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Original Article

Temporal trends in postoperative and ventilator-associated pneumonia in the United States

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Abstract

Objective: To determine change in rates of postoperative pneumonia and ventilator-associated pneumonia among patients hospitalized in the United States during 2009–2019.

Design: Retrospective cohort study.

Patients: Patients hospitalized for major surgical procedures, acute myocardial infarction, heart failure, and pneumonia.

Methods: We conducted a retrospective review of data from the Medicare Patient Safety Monitoring System, a chart-abstraction–derived database including 21 adverse-event measures among patients hospitalized in the United States. Changes in observed and risk-adjusted rates of postoperative pneumonia and ventilator-associated pneumonia were derived.

Results: Among 58,618 patients undergoing major surgical procedures between 2009 and 2019, the observed rate of postoperative pneumonia from 2009–2011 was 1.9% and decreased to 1.3% during 2017–2019. The adjusted annual risk each year, compared to the prior year, was 0.94 (95% CI, 0.92–0.96). Among 4,007 patients hospitalized for any of these 4 conditions at risk for ventilator-associated pneumonia during 2009–2019, we did not detect a significant change in observed or adjusted rates. Observed rates clustered around 10%, and adjusted annual risk compared to the prior year was 0.99 (95% CI, 0.95–1.02).

Conclusions: During 2009–2019, the rate of postoperative pneumonia decreased statistically and clinically significantly in among patients hospitalized for major surgical procedures in the United States, but rates of ventilator-associated pneumonia among patients hospitalized for major surgical procedures, acute myocardial infarction, heart failure, and pneumonia did not change.

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Nonventilator hospital-acquired pneumonia (NV-HAP), including postoperative pneumonia, and ventilator-associated pneumonia (VAP), are the most common nosocomial infections.[1] Postoperative pneumonia, a subset of NV-HAP and VAP, has been estimated to occur in ~1% of surgical inpatients,[2,3] similar to the rate among nonsurgical patients. The incidence of VAP is also substantial at ~10% of patients receiving mechanical ventilation for >48 hours.[4] The impacts of postoperative pneumonia and VAP are considerable. Although estimates vary, VAP may result in an attributable mortality of ~10%.[5] It also results in substantially increased costs and hospital lengths of stay.[6] Similarly, postoperative HAP has been associated with increased risk of mortality, hospital length of stay, and cost.[3,7]

Substantial efforts nationally and at the individual hospital level have been made to decrease the rate of VAP.[8,9] Nonetheless, a prior report by our group suggested that VAP rates remained constant in the United States between 2005 and 2013.[4] Although CDC data suggest a decrease in VAP rates during the same period,[10] these data may have been biased by self-reporting and imprecise definitions.[11] Less attention has been given to non–ventilator-associated postoperative pneumonia, with just a few reports from single hospitals or hospital systems[7,12–14] and no national interventions such as payment policy or quality improvement initiatives.

Data regarding trends in postoperative pneumonia rates are limited; however, a study reported conflicting results in 2 national databases. Based on the National Inpatient Sample, the incidence of postoperative pneumonia decreased significantly between 2009 and 2013. In the National Surgical Quality Improvement Program

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database, however, no significant trends have been identified other than a statistically significant increase in postoperative pneumonia in cardiothoracic surgery patients.[3]

The Medicare Patient Safety Monitoring System (MPSMS) is a nationwide chart-abstraction–based database of adverse events in hospitalized patients. The MPSMS has measured the rates of both VAP and postoperative pneumonia for many years using stable definitions for both entities. Here, we report trends in the rates of VAP and postoperative pneumonia from 2009 to 2019.

Methods

Study sample

Our study sample was drawn from MPSMS data, the nation's largest randomly selected hospital medical record–abstracted adverse-event database. The sample included only medical records for the 4 conditions (ie, acute myocardial infarction, heart failure, pneumonia, and major surgical procedures) included in the CMS Hospital Inpatient Quality Reporting Program and in the CMS Surgical Care Improvement Project. The data include patient demographics, comorbidities, and 21 selected in-hospital adverse-event measures jointly developed by federal agencies and private healthcare organizations. Hospitals were randomly selected each year and contributed approximately equal numbers of randomly selected medical records to the MPSMS. Medical record abstraction was conducted at the CMS Clinical Data Abstraction Center. Based on 80 monthly reabstractions, the agreement between abstraction and reabstraction ranged from 94% to 99% for data elements used to identify adverse events. Detailed information on the MPSMS has been reported elsewhere.[4,15–22] The Institutional Review Board at Yale University waived the requirement for informed consent based on the nature of the study.

