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Nonventilator hospital-acquired pneumonia: A call to action:

Recommendations from the National Organization to Prevent Hospital-Acquired Pneumonia (NOHAP) among nonventilated patients

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Executive Summary

In 2020 a group of U.S. healthcare leaders formed the National Organization to Prevent Hospital-Acquired Pneumonia (NOHAP) to issue a call to action to address non–ventilator-associated hospital-acquired pneumonia (NVHAP). NVHAP is one of the most common and morbid healthcare-associated infections, but it is not tracked, reported, or actively prevented by most hospitals. This national call to action includes (1) launching a national healthcare conversation about NVHAP prevention; (2) adding NVHAP prevention measures to education for patients, healthcare professionals, and students; (3) challenging healthcare systems and insurers to implement and support NVHAP prevention; and (4) encouraging researchers to develop new strategies for NVHAP surveillance and prevention. The purpose of this document is to outline research needs to support the NVHAP call to action. Primary needs include the development of better models to estimate the economic cost of NVHAP, to elucidate the pathophysiology of NVHAP and identify the most promising pathways for prevention, to develop objective and efficient surveillance methods to track NVHAP, to rigorously test the impact of prevention strategies proposed to prevent NVHAP, and to identify the policy levers that will best engage hospitals in NVHAP surveillance and prevention. A joint task force developed this document including stakeholders from the Veterans' Health Administration (VHA), the U.S. Centers for Disease Control and Prevention (CDC), The Joint Commission, the American Dental Association, the Patient Safety Movement Foundation, Oral Health Nursing Education and Practice (OHNEP), Teaching Oral-Systemic Health (TOSH), industry partners and academia.

Non–ventilator-associated hospital-acquired pneumonia (NVHAP) affects ~1 in every 100 hospitalized patients, has a crude mortality rate of 15%–30%, extends hospital length-of-stay by up to 15 days, requires ICU admission in up to 46% of non-ICU cases, increases antibiotic utilization, and is associated with readmission within 30 days in up to 20% of survivors.[1–5]

Despite the considerable morbidity, mortality, and cost associated with NVHAP, there are currently no requirements nor standards for hospitals to track or prevent this complication. Healthcare organizations and policy makers have dedicated considerable resources to preventing other healthcare-associated infections over the past 20 years. These actions have resulted in striking decreases in many device-associated infections, including ventilator-associated pneumonia; NVHAP rates, however, remain persistently high.[6,7]

Stakeholders from government, healthcare, industry, and academia formed the National Organization to Prevent Hospital Acquired Pneumonia (NOHAP) in 2020 to highlight the clinical importance of NVHAP and to catalyze a coordinated movement to prevent NVHAP. The purpose of this document is to summarize current knowledge gaps and needs regarding NVHAP pathogenesis, surveillance, prevention, policy needs, and impact. Our goal is to draw attention to NVHAP and to provide a practical roadmap regarding the information, tools, and policy levers required to advance NVHAP prevention.

Economic impact

Hospital-acquired pneumonia (HAP), including both ventilator-associated and non–ventilator-associated HAP, is estimated to cost the US healthcare system >$3 billion per year.[8] Scant data exist on the economic impact of NVHAP alone, but given that NVHAP accounts for 60% of HAP, the impact is likely substantial.[7] The cost of NVHAP to the healthcare system extends beyond the initial hospital stay; 1-year mortality rates are twice those of patients with community-acquired pneumonia, and many patients have considerable postacute and long-term care needs.[9] The specific attributable cost of NVHAP, including both predischarge and postdischarge costs, is needed to inform local and national policy deliberations and prioritization of prevention resources.[10,11]

