Hospital Volume-Outcome Relationships Among Medical Admissions to ICUs*

Lakshmi Durairaj, MD; James C. Torner, PhD; Elizabeth A. Chrischilles, PhD; Mary S. Vaughan Sarrazin, PhD; Jon Yankey, MS; and Gary E. Rosenthal, MD

**Background:** Positive relationships between hospital volume and outcomes have been demonstrated for several surgeries and medical conditions. However, little is known about the volume-outcome relationship in patients admitted to medical ICUs.

**Objective:** To determine the relationship between hospital volume and risk-adjusted in-hospital mortality for patients admitted to ICUs with respiratory, neurologic, and GI disorders.

**Design:** Retrospective cohort study.

**Setting:** Twenty-nine hospitals in a single metropolitan area.

**Patients:** Adult ICU admissions from 1991 through 1997.

**Methods:** Using Cox proportional hazards models, we compared in-hospital mortality between tertiles of hospital volume (high, medium, and low) for respiratory (n = 16,949), neurologic (n = 12,881), and GI (n = 11549) diseases after adjusting for age, gender, admission severity of illness, admitting diagnosis, and source. Severity of illness was measured using the APACHE (acute physiology and chronic health evaluation) III methodology.

**Results:** Among respiratory and neurologic ICU admissions, hazard ratios were similar (p ≥ 0.05) in patients in low-, medium-, and high-volume hospitals. However, among GI diagnoses, risk of mortality was lower in high-volume hospitals, relative to low-volume hospitals (hazard ratio, 0.68; 95% confidence interval [CI], 0.54 to 0.85; p < 0.001), and was somewhat lower in medium-volume hospitals (hazard ratio, 0.83; 95% CI, 0.68 to 1.01; p = 0.06). Among subgroups based on severity of illness, high-volume hospitals had lower mortality, relative to low-volume hospitals, among sicker patients (APACHE III score > 57) in the respiratory cohort (hazard ratio, 0.77; 95% CI, 0.59 to 0.99) and the GI cohort (hazard ratio, 0.67; 95% CI, 0.53 to 0.85).

**Conclusions:** Associations between ICU volume and risk-adjusted mortality were significant for patients with GI diagnoses and for sicker patients with respiratory diagnoses. However, associations were not significant for patients with neurologic diagnoses. The lack of a consistent volume-outcome relationship may reflect unmeasured patient complexity in higher-volume hospitals, relative standardization of care across ICUs, or lack of efficacy of some accepted ICU processes of care.

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**Key words:** hazard ratio; hospital volume; ICU; mortality; outcomes; risk adjustment; severity of illness; volume-outcome relationship

**Abbreviations:** APACHE = acute physiology and chronic health evaluation; CI = confidence interval; ED = emergency department; LOS = length of stay

Over the past 2 decades, several studies have shown a positive association between volume of hospital services and patient outcomes for certain medical diagnoses and surgical procedures. A review1 by the Institute of Medicine found that relationships were statistically significant in more than two thirds of published studies.

While a majority of studies of hospital volume-outcome relationships have focused on patients undergoing specific procedures (eg, percutaneous coronary intervention, coronary artery bypass graft surgery, carotid endarterectomy), several studies have found similar relationships for certain medical conditions such as AIDS and cystic fibrosis,2–11 as

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Correspondence to: Gary E. Rosenthal, MD, Professor of Internal Medicine, Division of General Internal Medicine, SE618 GH, 200 Hawkins Dr, Iowa City, IA 52242; e-mail: gary-rosenthal@uiowa.edu
well as mental disorders. This work has led to recent efforts by purchaser groups, such as the Leapfrog Group, to define minimum volume thresholds for certain surgical procedures. Similar positions are also emerging from professional societies. For example, the American College of Cardiology recommended minimum annual institutional and physician volumes for percutaneous coronary intervention of 400 cases and 75 cases, respectively. The effect of patient volume, however, on outcomes in ICUs is not well studied, and prior work is largely limited to pediatric and neonatal ICUs. For example, Tiford et al found inverse relationships between unit volume and risk-adjusted mortality and length of stay (LOS) among 19 pediatric ICUs.

