Relationship Between Trauma Center Volume and Outcomes

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THE PREMISE UNDERLYING REgionalization of trauma care is that optimal outcomes can be achieved at greatest efficiency if care is restricted to relatively few dedicated trauma centers. Limitation of the number of trauma centers based on community need has been proposed as a critical component of regional trauma systems and, in a recent evaluation of systems across the country, one of their most frequent deficiencies.[1,2] Implicit in this premise is that higher patient volumes will lead to greater experience and that this experience translates into better outcomes. This relationship appears to hold true for other areas of surgical care, including major oncologic, cardiac, vascular, and neurosurgical procedures.[3-7] In contrast, no such relationship is evident when less complex procedures like cholecystectomy or operative management of hip fractures are considered,[8] suggesting that the association between volume and outcomes is dependent on the complexity of care and the potential for adverse outcomes.

Care of trauma patients poses 2 challenges not encountered in other aspects of surgical care. First, time to definitive care is a critical factor influencing patient survival. The primacy of time renders an ad hoc approach to trauma

Context The premise underlying regionalization of trauma care is that larger volumes of trauma patients cared for in fewer institutions will lead to improved outcomes. However, whether a relationship exists between institutional volume and trauma outcomes remains unknown.

Objective To evaluate the association between trauma center volume and outcomes of trauma patients.

Design Retrospective cohort study.

Setting Thirty-one academic level I or level II trauma centers across the United States participating in the University Healthsystem Consortium Trauma Benchmarking Study.

Patients Consecutive patients with penetrating abdominal injury (PAI; n=478) discharged between November 1, 1997, and July 31, 1998, or with multisystem blunt trauma (minimum of head injury and lower-extremity long-bone fractures; n=541) discharged between June 1 and December 31, 1998.

Main Outcome Measures Inpatient mortality and hospital length of stay (LOS), comparing high-volume (>650 trauma admissions/y) and low-volume (≤650 admissions/y) centers.

Results After multivariate adjustment for patient characteristics and injury severity, the relative odds of death was 0.02 (95% confidence interval [CI], 0.002-0.25) for patients with PAI admitted with shock to high-volume centers compared with low-volume centers. No benefit was evident in patients without shock ($P=.50$). The adjusted odds of death in patients with multisystem blunt trauma who presented with coma to a high-volume center was 0.49 (95% CI, 0.26-0.93) vs low-volume centers. No benefit was observed in patients without coma ($P=.05$). Additionally, a shorter LOS was observed in patients with PAI and New Injury Severity Scores of 16 or higher (difference in adjusted mean LOS, 1.6 days [95% CI, −1.5 to 4.7 days]) and in all patients with multisystem blunt trauma admitted to higher-volume centers (difference in adjusted mean LOS, 3.3 days [95% CI, 0.91-5.70 days]).

Conclusions Our results indicate that a strong association exists between trauma center volume and outcomes, with significant improvements in mortality and LOS when volume exceeds 650 cases per year. These benefits are only evident in patients at high risk for adverse outcomes.

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care inappropriate, potentially increasing the magnitude of the relationship between institutional experience and outcomes. Second, polytrauma patients often require complex, cross-specialty surgical care. The necessity for interdisciplinary surgical management lessens the impact of any particular individual and increases the importance of institutional experience. These challenges suggest that a clear association between volume and outcomes should ex-

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ist. However, unlike in other aspects of surgical care, many institutions caring for trauma patients have already achieved a high level of quality by virtue of the trauma center designation and accreditation process, whereby an outside organization assesses the resources and capabilities of institutions caring for such patients.[9] In the setting in which all institutions have already met quality criteria, it is unclear whether any relationship between experience and outcome should exist. We used 2 distinct cohorts of trauma patients to evaluate whether institutional volume thresholds exist at which optimal outcomes can be achieved. These cohorts included patients with penetrating abdominal injury (PAI) and patients with multisystem blunt trauma with a minimum of a combination of head injury and lower-extremity long-bone fracture.