Determining the infection-specific attributable cost of NVHAP will require the application of state-of-the-art methods that account for patients' premorbid conditions, concurrent acute diagnoses, and time-dependent confounders to disentangle the costs associated with patients' underlying reasons for admission and other complications from the costs attributable to NVHAP itself. Data are also needed to determine the cost-effectiveness of potential NVHAP prevention strategies and to determine whether the most cost-effective approach is to implement prevention strategies that specifically target pneumonia (eg, oral care, mobility, and head-of-bed elevation) versus universal healthcare-associated infection prevention strategies (eg, hand hygiene, environmental cleaning) versus some combination of both. Investigators tackling other healthcare-associated infections have suggested that universal infection prevention interventions may be more cost-effective than targeted interventions, but it is not clear whether and to what extent this applies to NVHAP given the distinctive pathophysiology and epidemiology of NVHAP.[12,13] Important components of any economic evaluation of NVHAP prevention strategies should include intervention costs, healthcare provider time, procedures, intensive care unit utilization, pharmaceutical and medication administration costs, hospital length-of-stay, 30-day readmission, missed work for patients, and caregiver costs.[12]

Research questions in the realm of health economics include the following:

1. How variable is the attributable per-infection cost of NVHAP across underlying patient characteristics and settings of care?
2. Which patients are at higher risk for complications associated with NVHAP, and do sicker versus healthier patients have different attributable per-infection costs?
3. What are the differences in the average costs of NVHAP at the facility level and what is driving those cost differences?
4. What are the most cost-effective strategies for reducing NVHAP?
5. What interventions could potentially reduce the severity and thus the attributable costs of NVHAP?
6. Does the attributable cost of NVHAP differ by the organism causing the infection or by whether the organism is resistant or susceptible to antimicrobials?

7. What is the total economic burden of NVHAP in the United States and has this changed over time?

8. Did federal policies to provide financial incentives to reduce hospital acquired infections lead to a reduction in NVHAP cases?

Pathogenesis

Strategies to improve the prevention, recognition, and treatment of NVHAP are currently limited by gaps in understanding of the pathogenesis of NVHAP. Advances in diagnostic tools of the microbiome have helped us to better appreciate that the lung is not a sterile organ but rather a complex ecosystem of microbes that interact with each other and their host.[14] Microaspiration and impaired clearance of oral and oropharyngeal secretions facilitate the inoculation of potential pathogens into the lungs.[15,16] Poorly understood host factors then govern whether local inoculations and inflammatory reactions spontaneously resolve or progress to clinically overt infection. Infection can be viewed as a disruption of the normal equilibrium between the microbes of the oropharyngeal cavity and those in the lungs due to host, pathogen, and environmental factors that still need to be characterized.[15] Patient factors that increase the frequency, severity, and consequences of aspiration are likely contributors: impaired consciousness due to sedation or neurological disease or frailty, increased secretions, and/or overgrowth of organisms in the mouth due to poor oral hygiene. Better understanding of the host and microbial factors underlying susceptibility to NVHAP and poor outcomes may lead to new approaches and more individualized strategies for the prevention and treatment of NVHAP.

Research questions in pathogenesis include the following:

1. How does the oral microbiome influence risk for NVHAP? Is the normal lung microbiome protective? Are there particular changes in the lung microbiome that predispose or predict development of NVHAP? What factors govern changes in the lung microbiome?

2. Is it possible to modulate the microbiome to prevent NVHAP?

3. What is the role of specific oral pathogens in predisposing patients to develop NVHAP and to have poor outcomes? Can new diagnostic technologies and models of lung infection help elucidate the roles of specific pathogens?

4. Are there interactions between the lung, mouth, gut microbiome, and host immunity that moderate risk for NVHAP?

5. What are the best strategies to reduce host susceptibility to NVHAP?

Surveillance

Accurate, timely, and efficient surveillance for NVHAP is critical to inform prevention and monitoring efforts. Surveillance helps determine the scope of the problem, identify which patients are at greatest risk for NVHAP, and provides the data necessary to target, evaluate and quantify the impact of prevention initiatives. NVHAP surveillance is challenging,

however, because the clinical criteria for NVHAP are subjective, often inaccurate, variably documented, and labor intensive to apply.[17]

Claims data do not provide a valid basis for surveillance. The estimated sensitivity of administrative codes for NVHAP is 40%–60%, and the positive predictive value of administrative codes for NVHAP is 25%–50%.[18–20] Researchers have begun working on alternative surveillance strategies. Wolfensberger et al,[21] for example, developed a screening algorithm for NVHAP based on orders for radiographic procedures ≥48 hours after admission, absence of mechanical ventilation, and presence of fever and/or an abnormal white blood cell count. Screening for these criteria rapidly ruled out NVHAP in 94% of hospitalized patients; the remaining 6% of cases were manually reviewed for final classification. Although this technique helps make manual surveillance more efficient, final classifications remain complicated and subjective.

