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Impact of trauma center volume on major vascular injury: An analysis of the National Trauma Data Bank (NTDB)

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ABSTRACT

Background: The association of procedure volume and improved outcomes has been established with infrequently performed elective operations. However, effect of trauma center volume on outcomes in emergency surgery has not been defined. We hypothesized that high volume centers (HVC) would provide better outcomes for operative major vascular injuries (MVI) than low volume centers (LVC).
Methods: The NTDB was queried from 2010 to 2014. Patients with MVI were identified and HVC were compared to LVC. HVC were defined as >480 patients per year with ISS≥15.
Results: There were 37,125 patients with MVI, with 16,461 (44.3%) managed operatively. Of these, 15,965 (97%) underwent surgery at HVC and 496 (3%) at LVC. There was no difference in shunt utilization, however, HVC were more likely to utilize endovascular repair (31.0% vs. 21.9%, p < 0.001). Rates of death, amputation, and compartment syndrome were similar. HVC were more likely to develop pneumonia or sepsis. On logistic regression, HVC was not associated with survival (OR: 0.90, 95%CI: 0.60–1.34, p = 0.60). Variables associated with mortality for HVC and LVC included thoracic arterial injury (OR: 1.57, 95%CI: 1.27–1.94, p < 0.001), penetrating mechanism (OR:1.84, 95%CI: 1.57–2.15, p < 0.001), and open repair (OR: 1.95, 95%CI: 1.69–2.26, p < 0.001). Lower ISS (OR: 0.29, 95%CI: 0.24–0.34, p < 0.001) and higher presenting blood pressure (OR: 0.99, 95%CI: 0.99–1.00, p < 0.001) were associated with survival.
Conclusions: Although LVC may have less proficiency with endovascular techniques, trauma center volume does not influence survival in emergency surgery for MVI.

Background

Major vascular injuries represent a small percentage of traumatic injuries; however, vascular trauma is associated with significant morbidity and mortality.[1,2] The risk of mortality is increased if vascular trauma is present in the setting of concomitant injuries.[2] Several studies have demonstrated that high procedure volume is associated with better outcomes in infrequently performed operations.[3,4] These studies have been done almost exclusively in elective operations such as pancreaticoduodenectomy, pneumonectomy, and thyroidectomy.[3–6] Traumatic injuries often require emergent operations, where referral or transfer to a high volume center is not possible. While a prior study has shown that high procedural volume for emergency department thoracotomy results in improved outcomes,[7] how trauma center volume affects outcomes in emergency surgery for major traumatic injury has not been established.

High hospital and individual surgeon volume is associated with better outcomes for elective vascular surgery.[8,9] However, how trauma center volume affects outcomes after major vascular injury requiring surgery is unknown. We hypothesized that high volume trauma centers (HVC) would provide better outcomes for operative major vascular injuries (MVI) as compared to low volume trauma centers (LVC).

Methods

The National Trauma Data Bank (NTDB) of the American College of Surgeons (ACS) was queried for patients admitted from 2010 to

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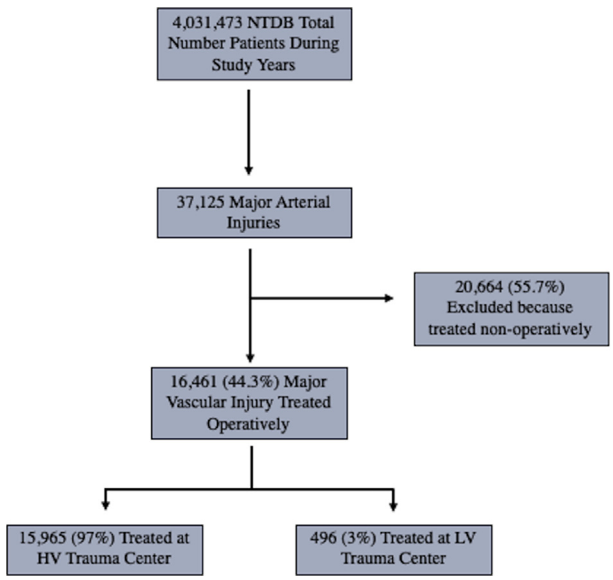

Fig. 1. PRISMA flow diagram showing patients included in the study.

