# Despite variation in volume, Veterans Affairs hospitals show consistent outcomes among patients with non-postoperative mechanical ventilation*

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***Objective:*** **To assess the relationship between volume of nonoperative mechanically ventilated patients receiving care in a specific Veterans Health Administration hospital and their mortality.**

***Design:*** **Retrospective cohort study.**

***Setting:*** **One-hundred nineteen Veterans Health Administration medical centers.**

***Patients:*** **We identified 5,131 hospitalizations involving mechanically ventilated patients in an intensive care unit during 2009, who did not receive surgery.**

***Interventions:*** **None.**

***Measurements and Main Results:*** **We extracted demographic and clinical data from the VA Inpatient Evaluation Center. For each hospital, we defined volume as the total number of nonsurgical admissions receiving mechanical ventilation in an intensive care unit during 2009. We examined the hospital contribution to 30-day mortality using multilevel logistic regression models with a random intercept for each hospital. We quantified the extent of interhospital variation in 30-day mortality using the intraclass correlation coefficient and median odds ratio. We used generalized estimating equations to examine the relationship between volume and 30-day mortality and risk-adjusted all models using a patient-level prognostic score derived from clinical data representing the risk of death conditional on treatment at a high-volume hospital. Mean age for the sample was 65 (SD 11) yrs, 97% were men, and 60% were white. The median VA hospital cared for 40 (interquartile range 19–62) mechanically ventilated patients in 2009. Crude 30-day mortality for these patients was 36.9%. After reliability and risk adjustment to the median patient, adjusted hospital-level mortality varied from 33.5% to 40.6%. The intraclass correlation coefficient for the hospital-level variation was 0.6% (95% confidence interval 0.1, 3.4%), with a median odds ratio of 1.15 (95% confidence interval 1.06, 1.38). The relationship between hospital volume of mechanically ventilated and 30-day mortality was not statistically significant: each 50-patient increase in volume was associated with a nonsignificant 2% decrease in the odds of death within 30 days (odds ratio 0.98, 95% confidence interval 0.87–1.10).**

***Conclusions:*** **Veterans Health Administration hospitals caring for lower volumes of mechanically ventilated patients do not have worse mortality. Mechanisms underlying this finding are unclear, but, if elucidated, may offer other integrated health systems ways to overcome the disadvantages of small-volume centers in achieving good outcomes. (Crit Care Med 2012; 40:2569–2575)**

**KEY WORDS: critical care; delivery of health care; health services research; intensive care units/organization and administration; respiratory insufficiency; risk adjustment**

The association between the volume of patients treated in a hospital and patient outcomes is one of the most consistent relationships observed in modern medicine. Across a broad array of high-risk surgical and medical diagnoses, care in centers with higher patient volume is associated with improved survival (1, 2). Several recent studies have identified a similar relationship in critical care (3–5). A particularly robust volume–outcome relationship exists among those patients who experience acute respiratory failure requiring mechanical ventilation (5–7). At least two large observational studies examining patients cared for in nonfederal hospitals demonstrated that mechanically ventilated (MV) nonsurgical patients who receive care in higher-volume hospitals have 5% to 10% lower absolute risk of hospital death compared to lower-volume centers (5, 7).

Although investigators have consistently demonstrated the volume–outcome relationship in critical care, they have not fully characterized the underlying mechanisms through which this relationship operates. Experts speculate that clinical experience or selective referral to high-volume centers may partially account for the observed volume–outcome relationship, but others argue that the most compelling mechanism underlying this relationship is variation in several

***See also p. 2713.**

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/ccmjournal).

Supported, in part, by U.S. Department of Veterans Affairs Health Services Research & Development Services IIR 11–109 (TJI).

The opinions expressed here are those of the authors and do not represent those of the Department of Veterans Affairs.

The authors have not disclosed any potential conflicts of interest.

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**DOI: 10.1097/CCM.0b013e3182591eee**

intensive care unit (ICU) organizational factors (2, 8). ICU organizational factors, including physician and nurse staffing, multidisciplinary rounds, and protocols for ventilator weaning and sedation, are known to impact the outcomes of critically ill individuals and vary widely across ICUs in both academic and community hospitals throughout the world (9). The significant variation in ICU organization across most hospitals allows for the possibility that "high-quality" organizational practices cluster in high-volume hospitals thereby contributing to the volume–outcome relationship observed in prior studies. However, the extent to which the volume–outcome relationship exists in health systems where variation in ICU organization is lower, such as the Veterans Health Administration (VA), is unclear.