Using natural language processing (NLP) to parse radiographic reports or digital analyses of chest radiographic images using machine learning are additional strategies for surveillance. The major limitation of radiograph NLP is the limited accuracy of chest imaging interpretation itself. Interobserver variability among radiologists is high, and the correlation between plain radiographs, computed tomography, and autopsy evidence of pneumonia is poor.[22]

A third strategy leverages clinical criteria from the electronic medical record (EMR) system to develop automated surveillance algorithms. Ji et al[5] proposed a surveillance definition based on concurrent evidence of sustained deterioration in oxygenation, ≥3 calendar days of new antibiotics, abnormal temperature or white blood cell count, and orders for chest imaging. The investigators were able to apply this definition to EMR data from 4 hospitals. They reported an NVHAP incidence of 0.6 episodes per 100 admissions, with a crude mortality rate of 28%, figures that match expected values, and good correspondence between NVHAP events and clinically diagnosed pneumonias.[23] Although this approach has the advantage of being objective and efficient, it does not improve the specificity of surveillance.

Research questions for surveillance include the following:

1. What are the most objective, efficient, and generalizable surveillance methods for NVHAP?
2. How can we decrease the subjectivity and increase the specificity of NVHAP surveillance?
3. To what extent do novel surveillance methods reliably detect and mirror meaningful improvements in patient care by demonstrating lower NVHAP rates?
4. What is the magnitude and consistency of associations between NVHAP and patient-centered outcomes such as length-of-stay, mortality, and readmissions?
5. How can hospitals easily and effectively leverage their EMR data to facilitate automated surveillance?

Prevention

The development of NVHAP requires a complex interaction of events that includes aspiration of microorganisms present in the oral cavity and a vulnerable host. Most prevention measures target primary source control (eg, oral care), maintaining patient mobility, head of bed elevation, reducing the use of acid-suppressing medications, nasogastric-tube care protocols, aspiration precautions, minimizing sedation, patient and family education, and the use of chest physiotherapy and incentive spirometry.[20,24–31] Many have proposed bundling 2 or more of these measures together. Data on the effectiveness of these strategies, however, both alone and in combination, are limited.

Oral care is the best-studied NVHAP prevention strategy. The potential importance of oral hygiene to prevent NVHAP is suggested by studies demonstrating an inverse association between oral hygiene and pneumonia as well as homology between the organisms found in HAP patients' gingival crevices and respiratory specimens.[32–34] It has been difficult, however, to demonstrate conclusively that improving oral hygiene prevents NVHAP. Many before-and-after studies suggest a possible effect of oral hygiene on lowering NVHAP rates, but parsing these studies is difficult because they are typically unblinded and thus are at substantial risk of bias due to the subjectivity and limited accuracy of NVHAP diagnostic criteria.[25,35,36] Randomized trials have been conducted, predominantly in ventilated patients and nursing-home patients; most have not reported significant associations between standardized oral care and lower pneumonia rates.[37,38] Combining the VAP prevention trials by meta-analysis does suggest that consistent oral care with chlorhexidine may lower pneumonia rates, but this signal is driven by open-label studies. There is no signal if one restricts the analysis to double-blind studies and no difference in antibiotic utilization, length-of-stay, or mortality rates.[38] Indeed, meta-analyses of oral care with chlorhexidine allow for the possibility that oral care with chlorhexidine may increase mortality rates.[39] Consequently, there is a pressing need for robust, randomized trials evaluating the impact of standardized oral care regimens without chlorhexidine on NVHAP in acute-care hospitals. Emerging strategies to track pneumonia using EMR data may facilitate more robust assessments of the impact of oral care by allowing investigators to track NVHAP more efficiently and objectively.[5]