METHODS

Institutions and Patients

The institutions on which this analysis is based are trauma centers voluntarily participating in the University Healthsystem Consortium (UHC) Trauma Benchmarking Study. The consortium participates in a variety of projects designed to improve clinical and operating efficiencies among its member institutions by pooling resources and by means of benchmarking projects not limited to trauma.[10] Currently, the consortium consists of 84 academic medical centers and associated institutions located throughout the United States. The UHC Trauma Benchmarking Study was designed to compare outcomes and resource utilization among centers in 2 separate and homogeneous cohorts of patients, those with isolated PAI and those with a minimum of a combination of long-bone fracture and head injury (ie, multisystem blunt trauma). This analysis was limited to level I or level II trauma centers that contributed at least 10 patients to the UHC Trauma Benchmarking Study. Not all members of the UHC participated in the Trauma Benchmarking Study and not all centers contributed patients to both cohorts. Trauma

Table 1. Study Inclusion and Exclusion Criteria

Multisystem Blunt Injury	Penetrating Abdominal Injury
Inclusion Criteria	
Age >18 y	Age >12 y
Head injury (Abbreviated Injury Scale[11] score ≥2)	Penetrating abdominal injury (highest Abbreviated Injury Scale[11] score in abdominal region)
Lower-extremity long-bone fracture (tibia/femur)	
Exclusion Criteria	
No vital signs on emergency department arrival	No vital signs on emergency department arrival
Burn injury	Burn injury
Pregnancy	Pregnancy
Spinal cord injury with neurologic deficit	Abbreviated Injury Scale[11] score >2 in any other body region
Length of stay >24 h at referring institution	Length of stay >24 h at referring institution

center volume was derived from a related UHC operational database containing information on the organizational structure of each institution. Trauma center volume was reported from institutional registries and represented the total number of trauma admissions with an Injury Severity Score (ISS) of greater than 15 who were admitted during 1998. Patients with an ISS of greater than 15 are considered to have experienced major multisystem trauma. Thus, institutional volume refers to the annual number of major trauma admissions to that institution rather than the number of cases with index injuries contributed to the UHC Trauma Benchmarking Study.

Inclusion and exclusion criteria for the 2 cohorts are shown in TABLE 1. The cohorts include consecutive patients meeting inclusion criteria and discharged from participating institutions during a 7-month period between June 1, 1998, and December 31, 1998 (multisystem blunt trauma), or a 9-month period between November 1, 1997, and July 31, 1998 (PAI). Data were collected by medical record abstraction and then collated by the UHC.

Statistical Analysis

The primary outcomes were inpatient mortality and hospital length of stay (LOS). We considered the possibility that risk factors for mortality and prolonged LOS may not be similarly distributed across centers, thus confounding the effect of institutional volume on

outcome. Several such risk factors were considered, including age, sex, mechanism of injury, injury severity, shock (systolic blood pressure <90 mm Hg) on admission to the emergency department, massive blood transfusion (>6 units in the first 24 hours), admission Glasgow Coma Scale score (GCS; 3-8, 9-12, or 13-15), and whether the patient had been transferred from another institution or was transported from the scene of injury. The New Injury Severity Score (NISS), a refinement of the ISS, was used as the summary measure of anatomic injury.[12-14] To adjust for these confounding variables, we constructed logistic (for mortality) and linear (for LOS) regression models separately for both multisystem blunt trauma and PAI. In-hospital deaths were excluded from all LOS analyses. Confounding variables were chosen for inclusion in these models by using a change in estimates approach. Briefly, if the addition of a variable to the model changed the estimate of the main effect (ie, trauma center volume) by greater than 10%, then the variable was considered to be an important confounder and was kept in the model.[15] We used variance estimators that allowed for the possibility that observations within each center might be correlated. To ensure optimal model fit, we used a backward stepwise regression technique using all variables, with the predetermined confounding variables forced into the model. We also considered the possibility that the ef-
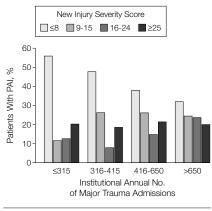
Table 2. Characteristics of Patients Admitted With Penetrating Abdominal Injury*

Characteristics	Total Major Trauma Admissions per y				P Value
	≤315	316-415	416-650	>650	
No. of institutions	5	6	6	5	
No. of patients	104	103	135	136	
Age, mean (SD), y	31 (10)	31 (11)	32 (11)	32 (11)	.77†
Male sex	87 (84)	92 (83)	112 (83)	121 (89)	.32‡
Mechanism of injury					
Firearm	51 (49)	46 (45)	78 (58)	65 (48)	.50
Stab	51 (49)	53 (51)	53 (39)	66 (49)	
Other	2 (2)	4 (4)	4 (2)	5 (4)	
Transferred from another center	27 (26)	33 (34)	23 (17)	28 (21)	.02‡
Shock§	2 (2)	4 (4)	14 (11)	16 (12)	.007‡
Massive blood transfusion‖	3 (3)	12 (12)	15 (11)	21 (16)	.02‡

*Data are No. (%) of all patients in that volume quartile unless otherwise specified.
†By analysis of variance.
‡By χ^2 test.
§Shock defined as systolic blood pressure <90 mm Hg on admission to hospital.
‖Massive blood transfusion defined as >6 units in the first 24 hours after admission.