We created 2 study cohorts from the MPSMS data: (1) the postoperative pneumonia cohort that included patients who underwent a major surgical procedure as defined by the Surgical Care Improvement Project (SCIP)[21] and (2) the VAP cohort that included patients who had acute myocardial infarction (AMI), heart failure (HF), pneumonia, or underwent a major surgical procedure, and were intubated for at least 48 hours. Postoperative pneumonia was defined when the following occurred after a patient underwent a major surgical procedure included in the national SCIP denominator: a new chest radiograph abnormality consistent with pneumonia, a documented physician diagnosis of pneumonia, and either a provider order for antibiotics to treat the pneumonia or death or discharge the day of pneumonia diagnosis. VAP was defined based on the same criteria, in patients who had required invasive mechanical ventilation for at least 48 hours, whether or not they had undergone surgery. Patients with a diagnosis of pneumonia prior to surgery or prior to mechanical ventilation were excluded from both denominators. Some patients were at risk for both outcomes (VAP and postoperative pneumonia) and were thus included in both cohorts. For both cohorts, we restricted the study to patients who were discharged from an acute-care hospital in the United States between January 1, 2009, and September 30, 2019, an 11-year period, although no data were captured from October 1 to December 31, 2009.

Patient, hospital characteristics, and outcomes

Patient characteristics for the MPSMS data were obtained from medical records, including demographics (age, sex, and race), comorbidities (heart failure, obesity, coronary artery disease, renal disease, cerebrovascular disease, chronic obstructive pulmonary disease, cancer, diabetes), and smoking status. Using the *International Classification of Disease, Ninth Revision* (ICD-9) and ICD-10 diagnosis codes, we also created an aggregated comorbidity variable that counts each of the 29 individual Elixhauser-specific comorbidities[23,24] for each patient in the MPSMS sample. This variable ranged from 0 to 29; a patient with a value of 0 presented no major Elixhauser-specific comorbidities and a patient with a value of 29 presented the highest number of comorbidities. We used this ordinal variable in addition to the MPSMS-abstracted comorbidities for the risk-adjustment analysis.

To address changes in the types of surgical procedures over time and to overcome the large volume of individual ICD-9 and ICD-10 procedure codes, we used the Clinical Classifications Software (CCS),[23] a diagnosis and procedure categorization algorithm developed by the Agency for Healthcare Research and Quality, to collapse >3,800 (ICD-9-CM) and 70,000 (ICD-10-PCS) individual procedure codes into 285 clinically homogeneous, meaningful, and mutually exclusive procedure categories (https://www.hcup-us.ahrq.gov/toolssoftware/ccs10/ccs10.jsp). Hospital characteristics were obtained from the 2010–2017 American Hospital Association's Annual Survey Database, including teaching status (teaching vs nonteaching), geographic location (urban vs nonurban), ownership (private not-for-profit vs others), bed size (continuous), performances of coronary artery bypass graft surgery (yes or no), and percutaneous coronary intervention (yes or no).

Our primary outcomes were the occurrence rate of postoperative pneumonia and ventilator-associated pneumonia. We also report trends in hospital length of stay and in-hospital mortality for patients in the study cohorts.

Statistical analysis

We conducted descriptive analyses to illustrate patient characteristics over the study period for both cohorts. We fit a sequence of linear mixed-effect models with a logit link function to evaluate the trend in the occurrence rate of adverse events. Specifically, model A was fit without adjustment for any covariates; model B was adjusted for patient characteristics; model C was adjusted for patient and hospital characteristics; and model D was adjusted for patient characteristics, hospital characteristics and type of surgery. To account for changes in the frequency of types of surgical procedures performed over time, we conducted a principal component analysis to convert the CCS-specific procedures into 5 components in which each component represented a linear combination relationship of all the CCS-specific procedures in Model D. We also included the top 6 CCS-specific procedure categories, which represented 78.1% of the cases during the study period in model D in addition to the following patient and hospital characteristics: arthroplasty knee (CCS 152); hysterectomy, abdominal and vaginal (CCS 124); hip replacement, total and partial (CCS 153); colorectal resection (CCS 78); coronary artery bypass graft (CCS, 44); and lower GI therapeutic procedures (CCS 96). All models were fit with hospital-specific random intercepts to account for within-hospital and between-hospital variations and included an ordinal time variable, ranging from 0 to 10, corresponding to years 2009 (time, 0) to 2019 (time, 10) to represent the annual change in adverse event rates. The odds ratio of the time variable was used to represent the average annual change in the occurrence rate of adverse event rates. To facilitate data

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presentation and increase the sample size in the baseline period, patient characteristics and adverse event rates were reported in 3-year intervals. Analyses were conducted using SAS version 9.4 64-bit software (SAS Institute, Cary, NC). We followed the guidelines for cohort studies, described in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement (ie, guidelines for reporting observational studies).[25]

