

SPECIAL ARTICLE

Hospital Volume and the Outcomes of Mechanical Ventilation

Jeremy M. Kahn, M.D., Christopher H. Goss, M.D., Patrick J. Heagerty, Ph.D., Andrew A. Kramer, Ph.D., Chelsea R. O'Brien, R.N., and Gordon D. Rubenfeld, M.D.

ABSTRACT

BACKGROUND

An increased volume of patients is associated with improved survival in numerous high-risk medical and surgical conditions. The relationship between the number of patients admitted (hospital volume) and outcome among patients with critical illnesses is unknown.

METHODS

We analyzed data from 20,241 nonsurgical patients receiving mechanical ventilation at 37 acute care hospitals in the Acute Physiology and Chronic Health Evaluation clinical information system from 2002 through 2003. Multivariate analyses were performed to adjust for the severity of illness and other differences in the case mix.

RESULTS

An increase in hospital volume was associated with improved survival among patients receiving mechanical ventilation in the intensive care unit (ICU) and in the hospital. Admission to a hospital in the highest quartile according to volume (i.e., >400 patients receiving mechanical ventilation per year) was associated with a 37 percent reduction in the adjusted odds of death in the ICU as compared with admission to hospitals in the lowest quartile (≤ 150 patients receiving mechanical ventilation per year, $P < 0.001$). In-hospital mortality was similarly reduced (adjusted odds ratio, 0.66; 95 percent confidence interval, 0.52 to 0.83; $P < 0.001$). A typical patient in a hospital in a low-volume quartile would have an adjusted in-hospital mortality of 34.2 percent as compared with 25.5 percent in a hospital in a high-volume quartile. Among survivors, there were no significant trends in the length of stay in the ICU or the hospital.

CONCLUSIONS

Mechanical ventilation of patients in a hospital with a high case volume is associated with reduced mortality. Further research is needed to determine the mechanism of the relationship between volume and outcome among patients with a critical illness.

From the Division of Pulmonary and Critical Care Medicine (J.M.K., C.H.G., C.R.O., G.D.R.) and the Department of Biostatistics (P.J.H.), University of Washington, Seattle; and the Cerner Corporation, Kansas City, Mo. (A.A.K.). Address reprint requests to Dr. Rubenfeld at Harborview Medical Center, University of Washington, Box 359762, 325 Ninth Ave., Seattle, WA 98104, or at nodrog@u.washington.edu.

N Engl J Med 2006;355:41-50.

Copyright © 2006 Massachusetts Medical Society.

THE ASSOCIATION BETWEEN THE NUMBER of patients treated in a hospital (hospital volume) and patient outcome is well established for numerous medical and surgical conditions.¹ This relationship has been extensively documented in the surgical literature, where higher patient volume is associated with improved survival in situations involving trauma care, cardiac surgery, ruptured aortic aneurysms, and several types of cancer surgery.²⁻⁶ Select medical conditions, including acute myocardial infarction⁷ and the acquired immunodeficiency syndrome,⁸ are also thought to have outcomes related to the volume of patients seen. Reasons for the relationship between volume and outcome in health care are unknown but may stem from either increased provider experience or selective referral to providers with better outcomes.⁹

Acute respiratory failure, like other conditions with established volume–outcome relationships, is common and is associated with a high mortality rate. It is estimated that more than 300,000 patients receive mechanical ventilation in an intensive care unit (ICU) in the United States each year; depending on the risk factor for respiratory failure, the in-hospital mortality can approach 50 percent.¹⁰⁻¹² Patients receiving mechanical ventilation also require a complex, well-organized, and technically sophisticated level of care. Consequently, it is likely that a relationship between hospital volume and outcome exists for patients receiving mechanical ventilation. Previous studies addressing this issue did not show an association between volume and outcome for general patients in the ICU, but those studies did not focus on patients who were receiving mechanical ventilation and used data from 1991 through 1997, which may not reflect current practice.^{13,14}

The purpose of the present study was to examine the relationship between hospital volume and outcome among patients receiving mechanical ventilation in the ICU. We used data from the Acute Physiology and Chronic Health Evaluation (APACHE) clinical outcomes database to examine mortality rates and the length of the stay at hospitals that care for a high volume of patients receiving mechanical ventilation as compared with those that care for a low volume of such patients.

