Potential Value of Regionalized Intensive Care for Mechanically Ventilated Medical Patients

Jeremy M. Kahn^{1,2}, Walter T. Linde-Zwirble³, Hannah Wunsch⁴, Amber E. Barnato^{5,6}, Theodore J. Iwashyna^{1,2}, Mark S. Roberts⁵⁻⁷, Judith R. Lave⁶, and Derek C. Angus⁸

¹Division of Pulmonary, Allergy, and Critical Care, Center for Clinical Epidemiology and Biostatistics, University of Pennsylvania School of Medicine; ²Leonard Davis Institute of Health Economics, University of Pennsylvania, Philadelphia, Pennsylvania; ³ZD Associates, LLC, Perkasie, Pennsylvania; ⁴Department of Anesthesiology, Columbia Presbyterian Medical Center, Columbia University, New York, New York; ⁵Section of Decision Sciences and Clinical Systems Modeling, Division of General Internal Medicine, University of Pittsburgh School of Medicine; ⁶Department of Health Policy and Management, Graduate School of Public Health, University of Pittsburgh; ⁷Department of Industrial Engineering, University of Pittsburgh School of Engineering; and ⁸Clinical Research, Investigation, and Systems Modeling of Acute Illness Laboratory, Department of Critical Care Medicine, University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania

Rationale: Regionalization has been proposed as a method to improve outcomes for medical patients receiving mechanical ventilation in the intensive care unit.

Objectives: To determine the number of patients who would be affected by regionalization and the potential mortality reduction under a regionalized system of care.

Methods: We performed a retrospective cohort study with Monte Carlo simulation, using 2001 state discharge data from eight states representing 42% of the U.S. population. Adult medical patients undergoing invasive mechanical ventilation were identified. Patient location and hospital mortality rates were obtained from the discharge data; estimates of the relative risk reduction in hospital mortality for high-volume hospitals compared with low-volume hospitals were obtained from the published literature and applied to the cohort.

Measurements and Main Results: Of 180,976 adult medical patients who underwent mechanical ventilation at 1,170 nonfederal hospitals, 83,050 (46%) received mechanical ventilation at 887 (76%) hospitals with low annual volumes (fewer than 275 patients per year). Using published risk estimates, approximately 4,720 lives per year (95% range, 2,522–6,744) could potentially be saved in the 8 states by routinely transferring patients from low- to high-volume hospitals, representing a number needed to treat of 15.7. The median distance that patients would need to travel to reach a high-volume hospital was 8.5 miles (interquartile range, 4.0–21.2 mi).

Conclusions: Regionalization of intensive care could potentially improve survival for patients undergoing mechanical ventilation. Transfer distances are modest for most patients.

Keywords: mechanical ventilation; triage; transportation of patients; critical care; Monte Carlo method

The movement for quality and safety in health care has stressed better organization and structure of health care systems (1). Many potential strategies exist to improve care delivery at the health system level. Regionalization of care is one example. By concentrating skill and resources in a few high-quality centers, regionalization offers the potential benefit of increased efficiency, particularly in medical fields in which outcome is positively as-

AT A GLANCE COMMENTARY

Scientific Knowledge on the Subject

Regionalization of care has been proposed as a method to improve outcomes for critically ill patients at small hospitals. Little is known about the relative number of small hospitals or the potential mortality benefit for patients under regionalization.

What This Study Adds to the Field

Many medical patients undergoing mechanical ventilation receive care at low-volume hospitals. Regionalization has the potential to improve the survival for these patients.

sociated with volume and in which there are significant economies of scale. In the United States, regionalized systems have developed in both trauma and neonatal care, and regionalization efforts are currently underway for several high-risk surgeries (2–4). These fields share a high risk of mortality, a positive volume–outcome relationship, and the potential for waste if expensive infrastructure is replicated across many sites within a region (5–7).

