Strategies to Prevent Ventilator-Associated Pneumonia in Neonates

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Ventilator-associated pneumonia (VAP) is defined by the Centers for Disease Control and Prevention (CDC) as an episode of pneumonia in a patient who requires a device to assist or control respiration through a tracheostomy or endotracheal tube within 48 hours before the onset of the infection.1 Health care-associated infections have a large impact on neonatal morbidity, survival, hospital costs, and length of stay.2,3 VAP is a common cause and accounts for 6.8% to 32.2% of health care-acquired infections among neonates.4–8 This article summarizes epidemiology, suspected pathogenesis, diagnosis, and strategies to prevent VAP in neonates.

EPIDEMIOLOGY

The exact rate of neonatal VAP is difficult to establish, because radiographic identification of pneumonia is difficult, especially among neonates with significant underlying lung disease, and diagnostic procedures commonly used in adults are rarely used in the neonatal intensive care unit (NICU). Differences in study methodology and case mix also influence the reported incidence of neonatal VAP.9 National Nosocomial Infections Surveillance system data from 2004 showed that VAP rates for neonates weighing less than 1000 g ranged from 2.4 to 8.5 episodes per 1000 ventilator days.10 In a cross-sectional study of 12 NICUs in children’s hospitals, the incidence of VAP among neonates weighing less than 1000 g was 0 to 21.2 (median 3.5) per 1000 ventilator days.11 Other investigators have reported rates varying from 12.5 to 52 infections per 1000 ventilator days.4,12–16 Differences in study design and the case mix are likely responsible for the wide range of reported rates.

KEYWORDS

- Ventilator-associated pneumonia
- Health care-associated infection
- Neonate

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Developmental abnormalities in the neonate’s immune system including greater permeability of the skin and mucous membranes, decreased complement activity, and lower levels of immunoglobulins increase the susceptibility to healthcare-acquired infections. In a cohort of 742 neonates, low birth weight (odds ratio [OR] 1.37; 95% confidence interval [CI], 1.01, 1.85) and mechanical ventilation (OR 9.7; 95% CI, 4.6, 20.4) increased pneumonia risk. Intravenous antibiotics were protective (OR 0.37; 95% CI, 0.21, 0.64). In another cohort of 229 ventilated neonates weighing 2000 g or less, VAP was more likely to occur in neonates who had a previous bloodstream infection (OR 3.5; 95% CI, 1.2, 10.8). Organisms responsible for bloodstream infections were different from those causing VAP, suggesting that bloodstream infections may serve as a surrogate for severity of illness in the population. Although prolonged intubation before the episode of pneumonia did not reach statistical significance in this cohort, it was associated with VAP in the cohort reported by Yuan and colleagues. Opiate treatment for sedation (OR 3.8; 95% CI, 1.8, 8.5), frequent endotracheal suctioning (OR 3.5; 95% CI 1.6, 7.4), and reintubation (OR 5.3; 95% CI, 2.0, 14.0) increased VAP risk in this study of ventilated neonates. Pneumonia is less common in neonates treated with nasal continuous positive airway pressure (NCPAP) when compared with those intubated on mechanical ventilation (12.5/1000 ventilator days vs 1.9/1000 NCPAP days, \( P = .04 \)). Finally, NICU design and staffing may affect VAP rates. Neonatal VAP decreased significantly when a NICU was moved from a crowded space to a larger unit with 50% more staffing.

**PATHOGENESIS**

VAP occurs when bacterial, fungal, or viral pathogens enter the normally sterile lower respiratory tract and lung parenchyma. Under normal circumstances, anatomic barriers, cough reflexes, tracheobronchial secretions, mucociliary lining, cell-mediated and humoral immunity, and the phagocytic system of the alveolar macrophages and neutrophils protect the lung parenchyma from infection. If these defenses are impaired, absent, or overcome by a high inoculum of organisms or those of unusual virulence, pneumonitis ensues.

Microorganisms responsible for VAP can originate from endogenous or exogenous sources (Figs. 1 and 2). Oropharyngeal or tracheobronchial colonization (endogenous source) with pathogenic bacteria begins with the adherence of microorganisms to the epithelial cells of the respiratory tract. Organisms causing VAP are often noted in the posterior pharynx. Several investigators have highlighted the role of oropharyngeal and subglottic secretions in the development of VAP in adults. Contaminated oral and gastric secretions can pool above the cuff of the endotracheal tube in adult patients and gain access to the lower aspect of the respiratory tract by leaking around the cuff. Neonates are likely at greater risk for such aspiration of contaminated oral secretions, because endotracheal tubes used to ventilate neonates are not cuffed. Gram-positive organisms in the mouth colonize the trachea and endotracheal tubes within the first 48 hours of mechanical ventilation. Gram-negative bacilli begin colonizing the endotracheal tube and trachea after 48 hours of respiratory support. VAP early after intubation tends to be more benign when compared with episodes that occur later in the hospital stay when gram-negative organisms begin to colonize the endotracheal tube.