The lack of empirical data on adult medical ICUs is particularly problematic, given that >4.4 million patients are admitted to medical and mixed medical/surgical ICUs every year and approximately half a million ICU patients die annually. We conducted the current retrospective cohort study to determine the relationship between hospital volume and risk-adjusted in-hospital mortality among ICU admissions with common respiratory, neurologic, and GI diagnoses. We hypothesized that, among ICU admissions for common diagnoses, high-volume hospitals would have lower mortality and that the volume-outcome relationship would be stronger among sicker patients.

Materials and Methods

The current study represented a secondary analysis of data that was originally collected through Cleveland Health Quality Choice, a regional initiative to measure hospital performance in 29 hospitals in Northeast Ohio. Within these hospitals, data were collected on 196,997 consecutive admissions to 44 medical, mixed medical and surgical, surgical, and neurosurgical ICUs during the period March 1991 to March 1997. Exclusion criteria have been previously described and included patients <16 years of age, patients with burn injuries, admissions solely for dialysis, patients who die within 1 h of admission to the ICU or within the first 4 h of admission to the ICU in cardiopulmonary arrest, and patients undergoing cardiac surgeries.

For the current study, the eligible sample included 18,242 patients with respiratory diagnoses, 15,468 patients with neurologic diseases, and 13,717 patients with GI diagnoses, as defined by a prior taxonomy of ICU diagnoses at the time of admission. Of these patients, we excluded patients with diagnoses of malignancy (470, 439, and 263 patients with respiratory, neurologic, and GI diagnoses, respectively) and patients who were discharged to another acute care hospital for further care (823, 1,224, and 573 patients with respiratory, neurologic, and GI diagnoses, respectively) because the data set did not include unique patient identifiers to allow determination of postdischarge outcomes following transfer. These exclusions left final study cohorts of 16,949 ICU admissions with respiratory diagnoses, 13,805 patients with neurologic diagnoses, and 12,881 patients with GI diagnoses.

Data elements include age, gender, primary admitting diagno-
six, location prior to admission (ie, admission source), dates of ICU and hospital admission and discharge, vital status at discharge, discharge destination, ICU and hospital LOS, presence of seven specific comorbid conditions (eg, AIDS, hepatic failure, lymphoma), and variables that are used to determine the APACHE (acute physiology and chronic health evaluation) III score. The primary admitting diagnosis was classified according to a prior taxonomy based on operative status and organ system. Trained reviewers abstracted data from medical records of eligible patients using standard forms and data collection software (APACHE Medical Systems; McLean, VA).

The APACHE III acute physiology score is based on the most abnormal value during the first 24 h of ICU admission for 17 specific physiologic variables (eg, mean arterial BP, serum sodium and BUN, arterial pH, abbreviated Glasgow coma score). Physiologic variables with missing data were assumed to have normal values, consistent with earlier applications of APACHE III. APACHE III acute physiology scores have a possible range of 0 to 252 and were determined using previously validated weights for each of the 17 variables. As previously described, explicit steps were taken to ensure the reliability and validity of the study data. All analyses were done using statistical software (SAS, version 8.2; SAS Institute; Cary, NC; and S-Plus, version 6.1, Insightful Corporation; Seattle, WA). For the analyses, hospitals were grouped into low, medium, and high volume based on cut-offs that yielded roughly equivalent number of patients in each volume category. In the pulmonary diseases cohort, low-volume hospitals had <500 admissions, medium-volume hospitals had between 500 and 1,000 admissions, and high-volume hospitals had >1,000 admissions during the study period. In the GI and neurology cohorts, low-volume hospitals admitted <400 patients, medium-volume hospitals admitted between 400 and 700 patients, and high-volume hospitals admitted >700 patients during the study period. Relationships between volume categories and demographic and clinical variables and in-hospital mortality and LOS were determined using the χ² test or analysis of variance.