2014. All data provided by the NTDB are deidentified and subject to quality screening. Patients with major vascular injuries were identified by International Classification (ICD-9-CM) codes D900-904 as established in prior studies[10] and those that had arterial injuries were identified as shown in the PRISMA flow diagram in Fig. 1. Patients treated non-operatively were excluded from the analysis.[10] High volume centers were defined as those with ≥480 trauma patients per year with an injury severity score (ISS) ≥ 15 as established in prior studies.[11] Those with <480 patients per year with ISS ≥15 were defined as low volume. Subset analysis was carried out defining high volume centers as > 20 operations for major vascular injury per year as previous studies have shown that hospital volume of 20 cases or less results in worse outcomes for vascular surgery.[12] Exploratory analysis was carried out using the number of patients per year with an injury severity score ≥15 and the number of operations for major vascular injury per year. These counts were used in logistic regressions to determine if either index of hospital size was particularly predictive of mortality.

Data examined included baseline patient characteristics such as age, gender, pay status, facility description, injury mechanism, presenting systolic blood pressure (SBP), Glasgow Coma Scale (GCS), injury severity score (ISS), associated injuries, and operative interventions. Primary outcome measured included in hospital mortality. Secondary outcomes included length of stay, intensive care unit (ICU) length of stay, discharge disposition, and in-hospital complications. In hospital complications included need for amputation, compartment syndrome, pneumonia, acute respiratory distress syndrome (ARDS), sepsis, and surgical site infection as established in prior studies.[10,13]

Statistical analysis

All data analyses were performed using SPSS Version 25 (Armonk, NY: IBM Corp). Student's t-test and Mann Whitney *U* test

Table 1
Baseline patient characteristics.

	High Volume Trauma Center N = 15,513, (%)	Low Volume Trauma Center N = 474, (%)	P-value
Demographics			
Median Age, years (IQR)	33 (24.00, 49.00)	34 (25.00, 50.00)	.38
Female	2855 (18.4)	93 (19.6)	.50
Male	12,658 (81.6)	381 (80.4)	.50
Primary Payment			
Medicaid	2572 (18.1)	54 (12.2)	.002
Medicare	1076 (7.6)	46 (10.4)	.002
Other	1492 (10.5)	61 (13.8)	.002
Private/Commercial Insurance	5238 (33.8)	161 (36.5)	.002
Self-Pay	3831 (27.0)	119 (27.0)	.002
Teaching Status			
University	9293 (59.9)	110 (23.2)	<0.001
Community	5019 (32.3)	229 (48.2)	<0.001
Non-teaching	1208 (7.8)	136 (28.6)	<0.001
ACS Level Verification			
ACS level I	6606 (42.6)	7 (1.5)	<0.001
ACS level II	2805 (50.4)	153 (32.2)	<0.001
ACS level III	67 (0.4)	32 (6.7)	<0.001
ACS level IV	0 (0)	3 (0.6)	<0.001
Unknown	6042 (38.9)	280 (58.9)	<0.001
Injury Type			
Penetrating	7826 (50.4)	230 (48.4)	.62
Blunt	7694 (49.6)	245 (51.6)	.62
Other Data			
+ETOH (Above Legal Limit)	2687 (17.3)	91 (19.2)	.16
+Drug screen	3168 (20.4)	84 (17.7)	.08
Median Systolic Blood Pressure	120 (98,140)	121 (98,139)	.28
Median Pulse Rate	100 (83,120)	94 (79,114)	<.001
GCS, mean ± SD	12.7 ± 4.3	13.5 ± 3.6	<0.001
Injury Severity Score > 15	8940 (56.0%)	206 (41.5%)	<0.001
Associated Injuries			
Traumatic Brain Injury	1649 (10.6)	24 (5.1)	<.001
Head and Neck	1148 (7.4)	17 (3.6)	<.001
Thorax	2731 (17.6)	64 (13.5)	<.001
Abdomen/Pelvis	3613 (23.3)	95 (20.0)	<.001
Upper Extremity	3177 (20.5)	125 (26.3)	<.001
Lower Extremity	4851 (31.3)	174 (36.6)	<.001

was used to evaluate continuous variables. Chi-squared analysis was used to evaluate categorical variables. Multiple variable logistic regression was used to identify factors independently associated with mortality. A p-value less than 0.05 was considered significant. All continuous variables are reported as mean ± standard deviation or median.