Patients with acute respiratory failure requiring mechanical ventilation make up another group who may benefit from regionalization. Mechanically ventilated patients are at high risk of death and consume a disproportionate amount of health care resources (8, 9). One study also found that nonsurgical mechanically ventilated patients at high-volume hospitals experience improved survival compared with patients at low-volume hospitals (10). Several stakeholder groups have stressed regionalization as a potential way to improve outcome for mechanically ventilated patients (11, 12). As yet, there are no empiric data on how many patients currently receive care in low-volume hospitals or how regionalizing care for these patients might impact outcomes. The purpose of this study was to investigate the potential value of regionalizing adult critical care in eight states representing a large proportion of the U.S. population. Specifically, we wished to determine the number of medical patients undergoing mechanical ventilation at low-volume hospitals, the potential number of lives saved if care were to be regionalized, and the consequences of regionalization for patient transport distances and hospital occupancy.

METHODS

Data Sources and Patients

We analyzed the 2001 hospital discharge records from eight U.S. states: California, Florida, Massachusetts, New Jersey, New York, Texas, Virginia,

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Correspondence and requests for reprints should be addressed to Jeremy M. Kahn, M.D., M.Sc., Division of Pulmonary, Allergy, and Critical Care, University of Pennsylvania School of Medicine, 723 Blockley Hall, 423 Guardian Drive, Philadelphia, PA 19104. E-mail: jmkahn@mail.med.upenn.edu

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and Washington. These states were chosen because of the size, availability, and quality of their state discharge records. Together, the states comprise 42% of the U.S. population, including a broad range of urban and rural regions of varying socioeconomic status. The records contain complete administrative data on inpatient hospitalizations, including hospital characteristics, patient demographic information, resource use, and *International Classification of Diseases, 9th Revision—Clinical Modification* (ICD-9-CM) diagnostic codes. Data were linked to the year 2000 U.S. Census by the hospital ZIP (Zone Improvement Plan) code and each patient's ZIP code of residence. Federal hospitals such as military hospitals, penal hospitals, and Veterans Affairs hospitals are not included in state discharge data.

We identified admissions involving mechanical ventilation on the basis of the ICD-9-CM procedure codes 96.70, 96.71, and 96.72 (mechanical ventilation—time unspecified, less than 96 consecutive hours, and 96 or more consecutive hours, respectively). We excluded admissions under the age of 18 years or of unknown age, admissions to pediatric hospitals, admissions involving a major surgical procedure based on an ICD-9-CM procedure code involving the operating room, and those with the ZIP code either missing or outside the eight-state sample. To avoid counting patients who would be transferred to hospitals in states not in our data set, we also excluded admissions to hospitals in Hospital Referral Regions when the central city for the region was outside our set of states (13).

Definitions for high- and low-volume hospitals and estimates of the potential mortality benefit from care at a high-volume hospital were obtained from a study examining the relationship between volume and in-hospital mortality for mechanically ventilated patients in the intensive care unit (ICU) (10). This study was a retrospective cohort analysis in 37 acute care hospitals throughout the United States, demonstrating improved in-hospital survival among patients receiving invasive mechanical ventilation for acute respiratory failure, using detailed clinical risk adjustment (14). The study was selected after a systematic review of MEDLINE for articles published between January 1, 1986 and December 31, 2006 using the terms “volume,” “outcome,” “mortality,” “hospital,” “intensive care unit,” and “critical care” failed to identify another volume–outcome study in the ICU that specifically examined mechanically ventilated patients and used clinical risk adjustment to account for variation in case mix (15–19).

Analysis

On the basis of the definitions from this study, we categorized hospitals as either very low volume (fewer than 150 admissions per year), low volume (151–275 admissions per year), intermediate volume (276–400 admissions per year), or high volume (more than 400 admissions per year) depending on the annual number of mechanically ventilated admissions (10). These categories were based on volume quartiles in the original studies. Annual volumes were calculated before patient exclusions. We compared the characteristics of hospitals across volume groups, using analysis of variance or a chi-square test, as appropriate. Travel distances may be a potential barrier to regionalization because of increased burden on the health care system, patients, and families. We calculated distances traveled under a regionalized scenario assuming patients at low- or very-low-volume hospitals (not more than 275 patients per year) were sent to the nearest intermediate- or high-volume hospital (more than 275 patients per year). Distances were calculated both from the admitting hospital to the new hospital and from the patient's residence to the new hospital. All travel distances were calculated as arc distances between patient and hospital ZIP code centroids.