We modeled the time to in-hospital death using frailty models, which are an extension of the usual Cox regression model. Frailty modeling is necessary in analyses, which are conducted at the patient level, but which evaluate differences across types of hospitals (or physicians). The need to use frailty modeling stems from the fact that patients are not independently distributed across hospitals (ie, specific types of patients are clustered within specific types of hospitals). In our data set, patients within a given hospital are likely to have correlated outcome variables. Accordingly, for parameter estimates to be accurate and interpretable, the clustering of patients within a given hospital must be taken in to account by including a hospital-specific frailty, or random effect, in the model. Thus, we chose to model time to in-hospital death using a frailty model with hospital specific frailties. For model estimation purposes, we assumed that the frailties were distributed according to a γ distribution with mean zero and variance one.

Independent variables included in the frailty models were age, gender, APACHE III score, admitting diagnoses, and admission source. Since the relationship between the risk of death and APACHE III score was nonlinear, we represented the score both as a continuous variable and a series of indicator variables for specific ranges. Hospital teaching status was not included in the model because of the high degree of correlation between volume and teaching status (eg, all high-volume hospitals were teaching hospitals). In addition, models included two indicator variables for high- and medium-volume hospitals using low-volume hospitals as the reference group. The estimated regression coefficients associated with these indicator variables were used to determine
the hazard of death in the high- and medium-volume category, relative to patients in low-volume hospitals.

Subgroup analysis was conducted to determine effect modification of the volume-outcome relationship by severity of illness. For this analysis, we classified each cohort into two groups of severity based on the median APACHE III score. For instance, in the pulmonary cohort, the median APACHE III score was 57. Separate analyses were done on the low-severity group (score < 57) and the high-severity group (score ≥ 57). The median APACHE III scores for neurology and GI cohorts were 46 and 47, respectively.

In additional analyses, hazard ratios for in-hospital mortality were estimated for each hospital relative to the mean across remaining hospitals. Cox regression, adjusting for patient risk factors, was used to obtain these estimates. Hospital-specific hazard ratios were plotted against hospital-specific volume and Pearson correlation was estimated between hospital volume and hospital-specific hazard ratios.

**Results**

The demographic characteristics of patients in the three cohorts are shown in Table 1. The mean age of patients was generally lower among patients in high-volume hospitals for all three diagnoses. Gender distributions differed only for patients with GI diagnoses. Patients in high-volume hospitals were less likely to be admitted from the emergency department (ED) and were more likely to be admitted from other acute-care hospitals or from other hospital floors. Mean APACHE III scores were highest in high-volume hospitals for respiratory and GI diagnoses and in medium-volume hospitals for neurologic diagnoses. Mean ICU LOS was significantly higher in high-volume hospitals for all three diagnoses. Higher proportions of patients received mechanical ventilation in high-volume hospitals. Unadjusted mortality was highest in high-volume hospitals for respiratory and GI diagnoses and in medium-volume hospitals for neurologic diagnoses (Fig 1). Unadjusted mortality rates mimicked mean APACHE III scores in the three volume categories.

Table 2 shows the most common admitting diagnoses among the three disease cohorts and the associated mortality rates. Among the respiratory cohort, the highest mortality rates were highest for ARDS (40%) and respiratory arrest (36%). Some of diagnoses in the "other" category included primary pulmonary hypertension, airway obstruction, smoke inhalation, and cystic fibrosis. Among neurologic diagnoses, mortality rates were highest for intracerebral hemorrhage (38%) and subarachnoid hemorrhage (36%).