METHODS

STUDY DESIGN

We conducted a cohort study with the use of the APACHE clinical database, which prospectively collects information on patients in 104 ICUs at 45 hospitals in the United States as part of its predictive capabilities. The APACHE database (Cerner) supplies data on risk-adjusted outcomes to participating hospitals for benchmarking purposes. Local, trained clinical coordinators supervise data collection. The primary diagnosis at admission, age, location of the patient before admission to the ICU, length of hospital stay before admission, and ventilator status, as well as detailed clinical and physiological variables, are collected in the first 24 hours after admission to the ICU. A standardized three-phase training session at each site ensures that data-collection techniques and definitions of data elements are consistent among the sites. The validity of clinical and laboratory values is checked with the use of specialized automated software that prevents inconsistent or implausible values. To ensure reliability in coding and data entry, each site undergoes a central audit after the first 100 admissions. Subsequent audits of at least 4 percent of patients for purposes of reliability occur quarterly at the local level.

PATIENT SELECTION

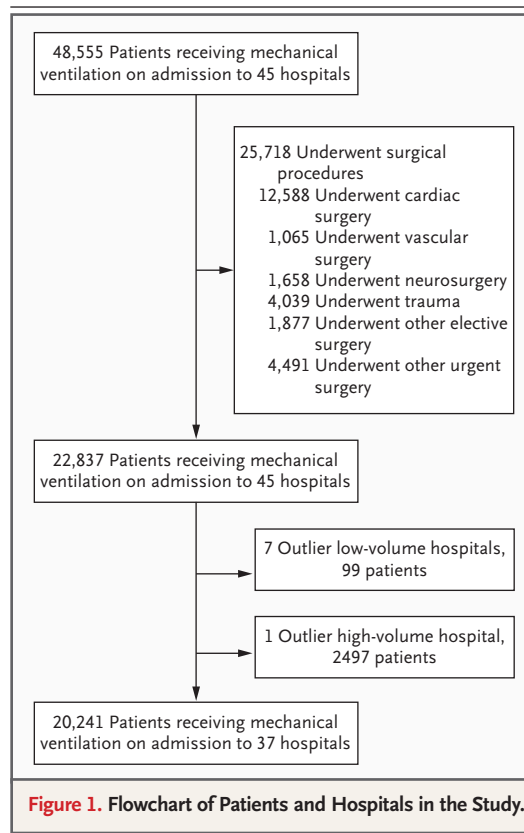
Detailed demographic and physiological variables were available for 122,498 patients admitted to 104 ICUs at 45 hospitals for the calendar years 2002 and 2003. All patients receiving mechanical ventilation on admission to the ICU were included in this analysis. To avoid counting multiple hospital outcomes for a single patient, only the first admission to an ICU for each patient was considered. To focus the analysis on care in the ICU, and because a relationship between hospital volume and outcome has already been established for many surgical procedures, patients receiving mechanical ventilation after a surgical procedure (as determined by the diagnosis at admission and coded by the admitting nurse) were excluded. We could not exclude patients whose primary diagnosis was nonsurgical but who may have undergone a surgical procedure during their stay in the

ICU. In addition, 21 ICUs at 12 of the hospitals did not collect or submit data to the APACHE database and are not represented in this cohort. Outlier hospitals at the extremes of annualized hospital volume (i.e., <50 or >1000 patients receiving mechanical ventilation per year, selected by examining a histogram of the volume distribution) were excluded so that they could not overly influence the results.

VARIABLES AND RISK ADJUSTMENT

The exposure variable was annualized hospital volume, defined as the mean number of patients receiving mechanical ventilation per year during the two-year study period. Hospital volume, rather than ICU volume, was chosen as the exposure, since staff and technology are shared among ICUs within a hospital; since the policy implications of the relationship between volume and outcome include selective referral to hospitals, rather than to specific ICUs within a hospital; and since ICU volume is collinear with other variables used to adjust for differences in case mix (e.g., type of ICU) and cannot be included in the same risk-adjustment model. The primary outcome variables were ICU and hospital mortality. Patients who were transferred directly from the ICU to other institutions (2.7 percent of total) were classified as alive at discharge. The lengths of stay in the ICU and the hospital among survivors were examined as secondary outcomes. The association between hospital volume and outcome was examined with volume as a continuous variable, in which the reference category is the lowest-volume hospital, and after categorizing volume into quartiles, in which the reference category is the lowest-volume quartile.

We addressed potential confounding due to variation in the case mix by controlling for the severity of illness and additional variables related to the outcome of critical care. The severity of illness was determined according to the APACHE III score (range, 0 to 299, with higher scores indicating a greater severity of illness and risk of death) on the day of admission. APACHE III is a validated summary score that assigns weighted points for the patient's age, coexisting medical conditions, and physiological derangements such as in vital signs, serum chemical values, arterial



blood gas values, and the Glasgow Coma Score.¹⁵ The list of the variables that contribute to the APACHE III score and their weights is available elsewhere.¹⁶