Figure 1. Distribution of NISS Across Quartiles of Trauma Center Volume in Patients Admitted With PAI

NISS indicates New Injury Severity Score; PAI, penetrating abdominal injury.

fect of volume on outcomes may be modified by other factors. We tested interactions between markers of injury severity (shock on admission, coma on admission, and NISS) and institutional volume to determine whether the effect of volume on outcomes depended on either anatomical or physiologic injury severity. If the interaction terms were statistically significant ($P<.05$), then the results are presented by severity strata to demonstrate the effect modification. The first GCS recorded at the scene was used if data regarding GCS at the time of ad-

mission were unreliable because of intubation or pharmacologic paralysis. If field data were unavailable and the patient was intubated but not paralyzed, we imputed GCS from the motor component using an approach similar to that described by Meredith et al.[16] Patients intubated and paralyzed on admission without a GCS recorded at the scene were excluded from analysis.

Trauma center volume was first modeled as a continuous variable using the fractional polynomial method described by Royston and Altman[17] to demonstrate the relationship between volume and outcome and to help identify volume thresholds at which outcomes appear to change. This method makes no underlying assumptions regarding the relationship between volume and outcome.[18] As a result, the model is not constrained by a simple linear relationship. A significant limitation to this approach is that the comparator is limited to the lowest volume center. Thus, this approach places undue emphasis on the outcomes at a particular center. To provide a second means of assessing any association between trauma center volume and outcome, the variable representing volume was reparametrized to a binary variable such that institutions were categorized as either high- or low-volume centers. The volume threshold used for this stratification was

derived graphically from the relationship between volume and outcomes obtained by using the first approach. For mortality, this was the point at which the odds of death began to change with increasing volume. Volume thresholds for LOS were estimated graphically by identifying the inflection point on the LOS-vs-institutional volume curve. As an approximation, this was the point at which increasing volumes yielded no further changes in LOS. Analyses were conducted with Stata statistical software, release 6.0 (Stata Corp, College Station, Tex).

RESULTS
Penetrating Abdominal Injury

A total of 478 patients who met the inclusion criteria for PAI were admitted to 22 academic trauma centers (21 level I and 1 level II). Among these centers, the institutional volume of major trauma ranged from 257 to 1050 per year. There were minimal differences in admission demographics and mechanism of injury of patients with PAI across institutional volume quartiles, with approximately half of all PAI patients admitted following injury from a firearm (**TABLE 2**). There were significant differences in the proportion of patients transferred from outside centers but no clear, consistent trend across quartiles. If anything, higher-volume centers admitted fewer transfer patients than lower-volume centers. Patients with PAI who were admitted to higher-volume institutions were significantly more likely to present with shock and require massive blood transfusion within 24 hours of admission. The NISS distribution was different across quartiles; admissions to higher-volume institutions had a significantly greater proportion of patients with more severe injuries ($P=.01$ by χ^2 test) (**FIGURE 1**).

In initial analyses, there was a significant interaction between the terms for shock at admission to the emergency department and trauma center volume. There was no discernible relationship between volume and crude mortality in patients without shock, while the crude risk of death appeared

to decline with increasing volume quartiles in patients with shock (**TABLE 3**). After adjusting for NISS, age, and need for massive blood transfusion, increasing volume had no effect on mortality in patients without shock (**FIGURE 2**A). In contrast, the adjusted odds of death in patients with PAI and shock declined dramatically as trauma center volume increased (Figure 2B). When a volume threshold of 650 cases per year was used to discriminate high- vs low-volume institutions, the crude odds ratio for death in high-volume centers was 0.22 (95% confidence interval [CI], 0.05-0.91); 12 (60%) of 20 patients with shock died at low-volume centers while only 4 (25%) of 16 died at high-volume centers. The adjusted relative odds of dying was 0.02 (95% CI, 0.002-0.25) in patients with shock admitted to high-volume institutions compared with similar patients admitted to low-volume centers.