Simulation

To determine the potential survival benefit under a regionalized scenario, we simulated the transfer of patients at low-volume and very-low-volume hospitals (not more than 275 admissions per year) to the nearest intermediate- or high-volume hospital (more than 275 admissions per year). We limited the number of patients transferred to 90% of admissions at each small hospital to allow for the possibility that some mechanically ventilated patients would either refuse transfer or die before transfer. We applied the published risk estimates on the odds scale under the assumption that all transferred patients would receive the benefit of care at a high-volume hospital. To incorporate the uncertainty of the true benefits of regionalization, we conducted a one-way

sensitivity analysis by probabilistically varying the benefit across the 95% confidence intervals of the published estimates. We accounted for uncertainty in the population of hospitals by creating different bootstrapped hospital samples for each simulation.

To assess how regionalization might affect hospitals in urban and rural areas differently, we ran separate simulations for hospitals in large urban (more than 1 million persons), small urban (100,000 to 1 million persons), and rural areas (fewer than 100,000 persons) based on metropolitan statistical area size. We also reran the simulations by limiting the allowable distance traveled to either 20 or 50 miles. Each simulation was repeated 1,000 times. In each simulation we calculated the total number of potential lives saved, the number needed to transfer to save one life, and the median travel distance between hospitals. We also calculated two different measures of occupancy under regionalization: the percent change in the annual number of ICU admissions and the absolute change in daily hospital census. The percent change in the annual number of ICU admissions was calculated by dividing the number of new admissions per year by the number of annual ICU admissions at each hospital. ICU admissions were obtained from the state discharge data and were available for each state except California—hospitals in California were omitted from this portion of the analysis. The absolute change in daily hospital census was calculated under the assumption that hospital length of stay for mechanically ventilated patients transferred to accepting hospitals would be similar to that of other mechanically ventilated patients at that hospital, accounting for increased lengths of stay for patients who survive.

To address the potential unintended consequences of regionalization on patients remaining at low-volume and very-low-volume hospitals, we estimated the relative risk of death that would have to occur in these patients to fully offset the benefits of regionalization. This analysis was performed for two populations: surgical admissions involving mechanical ventilation and all remaining ICU patients.

All analyses were performed with Stata 9.2 (StataCorp, College Station, TX). The University of Pennsylvania (Philadelphia, PA) Institutional Review Board granted this study an exemption from human subjects review. Portions of this work were originally published in abstract form (20, 21).

RESULTS

Demographic Evaluation

There were 1,222 nonfederal acute care hospitals in the eight states that cared for at least one adult medical patient undergoing mechanical ventilation during 2001. Fifty-two hospitals were located in Hospital Referral Regions that extended outside the eight-state sample, leaving 1,170 hospitals in the analysis (Table 1). Of these, 269 (23%) were classified as low-volume providers (151–275 admissions per year) and 618 (53%) were classified as very-low-volume hospitals (fewer than 150 admissions per year). Compared with high-volume hospitals, lower volume hospitals were smaller and less likely to have physicians-in-training. Lower volume hospitals also tended to be in smaller and rural communities compared with high-volume hospitals.

A total of 228,838 medical admissions involved mechanical ventilation at the study hospitals, representing 9.9% of ICU admissions in those hospitals. Of admissions, 32,176 (14.1%) were excluded because they were less than 18 years of age and 15,910 (7.0%) were excluded because of missing ZIP codes or ZIP codes outside the states, leaving 180,976 (79.1%) admissions (Table 2). Of these, 83,050 were managed at low- or very-low-volume hospitals (46%). Patients in lower volume hospitals were older and less likely to be minorities compared with patients in higher volume hospitals. Patients in lower volume hospitals were also less likely to have been transferred in from an outside hospital. The payer in high-volume hospitals was more likely to be Medicaid and less likely to be Medicare, typical of a younger, more urban population. As in prior reports, crude outcomes were similar among hospital groups, although patients in high-volume hospitals tended to have shorter ICU lengths of stay (10). Most