Other risk-adjustment variables included the length of the hospital stay before admission to the ICU, primary diagnosis at admission as assessed by the admitting nurse, the preadmission location of the patient, the academic status of the hospital, the type of ICU, the geographic region of the hospital, and the presence or absence of intensivists in the ICU.¹⁷⁻²⁰ All variables were assessed as part of data collection at the point of care, except for the presence or absence of intensivists, which was assessed by a secondary survey from all the ICUs except those excluded from the study as outliers. On the basis of this survey, each ICU was classified into one of the following four staffing models according to previous definitions: no intensivist available, optional intensivist consult, mandatory intensivist consult, or primary transfer of care to the intensivist

Table 1. Characteristics of Hospitals and Patients According to Quartile of Institutional Volume.*

Characteristic	Quartile 1 (87–150 patients/yr)	Quartile 2 (151–275 patients/yr)	Quartile 3 (276–400 patients/yr)	Quartile 4 (401–617 patients/yr)	P Value
Hospitals					
Total no.	10	9	9	9	
Teaching status (no. of hospitals)					<0.001
Academic†	3	1	1	4	
Community with house staff	2	3	5	3	
Community	5	5	3	2	
Region (no. of hospitals)					<0.001
Southeast	5	4	2	4	
Northeast	0	1	0	1	
Midwest	3	1	3	1	
West	2	3	4	2	
No. of hospital beds					0.04
Median	338	350	325	600	
Interquartile range	250–450	218–500	288–500	513–800	
No. of APACHE ICUs/hospital					<0.01
Median	1	1	3	3	
Interquartile range	1–4	1–2	1–5	2–6	
Non-APACHE ICU beds (%)	11	14	16	5	0.74
Patients					
Total no.	2221	3668	5830	8522	
Age (yr)	62±17	64±17	64±16	63±17	<0.001
Female sex (%)	48	51	48	49	0.05
APACHE III score	68±31	70±32	74±33	78±34	<0.001
Race or ethnic group (%)‡					<0.001
White	67	69	74	65	
Black	23	22	11	13	
Asian	1	3	2	2	
Hispanic	2	2	3	6	
Other	7	4	10	14	
Transferred from outside hospital (%)	6	9	16	16	<0.001
Discharged from ICU to outside hospital (%)	4	3	4	2	<0.01
Type of ICU (%)					<0.001
Multidisciplinary	72	76	44	30	
Medical	7	8	13	35	
Surgical	1	3	6	17	
Coronary care	13	11	31	9	
Neurologic	6	2	3	6	
Cardiothoracic surgery	<1	<1	3	3	

Table 1. (Continued.)

Characteristic	Quartile 1 (87–150 patients/yr)	Quartile 2 (151–275 patients/yr)	Quartile 3 (276–400 patients/yr)	Quartile 4 (401–617 patients/yr)	P Value
Diagnostic category (%)					<0.001
Pneumonia	10	8	8	9	
Congestive heart failure	10	11	11	8	
Neurologic disease	10	8	11	11	
Sepsis	9	11	13	13	
Chronic obstructive pulmonary disease	9	9	7	7	
Post–cardiac arrest	6	8	9	9	
Drug overdose	4	5	5	3	
Gastrointestinal bleeding	2	2	2	3	
Oncologic disease	2	1	1	1	
Acute coronary syndrome	2	2	2	3	
Arrhythmia	1	1	1	1	
Other respiratory disease	25	25	20	22	
Other medical disease	8	7	7	7	
Other gastrointestinal disease	2	2	3	3	
Other cardiac disease	1	1	1	1	
Intensivist physician staffing (%)					<0.001
Low-intensity care model	31	41	30	49	
High-intensity care model	69	59	70	51	
Length of mechanical ventilation (days)	3.1±4.6	3.0±4.3	3.6±4.4	4.5±5.7	<0.001
Length of stay in ICU (days)	6.2±6.9	5.9±6.6	5.5±6.0	6.7±6.9	<0.001
Length of hospital stay (days)	12.5±12.2	13.3±12.8	12.1±11.8	14.7±13.4	<0.001
Mortality in ICU (%)	25	22	23	27	<0.001
In-hospital mortality (%)	33	32	33	37	<0.001

* Plus–minus values are means ±SD. Percentages may not sum to 100 because of rounding.

† Academic hospitals were those belonging to the Council of Teaching Hospitals of the Association of American Medical Colleges.

‡ Race or ethnic group was determined according to the admission, discharge, and transfer system at each hospital or by the admitting nurse.

