ORIGINAL RESEARCH

Concordance of surveillance algorithms for the diagnosis of ventilator-associated pneumonia

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ABSTRACT

Background: Ventilator-associated pneumonia (VAP) is a leading cause of antibiotic prescribing and mortality in intensive care units. However, its diagnosis remains challenging because of non-specific clinical signs and subjective surveillance criteria. This study aimed to evaluate the diagnostic accuracy of four epidemiological surveillance algorithms: NHSN/CDC (USA), PNEU CDC (USA), RHOVE (México), and HELICS (Europe).

Methods: A retrospective observational study was conducted at a tertiary care hospital in northern México between August 2023 and August 2024. We analyzed the clinical records of 102 adult patients who received mechanical ventilation for ≥48 hours. Data collection included demographic, clinical, biochemical, radiological, and microbiological variables. Statistical analyses included sensitivity, specificity, and Cohen's kappa coefficient to assess agreement among the diagnostic algorithms.

Results: Of the 102 records, 80.3% yielded positive cultures, predominantly *Acinetobacter baumannii* (47%). VAP was identified in 40% of cases by NHSN/CDC, 54.9% by both PNEU CDC and RHOVE, and 55.8% by HELICS. Using NHSN/CDC as the reference standard, the PNEU CDC, RHOVE, and HELICS algorithms demonstrated 100% sensitivity but lower specificities (73.77%–75.41%). Cohen's kappa showed substantial agreement between NHSN/CDC and the other methods, with values ranging from 0.68 to 0.69 ($p < 0.001$). Notably, 45 patients who were clinically diagnosed by physicians did not meet sufficient criteria for a VAP surveillance diagnosis.

Conclusions: There is substantial concordance among the NHSN/CDC, PNEU CDC, RHOVE, and HELICS algorithms for VAP diagnosis. Although the latter three methods are highly sensitive, their lower specificity (average 74.5%) indicates a higher rate of false-positive results compared with the stricter NHSN/CDC criteria. These findings underscore the need to refine surveillance criteria to improve epidemiological comparability.

KEYWORDS:
Ventilator-associated pneumonia, epidemiological surveillance, diagnostic algorithms, ventilator-associated events (VAE), concordance analysis

INTRODUCTION

Ventilator-associated pneumonia (VAP) is clinically defined as a parenchymal lung infection in patients receiving invasive mechanical ventilation (MV) for at least 48 hours (Papazian et al., 2020) and is the leading reason for antibiotic prescribing in the intensive care unit.

VAP is estimated to affect 5% to 45% of patients receiving mechanical ventilation, with variation depending on the country and the criteria used to classify VAP (American Thoracic Society [ATS] & Infectious Diseases Society of America [IDSA], 2005; Koulenti et al., 2017). It is associated with increased length of hospitalization, morbidity, and mortality (Fihman et al., 2015; Vincent et al., 2009; Rello et al., 2002). Determining the precise incidence is challenging because of the lack of standardized pneumonia definitions, variability in their application, and diagnostic and microbiological limitations (Ego et al., 2015; Eggimann et al., 2003).

Moreover, in adult patients receiving mechanical ventilation, the accurate identification of VAP is often hindered by the presence of concurrent pulmonary complications such as acute respiratory distress syndrome (ARDS), pulmonary edema, and atelectasis (Klompas, 2007).

VAP surveillance is, therefore, necessary to determine its prevalence and measure the success of prevention efforts. However, the surveillance process is complex and subjective, as

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the inherent non-specific clinical signs and symptoms contribute to high diagnostic sensitivity. These sources of variability make VAP rates difficult to interpret and compare within and among institutions (Klompas & Platt, 2007; Rahimibashar et al., 2021; Kirtland et al., 1997).

To address these challenges, efforts have been made to develop standardized diagnostic algorithms that incorporate clinical, radiographic, and microbiological data.

