Blunt Thoracic Aortic Injury: Endovascular Repair Is Now the Standard

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BACKGROUND: Incidence and treatment of blunt thoracic aortic injury (BTAI) has evolved, likely from improved imaging and emergence of endovascular techniques; however, multicenter data demonstrating this are lacking. We examined trends in incidence, management, and outcomes in BTAI.

STUDY DESIGN: The American College of Surgeons National Trauma Databank (2003 to 2013) was used to identify adults with BTAI. Management was categorized as nonoperative repair, open aortic repair (OAR), or thoracic endovascular repair (TEVAR). Outcomes included demographics, management, and outcomes.

RESULTS: There were 3,774 patients. Median age was 46.0 years (interquartile range [IQR] 29.3, 62.0 years), with 70.8% males, and median Injury Severity Score (ISS) of 34.0 (IQR 26.0, 45.0). The number of BTAIs diagnosed over the decade increased 196.8% ($p < 0.001$), median ISS decreased from 38 to 33 ($p < 0.001$), and significantly more patients were treated at a level I trauma center ($p < 0.001$). After FDA approval of TEVAR devices, there was a significant increase in endovascular repair overall (1.0% to 30.6%, $p < 0.001$) and in those treated operatively (0.0% to 94.9%, $p < 0.001$), with a marked decrease in OAR. Use of TEVAR was associated with significantly reduced median ICU LOS (9.0 vs 12.0 days, $p = 0.048$) and mortality (9.3% vs 16.6%; $p = 0.015$) compared with OAR. In modern BTAI care, TEVAR has nearly completely replaced OAR.

CONCLUSIONS: The diagnosis of BTAI has increased, likely due to more sensitive imaging. Nearly 70% of patients get nonoperative care. Treatment with TEVAR improves outcomes relative to OAR. Part of the proportional increase in TEVAR use may represent overtreatment of lower grade BTAI amenable to medical management, and warrants further investigation. (J Am Coll Surg 2019;228:605–612. © 2019 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

Blunt thoracic aortic injury (BTAI) presents in markedly different ways, ranging from asymptomatic intimal tears to devastating uncontained aortic rupture.[1] The management of patients who survive to hospital admission has been revolutionized in the last 2 decades by the availability of CT for diagnosis, and the use of thoracic endovascular aortic repair (TEVAR).[2]

The use of TEVAR for the treatment of BTI was first described in 1997 using custom devices.[3] The Food and Drug Administration (FDA) approved these devices in 2005, and they are now available in multiple sizes. Therefore, TEVAR has become the most common method used to repair injured aortas.[4-6] Several issues remain unanswered, and there has never been a prospective, randomized trial of the various options for repair of BTAI.

As TEVAR has become established in surgical practice, how trends in its use have evolved is still unknown. The aim of this study was to use a national level, population-weighted dataset to characterize the temporal trends in TEVAR use and the mortality associated with

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Abbreviations and Acronyms

AIS = Abbreviated Injury Scale
BTAI = blunt thoracic aortic injury
IQR = interquartile range
ISS = Injury Severity Score
NSP = National Sample Program
NTDB = National Trauma Data Bank
OAR = open aortic repair
RDS = Research Dataset
TEVAR = thoracic endovascular aortic repair

it. We sought to compare results of TEVAR against those of open repair (OAR).

METHODS

The study used the dataset from the National Trauma Data Bank's (NTDB) National Sample Program (NSP). Because the data are anonymous and available to academic institutions, it is not considered protected health information. As such, institutional review board approval is not necessary. The NSP is a subset of the NTDB containing only data from a "probabilistic sample" of trauma centers. Because data submission is voluntary, the weighted NSP is designed to reflect the profile of care provided across the country.