In 2007, a study describing the organization of critical care services in the VA suggested that although the VA exhibited some variation in the organization of and services provided in ICUs, it was far less than that previously demonstrated in non-VA hospitals (10). On the basis of prior evidence, we hypothesized that the VA would exhibit a relationship between volume and outcome among nonsurgical MV patients. However, we believed this relationship would be attenuated relative to that reported in prior studies owing to the greater uniformity within the VA's system of critical care. To test this hypothesis we examined the relationship between hospital volume and risk-adjusted 30-day mortality among patients who received non-postoperative mechanical ventilation in a VA ICU.

## METHODS

### Data and Sample

We identified all patients who received mechanical ventilation in an ICU at one of 119 VA hospitals during the 2009 calendar year, excluding those undergoing a surgical procedure during their hospitalization. We extracted administrative, laboratory, and clinical data from the VA Inpatient Evaluation Center, an infrastructure for improving the quality of care in VA medical centers that includes data from the VA's electronic medical record system (11–14). For this analysis, we used data from the 24 hrs surrounding the exact ICU admission during which patients were mechanically ventilated. Data abstracted for each patient included age, gender, race, and admission source, one of 54 principal diagnoses, 30 comorbid condition indicators based upon Elixhauser (15), 11 laboratory values (sodium, blood urea nitrogen, glomerular filtration rate, glucose, albumin, bilirubin, white blood cell count, hematocrit, pH, $PaCO_2$, and $PaO_2$), discharge status, length of stay, and death at 30 days according to the VA death index file.

### Definitions

For each hospital, we defined MV volume as the total number of hospitalizations of non-postoperative patients who were mechanically ventilated in an ICU during the 1-yr study period. We did not focus on the ICU as the unit of analysis because most hospitals only had one ICU. We extracted hospital characteristics from the American Hospital Association database and the VA's National Bed Control Database, including hospital teaching status according to the Council of Teaching Hospitals, hospital region, and total number of hospital beds. Across hospitals, we defined the complexity of services offered using a four-level system with levels ranging from high-complexity (level 1) to low-complexity (level 4), as previously described (10). Hospitals with level 1 and 2 intensive care services are generally where most the subspecialty care and intervention are available, whereas in hospitals with level 3 and 4 intensive care services, subspecialty care and intervention are more limited (10). Other than characterizing the level of intensive care services at each hospital, we were unable to link each hospital in our cohort to previously collected data on individual ICU organization (10). The outcome of interest was death from any cause within 30 days of hospital admission. Multiple hospitalizations for a given patient during the study period were treated as independent and assigned outcomes accordingly.

### Statistical Analysis

*General Approach*. We compared hospital and patient characteristics across quartiles of hospital volume of non-postoperative MV patients using analysis of variance or chi-square tests as appropriate for the distribution of each variable, and plotted the distribution of 30-day mortality across hospitals. We used multilevel logistic regression models with empirical Bayes prediction to assess the variation in reliability- and risk-adjusted 30-day mortality across hospitals (16), and present reliability- and risk-adjusted rates of 30-day mortality and confidence intervals (CIs) across hospitals in a caterpillar plot. We used generalized estimating equations (GEE) to assess the relationship between hospital volume and risk-adjusted mortality (17). Both approaches account for the clustering of patients within hospitals, but multilevel models are most useful for estimating between-hospital variation and conditional within-hospital effects whereas GEEs are most useful for estimating between-hospital effects (18).

*Quantifying Variation*. We quantified the variation in 30-day mortality across hospitals using the intraclass correlation coefficient, using the latent variable method and median odds ratios (MOR) calculated from the multilevel logistic regression (19). In the context of a hierarchical model, the intraclass correlation coefficient represents the proportion of total variation in 30-day mortality attributable to the hospital level after accounting for differences in patients (e.g., case mix and severity of illness) across hospitals. The MOR is defined as the median value of the odds ratio (OR) between the hospital with the greater risk of 30-day mortality and the hospital with the lower risk when randomly picking out two hospitals from the sample (19). The MOR can be conceptualized as the increased risk of death that a patient (in median) would have if moving to another hospital with a greater risk. If the MOR was equal to one, there would be no differences between most hospitals in the probability of death. If there were strong hospital-level differences, the MOR would be large and the hospital would be relevant for understanding variations of the individual probability of death (19). Pertinently, the MOR is on the typical OR scale and is thus comparable to ORs for other patient-level factors.