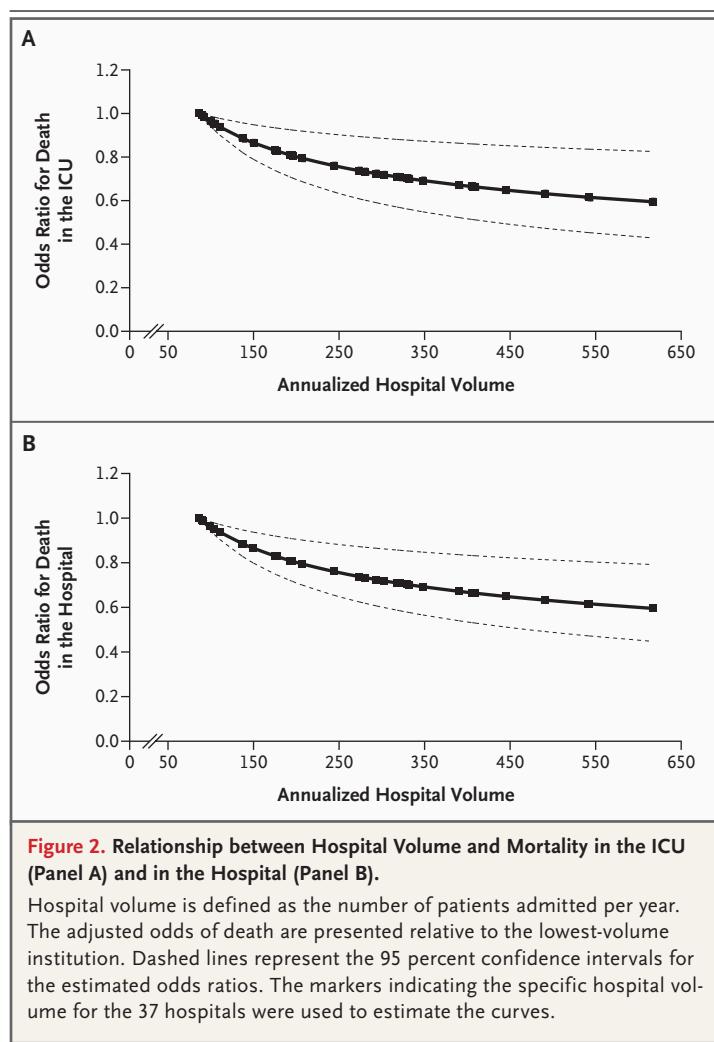
(i.e., “closed” ICU).²¹ For the analysis, we categorized the staffing as low intensity (no intensivist or optional consult) or high intensity (mandatory consult or transfer of care).¹⁹

STATISTICAL ANALYSIS

Bivariate analysis comparing demographic characteristics across the quartiles of hospital volume was performed with analysis of variance for continuous variables and the chi-square test for categorical variables. Multivariate modeling was performed with logistic regression for mortality and

linear regression for length of hospital stay, after adjusting for covariates specified a priori as potential confounders of the relationship between hospital volume and outcome.

For the assessment of volume as a continuous variable, we used the fractional polynomial method, an iterative estimation process that determines the best-fitting polynomial-regression function.²² This method makes no underlying assumptions about the relationship between hospital volume and outcome and thereby averts the potential bias involved in prespecifying the functional form.



Generalized estimating equations with robust variance estimators were used to account for in-hospital clustering.²³ To illustrate the absolute magnitude of the effect of volume on mortality, we performed conditional standardization of the regression results for a patient with median and modal values for the covariates in the model. We assessed the sensitivity of our findings by repeating the primary analysis under varying assumptions about the study population in a sensitivity analysis for mortality in the ICU.

Statistical analyses were performed with Stata software, version 9.1. All aspects of this work were approved by the human subjects review committee at the University of Washington.

RESULTS

A total of 48,555 patients received mechanical ventilation on admission to study hospitals in 2002 and 2003. A flowchart of patient entry into the study is shown in Figure 1. The final analysis included 20,241 patients receiving mechanical ventilation at 37 medical centers. Annualized hospital volume ranged from 87 to 617 such patients per year. The median was 274 patients per year (interquartile range, 150 to 391).

Characteristics of the hospitals and patients are shown in Table 1. Admitting hospitals were diverse in academic status, geographic region, and number of ICUs. As compared with hospitals with low volume, hospitals with high volume were more likely to have house staff in the ICU, tended to have a larger number of ICUs per hospital, and had more hospital beds. Characteristics of the hospitals were similar to those in a previous survey of the organization of ICUs in the United States, although smaller hospitals were underrepresented in the present study.²⁴ There were a small number of nonparticipating ICUs, which did not vary significantly across quartiles of volume. The severity of illness was greater at high-volume than at low-volume hospitals; the mean APACHE III score steadily increased with each quartile of hospital volume. Patients at high-volume centers were also more likely to have been transferred from another hospital, suggesting that high-volume hospitals were referral centers. Patients received care in a variety of types of ICUs; patients at low-volume centers were more likely to be admitted to a multidisciplinary ICU, whereas those at high-volume centers were more likely to be cared for in specialty ICUs.

