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Association Between Noninvasive Ventilation and Mortality Among Older Patients With Pneumonia

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Abstract

Objective—Despite increasing use, evidence is mixed as to the appropriate use of noninvasive ventilation in patients with pneumonia. We aimed to determine the relationship between receipt of noninvasive ventilation and outcomes for patients with pneumonia in a real-world setting.

Design, Setting, Patients—We performed a retrospective cohort study of Medicare beneficiaries (aged > 64 yr) admitted to 2,757 acute-care hospitals in the United States with pneumonia, who received mechanical ventilation from 2010 to 2011.

Exposures—Noninvasive ventilation versus invasive mechanical ventilation.

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Dr. Valley had full access to all of the data in the study and takes full responsibility for the integrity of the data and the accuracy of the data analysis. Drs. Valley and Cooke helped in study concept and design, acquisition of data, drafting of the article, and statistical analysis. Drs. Valley, Walkey, Lindenauer, Wiener, and Cooke helped in analysis and interpretation of data. Valley, Cooke. Drs. Valley, Walkey, Lindenauer, Wiener, and Cooke helped in critical revision of the article for important intellectual content. Dr. Cooke obtained funding.

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Measurement and Main Results—The primary outcome was 30-day mortality with Medicare reimbursement as a secondary outcome. To account for unmeasured confounding associated with noninvasive ventilation use, an instrumental variable was used—the differential distance to a high noninvasive ventilation use hospital. All models were adjusted for patient and hospital characteristics to account for measured differences between groups. Among 65,747 Medicare beneficiaries with pneumonia who required mechanical ventilation, 12,480 (19%) received noninvasive ventilation. Patients receiving noninvasive ventilation were more likely to be older, male, white, rural-dwelling, have fewer comorbidities, and were less likely to be acutely ill as measured by organ failures. Results of the instrumental variable analysis suggested that, among marginal patients, receipt of noninvasive ventilation was not significantly associated with differences in 30-day mortality when compared with invasive mechanical ventilation (54% vs 55%; $p = 0.92$; 95% CI of absolute difference, -13.8 to 12.4) but was associated with significantly lower Medicare spending (\$18,433 vs \$27,051; $p = 0.02$).

Conclusions—Among Medicare beneficiaries hospitalized with pneumonia who received mechanical ventilation, noninvasive ventilation use was not associated with a real-world mortality benefit. Given the wide CIs, however, substantial harm associated with noninvasive ventilation could not be excluded. The use of noninvasive ventilation for patients with pneumonia should be cautioned, but targeted enrollment of marginal patients with pneumonia could enrich future randomized trials.

Keywords

intensive care; noninvasive ventilation; pneumonia; respiratory insufficiency

The use of noninvasive positive pressure ventilation (NIV) for respiratory failure has increased dramatically over the past two decades (1–5). Clinical practice guidelines recommend NIV as the treatment of choice in patients with respiratory failure due to acute exacerbations of chronic obstructive pulmonary disease (COPD) and cardiogenic pulmonary edema, where it reduces mortality and complications associated with invasive mechanical ventilation (IMV) (6–9). However, many clinicians use NIV in patients with respiratory failure outside of these indications, a practice that has also increased (1, 5, 10, 11). For example, the use of NIV for pneumonia increased by 50% from 2000 to 2009 (5).

Guidelines do not provide recommendations regarding the use of NIV for patients with pneumonia (8, 9, 12). Although some randomized trials in patients with pneumonia demonstrated that NIV was associated with decreased need for endotracheal intubation (13–17), potential harms of NIV exist (18). For example, patients with pneumonia who received NIV were 56% and more likely to require intubation than patients with COPD who received NIV (5). NIV failure (going from NIV to IMV) has been implicated with increased complications and mortality compared to IMV alone (1, 2, 10, 18–23). NIV use for pneumonia may also lead to greater mortality than other modes of noninvasive oxygen supplementation such as high-flow nasal cannula (24).