*Risk Adjustment*. We used a prognostic score to account for variation in case mix and severity of illness across hospitals (i.e., risk adjustment) that may confound the relationship between MV volume and 30-day mortality (20, 21). In our setting, a prognostic score is a patient-level estimate of the probability of death within 30 days, conditional on covariate values and on being treated in a hospital in the top quintile of volume. Similar to the propensity score (22), the prognostic score not only reduces the number of variables required for risk adjustment, but also yields inferences as valid as those obtained if one were to include the full component covariates (20). We constructed the score using the variables that make up the VA ICU severity score (11–13), which is a previously validated risk-adjustment measure that includes age, diagnosis on admission, 30 comorbid conditions, and 11 laboratory values. Similar models perform on par with the Acute Physiology and Chronic Health Evaluation III model (23). To allow for flexible nonlinear structure in the prognostic score, we used a generalized additive model. The generalized additive model is a nonparametric spline-based form of regression that places minimal restrictions on the functional form of the relationship between a patient's covariate values and his or her mortality (24).

After estimating the prognostic score, we modeled the patient-level probability of death using multilevel models and GEEs, with natural cubic splines for the prognostic score and volume. The degrees of freedom for the splines (i.e., the number of knots) were chosen using Quasilikelihood under the Independence model Criterion, which is an extension of Akaike's information criterion for GEEs (25). Akaike's information criterion and Quasilikelihood under the Independence model Criterion are measures of model fit similar to $r$-squared for linear regression, except that they penalize models with a greater number of covariates, effectively preventing overfitting. In all models, the effect of volume on 30-day mortality is expressed as an OR.