Results

As shown in Fig. 1, there were 4,031,473 patients in the NTDB during the study period with 37,125 having major vascular injuries. 20,664 (55.7%) excluded because they were treated without surgery. There were 16,461 (44.3%) patients treated operatively. Of these, 15,965 (97%) underwent surgery at HVC and 496 (3%) at LVC.

Baseline patient characteristics

Baseline patient characteristics are shown in Table 1. Patients treated at HVC and LVC were not different with respect to age, gender, mechanism of injury, or presenting systolic blood pressure. Patients treated at HVC were more likely to have Medicaid (18.1% vs. 12.2%) and less likely to have Medicare (7.6% vs. 10.4%) or private/commercial insurance (33.8% vs. 36.5%); $p = 0.002$. HVC were more likely to be a university hospital (59.9% vs. 23.2%) and less likely to be a community (32.3% vs. 48.2%) or non-teaching hospital (7.8% vs. 28.6%); $p < 0.001$. HVC were more likely to have ACS Level I (42.6% vs. 1.5%) or II (50.4% vs. 32.2%) verification; $p < 0.001$. Presenting pulse rate (100 vs. 94, $p < 0.001$) and Glasgow Coma Scale (12.7 vs. 13.5, $p < 0.001$) were worse in the HVC group. The HVC group had a higher proportion of patients with ISS greater than or equal to 15 (56.0% vs. 41.5%, $p < 0.001$). Distribution of additional concomitant injuries was also different when comparing the two groups. HVC were more likely to have associated traumatic brain injury (10.6% vs. 5.1%), head and neck injury (7.4% vs. 3.6%), thoracic injuries (17.6% vs. 13.5%), abdomen/pelvic injury (23.3% vs. 20.0%); $p < 0.001$. LVC were more likely to have associated upper (20.5% vs. 26.3%) and lower extremity (31.3% vs. 36.6%) injuries; $p < 0.001$.

Anatomic location of major vascular injury

The distribution of anatomical location of major vascular injuries is shown in Table 2. HVC were more likely to treat patients with all types of carotid injuries; $p < 0.001$. Thoracic (13.5% vs. 10.3%) and abdominal aortic (3.4% vs. 2.7%) injuries were more common in HVC; $p < 0.001$. LVC were more likely to treat axillary (3.5% vs. 4.6%), brachial (16.4% vs. 19.8%), and popiliteal (10.5% vs. 15.8%) artery injuries.

Type of repair by center

As shown in Table 3, HVC were more likely to utilize endovascular repair for major vascular injuries (31.0% vs. 21.9%, $p < 0.001$). When looking at endovascular repair for major vascular injury by anatomic location, HVC were more likely to utilize endovascular repair for abdomen/pelvic vascular injuries (49.8% vs. 38.9%, $p = 0.048$). Use of endovascular repair was not different when comparing HVC and LVC for all other anatomical locations. As shown in Fig. 2, utilization of endovascular repair increased significantly ($p = 0.04$) over the study period for HVC, but not for LVC ($p = 0.45$). Similarly, shunt utilization increased over time in HVC ($p < 0.001$), but not for LVC ($p = 0.26$) as shown in Fig. 3.

Table 2
Anatomic distribution of major arterial injuries.