Inclusion criteria

The dataset was queried for all patients 18 years and older who sustained a BTAI between 2003 and 2013. Blunt traumatic aortic injury was identified using AIS codes (4202XXX) and ICD-9 codes (901 and 441.XX). The data contained basic demographics such as age, sex, year of admissions, and clinical data that included vital signs on admission, Injury Severity Score (ISS), and regional Abbreviated Injury Scale (AIS). Patients were divided into 1 of 3 treatment groups: no intervention, TEVAR, or OAR. Interventions were identified using ICD-9 procedural codes (38.45 and 39.73).

Statistical analysis

All data were analyzed using R, Version 3.5.0. Categorical variables were expressed as absolute numbers and percentages of the total. Continuous variables were expressed as mean and standard deviation when parametric, and as median and interquartile range when nonparametric. Kolmogorov-Smirnov test was used to test for normality.

Chi-square was used for hypothesis testing for categorical variables. When comparing continuous variables, the Student *t*-test (2-group comparison) and ANOVA (multiple-group comparison) were used for parametric variables and Wilcoxon signed rank test (2-group comparison) and Kruskal-Wallis test (multiple-group comparison) for nonparametric variables. In order to evaluate the significance of change over the study period, the chi-square test was used for linear trends, testing against a hypothesis of a zero slope in a linear regression of proportions.

In order to assess the use trend of TEVAR, the relative rate was calculated using the intervention rate of the first 2 years of the study as the baseline and compared across the subsequent years. To account for changes in the epidemiology of the populations, the dataset was standardized for key variables identified to have changed significantly across the study period. This permitted calculation of the relative rate (95% CI) of TEVAR per year, controlling for incidence and measured confounders.

Finally, in order to compare the mortality of TEVAR vs OAR, a propensity score was developed, based on a multivariate analysis of pre-treatment variables. This enabled the development of comparable patients from either cohort, permitting a balanced comparison. A nearest neighbor propensity score, with a 1:1 matching technique was used.

RESULTS

Overall cohort

Over the 11-year study, 3,774 patients met inclusion criteria. Most patients were male (70.8%), with a median age of 46 years. Hypotension (systolic blood pressure under 90 mm Hg) was present in 27.5% of patients. Coma (Glasgow Coma Scale < 8) was present in 41.1%, and there was severe thoracic injury (AIS ≥ 3) in 94% of patients. A significant number of patients also presented with a severe associated injury to the head (32.5%), abdomen (28.2%), and/or lower extremities (35.8%). The median ISS was 34.0 (IQR 26.0, 45). These findings are summarized in Table 1.

Temporal trends

Over the study period, there was a slight increase in median patient age, from 41 to 45 years, and a decrease in the median ISS, from 38 to 33 (Table 2). Patients were also cared for more frequently at level I (from 38% to 55.5%) rather than level II (26.9% to 13.9%) trauma centers as time progressed.

There was a marked increase in the number of BTAIs diagnosed during the study period (Table 3). Overall, 70% of the BTAIs diagnosed were treated nonoperatively. The rate of intervention, however, rose from 12.5% in 2003 to 32.2% in 2013 ($p < 0.001$). After 2005, when

Table 1. Overall Population Characteristics

Characteristic	Overall (n = 3,774)
Age, y, median (IQR)	46.00 (29.25, 62.00)
Male, n (%)	2,673 (70.8)
Hypotension, n (%)	1,006 (27.5)
Coma, n (%)	1,498 (41.1)
Head AIS ≥ 3, n (%)	1,225 (32.5)
Neck AIS ≥ 3, n (%)	68 (1.8)
Chest AIS ≥ 3, n (%)	3,547 (94.0)
Abdomen AIS ≥ 3, n (%)	1,064 (28.2)
Spine AIS ≥ 3, n (%)	401 (10.6)
Upper extremity AIS ≥ 3, n (%)	245 (6.5)
Lower extremity AIS ≥ 3, n (%)	1,351 (35.8)
Injury Severity Score, median (IQR)	34.00 (26.00, 45.00)

AIS, Abbreviated Injury Scale; IQR, interquartile range.