Table 1. Hospital and patient characteristics

| | All Hospitals | By Hospital Volume: First Quartile (2–19) | Second Quartile (20–40) | Third Quartile (41–62) | Fourth Quartile (63–117) | *p* |
|---|---|---|---|---|---|---|
| Dead within 30 days | 1892 (36.9%) | 97 (33.3%) | 349 (37.6%) | 564 (38.2%) | 882 (36.2%) | .34 |
| Patients | | | | | | |
| Number | 5131 (100%) | 291 (5.7%) | 929 (18.1%) | 1476 (28.8%) | 2435 (47.5%) | — |
| Age, yrs | 65.3 ± 11.5 | 66.0 ± 11.3 | 66.5 ± 11.9 | 65.5 ± 11.4 | 64.7 ± 11.4 | <.001 |
| Gender | — | — | — | — | — | .47 |
| Male | 4978 (97.0%) | 285 (97.9%) | 895 (96.3%) | 1432 (97.0%) | 2366 (97.2%) | — |
| Female | 153 (3.0%) | 6 (2.1%) | 34 (3.7%) | 44 (3.0%) | 69 (2.8%) | — |
| Race | — | — | — | — | — | <.001 |
| White | 3542 (69.0%) | 241 (82.8%) | 657 (70.7%) | 1027 (69.6%) | 1617 (66.4%) | — |
| African American/black | 1028 (20.0%) | 30 (10.3%) | 178 (19.2%) | 278 (18.8%) | 542 (22.3%) | — |
| Unknown | 488 (9.5%) | 17 (5.8%) | 79 (8.5%) | 149 (10.1%) | 243 (10.0%) | — |
| Other | 73 (1.4%) | 3 (1.0%) | 15 (1.6%) | 22 (1.5%) | 33 (1.4%) | — |
| Total length of stay, days | 14.5 ± 14.8 | 11.1 ± 11.3 | 14.7 ± 15.9 | 15.5 ± 16.0 | 14.3 ± 13.9 | <.001 |
| Admission source | — | — | — | — | — | <.001 |
| Veterans Health Administration emergency department | 2496 (48.6%) | 76 (26.1%) | 358 (38.5%) | 791 (53.6%) | 1271 (52.2%) | — |
| Veterans Health Administration outpatient clinic | 1853 (36.1%) | 159 (54.6%) | 437 (47.0%) | 491 (33.3%) | 766 (31.5%) | — |
| Other hospital | 423 (8.2%) | 17 (5.8%) | 38 (4.1%) | 107 (7.2%) | 261 (10.7%) | — |
| Nursing home | 351 (6.8%) | 39 (13.4%) | 94 (10.1%) | 86 (5.8%) | 132 (5.4%) | — |
| Other/unknown | 8 (0.2%) | 0 (0.0%) | 2 (0.2%) | 1 (0.1%) | 5 (0.2%) | — |
| Discharge status | — | — | — | — | — | <.001 |
| Outpatient (home) | 2292 (44.7%) | 105 (36.1%) | 389 (41.9%) | 631 (42.8%) | 1167 (47.9%) | — |
| Death | 1678 (33.0%) | 70 (24.1%) | 312 (33.7%) | 523 (36.2%) | 773 (31.9%) | — |
| Nursing facility | 734 (14.3%) | 58 (19.9%) | 133 (14.3%) | 202 (13.7%) | 341 (14.0%) | — |
| Hospital transfer | 258 (5.0%) | 53 (18.2%) | 57 (6.1%) | 74 (5.0%) | 74 (3.0%) | — |
| Other/unknown | 169 (3.3%) | 5 (1.7%) | 38 (4.1%) | 46 (3.1%) | 80 (3.3%) | — |
| Number of comorbid conditions | 3.0 ± 1.5 | 3.2 ± 1.6 | 3.1 ± 1.6 | 3.0 ± 1.6 | 3.0 ± 1.5 | .25 |
| Hospitals | | | | | | |
| Number | 119 (100%) | 30 (25.2%) | 31 (26.1%) | 29 (24.4%) | 29 (24.4%) | — |
| Region | — | — | — | — | — | .26 |
| South | 47 (39.5%) | 8 (26.7%) | 13 (41.9%) | 11 (37.9%) | 15 (51.7%) | — |
| Midwest | 29 (24.4%) | 11 (36.7%) | 7 (22.6%) | 5 (17.2%) | 6 (20.7%) | — |
| West | 24 (20.2%) | 7 (23.3%) | 4 (12.9%) | 6 (20.7%) | 7 (24.1%) | — |
| Northeast | 19 (16.0%) | 4 (13.3%) | 7 (22.6%) | 7 (24.1%) | 1 (3.4%) | — |
| Hospital beds | 274.1 ± 203.1 | 161.4 ± 119.7 | 258.9 ± 184.1 | 297.5 ± 213.0 | 383.4 ± 224.9 | <.001 |
| Teaching hospitals | 58 (48.7%) | 2 (6.7%) | 12 (38.7%) | 23 (79.3%) | 21 (72.4%) | <.001 |
| Complexity of intensive care unit services | — | — | — | — | — | <.001 |
| Level 1 (High) | 50 (42.0%) | 0 (0.0%) | 6 (19.4%) | 19 (65.5%) | 25 (86.2%) | — |
| Level 2 | 20 (16.8%) | 2 (6.7%) | 9 (29.0%) | 5 (17.2%) | 4 (13.8%) | — |
| Level 3 | 33 (27.7%) | 15 (50.0%) | 13 (41.9%) | 5 (17.2%) | 0 (0.0%) | — |
| Level 4 (Low) | 16 (13.4%) | 13 (43.3%) | 3 (9.7%) | 0 (0.0%) | 0 (0.0%) | — |

Number (percentage) is shown for categorical data, and mean ± SD is shown for continuous data.

## Sensitivity Analyses

In a series of additional analyses, we explored the sensitivity of the effect of volume of MV on 30-day mortality to how MV volume was modeled. First, we modeled MV volume using a categorical variable representing quintiles of volume of MV. Next, we modeled MV volume using a categorical variable using cut points from the previously published literature (<100, 100–199). We also repeated our GEE analysis after excluding repeat admissions (n = 499) and after excluding patients transferred into the VA from a non-VA facility (n = 312).

All statistical analyses were performed using *R* (26) and Stata (StataCorp, College Station, TX). Two-sided statistical tests were performed with $\alpha = 0.05$. The Institutional Review Board of the Ann Arbor VA approved the study.

## RESULTS

In the year 2009 there were a total of 564,244 medical/surgical admissions in 138 VA hospitals. After excluding patients not receiving MV, those receiving MV following surgery, and those ventilated outside the ICU, the final study cohort contained 5131 non-postoperative MV patients in 119 hospitals (Supplemental Fig. E1, Supplemental Digital Content 1, http://links.lww.com/CCM/A470).

*Hospital and Patient Characteristics*. Hospitals cared for a median of 40 (interquartile range: 19–62) non-postoperative MV patients (mean [SD] 43.1 [28.9]). Compared to hospitals in the lowest quartile of volume, those in the highest quartile of volume had more beds, were more often located in the South, were more often teaching hospitals, and offered greater complexity of ICU services (Table 1). Patients treated in the top quartile of hospitals by volume were slightly younger, were more often black, and were more likely to be admitted from the emergency department. There were no consistent differences in sex or number of comorbid conditions across quartiles of hospital MV volume.