Support for the role of oropharyngeal colonization and subsequent tracheal colonization in the pathogenesis of VAP in neonates comes from studies showing a role of positioning in the acquisition of airway colonization with potential pathogens. Elevation of the head of the bed may reduce the risk of aspiration of contaminated
oropharyngeal and gastrointestinal contents in adults. Aly and colleagues reduced tracheal colonization from oropharyngeal contamination through lateral positioning of infants. Tracheal colonization was less common after 5 days of ventilation among neonates placed in a lateral position when compared with neonates nursed in a supine position (30% vs 87%, \( P < .01 \)). The investigators speculate that by keeping the endotracheal tube and ventilator circuit in a horizontal position, secretions were less likely to track down from the oropharynx into the lower respiratory tract.

The stomach has been postulated as an additional reservoir for organisms responsible for VAP. The exact role gastric flora plays in the pathogenesis of VAP has been debated. The contribution of gastric organisms to the pathogenesis of VAP is influenced by medications (antibiotics, antacids), supine head positioning, enteral feedings, and the patient’s illness. The position of a patient’s body may reduce gastric reflux and subsequent tracheal aspiration and thus VAP risk. Torres and colleagues demonstrated that technetium-labeled colloid inserted into a nasogastric tube was more likely to be noted in tracheal secretions of patients in a supine position than in those patients in a recumbent position. Drakulovic and colleagues noted a higher rate of VAP in patients in a supine position when compared with patients in a semirecumbent position. Farhath and colleagues noted that pepsin, a marker for gastric contents, was detected in the trachea of 92% of a cohort of ventilated neonates. The investigators did not evaluate associations between pepsin and VAP.

In summary, studies using rigorous culturing techniques have shown that oropharyngeal colonization plays a more important role in the development of endogenously acquired VAP than gastric colonization and subsequent aspiration. Only rarely do organisms gain entry to the lower respiratory tract through blood or bacterial translocation from the gastrointestinal tract.
Pathogens may also originate from exogenous sources (see Fig. 2). The endotracheal tube can serve as a reservoir for infecting microorganisms that adhere to the surface. Ventilator circuits, airway suctioning equipment, humidifiers, and nebulizers can become contaminated with pathogens that subsequently cause VAP.19 Perhaps the most important source of exogenous contamination is from the caregivers’ hands.37 Gram-negative organisms, which begin colonizing the endotracheal tube later than gram-positive organisms, are frequently carried on the hands of caregivers.38,39

**MICROBIOLOGY**

*Staphylococcus aureus* and gram-negative organisms (*Pseudomonas aeruginosa*, *Escherichia coli*, *Klebsiella pneumoniae*, *Enterobacter* sp, and *Acinetobacter* sp) are the most common pathogens responsible for VAP in adults and pediatric patients. Apisarnthanarak and colleagues17 noted gram-negative organisms in 94% of tracheal aspirates from neonates with VAP (Table 1). Multiple organisms were recovered from airway secretions in 58% of cases, and *S. aureus* was recovered from approximately 25% of cases. Other investigators have also shown that neonatal VAP is mostly polymicrobial.40 Webber and colleagues40 cultured coliform species (44%), *P. aeruginosa* (34%), and *S. aureus* (15%) from the endotracheal tube or nasopharyngeal secretions of ventilated neonates with late-onset pneumonia. In a retrospective series examining risk factors for neonatal VAP,12 more than 75% of the 28 VAP cases were due to gram-negative organisms (*K. pneumoniae*, 39.3%; *P. aeruginosa*, 25%; *Enterobacter cloacae* and *Citrobacter* sp, 3.6%). All studies evaluating the microbiology of neonatal VAP are limited by the fact that cultures are obtained from endotracheal aspirates and not from invasive sampling of the lower airway as in adults and thus may represent the oropharyngeal flora at the time of VAP.

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**Fig. 2.** Exogenous sources of organisms responsible for VAP. (Courtesy of Walt Earhart, Wheaton Franciscan Healthcare; with permission. Reproduced from NeoreviewsPlus, copyright August 2010, Question 8, AAP; with permission.)