To evaluate whether there was any association between hospital LOS and institutional volume, we used a similar approach except that in-hospital deaths were excluded. Volume was first modeled as a continuous variable in a regression analysis adjusting for NISS, age, presence of shock at admission, mechanism of injury, and need for mas-

sive blood transfusion. As shown in **FIGURE 3**, a reduction in LOS with increasing trauma center volume was only evident in patients with an NISS of more than 15. Hospital LOS declined steadily until institutional volume approached 550 cases per year. At this volume threshold, the crude mean (SD) LOS in patients with an NISS of more than 15 who were admitted to high- and low-volume centers was 10.0 (7.9) and 12.3 (10.6) days, respectively. The adjusted mean LOS was 1.6 (95% CI, 4.7 to −1.5) days shorter among patients with an NISS of more than 15 who were admitted to high-volume centers.
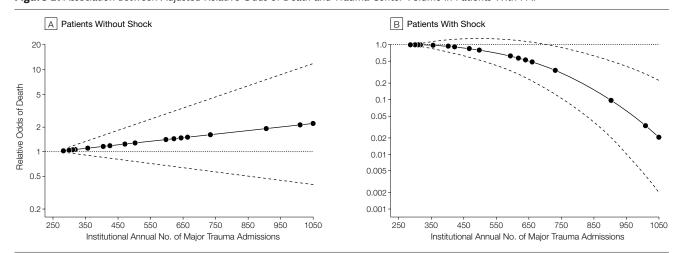
Multisystem Blunt Trauma

A total of 541 patients who met the inclusion criteria for multisystem blunt trauma were admitted to 25 academic level I trauma centers. Although only 16 of these 25 institutions contributed patients to the PAI cohort, the range of institutional volume of trauma

admissions was identical for both cohorts. There were minimal differences in age, sex, and mechanism of injury in patients admitted to centers across volume quartiles defined for the PAI cohort (**TABLE 4**). Approximately 70% of all injuries were due to motor vehicle crashes. Imputation of GCS from the motor component was required in 30 cases (5%) and 12 cases were excluded from analysis because no reliable GCS data were available. Patients admitted to higher-volume centers were similar to those admitted to lower-volume centers in most respects. There was no consistent pattern to the distribution of NISS across volume quartiles; however, these differences in distributions approached statistical significance ($P=.05$) (**FIGURE 4**). There was no consistent trend in the proportion of patients admitted following transfer from another center, although the differences across quartiles were statistically significant, with

Table 3. Crude Mortality as a Function of Trauma Center Volume in Patients With Penetrating Abdominal Injury

No. (%) of Patients	Total Major Trauma Admissions per y				P Value
	≤315	316-415	416-650	>650	
No shock	2/100 (2)	5/96 (5)	3/119 (3)	6/115 (5)	.50
Shock	0/2 (0)	3/4 (75)	9/14 (64)	4/16 (25)	.05

Figure 2. Association Between Adjusted Relative Odds of Death and Trauma Center Volume in Patients With PAI
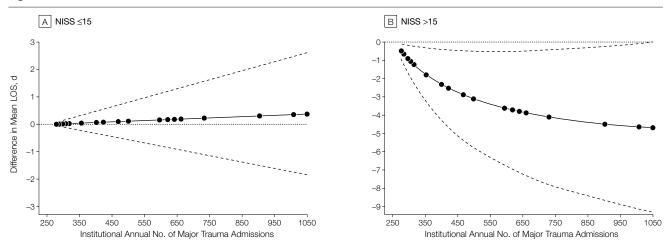

Relative odds of death compared with the lowest-volume institution are shown for patients admitted (A) without and (B) with shock. These estimates are adjusted for New Injury Severity Score, age, and need for massive blood transfusion. PAI indicates penetrating abdominal injury. Dashed lines represent 95% confidence intervals for estimated odds ratios.

Figure 3. Differences in Mean LOS for Patients Admitted With PAI as a Function of Trauma Center Volume

Data are shown for patients with (A) New Injury Severity Score (NISS) ≤15 and (B) NISS >15. The differences represent the number of days by which the mean hospital length of stay (LOS) differed using the lowest-volume institution as a baseline. These estimates are adjusted for NISS, presence of shock on admission, need for massive blood transfusion, and mechanism of injury. PAI indicates penetrating abdominal injury. Dashed lines represent 95% confidence intervals for differences in mean LOS.