Results

Postoperative pneumonia

Between 2009 and 2019, data were available for 58,618 patients at risk for postoperative pneumonia, an average of 5,329 patients per year (range, 1,847–9,721 per year) (Table 1). During this period, the median age increased, the percentage of female patients decreased, and changes were noted in the prevalences of several comorbidities (Table 1). We also identified some changes in the characteristics of the hospitals these patients were admitted to. Both the median hospital length of stay and the in-hospital mortality rate decreased significantly. Table 2 demonstrates the frequency of the 6 most common surgical procedure types, used in the multivariable models, as defined by Clinical Classification Software (CCS) codes. The 20 most frequent CCS codes are listed in Supplementary Table 1 (online). These 20 most frequent codes represented 96.8% of all included surgeries in during 2009–2011 and 95.8% of all included surgeries in 2017–2019. Notable changes occurred in the frequency of some of the types of surgery in our sample over time, most notably a marked decrease in the percentage of hysterectomies. Among these patients, 1,556 had a major surgical procedure and were at risk for VAP due to mechanical ventilation for at least 48 hours. Thus, they are also included in the VAP sample described in the next section. Table 3 lists data related to the trends in observed pneumonia rates. We detected a statistically significant yearly decrease in postoperative pneumonia rates over time. For the first 3 years of observation (2009–2011), the observed rate was 1.9%, (1.5% in 2009, 2.1% in 2010, and 1.8% in 2011), but this rate decreased to 1.3% during 2017–2019 (1.1% in 2017, 1.6% in 2018, and 1.3% in 2019).

Ventilator-associated pneumonia

In total, 4,007 patients were identified as being at risk for VAP during the study period (Table 4). No significant changes occurred in the median age of the sample (although there was an increase in the very elderly population) or other demographics over time. We detected changes in the frequency of several comorbidities over time. These changes included an increase in the prevalence of cancer, obesity, coronary artery disease, and renal disease. In addition, we identified an increase over time in hospital size and capacity to perform advanced procedures such as percutaneous coronary interventions and heart surgery. Median hospital LOS, while demonstrating a statistically significant trend, changed little in absolute terms. The mortality rate did not change. In contrast to postoperative pneumonia rates, there was no change in VAP rates, with rates each year clustering around 10% (Table 5).

Adjusted trends in postoperative pneumonia and VAP rates

Figure 1 demonstrates the annual change in adjusted pneumonia rates after considering patient and hospital characteristics and type of surgery. After adjusting for all factors (model D), the odds ratio (OR) for postoperative pneumonia by year was 0.94, (95% CI, 0.92–0.96), signifying an average 6% decrease in the odds of pneumonia each year. In contrast, we did not detect a decrease in VAP rates over time (OR, 0.99; 95% CI, 0.95–1.02.)

We also examined the trend in postoperative VAP among the 1,556 patients who had a major surgical procedure as well as mechanical ventilation for at least 48 hours. Consistent with the lack of improvement over time in VAP overall, there was no decrease in the observed or adjusted risk of VAP in these patients during the study period. The observed VAP rate varied from 10.1% in 2009–2011, 7.8% in 2012–2016, and 8.1% in 2017–2019 ($P = .2674$ for trend). The adjusted annual change in postoperative VAP was 0.95 (95% CI, 0.89–1.02).

Discussion

Using random sampling from a national cohort of patients, we documented a decrease in postoperative pneumonia rates between 2009 and 2019. The observed rate dropped from 1.9% during 2009–2011 to 1.3% during 2017–2019. This trend persisted after adjustment for patient and hospital-related factors and type of surgery; the annual adjusted decrease was 6%. In contrast, VAP rates remained largely unchanged between 2009 and 2019, a discouraging finding similar to that of our previous report for 2005–2013.[4]

In this observational study, we were unable to determine the reason for the significant decrease in postoperative pneumonia rates. Although efforts to prevent postoperative pneumonia have occurred, such efforts have only been reported from individual hospitals or hospital systems.[7,12,13] Although such efforts may have occurred at many other hospitals, we have insufficient data to attribute the improvements to these efforts. Improvements in surgical techniques, such as increasing use of minimally invasive and robotic surgery modalities have been associated with decreased postoperative pneumonia rates.[26–28] Other improvements might also be playing a role, including but not limited to advanced analgesia methods that improve postoperative pain control and likely improve the ability to cough, breathe deeply, and mobilize soon after surgery.[29,30] The increasing implementation of Enhanced Recovery After Surgery initiatives might also have contributed to decreases in postoperative pneumonia rates.[31] Furthermore, opioids may increase the risk for pneumonia[32,33] and recently efforts have been undertaken to reduce opioid use in hospitalized patients.[32]