<table>
<thead>
<tr>
<th>Table 1—Characteristics and Outcomes of Patients According to Hospital Volume for the Three Diagnostic Groups*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume Category</strong></td>
</tr>
<tr>
<td>Respiratory diagnoses (n = 16,949)</td>
</tr>
<tr>
<td>Patients (hospitals), No.</td>
</tr>
<tr>
<td>Mean age (SD), yr</td>
</tr>
<tr>
<td>Median APACHE III score (IQR)</td>
</tr>
<tr>
<td>Median hospital LOS (IQR), d</td>
</tr>
<tr>
<td>Median ICU LOS (IQR), d</td>
</tr>
<tr>
<td>Male gender, %</td>
</tr>
<tr>
<td>Mechanical ventilation, %</td>
</tr>
<tr>
<td>ED admissions, %</td>
</tr>
<tr>
<td>Interhospital transfers, %</td>
</tr>
<tr>
<td>GI diagnoses (n = 12,881)</td>
</tr>
<tr>
<td>Patients (hospitals), No.</td>
</tr>
<tr>
<td>Mean age (SD), yr</td>
</tr>
<tr>
<td>Median APACHE III score (IQR)</td>
</tr>
<tr>
<td>Median hospital LOS (IQR), d</td>
</tr>
<tr>
<td>Median ICU LOS (IQR), d</td>
</tr>
<tr>
<td>Male gender, %</td>
</tr>
<tr>
<td>Mechanical ventilation, %</td>
</tr>
<tr>
<td>ED admissions, %</td>
</tr>
<tr>
<td>Interhospital transfers, %</td>
</tr>
<tr>
<td>Neurologic diagnoses (n = 13,805)</td>
</tr>
<tr>
<td>Patients (hospitals), No.</td>
</tr>
<tr>
<td>Mean age (SD), yr</td>
</tr>
<tr>
<td>Median APACHE III score (IQR)</td>
</tr>
<tr>
<td>Median hospital LOS (IQR), d</td>
</tr>
<tr>
<td>Median ICU LOS (IQR), d</td>
</tr>
<tr>
<td>Male gender, %</td>
</tr>
<tr>
<td>Mechanical ventilation, %</td>
</tr>
<tr>
<td>ED admissions, %</td>
</tr>
<tr>
<td>Interhospital transfers, %</td>
</tr>
</tbody>
</table>

*IQR = interquartile range (25 to 75%).*
The "other" category of diagnoses included brain abscess, subdural hematoma, Guillain-Barré syndrome, anoxic coma, myasthenia gravis, and amyotropic lateral sclerosis. Among GI diagnoses, mortality was highest for fulminant hepatic failure (41%) and bowel obstruction/perforation (26%). The diseases in the "other" category include abscess, cholangitis, diverticulosis, vascular insufficiency, and chemical ingestion.

The adjusted risks of death of patients in medium- and high-volume hospitals, relative to patients in low-volume hospitals, based on Cox proportional hazard models are shown in Table 3. Among the respiratory and neurology cohorts, hazard ratios for patients in medium- and high-volume hospitals were not significantly different from 1.0 (ie, patients in low-volume hospitals). However in the GI cohort, the adjusted risk of death was lower in the high-volume hospitals (hazard ratio, 0.68; 95% confidence interval [CI], 0.54 to 0.85), relative to patients in low-volume hospitals.

We fit separate Cox models for the low- and high-severity subgroups within each disease cohort and then compared the parameter estimates for volume categories between the groups. As shown in Table 4, high-volume hospitals had lower mortality than low-volume hospitals among high-severity pa-
Table 4—Adjusted Risk of Death for Patients in Medium- and High-Volume Hospitals, Relative to Low-Volume Hospitals, Stratified by Severity of Illness, as Determined by Cox Proportional Hazard Analysis