In the current study, we sought to determine the real-world effect of NIV compared with IMV on 30-day mortality and Medicare payments among elderly Americans hospitalized for pneumonia. Because NIV use for pneumonia has been implicated with greater failure rates

and NIV failure has been linked with more complications, we hypothesized that NIV use would be associated with greater mortality and costs. Because patients may be started on NIV or IMV for reasons that may not be adequately measured by administrative data, we performed an instrumental variable analysis to account for observed and unobserved differences between patients.

METHODS

Data Source

We performed a retrospective cohort study of acute care hospitalizations from 2010 and 2011 among fee-for-service Medicare beneficiaries aged 65 years and older. We used the Medicare Provider Analysis and Review file linked to mortality data in the Medicare Beneficiary Summary File. Hospital characteristics were obtained from the 2010 American Hospital Association's Annual Survey and the 2010 Healthcare Cost Reporting Information System. Population and geographic information was obtained by linking to the 2010 U.S. Census by the patient's ZIP code of residence.

Study Cohort

All patients with an *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) present at admission 1) primary diagnosis code for pneumonia or 2) primary diagnosis code for respiratory failure or sepsis and secondary diagnosis code of pneumonia were identified (Supplementary Table 1, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>) (25, 26). We excluded patients with any ICD-9-CM code for COPD, cardiogenic pulmonary edema, or obstructive sleep apnea as they may have other indications for NIV use. Patients who did not receive any form of mechanical ventilation were excluded. Patients who were not admitted to the ICU were excluded, defined as the presence of an ICU or coronary care unit (CCU) revenue center code in the administrative billing record (27). Patients were also excluded if they were admitted to hospitals without ICU capabilities, were transferred from other acute-care hospitals, or were missing their residential ZIP code.

Treatment Variable and Patient Covariate Definitions

Our treatment variable was the type of mechanical ventilation received, defined as the presence of a NIV or IMV procedure code in the administrative record within the first 2 days after admission (Supplementary Table 1, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>). This method of identifying mechanical ventilation has been validated with high sensitivity and specificity (28). We identified the type of mechanical ventilation as the first mechanical ventilation procedure code (NIV or IMV). The timing of mechanical ventilation was identified by the date captured in separate timing variables for each procedure code (Fig. 1). When IMV and NIV codes occurred on the same date, NIV was assumed to precede IMV.

We measured preexisting comorbid illness according to Elixhauser et al (29) and captured severity of illness by using secondary ICD-9-CM diagnosis and procedural codes for acute organ dysfunction present at admission (30). Socioeconomic status was measured by the

median income of the patient's ZIP code of residence using 2010 U.S. Census data. Our analysis adjusted for a number of hospital characteristics, including hospital size and type (not-for-profit, for-profit, and government), hospital teaching status (based upon resident-to-bed ratio), proportion of ICU beds to total hospital beds, proportion of Medicaid patients cared for by the hospital, hospital nurse staffing ratio, hospital geographic region, and hospital technological index (31).

Outcome Measures

Our primary outcome was 30-day all-cause mortality measured from hospital admission. Thirty-day mortality was chosen as the primary outcome because it is a reasonable proxy for mortality attributable to a hospitalization and is less biased by hospital discharge practices (32–34). We evaluated Medicare reimbursements for each patient as a secondary outcome. Medicare reimbursements represent the real-world transaction of money paid by American taxpayers to compensate hospitals for the care provided to each patient.

Instrumental Variable

In a properly executed instrumental variable analysis, the instrument replicates random assignment of patients to a treatment group analogous to a randomized trial. In our study, the primary instrument was differential distance (35, 36). First, we examined the distribution of NIV rates across all hospitals and empirically defined “high NIV use” hospitals as those with an NIV rate in the top two quintiles (40%) of the included hospitals. A hospital's NIV rate was calculated as the number of patients to receive NIV for any reason divided by the total cases of mechanical ventilation (NIV + IMV) for each hospital. This definition for NIV rate was chosen because we believed that hospitals that use NIV frequently in general would be more likely to use NIV for pneumonia.