*Variation in 30-Day Mortality*. Thirty-day mortality was normally distributed across the 119 hospitals (Fig. 1). However, after risk- and reliability-adjustment in the estimates, variation in adjusted 30-day mortality across the 119 sites was small, and CIs for the 30-day mortality at each hospital had considerable overlap (Fig. 2). The intraclass correlation coefficient for the adjusted hierarchical model was 0.6% (95% CI 0.1–3.4%), which indicates that after adjustment for differences in patient case mix and severity of illness across hospitals, only 0.6% of the total variation in 30-day mortality for MV patients across hospitals was attributable to the hospital level. The MOR for 30-day mortality was 1.15 (95% CI 1.06–1.38), where a MOR equal to 1.0 indicates no difference between hospitals.

*Relationship Between Volume and 30-Day Mortality*. In unadjusted analysis, hospitals in the bottom quartile of MV volume had somewhat lower 30-day mortality (33.3%) compared to that of the other quartiles (37.6%, 38.2%, and 36.2% for second, third, and fourth quartiles, respectively) (Table 1). When the hospital volume of MV patients was added as a continuous term to the fully risk-adjusted model, a 50-patient increase in the volume of MV was associated with a nonsignificant 2.0% decrease in the odds of death within 30 days (OR 0.98; 95% CI 0.87–1.10; $p = .70$) (Fig. 3). This nonsignificant relationship persisted when hospital volume of MV was modeled categorically as quintiles (Model 2, Table 2) or as previously defined in the literature (Model 3, Table 2 (5, 7)).

We found no substantive differences in our primary results after excluding either repeat admissions or patients who were transferred into the VA from a non-VA facility. Results from these two analyses are presented in Table E1 (Supplemental Digital Content 1, http://links.lww.com/CCM/A470).

## DISCUSSION

In this large, retrospective cohort we examined the universe of VA medical centers that cared for MV patients in 2009 to determine the hospital-level variation in 30-day mortality and its relationship with hospital caseload. After risk adjusting our estimates using a clinically rich model, we determined that <1% of the variation in 30-day mortality for patients undergoing

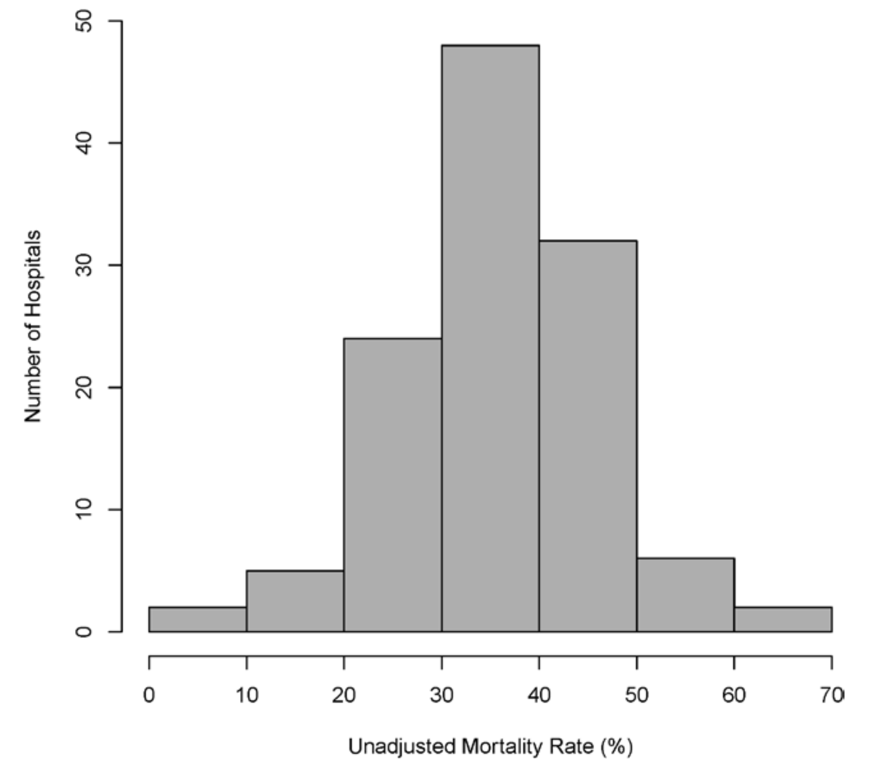


Figure 1. Distribution of unadjusted 30-day mortality across 119 Veterans Health Administration hospitals.