To date, several surveillance criteria for VAP have been developed. In the United States, the original VAP surveillance definitions were replaced in 2013 by the National Healthcare Safety Network of the Centers for Disease Control and Prevention (NHSN/CDC) definitions of ventilator-associated events (VAE). The NHSN definitions use more objective and readily measurable criteria to improve reproducibility (Magill et al., 2013; Centers for Disease Control and Prevention [CDC], 2024; Klompas, 2013; Papazian et al., 2020; ATS & IDSA, 2005). Another surveillance strategy is the PNEU/VAP algorithm, which is based on imaging, clinical, and laboratory criteria. In Mexico, the Hospital Network for Epidemiological Surveillance (RHOVE, for its Spanish acronym), which forms part of the National Epidemiological Surveillance System (SINAVE), published updated definitions for health care-associated infections (HAIs) in 2024, implementing a new algorithm for the diagnosis of health care-associated pneumonia (Table 1). In 2023, RHOVE reported 8,439 cases of VAP, making it the most prevalent health care-associated infection (HAI) in the country. VAP accounted for 14% of all reported HAIs, with an incidence of 14.0 cases per 1,000 mechanical ventilation days. Finally, the Hospital in Europe Link for Infection Control through Surveillance (HELICS) provides another diagnostic algorithm for ventilator-associated pneumonia and has served as a reference standard in previous studies (Rahimibashar et al., 2021; Xie et al., 2011; López-Pueyo et al., 2013). Therefore, the aim of the present study was to evaluate the concordance among these four epidemiological surveillance algorithms (NHSN/CDC, PNEU CDC, RHOVE, and HELICS) for the detection of ventilator-associated pneumonia and to assess their diagnostic accuracy.

METHODS

A retrospective observational study was conducted based on the analysis of clinical records from patients aged 18 years or older who underwent invasive mechanical ventilation (MV) for at least 48 hours and were admitted to a medical/surgical ICU at a tertiary care hospital in northern Mexico between August 19, 2023 and August 31, 2024. During the study period, 745 patients admitted to the ICU received MV for more than 48 hours. Over this period, the institution recorded an overall VAP rate of 18.3 cases per 1,000 ventilator-days. Patient selection and medical record review were performed independently by an enrolment team of two infectious diseases physicians. In cases of disagreement, the opinion of a third evaluator was sought to reach a consensus. Participants were included if they had a diagnosis of ventilator-associated pneumonia (VAP) documented either by the Hospital Epidemiological Surveillance Unit, which uses the RHOVE algorithm for case identification and classification or by the treating physician during the hospital stay, as documented in the medical record. For the analysis, only the first episode of VAP experienced by each patient was considered.

The data collection tool consisted of a two-part checklist that included demographic variables; clinical variables (cough, shortness of breath, increased respiratory secretions, respiratory rate, heart rate, temperature, rales on auscultation, ventilator parameters such as positive end-expiratory pressure [PEEP] and fraction of inspired oxygen [FiO_2], and initiation of antibiotic treatment); biochemical variables (total leukocyte count and C-reactive protein); radiological findings from chest radiographs or computed tomography (CT) scans; and microbiological variables.

Positive quantitative cultures of lower respiratory tract secretions were identified from the patient medical records. A positive result was defined as $\geq 10^4$ colony-forming units per millilitre (CFU/mL) for bronchoalveolar lavage (BAL) samples and $\geq 10^5$ CFU/mL for tracheobronchial aspirates. Bacterial isolates were identified by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS; Microflex LT system, Bruker Daltonics, Bremen, Germany) as part of routine clinical practice.

Ethics approval

The Research and Ethics Committees of Hospital Universitario "Dr. José Eleuterio González" approved the study (registration number IF25-00001).

Statistical analysis

Frequencies and percentages were used to describe categorical variables. Continuous variables with a normal distribution were expressed as mean and standard deviation (SD), whereas non-normally distributed variables were presented as median and interquartile range (IQR). In addition, 2 × 2 contingency tables were used to calculate sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and likelihood ratios. Agreement among the evaluated diagnostic algorithms was assessed using Cohen's kappa coefficient. Data were analyzed using SPSS version 31.0 (IBM Corp., Armonk, NY, USA).

RESULTS

A total of 102 clinical records from patients diagnosed with VAP by the attending physician were evaluated. The mean age was 45.6 ± 12 years, and most patients were male (68.6%). Positive cultures were identified in 80.3% of cases, with *Acinetobacter baumannii* (47%), *Pseudomonas aeruginosa* (28.4%), *Klebsiella* spp. (14.7%), and *Stenotrophomonas maltophilia* (8.8%) being the most frequently isolated organisms. Multidrug-resistant (MDR) organisms were identified in 49% of isolates.