TABLE 1. HOSPITAL CHARACTERISTICS BY HOSPITAL VOLUME*

Variable	Annual Hospital Admission Volume				P Value
	≤150	151–275	276–400	>400	
Hospitals, n	618	269	133	150	
Hospital beds [†]	103 (58–141)	204 (161–261)	294 (234–334)	438 (332–591)	<0.001
Critical care beds [†]	8 (6–12)	16 (12–24)	26 (17–36)	39 (26–60)	<0.001
Academic status, %					<0.001
Resident to bed ratio > 0.20	8.9	19.7	36.8	74.0	
Resident to bed ratio < 0.20	7.9	15.6	13.5	10.7	
Nonteaching	83.2	64.7	49.6	15.3	
Ownership, %					<0.001
Private for-profit	29.9	26.0	20.3	8.7	
Private not-for-profit	57.8	65.1	66.2	66.7	
Public/county	11.7	7.4	12.0	24.0	
Unknown	0.7	1.5	1.5	0.7	
Metropolitan statistical area size, %					<0.001
<100,000	20.4	0.4	0.8	0.7	
100,000 to 1 million	29.1	23.4	30.1	16.0	
>1 million	50.5	76.2	69.2	83.4	
Proportion of population living in rural area [‡]	0.25	0.07	0.08	0.06	<0.001
Standardized median patient income [§]	41,168 (9,609)	42,238 (10,055)	39,318 (9,474)	36,928 (9,283)	<0.001

* Number of admissions per year of adult medical patients undergoing invasive mechanical ventilation.

[†] Values are expressed as mean (standard deviation) or median (interquartile range).

[‡] Mean proportion of rural residents in each hospital's ZIP code.

[§] Average median income of census tract for patient population.

patients in low- or very-low-volume hospitals were located in hospitals in large cities (57,862; 69.7%). 20,673 patients (24.9%) were located in small cities and 4,515 patients (5.4%) were located in rural areas.

Simulated Benefits from Transfer

The estimated relative benefits of transfer from low- to high-volume hospitals are shown in Table 3. Applying these estimates in the simulation resulted in a clinically significant mortality reduction for mechanically ventilated patients (Table 4). Under the base assumptions, 4,720 lives per year (95% range, 2,522–6,744 lives) could be saved annually in the 8 states by routinely transferring patients at low-volume hospitals to the nearest high-volume hospital. On average, the number of patients needed to transfer to save 1 life was 15.7 (95% range, 11.9–29.6). Most of the benefit of regionalization was seen in urban areas. The absolute benefit was somewhat small in rural areas, where there are fewer patients undergoing mechanical ventilation. Limiting the allowable travel distance to 20 or 50 miles slightly attenuated the number of lives saved: at a maximal allowable distance of 20 miles, 3,310 lives per year could be saved (95% range, 1,700–4,948); at a maximum allowable travel distance of 50 miles, 4,212 lives per year could potentially be saved (95% range, 2,250–6,121).

Distance and Census Evaluation

Most patients at low- and very-low-volume hospitals would need to travel less than 9 miles to reach the nearest intermediate- or high-volume hospital (Figure 1A). At a maximal travel distance of 20 miles between hospitals, 73% of patients at small hospitals could reach an appropriate center. In large urban areas, this figure increases to 90% of patients in intermediate- or low-volume hospitals (Figure 1B). Average travel distances were greater for patients in rural areas. However, these represented a small minority of total patients, and most rural patients were still within 100 miles of the nearest intermediate- or high-volume hospital. Added travel distances from each patient's home to the higher volume hospital were similarly small (Figure 2). On average, families would have to travel an extra 4 miles to reach the new

hospital after transfer, and 26.4% would need to travel no extra distance.

Regionalization resulted in a median increase in total annual ICU census at accepting hospitals of 5.0% (interquartile range, 0.9–12.7%). Approximately 9.5% of accepting hospitals would observe a greater than 20% increase in total annual ICU census. The median percent increase in the number of admissions involving mechanical ventilation was 42.0% (interquartile range, 2.7–87.9%). On average, accepting hospitals would admit 3.4 extra mechanically ventilated patients per week and carry a hospital census (both ICU and ward) of 7.3 extra patients per day. The median percent decrease in total ICU census at referring hospitals was 6.8% (interquartile range, 3.8–11.5%).