<table>
<thead>
<tr>
<th>Volume Category</th>
<th>Hazard Ratio*</th>
<th>p Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Respiratory diagnoses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower severity (APACHE III ≤ 57; n = 8,366)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium volume</td>
<td>1.05</td>
<td>0.66</td>
<td>0.85–1.30</td>
</tr>
<tr>
<td>High volume</td>
<td>0.99</td>
<td>0.99</td>
<td>0.77–1.29</td>
</tr>
<tr>
<td>Higher severity (APACHE III &gt; 57; n = 8,521)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium volume</td>
<td>0.93</td>
<td>0.45</td>
<td>0.76–1.13</td>
</tr>
<tr>
<td>High volume</td>
<td>0.77</td>
<td>0.048</td>
<td>0.59–0.99</td>
</tr>
<tr>
<td><strong>GI diagnoses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower severity (APACHE III ≤ 47; n = 6,319)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium volume</td>
<td>1.04</td>
<td>0.85</td>
<td>0.67–1.61</td>
</tr>
<tr>
<td>High volume</td>
<td>1.02</td>
<td>0.94</td>
<td>0.61–1.68</td>
</tr>
<tr>
<td>Higher severity (APACHE III &gt; 47; n = 6,518)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium volume</td>
<td>0.81</td>
<td>0.04</td>
<td>0.66–0.99</td>
</tr>
<tr>
<td>High volume</td>
<td>0.67</td>
<td>0.001</td>
<td>0.53–0.85</td>
</tr>
<tr>
<td><strong>Neurologic diagnoses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower severity (APACHE III ≤ 46; n = 6,777)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium volume</td>
<td>0.69</td>
<td>0.05</td>
<td>0.48–1.00</td>
</tr>
<tr>
<td>High volume</td>
<td>0.83</td>
<td>0.20</td>
<td>0.59–1.17</td>
</tr>
<tr>
<td>Higher severity (APACHE III &gt; 46; n = 7,006)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium volume</td>
<td>0.93</td>
<td>0.44</td>
<td>0.76–1.13</td>
</tr>
<tr>
<td>High volume</td>
<td>0.84</td>
<td>0.17</td>
<td>0.65–1.08</td>
</tr>
</tbody>
</table>

*Adjusted for age, gender, APACHE III score, admitting diagnosis and source, and adjusted for clustering within hospitals using the frailty model.

Discussion

This is the first study to our knowledge to examine the relationship between hospital volume and outcome among medical admissions to adult ICUs. After adjusting for admission severity of illness using a robust physiologic-based measure, the study yielded mixed results. While there were no significant overall differences in mortality for patients with pulmonary and neurologic diagnoses, we did find lower mortality in high-volume hospitals for patients with GI diagnoses. Moreover, mortality was also lower in high-volume hospitals for higher-severity patients with pulmonary diagnoses. Analysis of the
results at the individual hospital level revealed a modest association with hospital volume measured as a continuous variable. Volume explained roughly 15% of the variation in mortality. We suspect that most of the variation in mortality is explained by hospital-level differences and/or random differences in hospital-level mortality, independent of volume.

These findings, while ambivalent and of a smaller magnitude compared to other studies, contribute to our understanding of volume-outcome relationships in a previously unstudied population. We believe that there are several possible explanations for the lack of a consistent volume-outcome relationship across all three diagnoses. First, the power to detect differences was limited by the relatively few hospitals (n = 29) that were studied. Second, it is possible that volume-outcome relationships may be relatively weak for some diagnoses treated in ICUs. This may arise because conditions are relatively common so that even low-volume hospitals surpass a critical threshold and attain adequate experience. As has been noted previously, performance gaps between low- and high-volume hospitals tend to narrow over time as specific treatment protocols and procedures become better established.1

Third, although we employed a validated method of adjusting for severity of illness with excellent predictive validity, it is possible that residual unmeasured severity of illness was also directly related to hospital volume or that other factors led to selection bias. Fourth, it is possible that some accepted practices in ICU patients may not yield better outcomes, as has been demonstrated previously for right-heart catheterization.22 Thus, “the practice makes perfect” axiom that is believed to underlie volume-outcome relationships may not have practical utility when the standard practices do not have a significant impact on outcome, even though high-volume facilities may be more proficient in such practices. Finally, the current findings may be confounded by differences in physician volume, in the quality of nursing care, or other unmeasured hospital differences, independent of volume, such as the presence of physicians who are board certified in critical care.