TEVAR was first approved, there was a significant increase in the rate of aortic injuries treated with some intervention ($p < 0.001$). In 2005, 8.1% received either OAR or TEVAR. This rose to 19.6% in 2007. The increase continued throughout the remainder of the study.

After FDA approval of TEVAR devices in 2005, there was significant increase in endovascular repair, from 1.0% to 30.6% of the total number of patients with BTAI ($p < 0.001$) and an associated significant decrease in OAR (Fig. 1). The transition from OAR to TEVAR resulted in a significant reduction in median ICU length of stay (9.0 vs 12.0 days, $p = 0.048$) and mortality (9.3% vs 16.6%; $p = 0.015$). Over the study period, as BTAI increased, the proportional rate of TEVAR nearly completely replaced OAR (Fig. 1).

After adjusting for age, sex, presence of coma, and ISS, the relative rate of TEVAR use for BTAI increased from 0.09 in 2005 to 2.81 in 2013, when compared with the rate of operative management in the 2 years preceding introduction of endovascular care (Fig. 2).

The decline in nonoperative management coupled with the increase in the use of TEVAR was observable across several sub-groups and regardless of ISS, trauma center level, or associated head and abdominal injury. Over the study period, there was also a steady decline in mortality, from 49.1% to 29.4% (Table 2).

Mortality analysis

After using propensity score matching in a 1:1 ratio, TEVAR was associated with a 50% lower mortality than OAR (8.1% vs 16.2%, $p = 0.05$).

DISCUSSION

In 2005, TEVAR was approved by the FDA. It was almost immediately recognized as an attractive alternative to OAR for the injured aorta. This study evaluates the national experience of BTAI management over a decade, which included introduction of this innovative strategy. The most significant trend identified was that the use of OAR declined significantly, while the use of TEVAR increased. In fact, TEVAR essentially replaced OAR. When adjusting for changes in the study population over time and the overall incidence of BTAI, the relative rate of TEVAR use continued to rise. Furthermore, the mortality associated with OAR use was found to be significantly higher when it was compared with a matched group of patients treated with TEVAR.

The first large cohort study to examine the outcome of BTI after the introduction of TEVAR was a prospective, observational multicenter study conducted by the American Association for the Surgery of Trauma (AAST). The investigators studied 193 patients, including 125 who underwent TEVAR and 68 treated with OAR. Patients treated with TEVAR were found to have a lower mortality (odds ratio of death for OAR 8.42). There was, however, a 20% device complication rate.

Since this initial report, several other multicenter studies have been reported. A prospective study from the Aortic Trauma Foundation (ATF) reviewed management of 453 patients with BTAI treated at 9 level 1 trauma centers from 2008 to 2013. Of patients treated with an intervention, 198 had a TEVAR, and 61 had OAR. Device-related complications (malposition, migration, device fracture, etc) occurred in only 10% of patients treated with a TEVAR, likely reflecting improvements in technology. A similar rate (9%) was reported in a retrospective Western Trauma Association (WTA) study of patients with BTAI treated from 2006 to 2016.[5]

Aortic-related mortality was 6.5% in the Aortic Trauma Foundation study and 6% in the Western Trauma Association study. When comparing TEVAR and OAR, the Aortic Trauma Foundation study reported a mortality of 8.6% vs 19.7% and the Western Trauma Association study reported 5.7% vs 22.7%, both favoring TEVAR. Although studies consistently demonstrated reduced device complications and improved survival with TEVAR, population-based studies that demonstrate outcomes nationally have been lacking.