To completely offset the benefits of regionalization, the risk of death for surgical mechanically ventilated admissions remaining in the low- and very-low-volume hospitals would have to increase by 97%. Alternatively, the risk of death for all remaining ICU patients would have to increase by 6%.

DISCUSSION

In a population-based sample of U.S. hospitals, more than 75% of acute-care hospitals admit numbers of mechanically ventilated patients below previously described volume thresholds. Approximately one-third of mechanically ventilated patients receive care in these hospitals. By routinely transferring these patients to higher volume regional referral centers, about 4,700 lives might be saved annually in 8 U.S. states. About 16 patients must be transferred to save 1 life, a number needed to treat that is comparable to other accepted therapies in the ICU (22–24). We expect this estimate to be conservative, because we excluded some patients who would potentially be eligible for regionalization, including patients with missing values for age and ZIP codes outside the eight-state area.

Travel distances did not appear to be a significant barrier to regionalization in this study. More than 70% of patients were within 20 miles of an intermediate- or high-volume hospital, and the average patient would need to travel less than 9 miles. Routinely transferring patients to high-volume centers also does not appear to create a large travel burden on patient's families.

TABLE 2. ADMISSION CHARACTERISTICS BY HOSPITAL VOLUME*

Variable	Annual Hospital Admission Volume				P Value
	≤150	151–275	276–400	>400	
Patients, n	35,931	47,119	34,351	63,575	—
Age (yr), mean (SD)	68 (16)	68 (16)	67 (17)	64 (18)	<0.001
Sex, % female	47.7	49.2	47.4	46.4	<0.001
Ethnicity, %					<0.001
White	69.5	64.7	60.2	54.2	
Black	9.2	11.2	13.5	19.7	
Hispanic	8.1	10.6	11.5	11.6	
Other	13.2	13.6	14.8	14.5	
Admitted from outside hospital, %	3.6	4.2	4.7	7.0	<0.001
Payer, %					<0.001
Private insurance	18.6	20.1	19.9	22.3	
Medicaid	10.2	9.5	11.8	15.1	
Medicare	60.3	61.2	58.5	49.7	
Other	6.6	4.9	5.6	6.2	
Self/uninsured	4.4	4.3	4.2	6.8	
Comorbidities [†]					
Myocardial infarction	2.9	3.3	3.1	2.9	<0.001
Peripheral vascular disease	2.8	2.8	2.8	2.1	<0.001
Cerebrovascular disease	2.8	3.0	2.8	2.8	0.07
Chronic obstructive pulmonary disease	18.3	16.3	16.5	12.6	<0.001
Diabetes	19.1	18.1	18.6	17.3	<0.001
Renal disease	3.8	3.4	3.6	3.2	0.25
Neoplasm	7.1	7.5	7.6	8.0	<0.001
Metastatic cancer	3.5	3.8	4.0	4.1	<0.001
Distance from home to hospital, [‡] mean (SD)	12 (35)	12 (35)	13 (32)	16 (34)	<0.001
Distance from home to nearest high-volume center, [‡] mean (SD)	27 (31)	15 (20)	8 (13)	8 (14)	<0.001
Discharge disposition, %					<0.001
Home	26.4	26.9	27.7	31.2	
Skilled nursing facility	17.8	19.1	19.2	18.8	
Other acute care hospital	10.7	7.2	4.8	3.7	
Dead	38.7	41.2	41.9	40.5	
Other	5.0	5.6	6.4	5.8	
Hospital length of stay (d), mean (SD)					<0.001
All patients	12.1 (32.9)	12.8 (31.8)	12.6 (20.9)	13.2 (56.6)	
Survivors	13.3 (30.7)	14.2 (28.4)	14.4 (23.4)	15.1 (71.5)	
Nonsurvivors	10.3 (36.0)	10.8 (36.1)	10.0 (16.6)	10.4 (20.0)	

* Number of admissions per year of adult medical patients undergoing invasive mechanical ventilation.

[†] From primary admission ICD-9-CM and Charlson Comorbidity Index. Categories are not mutually exclusive.

[‡] In miles, based on distance between ZIP code centroids of the patient's residence and the admission hospital.