Table 4. Characteristics of Patients Admitted With Multisystem Blunt Trauma*

Characteristics	Total Major Trauma Admissions per y				P Value
	≤315	316-415	416-650	>650	
No. of institutions	5	11	4	5	
No. of patients	80	233	85	143	
Age, mean (SD), y	38 (17)	42 (17)	40 (17)	42 (17)	.95†
Male sex	48 (60)	161 (69)	56 (60)	101 (71)	.37‡
Mechanism of injury					
Motor vehicle crash	60 (75)	143 (61)	69 (81)	100 (70)	.02‡
Pedestrian-motor vehicle crash	9 (11)	51 (22)	11 (13)	20 (14)	
Fall	2 (3)	16 (6)	3 (4)	11 (8)	
Other/unknown	9 (11)	23 (10)	2 (2)	12 (8.4)	
Transferred from another center	28 (35)	79 (34)	44 (52)	28 (20)	<.001‡
Shock§	11 (14)	25 (11)	8 (9)	20 (14)	.67‡
Glasgow Coma Scale score in emergency department					
3-8	23 (29)	58 (26)	15 (18)	46 (33)	.18‡
9-12	5 (6)	22 (10)	7 (8)	16 (11)	
13-15	51 (65)	143 (64)	63 (74)	79 (56)	
Massive blood transfusion‖	18 (23)	39 (17)	14 (16)	27 (19)	.67‡

*Data are No. (%) of all patients in that volume quartile unless otherwise specified.
†By analysis of variance.
‡By χ² test.
§Shock defined as systolic blood pressure <90 mm Hg on admission to emergency department.
‖Massive blood transfusion defined as >6 units in the first 24 hours after admission to emergency department.

centers in the highest-volume quartiles admitting the lowest proportion of transfer patients.

The effect of institutional trauma volume on mortality in this second cohort of patients was initially assessed by using a logistic regression model with volume as a continuous variable. There was significant interaction between the terms for coma at admission and trauma center volume. Crude mortality increased in patients without coma in higher-volume quartiles, an effect that approached statistical significance ($P=.05$), while mortality declined in increasing volume quartiles in patients with coma ($P=.02$) (**TABLE 5**). After adjusting estimates for NISS, age,

GCS, and presence of shock at admission, the adjusted odds of death was independent of institutional volume in patients without coma, although there appeared to be a trend toward increasing risk of death in the moderate-volume range (**FIGURE 5**A). In contrast, the adjusted odds of death were lower in patients with coma presenting to higher-volume institutions (Figure 5B). The volume threshold for this effect was between 650 and 750 cases per year. Using a conservative volume threshold of 650 cases per year, the crude odds ratio for death was 0.31 (95% CI, 0.14-0.68) in institutions whose volume exceeded this threshold compared with lower-volume centers; 48 (50%) of 96 patients presenting with coma died in low-volume centers while only 11 (24%) of 46 (24%) died in high-volume centers. The adjusted relative odds of death in patients admitted with coma to high- vs low-volume centers was 0.49 (95% CI, 0.26-0.93).

The relationship between institutional volume and LOS was not influenced by the degree of anatomical or physiologic injury severity in this cohort of patients. Hospital LOS adjusted for shock, sex, age, GCS, NISS, and need for massive blood transfusion as a function of trauma center vol-

ume is demonstrated in **FIGURE 6**. Hospital LOS following multisystem blunt trauma declined until institutional volume approached 600 cases per year, at which point no further reduction was evident. Crude LOS tended to be lower in centers above this threshold compared with those below, with a mean (SD) LOS of 13.4 (11.1) days in high-volume centers compared with 15.7 (15.8) days in low-volume centers. The adjusted mean LOS was 3.3 (95% CI, 0.91-5.7) days shorter in high-volume institutions.

COMMENT

This study provides strong evidence of a relationship between trauma center volume and outcome in severely injured persons with penetrating or blunt trauma. This association is only evident in the patient subgroups at highest risk of adverse outcomes. After adjusting for differences in injury severity, centers with total major trauma volume (ISS >15) in excess of 650 cases per year demonstrated measurable improvements in mortality and LOS. The relative odds of death in patients admitted with shock following PAI or coma following multisystem blunt trauma were significantly lower in high-volume centers compared with low-

volume centers. Furthermore, patients with complex or severe injuries (NISS >15) following PAI and all patients with multisystem blunt trauma tended to have a shorter LOS if admitted to a high-volume center.