Mobility is a second promising strategy to prevent NVHAP. Immobility is a risk factor for hospital-acquired pneumonia, thrombosis, delirium, prolonged length of stay, deconditioning, and aspiration.[31,40,41] Clinical audits show that hospitalized patients' muscles can atrophy at a rate of 3%—11% per day, and many patients suffer progressive declines in their mobility during hospitalization.[41–43] Enhancing mobility may therefore help maintain conditioning, limit the need for sedatives, reduce delirium, and prevent aspiration.[44] Unfortunately, mobility is commonly overlooked and under emphasized during routine clinical care.[20]

Additional strategies that may decrease NVHAP include reducing the use of sedating medications, peforming dysphagia screening in high-risk patients, using modified diets and feeding strategies for patients with abnormal swallowing, and following standardized processes to place and manage feeding tubes.[37] Acid suppressants, particularly proton-pump

inhibitors, have been associated with higher pneumonia rates in observational studies, but randomized trials have not demonstrated a clear impact on ventilator-associated pneumonia; it is unclear whether stopping proton-pump inhibitors may be more effective at decreasing NVHAP.[45,46] Other promising prevention measures include breathing exercises, chest physiotherapy, and head-of-bed elevation ("up to eat"), some of which have been associated with large decreases in pneumonia in before-and-after studies.[29,47] Lastly, higher nurse staffing ratios are associated with lower HAP rates and higher adherence to evidence-based processes of care and protocols.[48]

Research questions related to NVHAP prevention include the following:

1. How can we make prevention studies more rigorous and credible? What minimum standards should we require of prevention studies before using them to inform prevention practice or policy?
2. Can we develop objective consensus criteria to define NVHAP to harmonize clinical trials and facilitate comparability?
3. Can we create consensus definitions of prevention strategies, both in terms of the nature of each intervention as well as how and when each is measured?
4. Which prevention strategies are most effective in preventing NVHAP and improving patient outcomes?
5. Can we develop novel prevention strategies that will outperform current strategies?
6. What is the marginal impact of bundling multiple interventions into all-or-nothing care packages versus promoting individual interventions?

Implementation

It is not enough to know which prevention methods work under trial conditions; it is equally important to develop practical and generalizable strategies to help hospitals translate this evidence into real-world practice and to confirm that they remain effective in these settings.

Healthcare facilities face significant challenges operationalizing fundamental procedures to prevent NVHAP. Challenges include (1) obtaining buy-in from leadership and healthcare providers about the importance of NVHAP prevention; (2) overcoming beliefs that NVHAP prevention strategies such as oral hygiene and mobility are optional tasks rather than standard-of-care interventions; (3) procuring high-quality supplies, particularly for oral care; (4) maintaining staff competences in oral care, aspiration precautions, and mobilization including how to assist challenging patients; (5) tracking NVHAP prevention interventions and frequency; (6) empowering patients and family members to ask for assistance with oral care, feeding, and mobility and obtaining any needed supplies; (7) developing operational NVHAP tracking systems to assess the impact of prevention initiatives; and (8) spreading and sustaining NVHAP prevention for the long term.[49]

It can be difficult to operationalize the mobilization of patients. Barriers to mobilizing hospitalized patients include the presence of medical devices, such as intravenous lines and

Foley catheters, insufficient staff to provide assistance, concern about patients falling or causing them discomfort, obesity and frailty, lack of devices to facilitate ambulation (eg, gait belts), lack of patient motivation, absence of standing orders to mobilize patients, and overall, a failure to make mobility a priority.[50]

Some aspects of NVHAP prevention, such as oral care, safe feeding, and mobility, may be encouraged or completed by unlicensed staff, caregivers, patients, and their family members. Engaging patients and their families to assist in their own care may help with implementation by rechanneling their anxiety into productive tasks to improve the patient's well-being. Additionally, encouraging patients to mobilize themselves (if safe), perform their own oral care (if able), or inquire about when they will receive assistance helps elevate the importance of these interventions before and after discharge and may enable nurses to allocate their time to other patient-care priorities.