After adjustment for the severity of illness, the location of the patient before admission to the ICU, type of ICU, geographic region, preadmission length of stay, academic status of the hospital, diagnosis at admission, and the presence or absence of intensivists in the ICU, an increase in hospital volume was associated with a significant reduction in mortality in the ICU and the hospital. Figure 2 shows the effect of hospital volume when examined as a continuous variable in a multivariate model. Improvement in survival is seen throughout the distribution, as volume in-

Table 2. Association between Hospital Volume and Risk-Adjusted Mortality.*

Variable	Quartile 1	Quartile 2	Quartile 3	Quartile 4
No. of hospitals	10	9	9	9
No. of patients/yr	87–150	151–275	276–400	401–617
Odds ratio (95% CI)				
Mortality†				
ICU	1.0	0.75 (0.60–0.94)‡	0.67 (0.49–0.91)‡	0.63 (0.50–0.79)§
Hospital	1.0	0.86 (0.69–1.07)¶	0.72 (0.53–0.99)∥	0.66 (0.52–0.83)§
Adjusted percent (95% CI)				
Mortality**				
ICU	21.2 (16.9–26.3)	16.8 (13.1–21.2)	15.3 (11.2–20.1)	14.5 (11.6–18.0)
Hospital	34.2 (29.4–39.3)	30.8 (26.1–35.9)	27.3 (22.0–33.3)	25.5 (21.8–29.5)

* Models were adjusted for age, APACHE III score, chronic coexisting health conditions, preadmission length of stay, geographic region, teaching status, preadmission location of the patient, diagnosis, type of ICU, and staffing of intensivists. Confidence intervals (CI) and P values take into account clustering according to center.

† Mortality rates were compared across quartiles of patient volume according to adjusted odds ratios (with 95 percent confidence intervals); the lowest quartile of hospital volume served as the reference group.

‡ P=0.01.

§ P<0.001.

¶ P=0.17.

∥ P=0.04.

** The absolute magnitude of the effect of hospital volume on mortality was calculated with the use of conditional standardization of the regression results. Adjusted conditional mortality (with 95 percent confidence intervals) shows the predicted risk of death for a patient at approximately the 50th percentile of risk in each quartile of volume — in this case a 60-year-old patient with pneumonia and an APACHE III score of 70 who was admitted from the emergency department to a multidisciplinary ICU in a community hospital with high intensivist staffing in the southern region of the United States.

increases from the lowest value of 87 patients per year to the highest value of 617 patients per year.

An examination of hospital volume after categorization into quartiles showed a similar reduction in mortality in both the ICU and the hospital (Table 2). As compared with patients in the lowest quartile (quartile 1) of hospital volume, patients in quartiles 2, 3, and 4 had a reduction in the adjusted odds of death in the ICU of 25 percent (P=0.01), 33 percent (P=0.01), and 37 percent (P<0.001), respectively. Adjusted hospital mortality was also reduced across quartiles of volume, with admission to hospitals in the highest quartile associated with a 34 percent reduction in the adjusted odds of death as compared with the lowest quartile (odds ratio, 0.66; 95 percent confidence interval, 0.52 to 0.83; P<0.001). According to conditional standardization, the absolute risk of death in the hospital for a selected typical patient was 34.2 percent in the lowest-volume quartile and 25.5 percent in the highest-volume quartile.

Among survivors, there was no clear association between hospital volume and the length of

stay in either the ICU or the hospital. As compared with the lowest quartile of hospital volume, higher volume was associated with a slightly shorter length of stay in the ICU in quartiles 2, 3, and 4 (mean difference, –0.7 day, –1.1 days, and –0.4 day, respectively). However, this difference was significant only for quartile 3 (P<0.01). Similar relationships were seen for the length of hospital stay, although no differences were significant.

To explore the sensitivity of our findings, we repeated the analysis with varying assumptions about the patient population (Table 3). Our results were not affected by the inclusion of outlier hospitals or the exclusion of patients with cardiac conditions, transfer patients, or 10 additional hospitals with ICU beds not covered by the APACHE system.