The premise underlying the process of regionalization of trauma care is that the concentration of care in relatively few dedicated centers will increase institutional volume and experience, leading to improved outcome.[1,2,19] Despite its importance to trauma system development, there have been relatively few studies directly evaluating the effect of trauma center volume on outcome. In the studies that have been published, the relationship is far from clear. In 7 trauma centers in Chicago, Ill, there was a 30% reduction in mortality among patients admitted to a high-volume center, defined as more than 200 seriously injured cases per year.[20] Although these data are consistent with the data in the current study, a very crude adjustment

for differing case-mix across centers and a relatively arbitrary volume threshold hamper any definitive interpretation. Tepas et al[21] assessed the relationship between volume and mortality among pediatric patients admitted to 37 trauma

Figure 4. Distribution of New Injury Severity Score (NISS) Across Quartiles of Trauma Center Volume in Patients Admitted With Multisystem Blunt Trauma
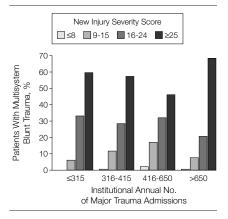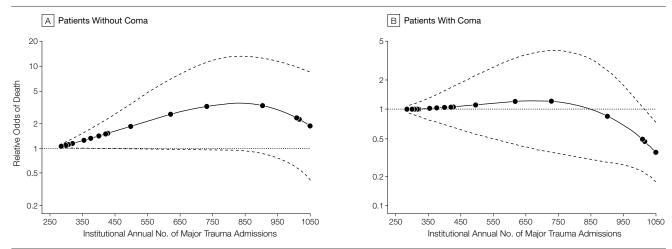

Table 5. Crude Mortality as a Function of Trauma Center Volume in Patients With Multisystem Blunt Trauma Injury

| No. (%) of Patients | Total Major Trauma Admissions per y | | | | P Value |
	≤315	316-415	416-650	>650	
No coma	1/56 (2)	7/163 (4)	4/70 (6)	11/94 (12)	.05
Coma	13/23 (57)	29/58 (50)	6/15 (40)	11/46 (24)	.02

Figure 5. Association Between Adjusted Relative Odds of Death and Trauma Center Volume in Patients Admitted With Multisystem Blunt Trauma
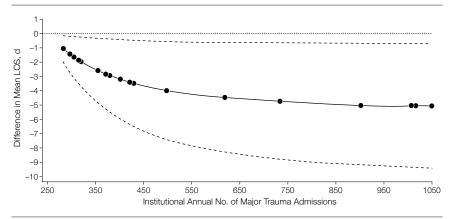

Relative odds of death compared with the lowest-volume institution are shown for patients (A) without and (B) with coma. These estimates are adjusted for New Injury Severity Score, age, Glasgow Coma Scale score, and presence of shock on admission. Dashed lines represent 95% confidence intervals for estimated odds ratios.

Figure 6. Differences in Mean LOS for Patients Admitted With Multisystem Blunt Trauma as a Function of Trauma Center Volume

The differences represent the number of days by which the mean hospital length of stay (LOS) differs using the lowest-volume institution as a baseline. These estimates are adjusted for New Injury Severity Score, age, sex, Glasgow Coma Scale score, need for massive blood transfusion, and presence of shock on admission. Dashed lines represent 95% confidence intervals for differences in mean LOS.

centers participating in the National Pediatric Trauma Registry. In this analysis, risk-adjusted mortality was lowest in the moderate-volume centers. The authors postulated that higher-volume centers functioned at a lower level because of an overwhelming number of admissions with minimal trauma. Finally, there appeared to be no association between trauma center volume and outcomes following an evaluation of trauma centers in Pennsylvania.[22] However, using a survival probability model, these authors demonstrated normative outcomes when individual surgeon volumes approached 35 seriously injured patients per year. Based on these studies and empirical data, the American College of Surgeons Committee on Trauma recommends that level I trauma centers admit a minimum of 1200 trauma patients annually, of which 20% should have an ISS of more than 15. Alternatively, volume per surgeon should exceed 35 patients per year with an ISS of more than 15.[9] However, Cooper et al,[23] in an evaluation of trauma center volume and outcomes in New York State, could not demonstrate any association between this and other volume thresholds and mortality. Unfortunately, the largest-volume center in that study admitted approximately 350 patients per year with an ISS of more than 15, a far lower number than that of most of the centers participating in the current analysis.