Engaging with both patients and staff and tailoring prevention strategies to each patient's specific circumstance can help shape implementation. Conversations about pneumonia prevention can occur within existing clinical workflows, for example, when mobilizing patients or assisting with their feeding or oral care. These discussions equip the patient with the knowledge they need to be active partners in their NVHAP prevention.

Efforts to enhance oral care, mobilize patients, and implement aspiration precautions should be aligned across disciplines. In addition to making prevention more reliable and efficient, aligning prevention initiatives across disciplines can help optimize message delivery for patients. For example, if a patient is given information about oral care and mobility during outpatient visits before admission, then inpatient nurses can build upon that foundation to solidify and amplify teaching about NVHAP prevention.

Research questions in implementation include the following:

1. Which NVHAP prevention strategies offer the best combination of feasibility, ease, cost, and impact?
2. How can components of an effective NVHAP prevention initiative be successfully implemented by licensed and unlicensed staff, caregivers, and patients?
3. What system-level changes, tools, and products are required to facilitate integration of NVHAP prevention activities into routine operations?
4. What types of EMR changes are required to track NVHAP prevention processes and outcome measures?
5. What cultural changes are necessary and what messaging resonates with healthcare providers, caregivers, and patients in NVHAP prevention?
6. What is the best method for lowering fear and perceived threat associated with oral care and mobility in patients with complex conditions such as dementia?
7. Does implementation of an oral care initiative in the inpatient or outpatient setting lead to further gains in oral, pulmonary, and general health?

8. How can providers from different disciplines best align their prevention, education, and patient engagement efforts?

Policy and research: A call to action

Currently, no national policy mandates flag NVHAP as a priority condition for prevention, surveillance, and reporting. Obstacles include hospitals' and regulators' historical focus on device-associated infections, the lack of practical and objective surveillance definitions for NVHAP, the absence of a single consensus diagnosis code for NVHAP, and the lack of high-quality studies to identify the most effective prevention measures and demonstrate how these can be efficiently integrated into routine care.

Unlike VAP, NVHAP is not recognized as one of the National Database of Nursing Quality indicators for which hospitals are accountable. It is not one of the conditions that the Centers for Medicare and Medicaid Services (CMS) requires hospitals to report to the CDC National Healthcare Safety Network, and it is not integrated into the CMS current pay-for-reporting or performance programs. Adding NVHAP to these lists of high-stakes conditions is one way to draw hospitals' attention to NVHAP, to catalyze the discovery of optimized prevention initiatives and implementation strategies, and thereby to drive down NVHAP incidence and morbidity. National dialogue is needed regarding the dimensions of optimal NVHAP programs, how to measure and reimburse the costs associated with NVHAP prevention, how to get insurers to cover NVHAP prevention interventions, and how to encourage researchers to explore uncharted territory in NVHAP surveillance and prevention. Engaging established networks of investigators in pneumonia, HAI transmission, and implementation science will enhance data sharing, trial design, and trial enrollment.

Research questions in the policy arena include the following:

1. Can we develop a national consensus definition of NVHAP universally recognized by stakeholders like the VHA, CDC, CMS, and The Joint Commission?
2. Should providers be required to report NVHAP rates to a national database, like requirements for other healthcare-associated infections?
3. Are there NVHAP prevention measures that are suitable for adoption as a national standard of care?
4. Are there standard diagnostic codes for NVHAP? How can we guide coders and clinicians to use these accurately?
5. Can we develop NVHAP quality metrics and reimbursement models that will effectively prevent cases?
6. Can we unify pneumonia prevention education and terminology for outpatients, hospitalized patients, and long-term care residents?
7. Can we develop a comprehensive curriculum for health professionals' education that addresses pneumonia prevention interventions including content and clinical competencies?

8. Are there consensus methods for data sharing, trial design, and trial enrollment across networks of investigators involved in hospital acquired infection investigation?