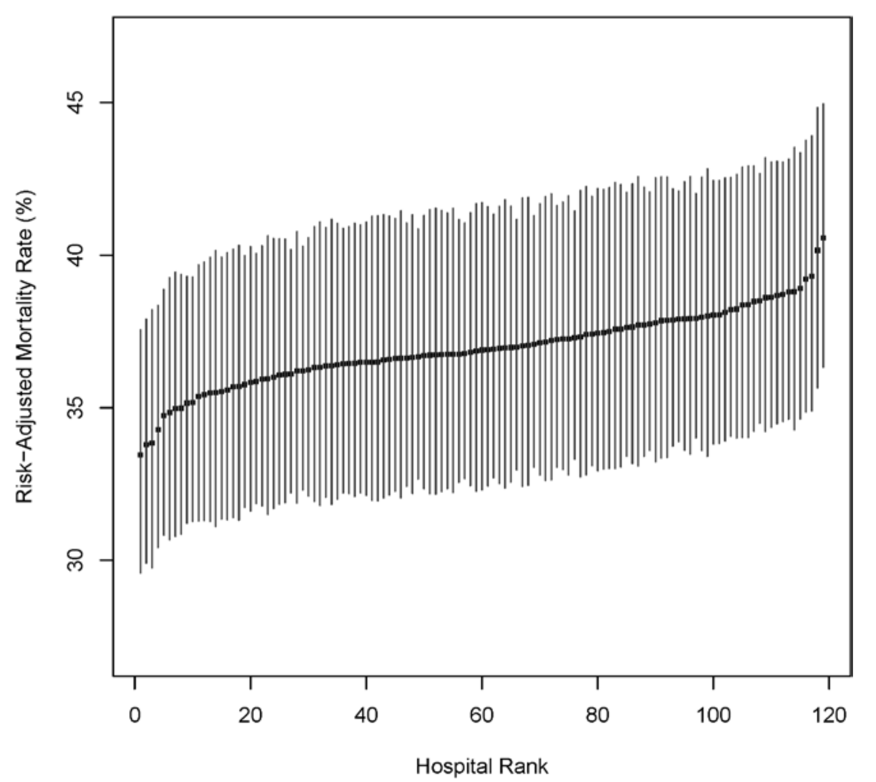


Figure 2. Reliability and risk-adjusted 30-day mortality ranked across hospitals (N = 119). The points represent each hospital's reliability and risk-adjusted 30-day mortality derived from multilevel logistic regression estimates. Risk-adjustment variables included age, diagnosis on admission, 30 comorbid conditions, and 11 laboratory values. Error bars represent 84% confidence intervals (1.4*SE) to allow inference when comparing points visually (44). For example, two points with 84% confidence intervals that do not overlap are statistically different with $p < .05$.