Overall, 57 patients met the criteria for at least one surveillance algorithm for ventilator-associated pneumonia. Specifically, 41 patients (40%) met the ventilator-associated event (VAE) definition according to the National Healthcare Safety Network of the Centers for Disease Control and Prevention (NHSN/CDC)

Table 1: Ventilator-associated pneumonia diagnostic algorithms

Algorithm	Clinical criteria	Chest criteria	Radiological criteria	Microbiological criteria
NHSN/ CDC	Temperature <36°C or >38°C WBC ≤4,000 or ≥12,000 cells/mm^3 Plus new antimicrobial agent is started for > four days (all beginning within two days before or two days after initiation of the VAE/VAC): IVAC*	After a period of stability or improvement on the ventilator (≥ 2 calendar days of stable or ↓ FiO_2 or PEEP): FiO_2 ↑ ≥ 0.20 lasting two days PEEP ↑ ≥ 3 cm H_2O lasting two days VAE/VAC*	Not included	Gram stain: (≥25 neutrophils/field and 10 epithelial cells/field) ≤and significative growth of a pathogen in respiratory samples or pleural fluid or histopathologic evidence of lung infection. PVAP*
PNEU CDC	At least one of the following: Fever >38°C WBC ≤4,000 or ≥12,000 cells/mm^3 If age < 70 years: AMS	Plus at least one of the following: New onset purulent sputum or change in sputum character or increased respiratory secretions, or increased suctioning requirements. New onset or worsening cough or dyspnea or tachypnea Rales or bronchial breath sounds. Worsening gas exchange (PaFi <240 or increased ventilation demands)	≥ two serial chest imaging studies with at least one of the following findings: new and progressive or persistent infiltrate, consolidation or cavitation	At least one of the following: organism identified from pleural fluid, positive quantitative culture result from minimally contaminated LRT specimen or histopathologic exam shows at least one of the following: abscess formation or foci of consolidation with intense PMN accumulation in bronchioles and alveoli
HELICS	At least one of the following: Temperature > 38°C (with no other cause) WBC > 12,000/mm^3 or < 4,000/mm^3 If age > 70 years: AMS without other cause	Plus at least one of following: New onset purulent sputum or change in sputum character (colour, quantity, consistency). Cough or dyspnea or tachypnea Suggestive auscultation (rales rhonchi, wheezing) Worsening gas exchange (increasing FiO_2 requirements or ventilation demands)	Image suggestive of pneumonia. (≥ two serial chest X-rays or CT scans with suggestive imaging for patients with underlying cardiac or pulmonary disease)	Positive quantitative culture result from minimally contaminated LRT specimen or growth in culture of pleural fluid or pleural or pulmonary abscess, histology, or pathogen antigen or antibody testing
RHOVE	At least one of the following: Fever >38°C or hypothermia <36°C WBC ≤4,000 or ≥12,000 cells/mm^3 New antibiotics started for > 4 days if age <70 years: AMS Increase in FiO_2 of >20% sustained for >2 days Increase in PEEP of >3 cm H_2O sustained for >2 days	Plus at least two of the following: New onset purulent sputum or change in sputum character (colour, quantity, consistency). Increased respiratory secretions, or increased suctioning requirements. New or worsening cough, dyspnea or tachypnea Rales or bronchial breath sounds	≥ one chest imaging with at least two of the following findings: new or progressive and persistent infiltrate, consolidation or cavitation	Positive quantitative culture result from minimally contaminated LRT specimen or histopathology showing the presence of lung or pleural abscesses

NHSN/CDC: National Healthcare Safety Network of the Centers for Disease Control and Prevention; **HELICS:** Hospital in Europe Link for Infection Control through Surveillance; **RHOVE:** Hospital Network for Epidemiological Surveillance; **PNEU CDC:** Centers for Disease Control and Prevention pneumonia surveillance algorithm; **LRT:** lower respiratory tract; WBC: white blood cell; FiO_2: fraction of inspired oxygen; AMS: altered mental status; significant growth in respiratory samples: endotracheal aspirate, ≥10^5 CFU/mL; bronchoalveolar lavage, ≥10^4 CFU/mL; lung tissue, ≥10^4 CFU/g; protected specimen brush, ≥10^3 CFU/mL; VAC/VAE: ventilator-associated condition/ventilator-associated event; IVAC: infection-related ventilator-associated complication; PVAP: possible ventilator-associated pneumonia.

algorithm, 56 (54.9%) met the PNEU CDC and Hospital Network for Epidemiological Surveillance (RHOVE) criteria, and 57 (55.8%) met the Hospital in Europe Link for Infection Control through Surveillance (HELICS) criteria.

In addition, 45 patients were clinically diagnosed with VAP by the attending physician but did not meet sufficient criteria under any of the surveillance algorithms. This was primarily due to the absence of radiographic progression and the lack of microbiological isolation on culture. For the purposes of this analysis, these patients were classified as false-positive cases (Table 2).