NVHAP is the ideal target for a team science approach. Epidemiologists, microbiologists, translational researchers, implementation scientists, evidence-based practice experts, professional organizations, educators, and patient advocacy groups all have a role to play in increasing the available evidence regarding NVHAP, its frequency, morbidity, and creating, implementing, and measuring rigorous prevention programs. Prevention of NVHAP has the potential to improve quality of care and patient safety, lower the risk of sepsis, reduce healthcare costs, and save lives. We urge the healthcare community to join us in studying and developing standardized processes to monitor and prevent NVHAP, ensuring that effective prevention measures are followed, educating patients and direct care staff, engaging patients and their families in prevention efforts, and developing policies to sustain the most promising practices.

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Conflicts of interest.

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References

1. See I, Chang J, Gualand N, et al. Clinical correlates of surveillance events detected by National Healthcare Safety Network pneumonia and lower respiratory tract definitions— Pennsylvania, 2011–2012. Infect Control Hosp Epidemiol 2016;37:818–824. [PubMed: 27072043]
2. Davis J, Finley E. A second breadth: hospital-acquired pneumonia in Pennsylvania, nonventilated versus ventilated patients. PA Patient Saf Advis 2018;15:48–59.
3. Giuliano KK, Baker D, Quinn B. The epidemiology of nonventilator hospital-acquired pneumonia in the United States. Am J Infect Control 2017. doi: 10.1016/j.ajic.2017.09.005.
4. Micek ST, Chew B, Hampton N, Kollef MH. A case–control study assessing the impact of nonventilated hospital-acquired pneumonia on patient outcomes. Chest 2016;150:1008–1014. [PubMed: 27102181]
5. Ji W, McKenna C, Ochoa A, et al. Development and assessment of objective surveillance definitions for nonventilator hospital-acquired pneumonia. JAMA Netw Open 2019;2:e1913674. [PubMed: 31626321]
6. Strassle PD, Sickbert-Bennett EE, Klompas M, et al. Incidence and risk factors of non-device-associated pneumonia in an acute-care hospital. Infect Control Hosp Epidemiol 2020;41:73–79. [PubMed: 31658914]
7. Magill SS, O'Leary E, Janelle SJ, et al. Changes in prevalence of health care-associated infections in US hospitals. N Engl J Med 2018;379:1732–1744. [PubMed: 30380384]
8. Zimlichman E, Henderson D, Tamir O, et al. Healthcare-associated infections: a meta-analysis of costs and financial impact on the US healthcare system. JAMA Intern Med 2013;173:2039–2046. [PubMed: 23999949]