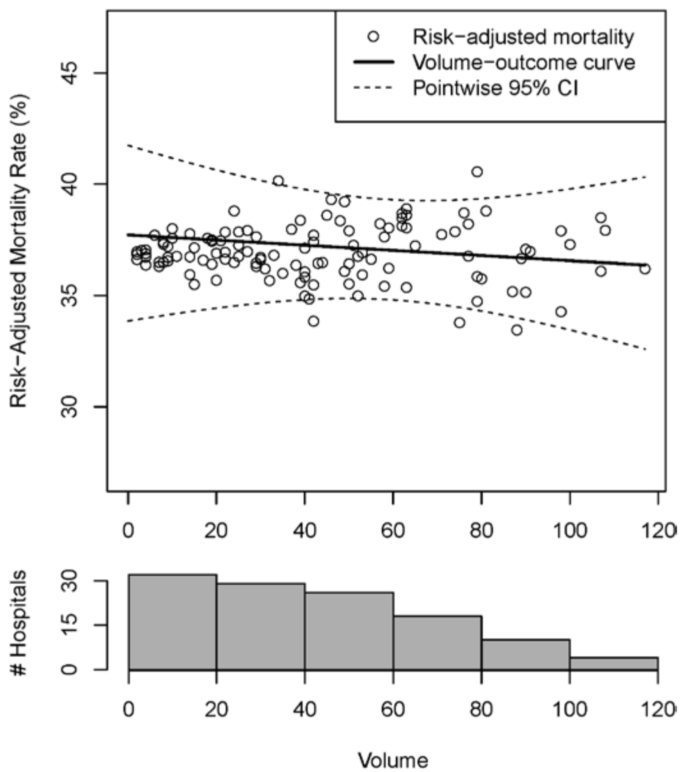


**Figure 3.** Relationship between mechanical ventilation volume and risk-adjusted 30-day mortality rate. In the top panel, the risk-adjusted 30-day mortality for each hospital (from a multilevel logistic model) is represented by a hollow dot. The *solid line* represents the relationship between volume and outcome derived from the generalized estimating equation, logistic regression model. Risk-adjustment variables included age, diagnosis on admission, 30 comorbid conditions, and 11 laboratory values. *Dashed lines* represent the pointwise 95% confidence interval for the *solid line*. The *bottom panel* presents the distribution of hospitals by their volume of mechanical ventilation.

**Table 2.** Generalized estimating equation variable estimates for volume effect

| Quintile | Volume Range (N) | Est Odds Ratio (95% Confidence Interval) | *p* |
|---|---|---|---|
| | Model 2: quintiles | | |
| 1 | 2–15 (25) | 0.98 (0.68–1.41) | .910 |
| 2 | 17–30 (23) | 1.12 (0.93–1.35) | .220 |
| 3 | 31–48 (23) | 0.98 (0.78–1.24) | .895 |
| 4 | 49–65 (24) | 1.11 (0.94–1.31) | .225 |
| 5 | 71–117 (24) | 1.00 (1.00–1.00) | — |
| | Model 3: 100+ cut-off | | |
| — | 2–99 (114) | 1.00 (1.00–1.00) | — |
| — | 100–117 (5) | 1.05 (0.91–1.21) | .526 |

nonsurgical MV was attributed to the hospital level. In contrast, VA hospitals varied considerably in the volume of nonsurgical MV patients they cared for; yet, we found no appreciable relationship between the volume of MV and risk-adjusted 30-day mortality. These results were robust to alternative approaches to modeling volume (e.g., continuous and categorical) in our analyses.

Mortality among patients with both surgical and nonsurgical MV reported in the literature is consistently high and congruent with that experienced by Veterans in our analysis. Published studies from non-VA hospitals in North America and from several European countries place the short-term mortality for all MV patients, regardless of cause, at 20% to 40% (5, 27–29). The 37% mortality at 30 days that we observed among Veterans is within this range despite exclusion of postoperative patients, a group known to have improved survival (28). Overlap in the risk-adjusted mortality between nonsurgical MV veterans and non-veterans suggest that patients treated in VA hospitals are equally sick and die at similar rates to that observed in non-VA hospitals, despite the VA being a low-volume system (5). Although the comparisons discussed here are only indirect, they add to the growing body of literature demonstrating that both processes and outcomes of care within VA hospitals are on par with that provided in the private sector (30–34).

Our results also demonstrate that the VA has achieved near-uniform outcomes of MV across their hospitals, effectively nullifying the disadvantage of care in low-volume centers. We believe there are three potential explanations for this finding (2). First, unlike the private sector, the VA is an integrated healthcare delivery system that has nearly universally implemented processes to improve the care it provides to its hospitalized patients. In 1995, the VA transformed its healthcare delivery system to include quality audit and feedback, improved care coordination, and use of information technology. Since 1995, there have been several important changes to care delivered in ICUs within the VA as well (10). For example, the VA developed an infrastructure to measure and report adherence to evidence-based practice in the ICU, making it one of the largest ICU quality-improvement collaboratives in the United States (14). Together these changes resulted in dramatic improvements in the quality and outcomes of care delivered to Veterans in diverse healthcare areas, not just those targeted for improvement (35, 36).

Second, compared to non-VA ICUs, ICUs in the VA have had greater penetration of several evidence-based care practices associated with improved outcomes in critically ill patients. For example, close to 60% of ICUs in the VA have high-intensity physician staffing—that is, ICUs in which patient care is directed by an intensivist-led team or units where consultation from an intensivist is mandatory for all patients admitted to the ICU. In contrast, data suggest only 26% of non-VA ICUs have high-intensity physician staffing (37). High-intensity staffing is associated with greater rates of adherence to evidence-based practice for MV patients (38), and decreased all-cause mortality (39). The VA also employs a single health-information technology system throughout its hospitals and outpatient clinics. Recent studies link the adoption of computerized order entry and comprehensive clinical information systems with reduced mortality and complications of care (40, 41). Health-information technology also improves the facility with which the VA can implement beneficial protocols for MV patients, such as daily interruption of sedation and lung-protective ventilation for patients with acute lung injury. The VA's widespread use of evidence-based practice suggests that it may be able to overcome the disadvantages of small-volume centers in achieving good outcomes.