The decreasing rate of postoperative pneumonia is undoubtedly an encouraging finding, even if the exact mechanism of this decrease cannot be determined. Fewer cases of postoperative pneumonia result in lower rates of mortality, morbidity, hospital length of stay, and cost.[3,34]

On the other hand, we have again demonstrated that VAP has been largely resistant to prevention efforts. This finding is not likely to be due to our definition of VAP not being responsive to change because the postoperative pneumonia definition is structurally similar, and we did detect a significant improvement over time. The VAP and postoperative pneumonia definitions differed only in the requirement for previous major surgery and lack of requirement for mechanical ventilation. Rather, as has been noted by previous researchers, few tools are clearly effective in preventing VAP.[35] Many interventions have been reported to lower VAP rates, but their interpretation is complicated because of risk of bias due to the subjectivity of VAP criteria as well as circularity between some preventive measures (eg, oral care with chlorhexidine) and VAP diagnostic criteria (eg, positive respiratory-tract cultures). The

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Table 1. Patient and Hospital Characteristics of Patients at Risk for Postoperative Pneumonia

Patient Characteristics	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	*P* Value
Total	5,318	8,948	9,721	8,364	4,658	5,373	2,772	5,871	3,839	1,907	1,847	. . .
Demographics, no. (%)												
Age, median y (IQR)	62.0 (49.0–73.0)	62.0 (49.0–73.0)	62.0 (50.0–72.0)	63.0 (51.0–73.0)	64.0 (53.0–73.0)	63.0 (53.0–72.0)	64.0 (54.0–72.0)	64.0 (54.0–73.0)	65.0 (55.0–73.0)	66.0 (57.0–74.0)	66.0 (56.0–74.0)	<.0001
Sex, female	3,522 (66.2)	5,853 (65.4)	6,305 (64.9)	5,330 (63.7)	2,843 (61.0)	3,209 (59.7)	1,703 (61.4)	3,617 (61.6)	2,283 (59.5)	1,125 (59.0)	1,073 (58.1)	<.0001
Race, white	4,375 (82.3)	7,371 (82.4)	8,018 (82.5)	6,932 (82.9)	3,905 (83.8)	4,504 (83.8)	2,314 (83.5)	4,844 (82.5)	3,226 (84.0)	1,574 (82.5)	1,484 (80.3)	.1541
Race, black	527 (9.9)	969 (10.8)	1013 (10.4)	866 (10.4)	474 (10.2)	535 (10.0)	281 (10.1)	611 (10.4)	339 (8.8)	170 (8.9)	202 (10.9)	
Race, other	416 (7.8)	608 (6.8)	690 (7.1)	566 (6.8)	279 (6.0)	334 (6.2)	177 (6.4)	416 (7.1)	274 (7.1)	163 (8.5)	161 (8.7)	
Comorbidities												
Cancer	1,058 (19.9)	1,852 (20.7)	1,971 (20.3)	1,731 (20.7)	998 (21.4)	1,154 (21.5)	525 (18.9)	1,083 (18.4)	703 (18.3)	375 (19.7)	356 (19.3)	.0011
Congestive heart failure	404 (7.6)	740 (8.3)	766 (7.9)	664 (7.9)	342 (7.3)	399 (7.4)	208 (7.5)	455 (7.7)	337 (8.8)	177 (9.3)	174 (9.4)	.0675
COPD	612 (11.5)	1,108 (12.4)	1,164 (12.0)	1,017 (12.2)	594 (12.8)	651 (12.1)	357 (12.9)	697 (11.9)	495 (12.9)	231 (12.1)	235 (12.7)	.2069
Cerebrovascular disease	451 (8.5)	763 (8.5)	772 (7.9)	666 (8.0)	414 (8.9)	415 (7.7)	228 (8.2)	444 (7.6)	337 (8.8)	168 (8.8)	165 (8.9)	.9247
Corticosteroids	155 (2.9)	225 (2.5)	275 (2.8)	252 (3.0)	139 (3.0)	145 (2.7)	88 (3.2)	161 (2.7)	131 (3.4)	64 (3.4)	63 (3.4)	.0217
Diabetes mellitus	1,136 (21.4)	1,986 (22.2)	2,214 (22.8)	1,872 (22.4)	1,078 (23.1)	1,191 (22.2)	635 (22.9)	1,347 (22.9)	912 (23.8)	478 (25.1)	433 (23.4)	.0011
Obesity	1,261 (23.7)	2,224 (24.9)	2,846 (29.3)	2,708 (32.4)	1,600 (34.3)	2,011 (37.4)	1,207 (43.5)	2,561 (43.6)	1,673 (43.6)	802 (42.1)	801 (43.4)	<.0001
Smoking	1,125 (21.2)	1,919 (21.4)	2,102 (21.6)	1,825 (21.8)	1,020 (21.9)	1,203 (22.4)	596 (21.5)	1,340 (22.8)	949 (24.7)	440 (23.1)	462 (25.0)	<.0001
Coronary artery disease	1,098 (20.6)	1,917 (21.4)	2,021 (20.8)	1,758 (21.0)	997 (21.4)	1,111 (20.7)	501 (18.1)	986 (16.8)	759 (19.8)	395 (20.7)	382 (20.7)	<.0001
Renal disease	409 (7.7)	771 (8.6)	831 (8.5)	817 (9.8)	488 (10.5)	614 (11.4)	313 (11.3)	645 (11.0)	519 (13.5)	278 (14.6)	308 (16.7)	<.0001
Elixhauser comorbidities,[a] median (IQR)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	1 (0–2)	2 (1–3)	.8976
Outcomes												
Length of stay, median d (IQR)	3.0 (2.0–6.0)	3.0 (3.0–6.0)	3.0 (2.0–5.0)	3.0 (3.0–6.0)	3.0 (2.0–6.0)	3.0 (2.0–5.0)	3.0 (2.0–5.0)	3.0 (2.0–5.0)	3.0 (2.0–5.0)	3.0 (2.0–5.0)	3.0 (2.0–5.0)	<.0001
In-hospital mortality	70 (1.3)	120 (1.3)	129 (1.3)	103 (1.2)	62 (1.3)	54 (1.0)	26 (0.9)	48 (0.8)	43 (1.1)	24 (1.3)	18 (1.0)	.0033
Hospital characteristics												
Large teaching	440 (8.3)	759 (8.5)	699 (7.2)	658 (7.9)	396 (8.5)	439 (8.2)	172 (6.2)	567 (9.7)	311 (8.1)	162 (8.5)	198 (10.7)	.0021
Private not for profit	3,185 (59.9)	5,420 (60.6)	5,298 (54.5)	4,807 (57.5)	2,666 (57.2)	2,936 (54.6)	1,373 (49.5)	3,350 (57.1)	2,408 (62.7)	1,208 (63.3)	1,178 (63.8)	.0481
Rural	1,084 (20.4)	1,963 (21.9)	2,046 (21.0)	1,689 (20.2)	1,032 (22.2)	1,191 (22.2)	536 (19.3)	1,260 (21.5)	862 (22.5)	430 (22.5)	303 (16.4)	.6314
JC accredited	4,299 (80.8)	7,278 (81.3)	7,769 (79.9)	6,762 (80.8)	3,657 (78.5)	4,162 (77.5)	2,176 (78.5)	4,477 (76.3)	3,017 (78.6)	1,546 (81.1)	1,525 (82.6)	<.0001
PCI capability	2,285 (43.0)	3,866 (43.2)	3,784 (38.9)	3,299 (39.4)	1,964 (42.2)	2,361 (43.9)	948 (34.2)	2,261 (38.5)	1,652 (43.0)	903 (47.4)	930 (50.4)	.0095
CABG capability	1,703 (32.0)	2,949 (33.0)	2,840 (29.2)	2,576 (30.8)	1,534 (32.9)	1,796 (33.4)	736 (26.6)	1,715 (29.2)	1,241 (32.3)	732 (38.4)	734 (39.7)	.0003
Beds, median (IQR)	165.5 (80.0–281.0)	169.0 (79.0–298.0)	144.0 (63.0–262.0)	153.0 (74.0–262.0)	168.0 (82.0–289.0)	160.0 (70.0–281.0)	144.5 (56.0–244.0)	154.0 (83.0–266.0)	173.0 (86.0–306.0)	175.0 (94.0–311.0)	177.0 (100.0–330.00)	<.0001