Indeed, most patients in low-volume hospitals are located in urban areas; 26% of these patients could reach a high-volume hospital closer to their home than the low-volume hospital to which they were originally admitted.

Regionalization would significantly increase the number of mechanically ventilated patients at higher volume hospitals. On average the increase would amount to about four extra patients

per week, and the average increase in total ICU annual census would be about 5%. Concerns about overloading higher volume hospitals are an important barrier to regionalization, and it is likely that this increase will require increases in staffing and bed numbers at many high-volume hospitals. However, the number of ICU beds in the United States is currently increasing independent of any large-scale reorganization efforts, in one report by more than 25% over a 15-year span (9). It may be possible to accommodate the changes in annual census simply by redirecting bed increases to regional referral centers. Regionalization might also result in unintended consequences to patients remaining in low-volume ICUs. The amount of risk necessary to offset the potential benefits of regionalization was large for surgical ventilated patients, but relatively small for ICU patients, which comprise a larger group. Unintended consequences represent an important challenge to regionalization and should be considered in any future research.

These analyses contribute to the current literature on regionalization of critical care services in the United States. The major critical care professional societies, including the American Association of Critical Care Nurses, the Society of Critical Care Medicine, the American College of Chest Physicians, and the American Thoracic Society, have endorsed regionalization as an important strategy to expand access to high-quality critical

TABLE 3. ESTIMATED SURVIVAL BENEFIT OF TRANSFER FROM LOW-VOLUME TO HIGH-VOLUME HOSPITALS

Annual Hospital Admission Volume		Assumed Reduction in Odds of Death* (95% Confidence Interval)	Patients in Each Category (n)
Originating Hospital	Nearest Accepting Hospital		
≤150	276–400	0.72 (0.53–0.99)	18,618
≤150	>400	0.66 (0.52–0.83)	17,313
151–275	276–400	0.84 (0.63–1.12)	23,122
151–275	>400	0.77 (0.64–0.92)	23,997

* Odds ratio for in-hospital death, from a study examining the relationship between admission volume and mortality in medical patients undergoing mechanical ventilation (10).

TABLE 4. POTENTIAL ANNUAL MORTALITY REDUCTION IN EIGHT STATES UNDER REGIONALIZED SYSTEM OF ADULT CRITICAL CARE

Variable	All Hospitals	By Originating Hospital Location*		
		Large Urban	Small Urban	Rural Area
Population at low-volume hospitals	83,050	57,862	20,673	4,515
Number transferred [†]	74,357	51,804	18,451	3,975
Number of accepting hospitals	283	283	283	283
Potential lives saved, [‡] mean (95% range)	4,720 (2,522–6,744)	3,253 (1,632–4,896)	1,153 (671–1,659)	284 (120–465)
Number needed to move to save one life, [‡] mean (95% range)	15.7 (11.9–29.6)	16.0 (10.8–32.7)	16.0 (11.5–27.3)	13.8 (9.2–31.4)
Travel distances between hospitals, miles, median (IQR)	8.5 (4.0–21.2)	6.4 (3.4–12.7)	23.3 (10.8–47.2)	56.6 (47.4–78.7)

Definition of abbreviation: IQR = interquartile range.

* Categorized by metropolitan statistical area size (large urban, more than 1 million persons; small urban, 1 million to 100,000 persons; rural, less than 100,000 persons or nonmetropolitan statistical area).

[†] Median number transferred over each simulation, assuming 10% of patients at each hospital would not be transferred for various reasons. This number is not exactly 10% of eligible patients because of random variation in bootstrapped samples.

[‡] Ranges represent the 5th and 95th percentile values over 1,000 simulations.

care (11). More recently, a multistakeholder panel of clinicians, payers, governmental agencies, and patients has directly called for development of a tiered, regionalized system of care for the critically ill (12). Although more data and analyses are needed before a strategy of regionalized care can be broadly applied, this study indicates that, in most areas, regionalization is possible and could potentially impact the survival of critically ill patients.

Independent of regionalization, the number of admissions to low-volume hospitals presents a major challenge and opportunity for efforts to improve the quality of care for critically ill patients. Quality improvement initiatives that focus on large academic centers will fail to benefit an unacceptably large number of patients. Innovative strategies to improve outcomes in this sizable population are warranted.