DISCUSSION

These data demonstrate an association between an increase in hospital volume and a lower risk-adjusted mortality among patients requiring me-

Table 3. Sensitivity Analysis for Mortality Rates in the ICU.*

Model	No. of Patients	No. of Hospitals	Odds Ratio (95% CI)
Base model	20,241	37	0.63 (0.50–0.79)
Including outlier hospitals†	22,836	45	0.62 (0.51–0.75)
Excluding patients with acute coronary syndromes‡	19,720	37	0.62 (0.49–0.78)
Excluding patients with any cardiac diagnosis§	17,558	37	0.63 (0.49–0.79)
Excluding patients in surgical ICUs¶	17,841	37	0.66 (0.53–0.82)
Excluding patients transferred from outside hospitals	17,462	37	0.64 (0.50–0.82)
Excluding patients transferred from the ICU to other hospitals	19,689	37	0.62 (0.49–0.78)
Excluding hospitals with less than complete APACHE coverage	15,031	27	0.63 (0.49–0.81)

* Odds ratios and 95 percent confidence intervals (CIs) are presented comparing the highest quartile of hospital volume (401 to 617 patients per year) with the lowest quartile of hospital volume (87 to 150 patients per year). Models were adjusted for age, APACHE III score, chronic coexisting health conditions, preadmission length of stay, geographic region, teaching status of the hospital, preadmission location of the patient, diagnosis, type of ICU, and staffing of intensivists. The model that includes hospitals that were outliers in terms of volume (22,836 patients) does not include intensivist staffing, since the outlier hospitals were not surveyed. Confidence intervals take into account clustering according to center.

† Hospitals that were outliers in terms of volume were seven hospitals that were excluded because their annualized volume was less than 50 patients per year (99 patients) and one hospital that was excluded because its annualized volume was greater than 1000 patients per year (2497 patients).

‡ This model excludes patients who had a primary diagnosis at admission of acute myocardial infarction or unstable angina.

§ This model excludes patients who had a primary diagnosis at admission of acute myocardial infarction, unstable angina, congestive heart failure, cardiogenic shock, or pericardial-related syndromes.

¶ This model excludes patients who were admitted to a surgical ICU regardless of diagnosis.

|| This model excludes 10 hospitals at which not all ICU beds were covered by APACHE.

chanical ventilation. The effect was seen after controlling for relevant confounders and after a sensitivity analysis in which a variety of patient populations and modeling assumptions were tested. Extrapolating from available estimates, at least 95,000 patients per year with respiratory failure receive mechanical ventilation at U.S. hospitals in the lowest two quartiles according to volume.¹⁰

There are many possible causes of a relationship between hospital volume and outcome among patients receiving critical care. High-volume hospitals may improve outcomes by implementing a broad range of best practices, including higher nurse-to-patient ratios, multidisciplinary care teams, a ventilation strategy involving a low tidal volume for lung injury and protocols for sedation, weaning, and glycemic control.^{25–30} Clinicians at high-volume hospitals may also gain experience in the care of the critically ill, which could translate into improved rates of survival. More experienced as opposed to less experienced clinicians may be better at recognizing and treating the complications of critical illness or may be better at translating evidence into practice.

The relationship between hospital volume and outcome that we observed was independent of academic status and staffing by trained intensiv-

ists. Multiple observational studies have shown that the presence of a trained intensivist is associated with a reduced rate of death in the ICU.¹⁹ As a consequence, some groups advocate the use of the staffing of intensivists as a measure of hospital quality.³¹ Our findings suggest that hospital volume is another important determinant of outcome among critically ill patients requiring mechanical ventilation.

More information is needed about the structure, process, and organization of care within high- and low-volume centers to identify the best way to improve outcomes. If the relationship between volume and outcome is determined by factors that are exportable, such as protocols or multidisciplinary care models, then low-volume centers might achieve the same outcome as high-volume centers by adopting these practices.³² An alternative strategy, used in trauma and neonatal care, would involve regionalization of care for patients requiring mechanical ventilation.^{33–35} Although our data provide support for a regionalized approach to providing critical care, the overall effect of such a strategy on patient outcome is unknown.

Like all studies that demonstrate an association between volume and outcome, our analysis

cannot determine the direction of the association.⁹ Instead of higher-volume hospitals' providing better outcomes, higher-quality hospitals might attract more patients on the basis of superior care. High-performing hospitals, however, have not reliably shown an increase in market share when performance data are publicly reported.³⁶

Our results differ from those of two previous studies that did not show an association between volume and outcome among critically ill patients.^{13,14} Unlike those studies, we limited our analysis to patients who were receiving mechanical ventilation. Many patients are in the ICU for observation purposes only, especially those not requiring mechanical ventilation or other interventions. An association between hospital volume and outcome would be unlikely in a population of patients who are at low risk for death and who do not receive active intervention in the ICU. The previous studies evaluated patient populations with a lower mortality rate and severity of illness than our cohort. In addition, the previous studies used data from 1991 through 1997, which may not reflect current practice in the ICU.

Limitations of our study include potential biases due to selection, referral, and coding. Study hospitals were not a random sample of all hospitals in the United States. They participated in the APACHE system to receive regular information about risk-adjusted outcomes for benchmarking and quality control. Small hospitals were underrepresented, and all the participating hospitals had access to intensivists.