The NTDB is an excellent source of national level data. The first evaluation of BTAI was performed in 2009 by Arthurs and colleagues.[7] They identified an overall BTAI incidence of 0.3% using the 2000 to 2005 data, with an overall mortality of 61.7%. Endovascular repair

Table 2. Population Characteristics Grouped by Year

Characteristic	2003 (n = 216)	2004 (n = 258)	2005 (n = 198)	2006 (n = 211)	2007 (n = 352)	2008 (n = 421)	2009 (n = 364)	2010 (n = 436)	2011 (n = 398)	2012 (n = 495)	2013 (n = 425)	p Value*
Age, y, median (IQR)	41 (28, 59)	43 (27, 62)	43.50 (25, 58)	48 (34, 62)	43 (28, 58.)	46 (29, 62)	46 (32, 62)	47 (30, 63)	47 (32, 62)	47 (30, 62)	45 (29, 62)	0.025
Male, n (%)	144 (66.7)	180 (69.8)	140 (70.7)	149 (70.6)	255 (72.4)	290 (68.9)	263 (72.3)	318 (72.9)	292 (73.4)	338 (68.3)	304 (71.5)	<0.001
Hypotension, n (%)	58 (26.9)	86 (33.3)	38 (19.2)	66 (31.3)	88 (26.9)	108 (26.6)	106 (30.6)	121 (28.5)	102 (26.4)	135 (28.2)	98 (24.0)	0.059
Coma, n (%)	94 (43.5)	122 (47.3)	76 (38.4)	107 (50.7)	135 (42.9)	157 (38.8)	141 (40.4)	176 (41.5)	139 (36.3)	199 (41.5)	152 (37.3)	0.023
Head AIS ≥ 3, n (%)	70 (32.4)	98 (38.0)	53 (26.8)	58 (27.5)	115 (32.7)	140 (33.3)	122 (33.5)	147 (33.7)	118 (29.6)	175 (35.4)	129 (30.4)	0.187
Neck AIS ≥ 3, n (%)	2 (0.9)	3 (1.2)	2 (1.0)	1 (0.5)	6 (1.7)	5 (1.2)	4 (1.1)	6 (1.4)	10 (2.5)	14 (2.8)	15 (3.5)	0.055
Chest AIS ≥ 3, n (%)	205 (94.9)	230 (89.1)	159 (80.3)	167 (79.1)	342 (97.2)	405 (96.2)	353 (97.0)	420 (96.3)	384 (96.5)	471 (95.2)	411 (96.7)	<0.001
Abdomen AIS ≥ 3, n (%)	62 (28.7)	82 (31.8)	46 (23.2)	46 (21.8)	87 (24.7)	99 (23.5)	98 (26.9)	125 (28.7)	125 (31.4)	170 (34.3)	124 (29.2)	0.003
Spine AIS ≥ 3, n (%)	27 (12.5)	29 (11.2)	15 (7.6)	16 (7.6)	24 (6.8)	27 (6.4)	25 (6.9)	68 (15.6)	52 (13.1)	61 (12.3)	57 (13.4)	<0.001
Upper extremities AIS ≥ 3, n (%)	26 (12.0)	16 (6.2)	11 (5.6)	6 (2.8)	16 (4.5)	23 (5.5)	22 (6.0)	34 (7.8)	16 (4.0)	40 (8.1)	35 (8.2)	0.002
Lower extremities AIS ≥ 3, n (%)	76 (35.2)	91 (35.3)	62 (31.3)	49 (23.2)	122 (34.7)	152 (36.1)	137 (37.6)	148 (33.9)	140 (35.2)	217 (43.8)	157 (36.9)	<0.001
Injury Severity Score, y, median (IQR)	38 (29, 50)	38 (29, 50)	36 (25, 45)	37 (29, 50)	38 (29, 50)	34 (29, 45)	35 (26, 43)	33 (25, 41)	33 (25, 43)	34 (25, 45)	33 (25, 43)	<0.001
Mortality, n (%)	106 (49.1)	129 (50.0)	80 (40.4)	88 (41.7)	144 (40.9)	167 (39.7)	132 (36.3)	169 (38.8)	148 (37.2)	177 (35.8)	45 (29.4)	<0.001

*$p < 0.005$ indicates statistically significant difference in the variable across time. Analysis of variance used to assess continuous variables and chi-square test were used to assess proportions.
AIS, Abbreviated Injury Scale; IQR, interquartile range.

was performed in 4% of patients, with 18% mortality, compared with 19% for OAR.[7] A more recent examination of the NTDB was performed by Grigorian and associates,[8] using the Research Dataset (RDS) to examine trends in BTAI care from 2007 to 2015. Similar to this study, this group identified an increase in the use of TEVAR, but did not adjust their data for important covariates. Furthermore, the RDS is not a weighted sample, limiting applications defining trends across the country.