Many potential barriers to regionalization still must be addressed. Whether or not patients transferred from low- to high-volume hospitals will actually receive a survival benefit is unknown. Current evidence suggests that mortality during interhospital transport of critically ill patients is rare (25). However, any risk associated with interhospital transfer is likely to attenuate the potential benefits of regionalization. Transfer patients tend to experience greater than expected mortality at the accepting hospital, although this finding may be due to indication bias rather than harm associated with transport (26, 27). The mortality reduction in our simulation represents only what could be achieved, not necessarily what will be achieved, under a regionalized system. A demonstration project of formal regionalization is needed to confirm the survival benefit and address the potential for harm in transferring large numbers of critical ill patients between hospitals. In addition, the overall economic impact of regionalization is unknown. Physicians at low-volume hospitals may be reluctant to participate in a regionalized system if doing so means giving up a source of revenue and control of their patients. Similarly, administrators at low-volume hospitals may be concerned about the impact on other hospital programs that rely on critical care services, such as cardiac and cancer care. Critical care has many stakeholders with potentially competing interests, all of whom must ultimately align should regionalization prove to be an efficient way to maximize health outcomes for the critically ill.

Our study has additional limitations. We based our risk estimates on a single volume–outcome study in mechanically ventilated patients, which may not generalize to the full population (10). Other studies examining the relationship between volume and outcome in the ICU have either examined select groups of patients (16, 19), included patients who were not mechanically

ventilated (15, 17), or did not use clinical risk adjustment to account for confounding (18). Of note, one study did examine a subgroup of critically ill patients classified as “high risk” by Simplified Acute Physiology score and found a similar effect of

Figure 1. Distance to nearest high-volume hospital (276 or more patients per year) for patients at low-volume hospitals (fewer than 276 patients per year): cumulative distribution. (A) Maximal travel distance for all patients originally admitted to low-volume hospitals. (B) Maximal travel distance for patients by hospital community type. Labels indicate the total number of patients and the percentage of total moved a maximal distance of 100 miles. Large urban area = metropolitan statistical area (MSA) greater than 1 million; small urban area = MSA 100,000 to 1 million; rural area = less than 100,000 or non-MSA.

Figure 2. Additional distance patients and families would have to travel to reach a high-volume hospital (276 or more patients per year) for patients at low-volume hospitals (fewer than 276 patients per year): cumulative distribution. (A) Additional travel distance for all patients originally admitted to low-volume hospitals. (B) Additional travel distance for patients by hospital community type. Labels indicate the total number of patients and the percentage of total moved a maximal distance of 100 miles.

high-volume care (odds ratio, 0.77; $P = 0.03$) (17). By varying the risk estimates over a wide range in a sensitivity analysis, we included the possibility that regionalization could be better or worse than prior point estimates suggest. We also chose to identify regional referral centers by volume criteria rather than by risk-adjusted outcome (28). We do not know that the high-volume hospitals identified in this study are necessarily also high-performing sites. However, the population-based data sets necessary to perform this analysis do not contain data for effective risk adjustment, making it impossible to validly identify high-performing hospitals. As risk adjustment methodology improves, future efforts can be directed at integrating volume and outcome standards in investigating regionalization of critical care (29). We did not examine the costs or cost-effectiveness of regionalization; such an analysis is outside the scope of this work. Finally, we analyzed data from eight U.S. states, rather than the entire country. It may not be possible to extrapolate these findings to other states, which tend to be more rural than those in this study. However, our data set is nationally representative with a mixture of urban and rural populations, and accounts for more than two-fifths of the U.S. population. Although distance is likely to be a greater barrier to regionalization in some rural states not included in our analysis, these states typically have small populations.

For regionalization efforts to proceed, more evidence is needed that a tiered, regional hospital system would improve outcomes in the ICU. Nonetheless, our results, although based on a limited cohort of hospitals, suggest that distance and hospital census changes may not be significant barriers to regionalization of adult critical care, and that regionalization has the potential to improve survival for severely ill patients. Hospital administrators, accreditation organizations, and payers can use this information as a basis for further policy discussions into the research, design, and implementation of formal regionalized system of ICU care.

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