While the current study is unable to delineate factors that underlie the volume-outcome relationship that was observed for GI diagnoses, such factors may include greater physician experience or better access in higher-volume hospitals to certain procedures, such as endoscopy or endoscopic retrograde cholangiopancreatography, which may have a positive impact on outcomes when performed in a timely manner. Unfortunately, the database used in this analysis did not include data on procedures used during the ICU stay. A strength of the current study is its use of clinical data, unlike most prior studies8,23 on volume-outcome relationship among medical admissions that have utilized administrative data. While administrative data can allow analysis of a larger number of hospitals, such datasets are limited by their reliance on the International Classification of Diseases coding system, and most importantly, by their lack of information on vital signs, physical examination findings, or laboratory findings. Such limitations of administrative data may be particularly relevant to ICU populations, for whom much prior research has demonstrated the predictive validity of acute physiologic abnormalities.24

There are several potential methodologic limitations to our study, in addition to factors previously noted. First, this study was retrospective in nature and could not relate differences in outcomes to potential differences in the structure and process of care in higher- and lower-volume hospitals. Second, findings may be confounded by selection bias and by differences in ICU services offered by higher- and lower-volume hospitals. For example, high-volume hospitals may admit patients for complex procedures that carry an inherent risk, independent of admission severity of illness, and that are not usually done in low-volume hospitals. Third, this study involved a small number of hospitals in a single geographic area. Hence, generalizability to other health-care settings is uncertain. Fourth, current physiologic-based severity measures, such as APACHE III, do not consider functional status or important psychosocial determinants of outcome. Such factors may be particularly relevant for certain diseases (eg, neurologic diagnoses). Similarly, the study did not consider patient preferences or family preferences for the aggressiveness of treatment, which have prognostic importance. Fifth, while we found a modest association between hospital volume and outcome, the observational nature of this study makes it difficult to infer a causal relationship. Lastly, the data used in the study predated many advances in ICU care (eg, low tidal volume ventilation for patients with ARDS and activated protein C for sepsis).25,26

In spite of these limitations, the current findings have important implications for policy and practice. Patient volume, a structural construct, has no direct effect on outcomes by itself and is likely a proxy for other structure or processes of care (eg, physician training or experience, standardized protocols, implementation of practice guidelines, technical resources) that have a more direct bearing on outcome. For example, several studies27–29 have found that ICUs that are staffed by intensivists have lower mortality. The Leapfrog Group, a coalition of > 135 Fortune 500 companies that provides health insurance to > 33 million Americans, estimated that implementation of ICU physician staffing standards...
would save 53,850 lives each year in the United States. In addition, data from the Society of Critical Care Medicine survey suggest that smaller hospitals in general have less technology, a smaller number of experienced personnel, and more deficiencies in organizational structures. High-volume hospitals, by virtue of having better resources and more experienced personnel, therefore might be expected to have better ICU outcomes.

Because of the evidence from prior studies, provider-specific volume information is likely to have increasingly important policy ramifications. Purchasers such as the Leapfrog Group currently encourage the use of volume data in the selection of providers, in the absence of other more specific information about outcomes or process of care. Hospital administrators could use this information for physician credentialing and to create units or services that focus on the management of certain conditions to increase provider experience. Professional organizations and regulatory agencies could use volume data as a part of the board-certification process or the institutional-accreditation process.

However, the mixed results of the current study highlight the need for caution in blindly using volume as a method for selecting and credentialing providers. Without understanding of the basic drivers of volume-outcome relationships, it is important that policy decisions not leap ahead of the evidence base. In the case of intensive care, we believe that several additional questions need to be addressed. For example, what are the specific thresholds of experience and volume for ICU care overall and for individual diagnoses that ensure competence? Among commonly performed ICU interventions that may be performed more proficiently in high-volume ICUs, how many can be explicitly linked to better outcomes?

Intensive care is currently associated with significant mortality, morbidity, and health-care costs. Given that the demand for intensive care will likely increase with an aging and more chronically ill population and with the introduction of novel therapies and technologies, unraveling the complexity of volume-outcome relationships in ICU settings and defining the specific structure and process factors in high-volume hospitals that may or may not lead to better outcomes is critical to improving the delivery of ICU services and the ways in which purchasers and regulators may use ICU volume data in the future. Our study is one of the earliest, if not the first, study to examine this relationship among medical admissions to the ICU. Given the mixed results seen this study, a prospective study of a larger number of hospitals with information on staffing patterns, physician training, and various process measures is needed to provide further insight into volume-outcome relationships in medical ICUs.

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