Finally, the lack of a volume–outcome relationship in our study may reflect secular trends in adherence to evidence-based ICU practice. Prior studies demonstrating a volume–outcome relationship derived from ICU populations admitted prior to 2007 (3–5, 7). Although comparing the volume–outcome effect across prior studies is challenging due to differences in methodology and included populations; studies conducted in earlier periods suggest a larger effect of volume than those conducted in later periods (3–5, 7). This secular trend may reflect improvement in ICU care across hospitals regardless of volume.

Although the near-uniform outcomes across the VA likely explain the absence of a volume–outcome relationship, an additional contributor may be the lack of selective referral within the VA. Under selective referral, hospitals might transfer patients to hospitals with high-quality ICUs, resulting in increased volume. Within the VA, current policy recommends that patients be transferred to an ICU with a higher level of care if they require intensive care for > 72 hrs in a level-4 hospital or > 5 days in a level-3 hospital. There are few mechanisms to guide only selected high-probability of survival patients to larger-volume centers.

In interpreting our findings it is important to consider the strengths of this study. One potential criticism of our study is that the range of volume of MV patients we observed across hospitals in the VA is relatively small compared to that observed outside the VA. As such, the volume observed in the entire VA system overlaps with only the lower end of that observed in the private sector (5). One might then fear that the reduced variation in volume observed in the VA compared to the private sector compromised our ability to detect a volume/outcomes effect. However, at least one prior study demonstrates that the volume/outcome effect is most prominent across lower-volume hospitals (<150 cases/yr (5)). In other words, the VA is exactly where one would expect to see a strong relationship. An additional strength includes our use of a clinically detailed and previously validated method for risk adjustment that has comparable performance to that of Acute Physiology and Chronic Health Evaluation III and National Surgical Quality Improvement Program (13). Prior studies failing to identify a volume outcome relationship in MV have not included a detailed risk-adjustment model (8). Thus our extensive risk adjustment provides confidence that our null finding is not attributable to failure to account for patient differences across hospitals. Finally, we evaluated 30-day mortality, in contrast to hospital mortality, because this measure is less sensitive to discharge practice, which is known to vary dramatically across hospitals (42).

It is also important to put the results of our study in the context of several limitations. First, we used a VA hospital's volume of MV patients as our measure of volume. Although this measure reflects the clinical experience with MV at a given hospital, it may not accurately reflect the clinical experience of the providers caring for MV patients within a VA hospital. For example, many VA hospitals are affiliated with high-volume academic medical centers and share house staff and faculty with these partners. If the mechanism underlying established volume/outcome relationships includes provider training, education, or experience, the total volume of MV for both the VA hospital and its academic partner may better reflect the clinical staff's cumulative experience with MV patients. Second, our study may have lacked power to detect small associations between volume and outcome. For example, the 95% CI for our estimate of the volume–outcome relationship includes the potential for a 13% decrease in the odds of death for each 50-patient increase in MV volume. While we cannot exclude such a difference, the point estimate for the volume/outcome relationship that we observed was relatively small (2% decrease in odds per 50-patient increase), and previous literature suggests a 10% decrease in odds per 50-patient increase over the same range of volume observed in our study (5). Third, we were unable to test whether ICU organizational characteristics modified or mediated our results. Fourth, despite our extensive risk adjustment our analysis may not fully capture differences in patient populations across hospitals, particularly those with extremely low volumes. Fifth, we were unable to account for patient referral outside of the VA. Low-volume centers may selectively refer their sickest patients to non-VA hospitals effectively reducing the mortality observed in such centers, which may be part of the mechanism by which they attenuated the relationship between volume and mortality. Finally, as we discussed above, our inability to detect a volume–outcome relationship likely resulted from the lack of variation in 30-day mortality across centers. Nevertheless, the lack of variation provides compelling evidence that a volume–outcome relationship for MV is not present within the VA.

## CONCLUSIONS

The finding of no volume–outcome relationship for VA medical centers was provocative, and leads to hypotheses about underlying mechanisms. Future work assessing mechanisms is clearly indicated, including assessment of the impact of relative homogeneity of organizational structure. A better understanding of structural characteristics that buffer the impact of variation in volume in the VA might offer opportunities for improving outcomes across other integrated health systems, such as Kaiser Permanente, Geisenger, and, more broadly, accountable care organizations (43).

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