rates and their distributions must be adapted so that the best possible risk-adjusted comparative data may be provided in future reports [3]. Inclusion of data for post-acute care facilities is warranted.

The definition and criteria for clinically defined pneumonia was re-evaluated in 2008 and published in 2011 [3], but facilities were not yet using this new definition at the time of data collection for this study. Walkey et al [24] found that in adult post-acute care, cases were frequently polymicrobial and associated with multidrug resistant pathogens and an increased length of stay. Additional study is needed to draw conclusions about bacterial etiology in pediatric post-acute care.

VAP has been reported as the most common reason for antibiotic use in pediatric intensive care. Treatment for VAP is often begun with broad-spectrum antibiotics and then subsequently replaced with a specific monotherapy agent, depending on the results of microbiological testing. Reported VAP treatment drugs for children include penicillins, third-generation cephalosporins, fourth-generation cephalosporins, monobactams, carbapenems, macrolides, aminoglycosides, lincosamides, glycopeptides, fluoroquinolones, and sulphonamides [25]. Treatment in the pediatric post-acute care programs in this study always included antibiotic use but involved a variety of antibiotics, given using a variety of routes and for variable intervals.

Prevention practices include changing and draining ventilator circuits to minimize colonization of circuit tubing with pathologic organisms and the accumulation of fluid. In a study by Hseih et al [26], weekly circuit changes as opposed to changes every 3 days did not increase VAP rates in 3 PICUs. In this study, ventilator circuits were reported to be changed as needed but could remain for as long as 1 month. Elements of a “PICU bundle” to prevent VAP in children who are intubated and ventilated may include elevation of head of bed 30% to 45%, peptic ulcer disease prophylaxis (eg, H-2 blockers, PPI), deep vein thrombosis prophylaxis for patients at risk, oral care every 8 to 12 hours, ventilator circuit draining every 4 hours, separate suction set-ups for in-line/tracheostomy secretions and oral secretions, and family education [12]. While VAP bundles are not specific to care facilities or specific areas of a hospital, a search of the medical literature failed to identify descriptions of prevention and treatment bundles used in the pediatric post-acute care setting where children are no longer intubated but receive mechanical ventilation.
Appendix. Data Collection Tool for VAP in Pediatric Post-Acute Care

Definition
1. Do you utilize the CDC definition of VAP?
   –If you do not use the CDC definition of VAP, please indicate the definition used at your facility:

Incidence
2. Do you track your incidence of VAP?
3. How many cases of VAP were documented from May 2009 through April 2010? How many ventilator days were there from May 2009 through April 2010?
4. Do you track the incidence of lower respiratory infections (eg, tracheitis, bronchitis) in infants and children who are ventilator dependant?
5. Do you count tracheitis and bronchitis in infants and children who are ventilator dependant as VAP?
6. What percentage of VAP cases occurred in infants/children on ventilators < 24 hours/day?
7. What percentage of VAP cases occurred in infants/children on portable ventilators?

Diagnosis
8. Do you diagnose VAP via clinical assessment?
9. Do you require radiographic confirmation of VAP?
10. Do you require a follow-up x-ray to determine if an infant/child no longer has VAP?
11. How many infants/children with VAP had a positive blood culture and were diagnosed with bacterial pneumonia from May 2009 through April 2010?

Prevention
12. What preventive measures are used to minimize the incidence of VAP?
13. What is the frequency of ventilator circuit changes?
14. How frequently do you drain the ventilator circuits?
15. Do you provide an annual inservice about VAP for clinical staff?
16. Do you routinely vaccinate infants/children in your facility for RSV and influenza?

Treatment
17. If antibiotic treatment is used
   –What is the method?
   –For how many days?
   –Which antibiotic(s)?

Etiology
18. What is the most common cause of VAP at your facility?
19. If aspiration is of concern, is a modified barium swallow performed?
20. How many infants/children with VAP (from May 2009 through April 2010) had gastroesophageal reflux disorder?
21. How many infants/children with VAP (from May 2009 through April 2010) had RSV, H1N1, or influenza?

Other
22. What methods of invasive ventilation do you use?
23. What percentage of tracheostomies are cuffed in the children with VAP?
24. What was the range of ages of infants and children at your facility (from May 2009 through April 2010) with VAP?
25. What percentage of the infants/children with VAP at your facility have a diagnosis of prematurity?
26. What percentage of the infants/children with VAP at your facility have a cardiac condition?
27. What percentage of the infants/children with VAP at your facility have multiple congenital anomalies?
28. What percentage of the infants/children with VAP at your facility have a neurological condition?
29. Are patients allowed to receive individual rehabilitation therapy when being treated for VAP?
30. Are patients allowed to participate in group rehabilitation therapy when being treated for VAP?
via tracheostomy. At the time of data collection for this study, no participating facility was using a specific VAP bundle.

Children were admitted to the facilities in this study for pulmonary rehabilitation with the primary aim of discontinuing or reducing dependence on ventilators. Length of stay in pediatric pulmonary rehabilitation programs has been reported to vary from as little as 2 weeks to more than 40 weeks [27] with discharge dispositions including home, acute care, and chronic care facilities [15,16,27,28]. VAP has the potential to prolong a hospitalization and increase the risk for re-admittance to an acute or intensive care setting [28].

Our findings are somewhat limited by the small sample size and retrospective data collection method, but we hope that the results will provide initial baseline and comparative data for clinicians in pediatric post-acute care rehabilitation programs regarding the incidence, diagnosis, treatment, and prevention of VAP. Additional studies in these areas are warranted, hopefully leading to the creation of care bundles to limit and prevent VAP in infants and children in post-acute care. Future research should address all of the areas examined and should also include the experimental investigation of the influence of the type of ventilator (eg, portable versus nonportable), mode of ventilation (pressure versus volume), the role of aspiration, particularly when it comes to oral feeding, and whether additional interventions (eg, cuffed tracheostomy) might reduce the incidence of VAP.

Corresponding author: Helene M. Dumas, PT, MS, Research Center, Franciscan Hospital for Children, 30 Warren St., Boston, MA 02135, hdumas@fhfc.org.

REFERENCES