	High Volume Center N = 15,520 (%)	Low Volume Center N = 675 (%)	P-value
Head/neck			
Internal carotid artery	487 (3.1)	6 (1.3)	<.001
Common carotid artery	374 (2.4)	6 (1.1)	<.001
External carotid artery	287 (1.8)	5 (1.1)	<.001
Thorax			
Thoracic Aorta	2099 (13.5)	49 (10.3)	<.001
Subclavian/brachiocephalic arteries	491 (3.2)	10 (2.1)	<.001
Pulmonary artery	141 (0.9)	5 (1.1)	<.001
Abdomen/pelvis			
Abdominal aorta	525 (3.4)	13 (2.7)	<.001
Celiac/mesenteric arteries	197 (1.3)	12 (2.5)	<.001
Gastric Artery	226 (1.5)	11 (2.3)	<.001
Hepatic Artery	263 (1.7)	5 (1.1)	<.001
Splenic Artery	237 (1.5)	6 (1.3)	<.001
Other specified branches of celiac artery	4 (0.0)	1 (0.2)	<.001
Superior Mesenteric Artery	181 (1.2)	5 (1.1)	<.001
Primary Branches of SMA	77 (0.5)	0 (0.0)	<.001
Inferior Mesenteric Artery	38 (0.2)	1 (0.2)	<.001
Other Celiac or Mesenteric Artery	45 (0.3)	0 (0.0)	<.001
Renal Artery	276 (1.8)	6 (1.3)	<.001
Hypogastric Artery	105 (0.7)	5 (1.1)	<.001
Iliac Artery	1439 (9.3)	30 (6.3)	<.001
Upper Extremity			
Axillary artery	536 (3.5)	22 (4.6)	<.001
Brachial Artery	2550 (16.4)	94 (19.8)	<.001
Palmar Artery	91 (0.6)	9 (1.9)	<.001
Lower Extremity			
Common Femoral Artery	786 (5.1)	21 (4.4)	<.001
Superficial Femoral Artery	1802 (11.6)	55 (11.6)	<.001
Popliteal Artery	1631 (10.5)	75 (15.8)	<.001
Anterior Tibial Artery	309 (2.0)	8 (1.7)	<.001
Posterior Tibial Artery	323 (2.1)	15 (3.2)	<.001

Table 3
Utilization of endovascular repair by anatomical location of injury.

	High Volume Center N = 15,520 (%)	Low Volume Center N = 475 (%)	P Value
Location of Arterial Injury			
Head/Neck	507 (44.2)	5 (29.4)	0.33
Thorax	1749 (64.0)	39 (60.9)	0.71
Abdomen/pelvis	1798 (49.8)	37 (38.9)	0.048
Upper Extremity	217 (6.8)	8 (0.1)	0.84
Lower Extremity	546 (11.3)	15 (8.6)	0.28
Total	4817 (31.0)	104 (21.9)	<0.001

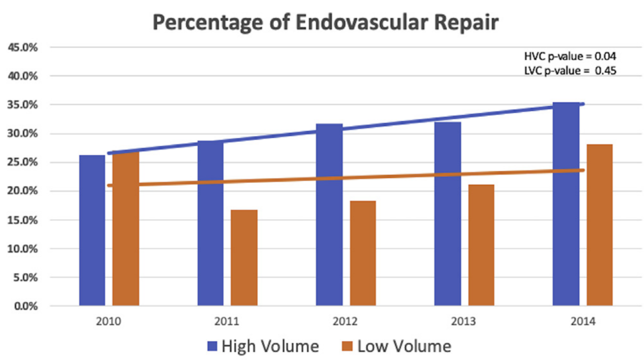

Fig. 2. Percentage of endovascular repair over time.

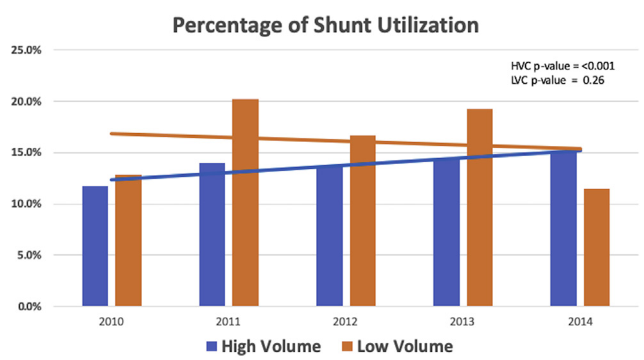

Fig. 3. Percentage of shunt utilization over time.