Note. IQR, interquartile range; COPD, chronic obstructive pulmonary disease; JC accredited, Joint Commission accredited; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft surgery.
[a]Elixhauser-specific comorbidity information was composited from 29 Elixhauser-specific comorbidity variables, ranging from 0 to 29. A patient with a value of 0 presents no major Elixhauser-specific comorbidities and a patient with a value of 29 presents the highest number of comorbidities.

Table 2. Six Most Frequent Clinical Classification Software (CCS) Codes

Frequency Rank	CCS Code	CCS Category	2009–Q3 2011, No. (%)	CCS Code	CCS Category	2017–Q3 2019, No. (%)
Total discharges			23,987			7,593
1	152	Arthroplasty knee	6,442 (26.9)	152	Arthroplasty knee	2,415 (31.8)
2	124	Hysterectomy; abdominal and vaginal	4320 (18.0)	153	Hip replacement; total and partial	1,827 (24.1)
3	153	Hip replacement; total and partial	4,176 (17.4)	124	Hysterectomy; abdominal and vaginal	437 (5.8)
4	78	Colorectal resection	2,440 (10.2)	78	Colorectal resection	409 (5.4)
5	44	Coronary artery bypass graft (CABG)	790 (3.3)	96	Other OR lower GI therapeutic procedures	369 (4.9)
6	90	Excision; lysis peritoneal adhesions	552 (2.3)	44	Coronary artery bypass graft (CABG)	270 (3.6)
Total discharges included in top 6 CCS codes			18,720 (78.0)			5,727 (75.4)

Note. CCS, clinical classifications software; OR, operating room; GI, gastrointestinal; CNS, central nervous system.