We calculated differential distance as the difference between 1) the distance from a patient's residence to the nearest high NIV use hospital and 2) the distance from a patient's residence to the nearest hospital of any type. The differential distance is the extra distance, beyond the closest hospital, a patient would have to travel to arrive at a hospital that uses NIV frequently. The instrument's validity was assessed through several methods (Supplementary Appendix 1, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>).

Although standard multivariable regression results represent the adjusted treatment effect for the average patient, the results from an instrumental variable analysis represent the adjusted treatment effect for the marginal patient—those who received NIV solely due to their proximity to a hospital that used NIV frequently (37).

Sensitivity Analyses

We analyzed the robustness of our findings by performing several sensitivity analyses. First, because we were unable to identify patients with advanced directives specifying wishes against receiving IMV, we repeated the primary analysis after excluding, separately, patients older than 80 years, those with metastatic cancer, and patients who died after receiving only NIV and not IMV. Second, because patients admitted to a CCU may be more likely to have a cardiovascular condition and have better outcomes with the use of NIV, we repeated the

primary analysis after excluding patients admitted to the CCU. Third, we performed a separate instrumental variable analysis with an alternative instrument: the 2009 hospital-specific all-cause NIV rate because we theorized that hospitals that used NIV more frequently in the past would be more likely to use it in the future. The secondary instrument's validity was tested (Supplementary Table 2, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>), and we evaluated the distribution of patient characteristics across median 2009 all-cause NIV rates (Supplementary Table 3, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>). Differential distance was chosen as the primary instrument over the hospital's 2009 NIV rate because differential distance is more likely to randomly assign individuals to the treatment—receiving NIV or IMV. Fourth, to assess the robustness of the results based on modeling method, we performed a propensity-score–matched analysis to balance measured confounders between groups using three matches per observation with a maximum probability distance of 0.2 between neighbors.

Statistical Analysis

We used chi-square tests or analysis of variance, as appropriate, to evaluate associations between NIV use and patient characteristics. Baseline patient characteristics were stratified by median differential distance and were compared using the standardized difference (38). We used regression to determine the relationship between receipt of NIV and 30-day mortality and Medicare payments without covariates. We then adjusted for patient and hospital characteristics to evaluate the association between NIV use and 30-day mortality and Medicare spending for the average patient. All regression models estimated robust SES with clustering at the hospital level.

For the instrumental variable analyses, we performed two-stage least squares regressions after adjusting for patient and hospital characteristics and estimating robust SES with clustering at the hospital level (36). In the first stage, the linear probability of receiving NIV was estimated by an individual's differential distance to a high NIV hospital, conditional on patient and hospital characteristics. In the second stage, the probability of 30-day mortality was estimated based on the fitted values from the first stage. Because the analysis focuses on the marginal effects at the mean, two-stage least squares regression is thought to have accurate estimates despite the use of a binary outcome (39). The instrumental variable-adjusted outcomes represent the mean absolute difference in the probability of death at 30 days or of Medicare spending for marginal patients. We estimated adjusted rates of outcomes using predictive margins.

All analyses were performed using Stata 14.1 (Stata Corporation, College Station, TX). All tests were two sided with *p* value of less than 0.05 considered significant. The University of Michigan Institutional Review Board reviewed and approved the study (HUM00053488).