Post-operative complications/disposition

A comparison of in-hospital outcomes between HVC and LVC are shown in Table 4. HVC had higher median days on a ventilator (1.0 vs. 0.0 days), longer ICU length of stay (3.0 vs. 2.0 days), and longer hospital length of stay (9.0 vs. 7.0 days); $p < 0.001$. HVC had higher incidence of ARDS (5.1% vs. 1.3%; $p < 0.01$) and pneumonia (9.3% vs. 4.6%; $p = 0.001$). The incidence of sepsis, surgical site infection, compartment syndrome, and extremity amputation was not significantly different between HVC and LVC.

Disposition

As shown in Table 5, patients from HVC were more likely to be discharged to rehab or long-term facilities (15.9% vs. 12.6%, $p = 0.004$) or skilled nursing facilities (6.4% vs. 4.1%, $p = 0.04$). LVC were more likely to discharge patients to home (59.0% vs. 64.7, $p = 0.04$).

Mortality

As shown in Table 6, mortality rate was higher in the HVC group (11.5% vs. 8.8%; $p = 0.004$). On multiple variable analysis, being at a HVC was not associated with survival (OR: 0.93, 95%CI: 0.62–1.38, $p = 0.71$). Variables associated with survival including higher presenting systolic blood pressure, utilization of endovascular repair, and upper extremity, or lower extremity vascular injury. Variables associated with mortality included increasing age, worsening injury severity score, penetrating mechanism of injury, and thoracic vascular injury.

Discussion

Prior studies have shown that infrequently performed, elective operations carried out at high volume institutions have better outcomes. However, how institutional procedural volume affects outcomes in emergent procedures has yet to be established. Major, traumatic vascular injuries generally require emergent operative intervention. In this study, the effect of trauma center volume on surgical outcomes after repair of major vascular injury was examined.

This study determined that HVC may not have better outcomes than LVC after major vascular repair. One potential explanation is that while traumatic vascular injuries may be rare, vascular procedures are performed frequently throughout the United States, which may render even smaller, low volume trauma centers to be equally as proficient in traumatic vascular repairs. While one study in 2009 predicted a shortage of vascular surgeons,[14] whether this shortage has actually occurred in present day has yet to be established. In addition, how a nationwide shortage of vascular surgeons may affect verified trauma centers where vascular expertise may be abundant, has not been established. Another potential explanation for our findings, is that the number of trauma patients with ISS 15 or greater is not a good measure of volume for repair of major traumatic vascular injury. For this reason, we examined whether the number of vascular repairs per year by trauma center correlated with better outcomes. We found that increased volume of operative vascular procedures did not result in better survival.

While survival was not different, technique of vascular repair was different in HVC as compared to LVC. Over the study period, HVC had a significant increase in percentage of patients undergoing endovascular repairs. By 2014, over 35% of major vascular repairs were done endovascularly at HVC. This mirrors the nationwide trend in vascular surgery, as the emergence of endovascular technology has resulted in more minimally invasive repairs and less open surgeries.[15–17] Increasing use of endovascular repair in the trauma population over time has been corroborated in prior studies.[10] This suggests that HVC may be more proficient in endovascular repair techniques than LVC. Use of endovascular repair was associated with survival in this study and in prior studies.[10,18,19] This highlights the importance of adopting endovascular techniques in trauma surgery and stresses that further studies are needed to examine the barriers that exist for endovascular surgery in LVC. One metric not tracked in the NTDB is the number of endovascular repairs that are converted to open. How HVC and LVC compare to each other in conversion to open surgery is unknown and needs further investigation.

Interestingly, shunts were increasingly employed at HVC over the study period, while LVC had no difference in shunt utilization over time. Shunts are a useful adjunct in damage control operations and their use has become more accepted in recent years.[20,21] Patients at HVC were more severely injured than those at LVC and the reason for this finding could simply be a higher number of damage control operations at HVC. In addition, greater use of shunts may

Table 4
Comparison of in hospital outcomes.