Table 3. Observed Rates of Postoperative Pneumonia

Postoperative Pneumonia	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	*P* Value
No. at risk (exposed)	5,318	8,948	9,721	8,364	4,658	5,373	2,772	5,871	3,839	1,907	1,847	. . .
No. with pneumonia (%)	82 (1.5)	186 (2.1)	177 (1.8)	149 (1.8)	65 (1.4)	81 (1.5)	38 (1.4)	66 (1.1)	42 (1.1)	30 (1.6)	23 (1.3)	<.0001

evidence supporting most interventions commonly employed to prevent VAP is of low quality in most cases.[36–38] Likewise, a meta-analysis of randomized trials in critical care reported that the only preventative strategies for critically ill patients associated with a mortality benefit were interventions designed to minimize iatrogenic ventilator injury (ie, noninvasive positive pressure ventilation in selected patients and low tidal volume ventilation, neuromuscular blockade, and prone positioning for patients with ARDS).[39]

Few data to which ours can be compared are available, but the available data mirror our findings for VAP, whereas postoperative data are mixed. A point-prevalence study across the United States demonstrated no change in either VAP or non-VAP hospital-acquired pneumonia rates between 2011 and 2015.[1] Similarly, Chugtai et al[3] reported a national postoperative pneumonia rate of 0.97% per the National Inpatient Sample during 2009–2013 and a statistically significant decrease in this rate during that period.[3] In contrast, NSQIP data reported in the same manuscript demonstrated a 1.3% rate and no overall change over the same period, except for an increase among cardiothoracic surgery patients.[3]

This study had several limitations. First, we were unable to report on nonpostoperative, non-VAP, hospital-acquired pneumonia because the MPSMS does not collect data on this adverse event. Second, this was a retrospective study, and as such was dependent on documentation; we may have missed episodes of pneumonia that were not diagnosed or documented. Finally, limited by sample size, we were not able to calculate rates of postoperative pneumonia after specific types of surgery; rather, we report on the universe of surgeries in the MPSMS sample. Due to the large number of types of surgeries included in our sample, we could not add each type to the risk-adjustment model. Rather, we adjusted for the 6 most common procedures; these 6 procedures comprised 78.1% of all cases. Changes in the frequency of the remaining surgery types were minor in absolute terms (Supplementary Table 1 online). Furthermore, temporal trends unrelated to safety and quality could have introduced bias into the results. For example, our sample includes inpatients only. The increasing tendency for many surgeries to be performed on an outpatient basis likely selects for more complex patients with more comorbidities included in an inpatient sample, but this trend would have resulted in a bias against a decrease in pneumonia rates. Thus, among patients undergoing major surgical procedures, whether subsequently admitted to the hospital as inpatients, the decrease in postoperative pneumonia rates might have been more than we measured in this inpatient population. Finally, although we present data on postoperative VAP, the numbers of at-risk patients in this subgroup were relatively low, and the lack of a statistically significant decrease might be a type 2 statistical error because the adjusted yearly decrease of 5% was not much less than the 6% adjusted yearly decrease for all postoperative pneumonia.

In summary, we report a clinically and statistically significant decrease in observed and adjusted postoperative pneumonia rates in a nationally representative sample between 2009 and 2019. VAP rates, in contrast, remained static at ~10% of patients at risk. These results suggest an improvement in patient safety among surgical patients, although the exact mechanism of this improvement cannot be determined. The lack of decrease in VAP rates points to the

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Table 4. Patient and Hospital Characteristics Among Patients at Risk for Ventilator-Associated Pneumonia[a]