Pathogenesis of Ventilator Associated Pneumonia

**Exogenous Sources of Micro-organism**

1) Hands of healthcare worker

2) Ventilator circuit

3) Biofilm of endotracheal tube

**Mechanism for pneumonia**

Pneumonia occurs when colonized secretions are inhaled into lungs through the endotracheal tube
DIAGNOSIS AND TREATMENT

The major controversy regarding VAP in neonates is the criteria used to establish the diagnosis. Stringent clinical criteria to define VAP have been developed by the CDC and the National Hospital Safety Network (NHSN). Criteria include mechanical ventilation within 48 hours of onset of suspected VAP; worsening gas exchange with an increase in oxygen or ventilatory requirements; 2 or more chest radiographs that show new infiltrates, consolidation, cavitation, or pneumatoceles; and at least 3 signs and symptoms. Signs and symptoms may include temperature instability, wheezing, tachypnea, cough, abnormal heart rate, change in secretions, or an abnormal leukocyte count. The problem with the criteria is the lack of a gold standard—microbiological identification of a pathogen from the lower respiratory tract, and thus the diagnostic value of the CDC surveillance recommendations is unknown. The criteria have not been validated in neonates, and they are often open to subjective interpretation because they overlap with other diseases. Low-birth-weight neonates rarely develop cough, rhonchi, fever, or wheezing during an episode of pneumonia, and determining the presence of pneumonia from radiographs of low-birth-weight neonates with underlying chronic lung disease can be difficult. Despite the difficulties with the CDC and NHSN criteria, they are still used to monitor VAP in NICUs and are frequently used by public and private reporting agencies.

Invasive testing is frequently used to diagnose pneumonia in ventilated adults with suspected VAP. Microbiologic examination of bronchoalveolar lavage (BAL) samples or those taken from a protected specimen brush (PBS) has an estimated 70% sensitivity and 77% specificity when compared with histopathology and/or lung tissue culture. A meta-analysis of adult trials determined that VAP could be confirmed

### Table 1

<table>
<thead>
<tr>
<th>Organism</th>
<th>Neonates with VAP (%)</th>
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<tr>
<td>Gram-Negative Rods</td>
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<tr>
<td><em>P. aeruginosa</em></td>
<td>38</td>
</tr>
<tr>
<td><em>Enterobacter</em> spp</td>
<td>38</td>
</tr>
<tr>
<td><em>Klebsiella</em> spp</td>
<td>23</td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>15</td>
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<tr>
<td><em>Acinetobacter</em> spp</td>
<td>8</td>
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<tr>
<td><em>Citrobacter</em> spp</td>
<td>8</td>
</tr>
<tr>
<td><em>Stenotrophomonas maltophilia</em></td>
<td>4</td>
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<tr>
<td>Gram-Positive Cocci</td>
<td></td>
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<tr>
<td><em>S. aureus</em></td>
<td>23</td>
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<tr>
<td><em>Enterococcus</em></td>
<td>15</td>
</tr>
<tr>
<td>Group B <em>Streptococcus</em></td>
<td>4</td>
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</table>

* VAP was considered to be present in infants receiving mechanical ventilation for at least 48 h who (1) developed new and persistent radiographic evidence of focal infiltrates at least 48 h after ventilation initiated and (2) received antibiotics for at least 7 days. Diagnosis of VAP confirmed by pediatric infectious disease fellow and neonatology attending. Because most infants had polymicrobial microorganisms, the sum of percentages is >100%.

with bronchoscopic samples in 44% to 69% of patients, and antibiotics were 3 times more likely to be changed when a bronchoscopy was done.

Bronchoscopy with lavage and PBS is not practical in neonates because of the size of the neonatal airway. Köksal and colleagues used invasive testing with nonbronchoscopic BAL (NB-BAL) to obtain specimens from 145 ventilated neonates with suspected pneumonia. During the procedure, a 6F or 8F sterile catheter was passed through the endotracheal tube and wedged in the airway. About 90% of the 40 neonates with clinically diagnosed VAP had positive NB-BAL cultures. Sensitivity, specificity, positive predictive, and negative predictive values were 90%, 90%, 70%, and 97%, respectively. The percentage of intracellular bacteria in 2% or more of polymorphonuclear cells on Giemsa-stained smears was significantly higher in neonates with VAP when compared with colonized neonates (84% vs 26%, \( P < .0001 \)). There were no significant complications. Although the results of Köksal and colleagues’ study are intriguing, they are tempered by the fact that they were compared with clinically diagnosed VAP and not with a gold standard, such as a lung biopsy or tissue sample. Before accepting these results, the study should be replicated further to determine the diagnostic value and safety profile of the procedure.