	High Volume Center N = 15,520 (%)	Low Volume Center N = 475 (%)	P Value
Days on Ventilator, median (IQR)	1.0 (1.0,8.0)	0.0 (0.0,1.0)	<.001
ICU LOS, median (IQR)	3.0 (0.0,4.0)	2.0 (0.0,4.0)	<.001
Hospital LOS, median (IQR)	9.0 (4.0,19.0)	7.0 (3.0,14.0)	<.001
Expired	1767 (11.5)	41 (8.8)	.004
Complications			
ARDS	786 (5.1)	6 (1.3)	<.001
Pneumonia	1436 (9.3)	22 (4.6)	.001
Sepsis	379 (2.4)	5 (1.1)	.07
Surgical Site Infection	674 (4.3)	13 (2.7)	.11
Compartment Syndrome	836 (5.4)	23 (4.8)	.68
Extremity Amputation	718 (4.6)	14 (2.9)	.11

Table 5
Comparison of disposition.

	High Volume Center N = 15,357 (%)	Low Volume Center N = 467 (%)	P Value
Rehab or Long Term Facility	2435 (15.9)	59 (12.6)	.004
Skilled Nursing Facility	988 (6.4)	19 (4.1)	.004
Home	9056 (59.0)	302 (64.7)	.004
Hospice Care	35 (0.2)	0 (0.0)	.004
Intermediate or Short-term Hospital	973 (6.3)	43 (9.2)	.004
Against Medical Advice or Discontinued Care	103 (0.7)	3 (0.6)	.004
Expired	1767 (11.5)	41 (8.8)	.004

Table 6
Multivariate logistic regression for variables associated with mortality.

	Odds Ratio	95% Confidence Interval	p Value
High Volume Trauma Center	0.93	0.62–1.38	0.71
Age	1.02	1.02–1.03	<0.001
Systolic Blood Pressure	0.99	0.99–1.00	<0.001
Endovascular Repair	0.51	0.44–0.59	<0.001
Injury Severity Score 0–8	Reference	Reference	Reference
Injury Severity Score 9–15	2.94	1.53–5.78	0.001
Injury Severity Score 16–24	9.19	4.81–17.56	<0.001
Injury Severity Score 25–49	24.61	12.91–48.94	<0.001
Injury Severity Score 50–75	85.60	44.07–166.28	<0.001
Penetrating Mechanism	2.44	2.11–2.83	<0.001
Abdominal/Pelvic Vascular Injury	Reference	Reference	Reference
Head and Neck Vascular Injury	0.91	0.72–1.15	0.43
Thoracic Vascular Injury	1.59	1.28–1.98	<0.001
Upper Extremity Vascular Injury	0.43	0.31–0.60	<0.001
Lower Extremity Vascular Injury	0.55	0.42–0.71	<0.001

reflect higher complexity of repair. Whether increased usage of shunts in HVC reflects greater proficiency with damage control surgery or greater complexity of repair cannot be determined from this study and needs further investigation.

Morbidity for patients treated in HVC was found to be higher than those at LVC. HVC had a higher rate of respiratory complications, including ARDS and pneumonia. In addition, HVC had longer ventilation days, total hospital length of stay, and ICU length of stay. Patients at HVC were less likely to be discharged home and more likely to be discharged to a rehab facility. This likely reflects that patients at HVC were more injured as demonstrated by their higher ISS.

This study was not without limitations, including those related to retrospective analysis of large, administrative databases. Such large data sets rely on accurate reporting and coding. While we cannot confirm that the data is devoid of coding errors, any such errors are likely random and unlikely to create bias with such a large sample size. Because we studied a cohort of operations at low volume centers, by nature of design, the number of operations in LVC is much lower than those in HVC. However, the total number of patients in the LVC cohort (n = 496) still provides for adequate statistical analysis. In addition, the types of vascular injuries in the two cohorts are significantly different as shown in Table 2. For this reason, we controlled for anatomical injury in the multiple variable analysis to control for these factors. Data on procedures is limited to ICD-9-CM procedure codes, which limits our ability to determine specifics on endovascular procedures. In addition, information on mortality is limited to the initial hospitalization, which prevents any long-term survival analysis.

In conclusion, trauma center volume may not influence survival for emergency surgery due to major vascular injury. However, HVC may be more proficient in endovascular techniques and use of temporary shunts. Endovascular repair may result in improved survival as compared to open technique.

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Declaration of competing interest

The authors have no conflicts of interest to report.

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