9. Hsu JL, Siroka AM, Smith MW, Holodniy M, Meduri GU. One-year outcomes of community-acquired and healthcare-associated pneumonia in the Veterans' Affairs healthcare system. Int J Infect Dis 2011;15:e382–e387. [PubMed: 21393043]
10. Nelson RE, Samore MH, Jones M, et al. Reducing time-dependent bias in estimates of the attributable cost of health care-associated methicillin-resistant *Staphylococcus aureus* infections: a comparison of three estimation strategies. Med Care 2015;53:827–834. [PubMed: 26225444]
11. Nelson RE, Jones M, Liu CF, et al. The impact of healthcare-associated methicillin-resistant *Staphylococcus aureus* infections on postdischarge healthcare costs and utilization across multiple healthcare systems. Health Serv Res 2018;53 suppl 3:5419–5437. [PubMed: 30298924]
12. Arefian H, Vogel M, Kwetkat A, Hartmann M. Economic evaluation of interventions for prevention of hospital-acquired infections: a systematic review. PLoS One 2016;11:e0146381. [PubMed: 26731736]
13. Rennert-May E, Conly J, Leal J, Smith S, Manns B. Economic evaluations and their use in infection prevention and control: a narrative review. Antimicrob Resist Infect Control 2018;7:31. [PubMed: 29492261]
14. Dickson RP, Erb-Downward JR, Huffnagle GB. Towards an ecology of the lung: new conceptual models of pulmonary microbiology and pneumonia pathogenesis. Lancet Respir Med 2014;2:238–246. [PubMed: 24621685]
15. Fine LS. Nonventilator healthcare-associated pneumonia (NV-HAP): pathogenesis and microbiology of NV-HAP. Am J Infect Control 2020;48:A7–A9. [PubMed: 32331565]
16. Pettigrew MM, Tanner W, Harris AD. The lung microbiome and pneumonia. J Infect Dis 2020.
17. Roulson J, Benbow EW, Hasleton PS. Discrepancies between clinical and autopsy diagnosis and the value of post mortem histology; a meta-analysis and review. Histopathology 2005;47:551–559. [PubMed: 16324191]
18. Wolfensberger A, Meier AH, Kuster SP, Mehra T, Meier MT, Sax H. Should International Classification of Diseases codes be used to survey hospital-acquired pneumonia?J Hosp Infect 2018;99:81–84. [PubMed: 29410280]
19. van Mourik MS, van Duijn PJ, Moons KG, Bonten MJ, Lee GM. Accuracy of administrative data for surveillance of healthcare-associated infections: a systematic review. BMJ Open 2015;5:e008424.
20. Baker D, Quinn B. Hospital-Acquired Pneumonia Prevention Initiative-2: incidence of nonventilator hospital-acquired pneumonia in the United States. Am J Infect Control 2018;46:2–7. [PubMed: 29050903]
21. Wolfensberger A, Jakob W, Faes Hesse M, et al. Development and validation of a semi-automated surveillance system-lowering the fruit for non–ventilator-associated hospital-acquired pneumonia (nvHAP) prevention. Clin Microbiol Infect 2019;25:1428.e7–1428.el3.
22. Roberts IS, Benamore RE, Benbow EW, et al. Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. Lancet 2012;379:136–142. [PubMed: 22112684]
23. Ramirez Batlle H, Klompas M. Accuracy and reliability of electronic versus CDC surveillance criteria for nonventilator hospital-acquired pneumonia. Infect Control Hosp Epidemiol 2020;41:219–221. [PubMed: 31818337]
24. Klompas M, Branson R, Eichenwald EC, et al. Strategies to prevent ventilator-associated pneumonia in acute-care hospitals: 2014 update. Infect Control Hosp Epidemiol 2014;35:915–936. [PubMed: 25026607]
25. Quinn B, Baker DL, Cohen S, Stewart JL, Lima CA, Parise C. Basic nursing care to prevent nonventilator hospital-acquired pneumonia. J Nurs Scholarsh 2014;46:11–19. [PubMed: 24119253]
26. Cassidy MR, Rosenkranz P, Macht RD, Talutis S, McAneny D. The I COUGH multidisciplinary perioperative pulmonary care program: one decade of experience. J Qual Patient Saf 2020;46:241–249.
27. Sopena N, Sabria M. Multicenter study of hospital-acquired pneumonia in non-ICU patients. Chest 2005;127:213–219. [PubMed: 15653986]