Patient Characteristics	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	*P* Value
Total	296	697	636	586	357	416	227	321	251	139	81	...
Demographic, no. (%)												
Age, median y (IQR)	66.0 (56.0–77.0)	68.0 (58.0–78.0)	69.0 (58.0–78.0)	68.0 (58.0–79.0)	67.0 (58.0–75.0)	67.0 (57.0–75.0)	68.0 (59.0–79.0)	65.0 (57.0–74.0)	66.0 (57.0–74.0)	66.0 (58.0–77.0)	66.0 (58.0–76.0)	.1119
Sex, female	136 (45.9)	306 (43.9)	299 (47.0)	280 (47.8)	170 (47.6)	183 (44.0)	95 (41.9)	143 (44.5)	114 (45.4)	70 (50.4)	31 (38.3)	.6544
Race, white	223 (75.3)	536 (76.9)	468 (73.6)	449 (76.6)	280 (78.4)	319 (76.7)	171 (75.3)	229 (71.3)	176 (70.1)	103 (74.1)	61 (75.3)	.0988
Race, black	38 (12.8)	98 (14.1)	122 (19.2)	87 (14.8)	47 (13.2)	58 (13.9)	36 (15.9)	65 (20.2)	43 (17.1)	23 (16.5)	14 (17.3)	
Race, other	35 (11.8)	63 (9.0)	46 (7.2)	50 (8.5)	30 (8.4)	39 (9.4)	20 (8.8)	27 (8.4)	32 (12.7)	13 (9.4)	6 (7.4)	
Comorbidities												
Cancer	54 (18.2)	131 (18.8)	135 (21.2)	115 (19.6)	71 (19.9)	85 (20.4)	45 (19.8)	81 (25.2)	40 (15.9)	37 (26.6)	19 (23.5)	.1074
Congestive heart failure	156 (52.7)	380 (54.5)	338 (53.1)	302 (51.5)	192 (53.8)	202 (48.6)	127 (55.9)	161 (50.2)	138 (55.0)	82 (59.0)	31 (38.3)	.4185
Chronic obstructive pulmonary disease	92 (31.1)	287 (41.2)	256 (40.3)	245 (41.8)	138 (38.7)	147 (35.3)	84 (37.0)	124 (38.6)	106 (42.2)	52 (37.4)	28 (34.6)	.8726
Cerebrovascular disease	76 (25.7)	169 (24.2)	154 (24.2)	129 (22.0)	84 (23.5)	98 (23.6)	46 (20.3)	82 (25.5)	56 (22.3)	38 (27.3)	15 (18.5)	.5348
Corticosteroids	17 (5.7)	60 (8.6)	45 (7.1)	53 (9.0)	34 (9.5)	34 (8.2)	18 (7.9)	24 (7.5)	22 (8.8)	16 (11.5)	11 (13.6)	.0946
Diabetes mellitus	137 (46.3)	328 (47.1)	308 (48.4)	267 (45.6)	178 (49.9)	179 (43.0)	106 (46.7)	150 (46.7)	114 (45.4)	69 (49.6)	32 (39.5)	.467
Obesity	108 (36.5)	230 (33.0)	223 (35.1)	216 (36.9)	135 (37.8)	171 (41.1)	87 (38.3)	135 (42.1)	109 (43.4)	63 (45.3)	34 (42.0)	<.0001
Smoking	94 (31.8)	221 (31.7)	198 (31.1)	201 (34.3)	114 (31.9)	144 (34.6)	80 (35.2)	107 (33.3)	100 (39.8)	51 (36.7)	38 (46.9)	.0019
Coronary artery disease	200 (67.6)	449 (64.4)	415 (65.3)	375 (64.0)	236 (66.1)	269 (64.7)	159 (70.0)	180 (56.1)	147 (58.6)	86 (61.9)	46 (56.8)	.0071
Renal disease	123 (41.6)	297 (42.6)	281 (44.2)	285 (48.6)	201 (56.3)	230 (55.3)	114 (50.2)	181 (56.4)	144 (57.4)	79 (56.8)	41 (50.6)	<.0001
Elixhauser comorbidities, median (IQR)[b]	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–3)	.9978
Outcomes												
Length of stay, median d (IQR)	12.0 (8.0–19.0)	12.0 (7.0–18.0)	12.0 (8.0–18.5)	12.0 (8.0–19.0)	13.0 (8.0–20.0)	12.0 (7.0–19.0)	11.0 (7.0–17.0)	11.0 (7.0–19.0)	12.0 (7.0–17.0)	10.0 (6.0–16.0)	13.0 (8.0–21.0)	.0303
In-hospital mortality	79 (26.7)	188 (27.0)	188 (29.6)	141 (24.1)	89 (24.9)	101 (24.3)	64 (28.2)	84 (26.2)	59 (23.5)	38 (27.3)	16 (19.8)	.166
Hospital characteristics												
Large teaching	59 (19.9)	95 (13.6)	131 (20.6)	70 (11.9)	66 (18.5)	55 (13.2)	35 (15.4)	74 (23.1)	49 (19.5)	22 (15.8)	18 (22.2)	.1299
Private not for profit	200 (67.6)	463 (66.4)	411 (64.6)	365 (62.3)	213 (59.7)	263 (63.2)	117 (51.5)	183 (57.0)	149 (59.4)	91 (65.5)	47 (58.0)	.0002
Rural	69 (23.3)	148 (21.2)	123 (19.3)	118 (20.1)	81 (22.7)	104 (25.0)	43 (18.9)	58 (18.1)	46 (18.3)	22 (15.8)	11 (13.6)	.0546
JC accredited	254 (85.8)	595 (85.4)	565 (88.8)	517 (88.2)	312 (87.4)	360 (86.5)	204 (89.9)	285 (88.8)	219 (87.3)	116 (83.5)	63 (77.8)	.7254
PCI capability	183 (61.8)	410 (58.8)	390 (61.3)	351 (59.9)	228 (63.9)	273 (65.6)	139 (61.2)	182 (56.7)	158 (62.9)	88 (63.3)	60 (74.1)	.1403
CABG capability	160 (54.1)	348 (49.9)	337 (53.0)	300 (51.2)	201 (56.3)	241 (57.9)	121 (53.3)	154 (48.0)	146 (58.2)	77 (55.4)	52 (64.2)	.0533
Beds, median (IQR)	260.0 (156.0–437.0)	246.0 (142.0–366.0)	251.0 (141.0–406.0)	225.5 (134.0–350.0)	275.0 (153.0–431.0)	234.0 (152.5–396.5)	219.0 (136.0–373.0)	238.0 (154.0–415.0)	287.0 (169.0–423.0)	233.0 (146.0–357.0)	262.0 (193.0–373.0)	.0017