Tracheal aspirate cultures and Gram stains are often included in the evaluation of neonates with suspected pneumonia. These tests have low sensitivity, specificity, and positive predictive value because it is difficult to distinguish between tracheal colonization and pneumonia. In a retrospective cohort of neonates treated for VAP defined by clinical, radiographic, and tracheal aspirate results, 92% of cases had purulent tracheal aspirates (>25 leukocytes per high-power field); however, just 53% of cases had a positive tracheal culture. In a cohort of very low-birth-weight infants, VAP, defined by the presence of clinical and radiographic findings as well as the presence of pathogens in the trachea or blood, was diagnosed in 5% of neonates without purulent aspirates and in just 10% of neonates with purulent aspirates. When bacteria were not seen by Gram staining, purulence was noted in 11% of infants and 58% of infants had culture-positive tracheal aspirates. At the time of the first purulent tracheal aspirate, just 66% of neonates were symptomatic. The investigators did note that when a positive tracheal aspirate was associated with VAP, gram-negative organisms such as Klebsiella, Pseudomonas, and E coli were the most common isolates. The predictive value of tracheal aspirates in ventilated adult patients is also limited. Although tracheal aspirate findings have a low positive predictive value for pneumonia, they may play a role in helping to identify organisms colonizing the airway of infants at the time of a clinically diagnosed VAP. The knowledge of the sensitivities of the organisms colonizing the airway may help to guide antimicrobial choices, because the use of incorrect drugs has been associated with a significantly greater risk of death in adults with VAP. A tracheal aspirate culture may also be of some value if it is negative in an adult patient who is either not on antibiotics or whose antibiotics have not been recently modified. In this instance, the negative predictive value is very high and the likelihood of pneumonia is close to zero.

As with the diagnosis of VAP in neonates, there are no clear consensus guidelines for the optimal treatment of neonatal VAP. Based on adult trials, initial treatment should include broad empiric therapy. In selecting antimicrobial agents, likely flora and local resistance patterns should be considered. In most instances, a combination of several drugs is started. Initiating appropriate therapy has been shown to improve outcomes; however, the use of broad empiric coverage does carry the risk of increased resistance, toxicity, and cost. In adults, empiric monotherapy is
recommended for uncomplicated VAP that is not likely due to a multidrug-resistant organism. Empiric combination therapy is recommended for more complicated disease. Adult treatment is tailored or discontinued based on culture results and clinical status. Because most neonates have multiple risk factors for multidrug resistance (such as prolonged mechanical ventilation, prior antibiotic exposure, multisystem illness) and there is no validated means of assessing VAP severity and improvement in neonates, most neonates with VAP usually receive a full course of empiric broad-spectrum antibiotics.

Empiric therapy usually includes an antipseudomonal agent such as piperacillin-tazobactam or ticarcillin-clavulanate that provides coverage for most gram-negative organisms and many gram-positive organisms. If local flora includes extended-spectrum β-lactamase producing organisms, carbapenems may be more appropriate for initial empiric therapy. The addition of another gram-negative agent such as an aminoglycoside is controversial. The addition of an aminoglycoside is appropriate if bacteremia is suspected or significant systemic symptoms are present. If the blood culture is negative and systemic symptoms are absent, de-escalating the therapy by discontinuing aminoglycosides is appropriate. Local epidemiology may dictate the use of dedicated gram-positive coverage for resistant organisms such as methicillin-resistant Staphylococcus. Depending on the quality and type of respiratory cultures, if no resistant organisms are detected, such therapy can be discontinued when the culture results are available.

PREVENTING VAP

The CDC and American Thoracic Society have published guidelines for the prevention of health care-associated pneumonia. Several studies have shown a reduction in VAP after the guidelines were implemented into a bundle of interventions that were implemented as a single intervention. The power of the bundle is that it brings together several evidence-based practices that individually improve care but when applied together, may result in an even greater improvement in the desired outcome.