The fact that we observed a volume–outcome relationship in this cohort suggests that the effect of hospital volume on the rate of survival might be even greater if smaller hospitals with worse outcomes were included. It is also possible that the association was driven by a small number of low-volume hospitals with poor outcomes. This is unlikely, however, for the following reasons: the smallest hospitals were excluded from the analysis; a significant association was seen across the quartiles, which grouped together the 10 centers with the lowest volume; and a dose–response relationship was observed across the ranges of volume.

Patient-referral practices could influence the results of this study. In this cohort, high-volume

hospitals were both more likely to receive patients who were transferred from another hospital and less likely to transfer patients from their ICUs than were other hospitals. Because patients transferred to ICUs have a higher rate of death than predicted on the basis of severity-of-illness measures, and because patients transferred from ICUs do not all survive, the referral bias of this study would tend to make high-volume hospitals seem to have worse risk-adjusted mortality.²⁰ Therefore, the direction of the referral bias of this study strengthens the observed association of lower risk-adjusted rates of death with higher hospital volume.

The improved risk-adjusted outcomes at high-volume hospitals may simply reflect more accurate coding or even “up-coding” of the severity of illness (i.e., designating an illness as more severe than it is) at these centers.³⁷ Outcomes at APACHE sites, however, are not publicly reported, reducing the incentive to up-code the severity of illness. The extensive procedures for training, standardized data entry, and quality control at APACHE sites further reduce the likelihood that differences in coding affected our risk adjustment or the results.

For nonsurgical patients with acute respiratory failure who are receiving mechanical ventilation, care at high-volume hospitals is associated with improved survival in the ICU and in the hospital. This finding was independent of the academic status of the hospital or the presence or absence of intensivists in the ICU. Our results suggest that clinician experience or specific processes of care common to high-volume centers may be associated with the outcome among patients requiring mechanical ventilation. Additional research is needed to determine these care processes and assess the ability to export them to low-volume centers, as well as to investigate the feasibility of regionalizing care in the ICU for select high-risk patients.

Supported by an individual fellowship grant (F32HL080785) from the National Institutes of Health and a research grant from the American Lung Association. Dr. Rubinfeld is supported in part by a grant (RO1HL67939) from the National Institutes of Health.

No potential conflict of interest relevant to this article was reported.

We are indebted to Vickie Snively for her valuable assistance in conducting the survey of APACHE ICUs.