RESULTS

We identified 883,913 acute-care hospitalizations of Medicare beneficiaries with pneumonia in 2010 and 2011. After application of exclusion criteria, the final sample included 65,747 patients admitted to 2,757 hospitals (Supplementary Fig. 1, Supplemental Digital Content 1,

<http://links.lww.com/CCM/C119>). Among these patients, 53,267 (81.0%) received IMV first and 12,480 (19.0%) received NIV first (Table 1). Of the patients who received NIV first, 2,485 (19.9%) subsequently received IMV. Patients receiving NIV were more likely to be older, male, white, rural-dwelling, and have less comorbidities. Patients receiving NIV were also less acutely ill by organ failure scores than patients receiving IMV (one organ failure vs two organ failures). In our sample, 1,126 hospitals (40%) were defined as “high NIV” hospitals. Hospital characteristics by NIV utilization are listed in Table 2.

In the unadjusted analysis, individuals receiving NIV had lower 30-day mortality compared with patients receiving IMV first (52.1% for NIV vs 55.4% for IMV; $p < 0.001$). Medicare payments were lower for NIV patients than for those receiving IMV (\$15,712 for NIV vs \$27,694 for IMV; $p < 0.001$). In contrast to the unadjusted results, the adjusted multivariable regression model demonstrated that NIV patients had higher risk-adjusted 30-day mortality compared with IMV patients (57.6% for NIV vs 54.2% for IMV; $p < 0.001$) (Table 3). Risk-adjusted payments by Medicare were lower for patients treated with NIV than for those treated with IMV (\$17,406 for NIV vs \$27,293 for IMV; $p < 0.001$).

The median differential distance to a hospital with high NIV use was 1.4 miles. Of the patients for whom the differential distance was less than 1.4 miles, 27% (8,898 of 32,878 patients) received NIV compared with 12% (3,777 of 32,869 patients) of those patients with pneumonia whose differential distance was more than 1.4 miles (Supplementary Table 4, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>). Therefore, 15% of patients could be considered marginal, in whom NIV use appeared to depend on distance (40). An absolute standardized difference greater than 10 indicates significant imbalance of covariates (41), and baseline patient characteristics were similar when stratified by median differential distance, other than race, urbanicity, and income—differences expected when using a geographic instrument (Supplementary Table 4, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>) (42). Patients with greater differential distance tended to have slightly higher severity of illness.

In the instrumental variable analysis, which estimates the effect in the subset of marginal patients and which also controls for patient and hospital characteristics, there was no significant difference in 30-day mortality between patients receiving NIV compared with patients receiving IMV (54.3% for NIV vs 55.0% for IMV; $p = 0.92$) with an absolute difference in 30-day mortality of 0.7% points favoring NIV (95% CI, −13.8 to 12.4) (Table 3). However, NIV use was associated with significantly lower payments by Medicare (\$18,433 vs \$27,051; $p = 0.02$), resulting in an absolute difference in Medicare payments of \$8,618 favoring NIV (95% CI −\$15,771 to −\$1,464).

Sensitivity analyses were consistent with our primary results as there were no significant differences in 30-day mortality between NIV and IMV use after excluding patients most likely to have advanced directives declining intubation, after excluding patients admitted to the CCU, when the 2009 hospital NIV rate was used as the instrumental variable, or in the propensity-score analysis (Supplementary Table 5, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>). These sensitivity analyses also consistently demonstrated that

NIV use was associated with a significant reduction in Medicare spending (Supplementary Table 6, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>).

DISCUSSION

Pneumonia is associated with considerable inpatient mortality and healthcare costs (43), particularly among the elderly. Yet, it remains unclear whether NIV benefits patients with pneumonia. We demonstrated that, on average, patients with pneumonia receiving NIV had worse outcomes than patients receiving IMV. However, among marginal patients with pneumonia, who received NIV instead of IMV solely because of their proximity to a hospital that used NIV frequently, we identified no significant difference in 30-day mortality and significantly lower Medicare spending associated with NIV use compared to IMV.

Prior studies provide mixed evidence that does not definitively support a first-line mode of ventilation for pneumonia. NIV use for pneumonia may reduce the need for endotracheal intubation (13–17); yet, randomized trials of pneumonia patients have been unable to replicate these benefits while demonstrating the potential for harm (1, 2, 5, 18–24, 44). Our study provides real-world evidence of the equipoise between NIV and IMV in a large sample of patients with pneumonia.