Most adult VAP prevention bundles recommend elevating the head of a ventilated patient’s bed to between 30° and 45° to reduce the risk of aspiration of contaminated oropharyngeal and gastrointestinal contents. Drakulovic and colleagues demonstrated that a semirecumbent position reduced the rate of clinically suspected (95% CI for difference, 10%–42%; \( P = .003 \)) and microbiologically confirmed VAP (95% CI for difference, 4%–32%; \( P = .018 \)). Only 1 underpowered pediatric trial presented in abstract form has evaluated this intervention and showed no effect. The results of Aly and colleagues and Farhath and colleagues studies suggest that using gravity may be an important means of preventing pathogens from gaining entry into the lower respiratory tract. However, Farhath and colleagues did not evaluate the association between the presence of pepsin in the trachea and VAP, and Aly and colleagues’ work involved tracheal colonization and not pneumonia. Whether the best position to prevent VAP in ventilated neonates is the head of the bed kept up or a horizontal left or right lateral position of the neonate needs further study.

Because most organisms responsible for VAP originate from the oropharynx of ventilated patients, the CDC recommends that secretions be cleared from above the cuff of the endotracheal tube whenever the tube is repositioned or removed. Although endotracheal neonatal tubes lack cuffs, the principle of suctioning out the oropharynx around the endotracheal tube before adjusting it or removing the tube could help reduce the risk of microaspiration of oropharyngeal secretions.
Introduction of closed multiuse suction catheters allowed endotracheal suctioning without disconnecting patients from the ventilator. Such closed suctioning methods reduce physiologic disruptions and arrhythmias, and nurses in the NICU judged such methods to be easier to use than an open suction system. Closed suction systems present the potential for bacterial contamination when pooled secretions in the lumen are reintroduced into the lower respiratory tract with repeated suctioning. On the other hand, closed suctioning could potentially reduce environmental contamination of the endotracheal tube. Airway colonization is more common in ventilated adult patients suctioned with a closed system, but VAP rates have been reported to be equivalent or slightly less than rates among patients with open system suctioning. CDC recommendations do not endorse one system over the other, and there are no recommendations addressing the frequency at which closed suctioning systems should be changed. In a study of 133 ventilated neonates randomized to a closed or open suction system, there were no differences in tracheal colonization patterns between groups nor in the VAP or bloodstream infection rates among treatment groups.

Breathing circuit condensate contamination can also serve as a mechanism for pathogenesis of VAP. The condensate that collects in the tubing should be drained away to prevent aspiration. Breathing circuits do not need routine changing unless they become visibly soiled or malfunction. Most adult VAP reduction bundles recommend sedation vacations that allow a more accurate assessment of extubation readiness. In adults, the CDC recommends that the endotracheal tube be removed as soon as clinical indications allow and that noninvasive forms of respiratory support be used when feasible. Because many centers use minimal or no sedation for ventilated neonates, actual use of sedation vacation is uncommon in most units. However, the process of assessing ventilated neonates on a daily basis to determine readiness for extubation should be built into the care team’s daily rounds. The use of noninvasive measures such as NCPAP and nasal prong ventilation may help to reduce VAP rates. In time-sequenced cohort studies, reducing days of mechanical ventilation with either a high-flow nasal cannula or NCPAP decreased VAP incidence. After extubation, repeat intubation should be avoided because of the increased risk of VAP associated with reintubation.

Acidification of gastric contents decreases colonization with potential pathogens. Medications to prevent stress ulcer, such as H₂ antagonists and antacids that increase gastric pH, may increase gastric colonization and VAP risk. In 2 pediatric studies, there was no difference in VAP incidence among ventilated patients treated with sucralfate when compared with patients treated with agents that alter gastric pH. Pathogens responsible for VAP were similar across treatment groups. No studies have examined the associations between H₂ blockers and VAP among neonatal patients. However, necrotizing enterocolitis and gram-negative bacteremia have been associated with H₂ blocker use in neonates. Current data do not support the use of peptic ulcer prophylaxis for the prevention of VAP among ventilated neonates.

Enteral nonabsorbable antimicrobials and topical antimicrobials applied to the oropharynx to decrease gastrointestinal colonization, better known as selective digestive tract decontamination (SDD), could potentially reduce respiratory tract infections caused by microaspiration of gastrointestinal organisms. Although several adult studies are supportive of SDD, CDC guidelines offer no recommendation for this procedure. Studies of SDD to prevent VAP in ventilated children have conflicting results. In a randomized study of 226 ventilated patients in the pediatric intensive care unit, those randomized to the SDD treatment group (colistin, tobramycin, and nystatin orally...
or through a nasogastric tube) had a lower frequency of pneumonia (2.6% vs 7.2%). Mortality was similar among treatment groups. In a small randomized trial (n = 23) of ventilated pediatric burn patients, there was no significant difference in VAP rates among controls and SDD-treated patients. In a nonrandomized prospective trial of ventilated neonates, those who had SDD with administration of polymyxin E, tobramycin, and nystatin within the first 5 days of life had fewer nosocomial infections of intestinal origin. VAP was not reported separately. Although SDD may have the potential for decreasing VAP risk, it could increase antibiotic resistance and certainly should be further evaluated before it is considered for neonates outside of clinical trials.