Using the NHSN/CDC criteria as the reference standard, the sensitivity and specificity of the evaluated diagnostic algorithms were as follows: PNEU CDC (sensitivity 100%; specificity 75.41%), RHOVE (sensitivity 100%; specificity 75.41%), and HELICS (sensitivity 100%; specificity 73.77%) (Table 3).

Table 2: Baseline clinical, demographic characteristics and VAP diagnosis by each definition of the study population

Charactheristics	Total population (N = 102)	VAP by ≥1 different definition (n = 57)	Without VAP † (n = 45)	Kappa agreement coefficient ‡
Age (years), mean ± SD	45.6 ± 12	47.8 ± 18.5	42.8 ± 16.5	NA
Male, n (%)	70 (68.6%)	39 (68.4%)	31 (68.9%)	NA
ICU admission diagnosis, n (%) ¶				
CKD decompensated	19 (18.6%)	CKD-d 12 (21.1%)	CKD-d 7 (15.6%)	NA
Acute myocardial infarction	12 (11.8%)	AMI 7 (12.3%)	TBI 7 (15.6%)	
Traumatic brain injury	12 (11.8%)	Polytrauma 6 (10.5%)	AMI 5 (11.1%)	
Polytrauma	10 (9.8%)	Post-craniectomy 6 (10.5%)	Abdominal sepsis 5 (11.1%)	
Abdominal sepsis	9 (8.8%)	TBI 5 (8.8%)	Polytrauma 4 (8.9%)	
Post-craniectomy	8 (7.8%)			
Days on MV until VAP* median [IQR]	8 [2 – 20]	8 [2 – 20]	8 [2 – 18]	NA
Type of ICU				
Medical	40 (39.2%)	24 (42%)	16 (36%)	NA
Medical/Surgical	55 (53.9%)	33 (58%)	22 (49%)	
No Info in the record	7 (6.9%)	0 (0%)	7 (15%)	
VAP definitions				
NHSN/CDC	41 (40%)	16 (28%)	0 (0%)	NA
PNEU/CDC	56 (54%)	1 (1.8%)	0 (0%)	0.69 (p < 0.001)
RHOVE	56 (54%)	1 (1.8%)	0 (0%)	0.69 (p < 0.001)
HELICS	57 (55%)	0 (0%)	0 (0%)	0.68 (p < 0.001)

* Days of mechanical ventilation until VAP diagnosis by any definition.

† Patients who does not meet enough criteria to VAP.

‡ Agreement between NHSN/CDC and the rest based on score: ≤ 0 (no agreement); 0.01–0.20 (slight); 0.21–0.40 (fair); 0.41–0.60 (moderate); 0.61–0.80 (substantial); and 0.81–1.00 (almost perfect agreement).

¶ The most common diagnosis in the study population.

ICU: Intensive Care Unit. CKD-d: Chronic Kidney Disease decompensated. **AMI:** Acute Myocardial Infarction. **TBI:** Traumatic Brain Injury. **NHSN/CDC:** National Healthcare Safety Network of the Centers for Disease Control and Prevention; **HELICS:** Hospital in Europe Link for Infection Control through Surveillance; **RHOVE:** Hospital Network for Epidemiological Surveillance; **PNEU CDC:** Centers for Disease Control and Prevention; **VAP:** Ventilator associated pneumonia.

Return to TABLE OF CONTENTS

Agreement between the NHSN/CDC algorithm and the other diagnostic methods was assessed using Cohen's kappa coefficient. The agreement between NHSN/CDC and PNEU CDC yielded a kappa value of 0.69 ($p < 0.001$), as did the agreement between NHSN/CDC and RHOVE (K = 0.69, $p < 0.001$). Agreement between NHSN/CDC and HELICS yielded a kappa value of 0.68 ($p < 0.001$). These findings indicate substantial agreement among the evaluated diagnostic methods for case classification (Table 2).

Table 3: Sensitivity and specificity of the evaluated methods for the diagnosis of ventilator-associated pneumonia compared with the NHSN/CDC criteria as the reference standard

Algorithm	% Sensitivity	% Specificity	% PPV	% NPV	% Accuracy
PNEU CDC	100	75.41	73.21	100	85.29
RHOVE	100	75.41	73.21	100	85.29
HELICS	100	73.77	71.93	100	84.31

NHSN/CDC: National Healthcare Safety Network of the Centers for Disease Control and Prevention; **HELICS:** Hospital in Europe Link for Infection Control through Surveillance; **RHOVE:** Hospital Network for Epidemiological Surveillance; **PNEU CDC:** Centers for Disease Control and Prevention; **PPV:** positive predictive value; **NPV:** negative predictive value.