Our study could not exclude significant benefit or harm with NIV use but demonstrated the potential for cost savings. Some may argue that the similar mortality rate between NIV and IMV combined with lower costs should be sufficient to guide treatment. However, given the results of our multivariable regression analysis and the wide CIs seen in our instrumental variable analysis, substantial harm could not be ruled out, and the application of NIV for marginal, or clinically borderline, patients with pneumonia and respiratory failure, who could receive NIV or IMV, should be cautioned. Because average patients appeared to have worse outcomes with receipt of NIV in our analysis, identifying these marginal patients may provide a means to enrich future randomized trials.

As noted above, the marginal patient population does not immediately translate into specific clinical criteria; however, it is likely that these are patients who would receive NIV in one hospital but not another because clinicians may be unsure about which mode to use (Supplementary Fig. 2, Supplemental Digital Content 1, <http://links.lww.com/CCM/C119>) (37). In other words, for a marginal patient with pneumonia and respiratory failure, some clinicians may choose to offer NIV, whereas others may opt for IMV. Our results should not be applied to patients who clearly require IMV (e.g., respiratory arrest and unstable airway) or to patients who do not require any form of mechanical ventilation. In addition, our results should not be extrapolated to patients with COPD, pulmonary edema, or obstructive sleep apnea because they might have other reasons to benefit from NIV.

Our study should be interpreted in the context of several limitations. First, we used administrative data, which may underidentify conditions and procedures but has high specificity (27). Administrative data lack clinical variables, such as vital signs, mechanical ventilation settings, and duration of mechanical ventilation, which are necessary to guide clinical practice. We were also unable to identify where in the hospital mechanical

ventilation was initiated. Second, we could not identify patients from the administrative record who had “do-not-intubate” orders or who were immunocompromised. Patients with advanced directives limiting care could be more likely to receive NIV and die without aggressive measures, which could bias the results. To address this concern, we performed sensitivity analyses excluding patients most likely to decline endotracheal intubation as a treatment option. Third, we are unable to prove that our instrument fully addresses confounding (37, 42). After stratifying by median differential distance, severity of illness crossed the threshold for covariate imbalance although this difference appeared to be clinically trivial. Fourth, although there was no significant difference in 30-day mortality between NIV and IMV use, the wide CIs cannot exclude either substantial benefit or harms. Finally, our study included only inpatient hospital costs and did not include physician, facility, posthospitalization, or outpatient payments. Our study measured costs by Medicare spending, in which hospitals are reimbursed based on the diagnosis-related group (DRG) code for a patient’s condition. By definition, the DRG for IMV reimburses at a higher amount than the DRG for NIV; thus, cost savings demonstrated in this study may not be applicable outside of Medicare’s DRG-weighted system.

Despite these limitations, our findings have important implications. It is the first study to use an instrumental variable analysis to assess the optimal mode of mechanical ventilation for patients with pneumonia and a borderline need for IMV, which is valuable information for clinicians at the bedside. Previous studies have focused on the outcomes of average patients, through either underpowered randomized designs or observational studies confounded by indication. For example, patients may be started on NIV or IMV for reasons that cannot be measured by administrative data (e.g., patient preferences or clinician expertise). Our study focuses on patients with a borderline need for IMV, addresses the potential for unmeasured confounding, has a large sample size, and provides real-world context. Enriching randomized trials by targeting marginal patients with pneumonia or utilizing noninferiority designs may offer means to improve randomized trials assessing whether NIV should be used in pneumonia.