In an effort to understand the issues around the management of BTI, this study used data from the NTDB NSP. The data were adjusted for clinically important confounders, which could have influenced the use of TEVAR over time. These included age, sex, severity of injury (ISS > 25), and the presence of coma. Even after controlling for these, the trend of increasing use of TEVAR persisted. This will most certainly mean that the intervention is being applied to a broader group of patients, rather than that more patients are suitable for TEVAR.

Our findings can possibly be explained in several ways. The technology is still relatively young, within its introductory phase, and experience is likely growing. It may be that as more clinicians become comfortable with it, it is simply being used more often. It is also possible that more patients are being treated with TEVAR than necessary. When OAR was the only option, patients who were marginally stable may have been treated nonoperatively. Those same patients, who may have done well with nonoperative management, could now be being treated with TEVAR. As endovascular care has become more commonly used, the number of surgeons comfortable with large open vascular repairs is likely decreasing. Because these procedures are less common during residency and/or fellowship training, young surgeons may not be comfortable performing them. Therefore, patients who may actually be better candidates for OAR are still treated with TEVAR.

Although consensus exists for the management of uncontained aortic rupture (intervention) and minor intimal tears (observation), controversy surrounds the management of contained pseudoaneurysms. Guidance on the subject is mixed, with the Society of Vascular Surgery recommending that any injury greater than an intimal tear requires endoluminal stenting.[9] Since this clinical practice guideline was published, there have been several studies reporting the successful conservative management of small pseudoaneurysms.[10-12] It is unclear from this study which of these factors is driving the increased rate of TEVAR because the morphology of the BTAI is not reported within the NTDB.

Fundamentally, the natural history of intermediate grade lesions is poorly understood and therefore, the

Table 3. Annual Count of Blunt Thoracic Aortic Injuries per Year (2003 to 2013), with Count and Percentage of Open-Aortic Repair, Thoracic Endovascular Aortic Repair, and Nonoperative Management

Variable	2003 (n = 216)	2004 (n = 258)	2005 (n = 198)	2006 (n = 211)	2007 (n = 352)	2008 (n = 421)	2009 (n = 364)	2010 (n = 436)	2011 (n = 398)	2012 (n = 495)	2013 (n = 425)	p Value*
OAR, n (%)	27 (12.5)	25 (9.7)	14 (7.1)	16(7.6)	23 (6.5)	17 (4.0)	9 (2.5)	9 (2.1)	12 (3.0)	6 (1.2)	7 (6.6)	<0.001
TEVAR, n (%)	0 (0)	0 (0)	2 (1.0)	12 (5.7)	46 (13.1)	54 (12.8)	65 (17.8)	101 (23.2)	103 (25.9)	126 (25.4)	130 (30.6)	<0.001
Nonop, n (%)	189 (87.5)	233 (90.3)	182 (91.9)	183 (86.7)	283 (80.4)	350 (83.1)	290 (79.7)	326 (74.8)	283 (71.1)	363 (73.3)	288 (67.8)	<0.001

*$p < 0.005$ indicates statistically significant difference in the variable across time. Analysis of variance used to assess continuous variables and chi squared test used to assess proportions.
Nonop, nonoperative management; OAR, open-aortic repair; TEVAR, thoracic endovascular aortic repair.