The CDC recommends a comprehensive oral hygiene program in patients at high risk for health care-associated pneumonia. A meta-analysis by Pineda and colleagues showed a reduction in VAP among adult patients treated by decontamination with oral hygienic practices.

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<th>Interventions Often Included in Bundles to Prevent VAP</th>
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<tr>
<td><strong>Cuffed Endotracheal Tubes (II)</strong></td>
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<tr>
<td><strong>Subglottic Suctioning of Secretions (II)</strong></td>
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<td><strong>Silver-Coated Endotracheal Tubes</strong></td>
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<td><strong>Deep Venous Thrombosis Prophylaxis</strong></td>
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CDC categorization of evidence-based recommendations.

Recommendations categorized based on existing scientific evidence, theoretic rationale, applicability, and potential economic impact in adult patients.

Category IA: Strongly recommended for implementation and supported by well-designed experimental, clinical, or epidemiologic studies.

Category IB: Strongly recommended for implementation and supported by certain clinical or epidemiologic studies and by strong theoretic rationale.

Category II: Suggested for implementation and supported by suggestive clinical or epidemiologic studies or strong theoretic rationale.

*a Category of recommendation for adult patients.*
chlorhexidine, although the reduction in VAP did not reach statistical significance. A meta-analysis by Chlebicki and Safdar revealed a similar protective effect with chlorhexidine rinse. However, the CDC makes no recommendation for the use of an oral chlorhexidine rinse for the prevention of VAP in ill patients. Chlorhexidine gluconate is not approved for neonates younger than 2 months, and there are little neonatal data to evaluate oral hygiene and VAP risk. It is likely that VAP pathogenesis differs in neonates who do not have gingivitis or the dental diseases of adults that would predispose them to abnormal oral colonization. Until further data are available, it seems prudent to follow the recommendation of the American Dental Association to wipe the gums and keep the mouth clean after feedings and when needed. Because oral suction equipment can become colonized with pathogens within 24 hours, separate suctioning equipment should be used for tracheal and oral secretions.

Reducing person-to-person transmission of bacteria is crucial to preventing nosocomial infections. Hand hygiene is likely the most important infection-control intervention in health care settings. Pathogens responsible for neonatal VAP are carried on the hands of health care workers and in the gastrointestinal tracts of infants. Respiratory equipments can become colonized with these organisms. Thorough hand washing before and after contact with respiratory equipments should reduce cross-contamination between patients. In a time-sequence trial aimed at improving hand hygiene in the NICU, the rate of appropriate hand cleansing increased from 43% at baseline to 80% during the intervention period. The rate of respiratory infections decreased from 3.35 to 1.06 per 1000 patient days ($P < .002$). However, the trial was not randomized and other clinical practices may have changed during the study period.

Changes in endotracheal tube design have decreased the incidence of VAP in adults. Aspiration of subglottic secretions through a hole in the dorsal aspect of endotracheal tubes above the inflated cuff decreased VAP rates in adults. The CDC recommends the use of such tubes in ventilated adults. Such tubes are not available for neonates. In a randomized trial, VAP was reduced by 35% in patients ventilated with a silver-coated endotracheal tube when compared with patients ventilated with a conventional tube. The investigators suggest that the silver coating works to

![Fig. 3. Relationship between pathogenesis and strategies to prevent VAP.](image-url)
prevent biofilm formation and bacterial colonization. Silver-coated endotracheal tubes are not available for neonates.

**SUMMARY**

Table 2 summarizes interventions that have been shown to effectively reduce VAP in adults and neonates. Potential interventions for inclusion in a neonatal VAP prevention bundle, which have not been evaluated in neonates but seem biologically plausible with good safety profiles, are also given. Fig. 3 summarizes how practical preventative interventions relate to the steps in the pathogenesis of VAP. Improved diagnostic criteria and surveillance techniques for VAP in the neonatal population need to be established before the effectiveness of these strategies can be accurately assessed.

**ACKNOWLEDGMENTS**

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**REFERENCES**