CONCLUSIONS

Among marginal patients with pneumonia and respiratory failure, we found no difference in mortality between NIV and IMV although Medicare payments were significantly lower among patients who received NIV. Ease of use and cost savings with NIV use for pneumonia must be weighed against the risk of increased mortality. The application of NIV to patients with pneumonia should be cautioned until enriched or well-powered randomized trials can be performed.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Explanation of mechanical ventilation definitions. Analysis of patients with noninvasive ventilation (NIV) as their first mechanical ventilation procedure code versus patients with invasive mechanical ventilation (IMV) as their first mechanical ventilation procedure code.

TABLE 1**Patient Characteristics by Type of Mechanical Ventilation**

Characteristics^a	NIV First	IMV First	<i>p</i>
No. of patients	12,480 (19.0)	53,267 (81.0)	
Age, mean (SD)	80 (8)	78 (8)	< 0.001
65–74	3,573 (28.6)	18,800 (35.3)	
75–84	4,338 (34.8)	19,553 (36.7)	
85	4,569 (36.6)	14,914 (28.0)	
Women	6,430 (52.1)	26,165 (49.1)	< 0.001
Race/ethnicity			< 0.001
White	10,402 (83.4)	39,714 (74.6)	
Black	1,222 (9.8)	9,177 (17.2)	
Other	856 (6.8)	4,376 (8.2)	
Urbanicity			< 0.001
Population < 50,000	1,597 (12.8)	5,036 (9.5)	
Population 50,000–2,500,000	6,927 (55.5)	30,337 (57.0)	
Population > 2,500,000	3,956 (31.7)	17,894 (33.6)	
Median household income by zip code			< 0.001
< \$40,000	2,747 (22.0)	14,320 (26.9)	
\$40,000–\$100,000	8,746 (70.1)	35,235 (66.2)	
\$100,000	987 (7.9)	3,712 (7.0)	
Elixhauser comorbidities, mean (SD)	2.0 (0.9)	1.8 (0.9)	< 0.001
Congestive heart failure	4,201 (33.7)	11,879 (22.3)	< 0.001
Diagnoses			< 0.001
Pneumonia as primary diagnosis	4,392 (35.2)	9,009 (16.9)	
Respiratory failure	10,700 (85.7)	49,715 (93.3)	
Sepsis	7,272 (58.3)	36,104 (67.8)	
Angus organ failure score, mean (SD)	1.0 (1.0)	2.0 (0.9)	< 0.001
Outcomes^a	NIV Alone	IMV First	
Other hospital diagnoses			< 0.001
Shock	3,773 (30.2)	25,433 (47.8)	
Cardiac or respiratory arrest	206 (1.7)	4,394 (8.3)	
Procedures performed during hospitalization			< 0.001
Central venous catheterization	4,173 (33.4)	25,175 (47.3)	
Cardiopulmonary resuscitation	211 (1.7)	3,917 (7.4)	
Tracheostomy	225 (1.8)	3,771 (7.1)	

Characteristics ^a	NIV First	IMV First	<i>p</i>
Length of stay, median (interquartile range)	7 (4–11)	8 (4–14)	< 0.001
Quartiles of total Medicare payment			< 0.001
Quartile 1 (\$0–\$5,339)	269 (2.2)	1,168 (2.2)	
Quartile 2 (\$5,340–\$8,871)	747 (6.0)	444 (0.8)	
Quartile 3 (\$8,872–\$12,274)	5,245 (42.0)	8,448 (15.9)	
Quartile 4 (\$12,275–\$1,070,842)	6,219 (49.8)	43,207 (81.1)	
Discharge destination			< 0.001
Home	2,149 (17.3)	5,419 (10.2)	
Rehabilitation or nursing facility	4,232 (34.0)	18,540 (34.9)	
Dead	4,386 (35.3)	22,613 (42.6)	
Other	6,530 (13.4)	3,821 (12.3)	
30-d mortality	6,508 (52.2)	29,501 (55.4)	< 0.001

^aNumbers represent % unless otherwise specified.