DISCUSSION

Historically, the diagnosis of ventilator-associated pneumonia (VAP) has been based on a tripartite assessment of clinical, radiological, and microbiological parameters (Tejerina et al., 2010). The inherent challenges of clinical diagnosis are mainly attributable to the non-specific signs and symptoms, which frequently overlap with other complications associated with mechanical ventilation, including pulmonary edema and atelectasis (Vincent et al., 2009; Klompas, 2007; Rahimibashar et al., 2021).

Evaluating the correlation and diagnostic performance of VAP surveillance algorithms is crucial for ensuring accurate epidemiological assessments and facilitating robust comparisons across studies (Waltrick et al., 2015; Ego et al., 2015).

The agreement among the surveillance algorithms observed in our study is consistent with previous reports. A prospective study comparing the Johanson criteria, the Clinical Pulmonary Infection Score (CPIS), and the NHSN/CDC definitions against HELICS reported that, using HELICS as the reference standard, the sensitivity and specificity of the evaluated diagnostic algorithms were as follows: NHSN/CDC (sensitivity 54.2%; specificity 100%), CPIS (sensitivity 68.75%; specificity 95.23%), and Johanson criteria (sensitivity 67.69%; specificity 95%) (Rahimibashar et al., 2021).

Another study of 168 ICU patients evaluated the agreement between CPIS, using a score of ≥7 points to diagnose VAP, and the NHSN/CDC criteria. The NHSN/CDC method demonstrated high specificity (100%), a positive predictive value (PPV) of 100%, and a negative predictive value (NPV) of 84%, but relatively low sensitivity (37%). These differences resulted in substantial discrepancies in the estimated incidence density (NHSN/CDC: 5.2 per 1,000 mechanical ventilation days; CPIS >7 points: 13.1 per 1,000 mechanical ventilation days) (Waltrick et al., 2015).

These studies concluded that the low sensitivity of the NHSN/CDC method for identifying VAP was attributable to its stringent criteria, including higher thresholds for positive end-expiratory pressure (PEEP) and fraction of inspired oxygen (FiO_2), as well as the requirement for a 48-hour period of ventilatory stability, which is not observed in all patients with VAP (Rahimibashar et al., 2021; Waltrick et al., 2015).

Additionally, the international EUVAE cohort examined the relationship between ventilator-associated events (VAE) and VAP and found that only 59% of patients with suspected pulmonary infection met the criteria for possible ventilator-associated pneumonia (PVAP). This finding suggests that the VAE algorithm identifies only the most severe cases and excludes patients who do not experience sufficient deterioration in oxygenation to meet the diagnostic thresholds based on ventilator support requirements (Tejerina et al., 2010).

In the present study, concordance analysis using Cohen's kappa coefficient demonstrated substantial agreement between the NHSN/CDC algorithm and the PNEU CDC, RHOVE, and HELICS criteria. The kappa values (0.68–0.69) indicate agreement beyond chance, suggesting that these algorithms classify cases similarly. The statistical significance of these findings ($p < 0.001$) further supports the robustness of the observed agreement.

Nonetheless, although the PNEU CDC, RHOVE, and HELICS algorithms demonstrated 100% sensitivity relative to the NHSN/CDC reference standard, their specificities ranged from 73.77% to 75.41%. This translates to a false-positive rate of 24.59% to 26.23%, indicating that a considerable proportion of patients without VAP according to the reference standard would be classified as positive by these algorithms. These findings underscore the inherent trade-offs in surveillance design: highly specific algorithms such as NHSN/CDC, minimize subjectivity but may underestimate the true clinical burden of VAP.

Our findings underscore the importance of comparative evaluations of VAP surveillance algorithms. Although substantial concordance was observed among the evaluated methods, meaningful differences in specificity remained. These observations highlight the need for further research to

refine surveillance criteria and improve the consistency and reproducibility of VAP surveillance across institutions.

This study has several limitations that should be acknowledged. First, the retrospective design is susceptible to selection bias and residual confounding. Second, the single-centre setting may limit the generalizability of the findings. Finally, interobserver reproducibility of the algorithm assessments was not evaluated.

CONCLUSION

Our findings demonstrate substantial concordance among the NHSN/CDC, PNEU CDC, RHOVE, and HELICS algorithms for the diagnosis of ventilator-associated pneumonia. Using the NHSN/CDC algorithm as the reference standard, the evaluated algorithms demonstrated 100% sensitivity and an average specificity of 74.5%.

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