Note. IQR, interquartile range; JC accredited, Joint Commission accredited; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft surgery.

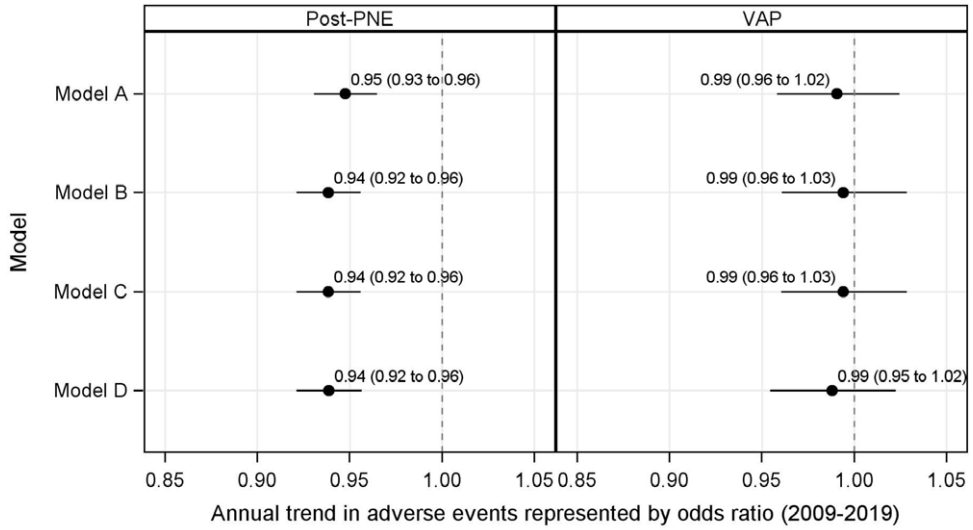
[a]Includes nonsurgical patients and 1,556 surgical patients at risk for VAP.

[b]Elixhauser-specific comorbidity information was composited from 29 Elixhauser-specific comorbidity variables, ranging from 0 to 29. A patient with a value of 0 presents no major Elixhauser-specific comorbidities and a patient with a value of 29 presents the highest number of comorbidities.

Table 5. Observed Rates of Ventilator-Associated Pneumonia

Ventilator-Associated Pneumonia[a]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	*P* Value
No. at risk (exposed)	296	697	636	586	357	416	227	321	251	139	81	. . .
No. (%) with pneumonia	21 (7.1)	81 (11.6)	77 (12.1)	60 (10.2)	40 (11.2)	46 (11.1)	23 (10.1)	30 (9.4)	24 (9.6)	15 (10.8)	11 (13.6)	0.9556

[a]Includes operative and nonoperative patients at risk for VAP.



Model A unadjusted, Model B adjusted for patient characteristics, Model C adjusted for patient and hospital characteristics, and Model D adjusted for patient, hospital characteristics, and type of procedures
Post-PNE=Postoperative pneumonia and VAP=Ventilator-associated pneumonia

Fig. 1. Annual change in adjusted postoperative and ventilator-associated pneumonia and rates accounting for patient and hospital characteristics and type of surgery.

need for innovative interventions or more aggressive use of protocols to avoid invasive mechanical ventilation, lighten sedation, and speed extubation.[39]

Supplementary material. For supplementary material accompanying this paper visit https://doi.org/10.1017/ice.2022.264

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