TABLE 2

Hospital Characteristics by Noninvasive Ventilation Use

Characteristic ^a	High NIV Utilization Hospital ^b	Low NIV Utilization Hospital
No. of hospitals	1,126 (40.8)	1,631 (59.2)
Hospital type		
For-profit	183 (16.3)	408 (25.1)
Not-for-profit	799 (71.0)	950 (58.3)
Government	143 (12.7)	271 (16.6)
Medical school affiliation	332 (29.5)	580 (35.6)
Teaching status		
No. of residents	953 (84.6)	1,300 (79.7)
Minor teaching program (< 0.25 residents per bed)	118 (10.5)	203 (12.5)
Major teaching program (≥ 0.25 residents per bed)	55 (4.9)	128 (7.9)
Hospital beds		
< 100	298 (26.5)	315 (19.3)
100–199	367 (32.6)	391 (30.1)
200	461 (40.9)	825 (50.6)
Percent of ICU beds (%)		
5	252 (22.4)	310 (19.0)
5–10	472 (41.9)	614 (37.7)
> 10	402 (35.7)	707 (43.4)
Nursing full-time equivalents per 1,000 patient-days, mean (SD)	3.5 (1.3)	3.8 (1.4)
Technology index, ^c mean (SD)	19.8 (13.3)	22.9 (14.8)
Medicaid patients		
< 7	447 (39.7)	490 (30.0)
7–11	364 (32.3)	507 (31.1)
> 11	315 (28.0)	634 (38.9)
Census regions		
Northeast	273 (24.3)	199 (12.2)
Midwest	398 (35.4)	566 (34.7)
South	267 (23.8)	525 (32.2)
West	185 (16.5)	340 (20.9)

NIV = noninvasive ventilation.

^aNumbers represent % unless otherwise specified.

^bHigh noninvasive ventilation (NIV) utilizing hospitals were defined as hospitals with an all-cause NIV rate in the top 40% with a minimum NIV rate of 31.7%.

^cThe technology index is the weighted sum of hospital capabilities including obstetrics, medical/surgical intensive care unit, cardiac ICU, emergency department, trauma center, open heart surgery, radiation therapy, computed tomography, diagnostic radiology, magnetic resonance imaging, positron-emission tomography, single-photon emission CT, ultrasonography, and transplantation service.

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TABLE 3

Effect of Noninvasive Ventilation First Compared With Invasive Mechanical Ventilation Alone on 30-Day Mortality and Medicare Payments

Model	NIV First	IMV First	Absolute Difference (95% CI)	<i>p</i>
30-d mortality				
Unadjusted regression	52.1%	55.3%	−3.2% (−4.3 to −2.2)	< 0.001
Average patients ^a	57.6%	54.2%	3.4% (2.1 to 4.6)	< 0.001
Marginal patients ^b	54.3%	55.0%	−0.7% (−13.8 to 12.4)	0.92
Medicare payments				
Unadjusted regression	\$15,712	\$27,695	−\$11,983 (−12511 to −11454)	< 0.001
Average patients ^a	\$17,406	\$27,292	−\$9,886 (−10464 to −9309)	< 0.001
Marginal patients ^b	\$18,433	\$27,051	−\$8,618 (−15771 to −1464)	0.02

^aModel adjusted for patient characteristics (demographics [age, gender, and race], urbanicity, median income by zip code, comorbidities, source of admission, severity of illness, diagnoses/procedures associated with mechanical ventilation (respiratory failure, sepsis, shock, cardiac/respiratory arrest, ICU admission, and cardiopulmonary resuscitation) and hospital characteristics (hospital ownership type, proportion of Medicaid patients, nursing ratio, teaching status, hospital size, ICU size, and technology index). All SES for models were adjusted for clustering of patients within hospitals.

^bTwo-stage least squared regression using differential distance to nearest high noninvasive ventilation utilizing hospital as instrumental variable and adjusted for the above characteristics.