The current study offers several methodological strengths and improvements in design compared with prior reports. By first modeling volume as a continuous variable, we avoided the use of arbitrary volume thresholds to categorize trauma centers into volume quartiles. This approach provides an estimate of the relative difference in outcome at any particular volume compared with the lowest-volume center and suggests appropriate volume thresholds for further analysis. In addition, we controlled for differences in injury severity and patient demographics across centers, thus mitigating the effects of potentially confounding variables. We also considered the possibility that the effect of volume on outcomes may relate to the severity of injury. In fact, there is no a priori reason to believe that patients with minimal trauma in whom mortality risk approaches zero would demonstrate a mortality benefit from the resources of a high-volume level I trauma center. The geographic diversity of institutions studied in this analysis provides an additional benefit. Other studies comparing institutions within the same geographic locale may confound the relationship between volume and outcomes in the form of selective referral bias, in which volumes increase at a given center because of improved outcomes, rather than the converse. Due to the urgent nature of trauma care, referrals and transfers across regions from one level I trauma center to another are extraordinarily rare. As a result, the volume of any particular center in this analysis is not higher than the volume in any other because of superior outcomes, because these centers are not competing for the same pool of patients. Finally, the relative consistency in the volume threshold using 2 different (albeit homogeneous) cohorts provides compelling evidence that patients admitted to institutions above this threshold do achieve a mortality benefit from this level of experience.

There are several significant limitations to this study. As volunteer participants in the UHC Trauma Benchmarking Study, all of the centers function as level I or level II academic trauma centers, with a full complement of surgical residents and an active teaching program. Furthermore, because of their participation in the UHC Benchmarking Study, these centers are committed to quality improvement. For these reasons, their performance may exceed those of other trauma centers not participating in the study. Similarly, all of the institutions have reached a predetermined level of quality by virtue of being designated by either the American College of Surgeons or regional authorities. As a result, the volume thresholds reported here might be higher than previously reported to demonstrate benefit in addition to what might already be considered optimal care. Nevertheless, an association between experience and outcomes appears to exist even at this level of quality.

The potential for poor interinstitutional reliability in coding injury severity may represent an additional limitation to this analysis. This phenomenon could have important effects on our ability to adjust for risk differences across centers and might account for the vary-

ing effects of institutional volume on mortality in patients without coma. The GCS is one of the most important predictors of mortality in blunt trauma patients. Unfortunately, it is also the least reliable, particularly in patients who are intubated or paralyzed.[24] It is possible that lower-volume institutions tend to underestimate GCS in patients with minor head injuries. Alternatively, lower-volume institutions may have better outcomes for patients with minor head injuries, an effect due to a lesser demand on resources; however, the downward trend in the highest-volume institutions argues against this possibility.

Additionally, patients were excluded from their respective cohorts if they had no vital signs at admission to the emergency department. The state of presentation may be altered by prehospital care such that a patient whose death is attributed to the care of one center may be considered dead on arrival at another, excluding them from inclusion in the evaluable cohort. Finally, it is possible that patients traveling long distances to receive definitive care at a high-volume center may

die en route and, thus, will not be considered a death attributable to these centers while those who survive are self-selected, having already survived a prolonged period of prehospital care. These biases may be problematic if they relate to trauma center volume. The extent to which this may impact our results cannot be assessed given the data available.

In summary, these data provide further support emphasizing the importance of regionalization of trauma care and provide guidelines for estimating the number of trauma centers per unit population. The volume threshold of approximately 650 cases per year with an ISS of more than 15 may be difficult to attain in all but a few large metropolitan areas. In this study, only 6 (20%) of 31 level I or level II trauma centers exceeded this threshold. Although these volumes may not be attainable in most centers, these data support the hypothesis that greater experience leads to better outcomes. Trauma care systems should ensure triage of the most severely injured patients to relatively few dedicated trauma centers.

Consideration should be given to consolidation of urban trauma programs to maximize institutional volume. Further work is needed to identify differences in process of care, the impact of individual surgeon volume, the role of fellowship training programs, trauma research activities, and other factors that may contribute to the observed outcome benefit at high-volume trauma centers.

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