28. Brogan E, Langdon C, Brookes K, Budgeon C, Blacker D. Dysphagia and factors associated with respiratory infections in the first week post stroke. Neuroepidemiology 2014;43:140–144. [PubMed: 25402187]
29. Lacerna CC, Patey D, Block L, et al. A successful program preventing non-ventilator hospital-acquired pneumonia in a large hospital system. Infect Control Hosp Epidemiol 2020;41:547–552. [PubMed: 31939344]
30. Kaneoka A, Pisegna JM, Miloro KV, et al. Prevention of healthcare-associated pneumonia with oral care in individuals without mechanical ventilation: a systematic review and meta-analysis of randomized controlled trials. Infect Control Hosp Epidemiol 2015;36:899–906. [PubMed: 25857604]
31. Brogan E, Langdon C, Brookes K, Budgeon C, Blacker D. Respiratory infections in acute stroke: nasogastric tubes and immobility are stronger predictors than dysphagia. Dysphagia 2014;29:340–345. [PubMed: 24445382]
32. Heo SM, Haase EM, Lesse AJ, Gill SR, Scannapieco FA. Genetic relationships between respiratory pathogens isolated from dental plaque and bron-choalveolar lavage fluid from patients in the intensive care unit undergoing mechanical ventilation. Clin Infect Dis 2008;47:1562–1570. [PubMed: 18991508]
33. Hamuro A, Kawaguchi H, Yamazoe K, Honda M, Tanaka R. Oral care and prevention of pneumonia in hospitalized patients with psychiatric disorders in Japan. Jpn Clin Med 2017;8:1179670717720407. [PubMed: 28811746]
34. Akutsu Y, Matsubara H, Okazumi S, et al. Impact of preoperative dental plaque culture for predicting postoperative pneumonia in esophageal cancer patients. Dig Surg 2008;25:93–97. [PubMed: 18379186]
35. Fox J, Frush K, Chamness C, Malloy J, Hyde S. Preventing hospital-acquired pneumonia (HAP) outside of the ventilator-associated pneumonia bundle. Prevent Strateg 2015;Fall:45–48.
36. Warren C, Medei MK, Wood B, Schutte D. A nurse-driven oral care protocol to reduce hospital-acquired pneumonia. Am J Nurs 2019;119:44–51.
37. Juthani-Mehta M, Van Ness PH, McGloin J, et al. A cluster-randomized controlled trial of a multicomponent intervention protocol for pneumonia prevention among nursing home elders. Clin Infect Dis 2015;60:849–857. [PubMed: 25520333]
38. Klompas M, Speck K, Howell MD, Greene LR, Berenholtz SM. Reappraisal of routine oral care with chlorhexidine gluconate for patients receiving mechanical ventilation: systematic review and meta-analysis. JAMA Intern Med 2014;174:751–761. [PubMed: 24663255]
39. Price R, MacLennan G, Glen J. Selective digestive or oropharyngeal decontamination and topical oropharyngeal chlorhexidine for prevention of death in general intensive care: systematic review and network meta-analysis. BMJ 2014;348:g2197. [PubMed: 24687313]
40. Stenlund M, Sjodahl R, Pia Yngman-Uhlin RN. Incidence and potential risk factors for hospital-acquired pneumonia in an emergency department of surgery. Int J Qual Health Care 2017;29:290–294. [PubMed: 28339769]
41. Teodoro CR, Breault K, Garvey C, et al. STEP-UP: study of the effectiveness of a patient ambulation protocol. Medsurg Nurs 2016;25:111–116. [PubMed: 27323470]
42. Fan E, Dowdy DW, Colantuoni E, et al. Physical complications in acute lung injury survivors: a two-year longitudinal prospective study. Crit Care Med 2014;42:849–859. [PubMed: 24247473]
43. Hopkins RO, Miller RR 3rd, Rodriguez L, Spuhler V, Thomsen GE. Physical therapy on the wards after early physical activity and mobility in the intensive care unit. Phys Ther 2012;92:1518–1523. [PubMed: 22491481]
44. Stolbrink M, McGowan L, Saman H, et al. The early mobility bundle: a simple enhancement of therapy which may reduce incidence of hospital-acquired pneumonia and length of hospital stay. J Hosp Infect 2014;88:34–39. [PubMed: 25063011]
45. Herzig SJ, Howell MD, Ngo LH, Marcantonio ER. Acid-suppressive medication use and the risk for hospital-acquired pneumonia. JAMA 2009;301:2120–2128. [PubMed: 19470989]
46. Krag M, Marker S, Perner A, et al. Pantoprazole in patients at risk for gastrointestinal bleeding in the ICU. N Engl J Med 2018;379:2199–2208. [PubMed: 30354950]

47. Wren SM, Martin M, Yoon JK, Bech F. Postoperative pneumonia-prevention program for the inpatient surgical ward. J Am Coll Surg 2010; 210:491–495. [PubMed: 20347742]

48. Kane RL, Shamliyan TA, Mueller C, Duval S, Wilt TJ. The association of registered nurse staffing levels and patient outcomes: systematic review and meta-analysis. Med Care 2007;45:1195–1204. [PubMed: 18007170]

49. Munro S, Haile-Mariam A, Greenwell C, Demirci S, Farooqi O, Vasudeva S. Implementation and dissemination of a Department of Veterans' Affairs oral care initiative to prevent hospital-acquired pneumonia among nonventilated patients. Nurs Adm Qtrly 2018;42:363–372.

50. Wood W, Tschannen D, Trotsky A, et al. A mobility program for an inpatient acute-care medical unit. Am J Nursing 2014;14:7.