REFERENCES

1. Halm EA, Lee C, Chassin MR. Is volume related to outcome in health care? A systematic review and methodologic critique of the literature. *Ann Intern Med* 2002;137:511-20.
2. Hannan EL, O'Donnell JF, Kilburn H Jr, Bernard HR, Yazici A. Investigation of the relationship between volume and mortality for surgical procedures performed in New York State hospitals. *JAMA* 1989;262:503-10.
3. Begg CB, Cramer LD, Hoskins WJ, Brennan MF. Impact of hospital volume on operative mortality for major cancer surgery. *JAMA* 1998;280:1747-51.
4. Bach PB, Cramer LD, Schrag D, Downey RJ, Gelfand SE, Begg CB. The influence of hospital volume on survival after resection for lung cancer. *N Engl J Med* 2001;345:181-8.
5. Nathens AB, Jurkovich GJ, Maier RV, et al. Relationship between trauma center volume and outcomes. *JAMA* 2001;285:1164-71.
6. Birkmeyer JD, Finlayson EV, Birkmeyer CM. Volume standards for high-risk surgical procedures: potential benefits of the Leapfrog initiative. *Surgery* 2001;130:415-22.
7. Thiemann DR, Coresh J, Oetgen WJ, Powe NR. The association between hospital volume and survival after acute myocardial infarction in elderly patients. *N Engl J Med* 1999;340:1640-8.
8. Stone VE, Seage GR III, Hertz T, Epstein AM. The relation between hospital experience and mortality for patients with AIDS. *JAMA* 1992;268:2655-61.
9. Luft HS, Hunt SS, Maerki SC. The volume-outcome relationship: practice-makes-perfect or selective-referral patterns? *Health Serv Res* 1987;22:157-82.
10. Behrendt CE. Acute respiratory failure in the United States: incidence and 31-day survival. *Chest* 2000;118:1100-5.
11. Esteban A, Anzueto A, Frutos F, et al. Characteristics and outcomes in adult patients receiving mechanical ventilation: a 28-day international study. *JAMA* 2002;287:345-55.
12. Rubenfeld GD, Caldwell E, Peabody E, et al. Incidence and outcomes of acute lung injury. *N Engl J Med* 2005;353:1685-93.
13. Jones J, Rowan K. Is there a relationship between the volume of work carried out in intensive care and its outcome? *Int J Technol Assess Health Care* 1995;11:762-9.
14. Durairaj L, Torner JC, Chrischilles EA, et al. Hospital volume-outcome relationships among medical admissions to ICUs. *Chest* 2005;128:1682-9.
15. Knaus WA, Wagner DP, Draper EA, et al. The APACHE III prognostic system: risk prediction of hospital mortality for critically ill hospitalized adults. *Chest* 1991;100:1619-36.
16. Cerner critical outcomes: Acute Physiology and Chronic Health Evaluation IV. Kansas City, Mo. Cerner Corporation. (Accessed June 9, 2006, at <http://www.criticaloutcomes.cerner.com>.)
17. Escarce JJ, Kelley MA. Admission source to the medical intensive care unit predicts hospital death independent of APACHE II score. *JAMA* 1990;264:2389-94.
18. Knaus WA, Wagner DP, Zimmerman JE, Draper EA. Variations in mortality and length of stay in intensive care units. *Ann Intern Med* 1993;118:753-61.
19. Pronovost PJ, Angus DC, Dorman T, Robinson KA, Dremsizov TT, Young TL. Physician staffing patterns and clinical outcomes in critically ill patients: a systematic review. *JAMA* 2002;288:2151-62.
20. Rosenberg AL, Hofer TP, Strachan C, Watts CM, Hayward RA. Accepting critically ill transfer patients: adverse effect on a referral center's outcome and benchmark measures. *Ann Intern Med* 2003;138:882-90.
21. Rapoport J, Teres D, Steingrub J, Higgins T, McGee W, Lemeshow S. Patient characteristics and ICU organizational factors that influence frequency of pulmonary artery catheterization. *JAMA* 2000;283:2559-67.
22. Royston P, Ambler G, Sauerbrei W. The use of fractional polynomials to model continuous risk variables in epidemiology. *Int J Epidemiol* 1999;28:964-74.
23. Zeger SL, Liang KY. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics* 1986;42:121-30.
24. Groeger JS, Strosberg MA, Halpern NA, et al. Descriptive analysis of critical care units in the United States. *Crit Care Med* 1992;20:846-63.
25. Tarnow-Mordi WO, Hau C, Warden A, Shearer AJ. Hospital mortality in relation to staff workload: a 4-year study in an adult intensive-care unit. *Lancet* 2000;356:185-9.
26. Young MP, Goeder VJ, Oltermann MH, Bohman CB, French TK, James BC. The impact of a multidisciplinary approach on caring for ventilator-dependent patients. *Int J Qual Health Care* 1998;10:15-26.
27. The Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med* 2000;342:1301-8.
28. Ely EW, Baker AM, Dunagan DP, et al. Effect on the duration of mechanical ventilation of identifying patients capable of breathing spontaneously. *N Engl J Med* 1996;335:1864-9.
29. Brook AD, Ahrens TS, Schaiff R, et al. Effect of a nursing-implemented sedation protocol on the duration of mechanical ventilation. *Crit Care Med* 1999;27:2609-15.
30. van den Berghe G, Wouters P, Weekers F, et al. Intensive insulin therapy in critically ill patients. *N Engl J Med* 2001;345:1359-67.
31. Angus DC, Black N. Improving care of the critically ill: institutional and health-care system approaches. *Lancet* 2004;363:1314-20.
32. Thompson DR, Clemmer TP, Applefeld JJ, et al. Regionalization of critical care medicine: task force report of the American College of Critical Care Medicine. *Crit Care Med* 1994;22:1306-13.
33. Sampalis JS, Denis R, Lavoie A, et al. Trauma care regionalization: a process-outcome evaluation. *J Trauma* 1999;46:565-79.
34. Cifuentes J, Bronstein J, Phibbs CS, Phibbs RH, Schmitt SK, Carlo WA. Mortality in low birth weight infants according to level of neonatal care at hospital of birth. *Pediatrics* 2002;109:745-51.
35. Milstein A, Galvin RS, Delbanco SF, Salber P, Buck CR Jr. Improving the safety of health care: the Leapfrog initiative. *Eff Clin Pract* 2000;3:313-6. [Erratum, *Eff Clin Pract* 2001;4:94.]
36. Baker DW, Einstadter D, Thomas C, Husak S, Gordon NH, Cebul RD. The effect of publicly reporting hospital performance on market share and risk-adjusted mortality at high-mortality hospitals. *Med Care* 2003;41:729-40.
37. Hannan EL, Wu C, Ryan TJ, et al. Do hospitals and surgeons with higher coronary artery bypass graft surgery volumes still have lower risk-adjusted mortality rates? *Circulation* 2003;108:795-801.

Copyright © 2006 Massachusetts Medical Society.