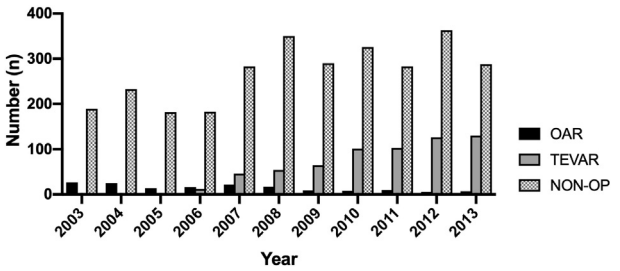

Figure 1. Count of patients with blunt thoracic aortic injury who undergo either open repair (OAR), thoracic endovascular aortic repair (TEVAR) or nonoperative management (nonop).

specific subset of patients who may benefit from TEVAR has yet to be defined. Experience from nontraumatic aortic pathology suggests that the aorta has a significant capacity to remodel when blood pressure control is optimized.[13] Prospective registries, such as that of the Aortic Trauma Foundation, are collecting more granular detail on lesion morphology, treatment, and outcomes, and will hopefully be able to answer these questions in the future.[4]

This study has a number of important limitations. The data for the study were extracted from the NSP version of the NTDB. This dataset is produced from the RDS using a proprietary weighting technique developed by the American College of Surgeons in 2013. This was in anticipation of the more comprehensive Trauma Quality Improvement Program (TQIP). A potential solution is to use the RDS, which is more current. We deliberately elected not to use this dataset because it is not weighted relative to the distribution and volume of trauma centers across the US. We believed that this was important because without weighting, a commentary on the national trend in practice would be less robust.

A further limitation is the lack of specific information about the extent of aortic injury. This is the main limitation

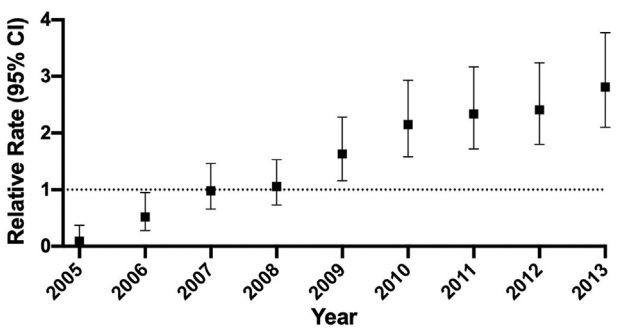

Figure 2. Rate of thoracic endovascular aortic repair (TEVAR), relative to the intervention rate before the availability of TEVAR (2003 to 2004), standardized for age, sex, coma, and Injury Severity Score.

in understanding the indication for intervention (or not) within this dataset; however, we have specifically sought to control for all other available variables, allowing us to refine future questions relating to management of BTAI.

CONCLUSIONS

Analysis of a national level dataset demonstrates that TEVAR has largely replaced OAR, resulting in a 50% reduction in mortality from BTAI. The rate of TEVAR use has increased significantly in the decade after introduction of the technique. This trend persists despite controlling for incidence and changes in population demography. It is unclear whether this trend relates to an increase in eligible patients or a broadening of the use of the technique. Further study is required to better define the indications for TEVAR in BTAI.

Author Contributions

Study conception and design: Scalea, Feliciano, DuBose, Ottochian, O'Connor, Morrison

Acquisition of data: DuBose, Ottochian, Morrison

Analysis and interpretation of data: DuBose, Ottochian, Morrison

Drafting of manuscript: Scalea, Feliciano, DuBose, Ottochian, O'Connor, Morrison

Critical revision: Scalea, Feliciano, DuBose, Ottochian, O'Connor, Morrison

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Discussion

DR LOUIS MAGNOTTI FOR DR TIMOTHY FABIAN (Memphis, TN): Perhaps no injury management has advanced more dramatically over the past 20 years than injury to the thoracic aorta. Major progress has been made in diagnosis and treatment. This work highlights some of the important progress and also points to further challenges.

Computed tomography has replaced aortography and has such high sensitivity that, in patients who undergo chest CT, nearly all injuries are diagnosed. Indeed, the authors report that data from the National Trauma Data Bank (NTDB) demonstrate that diagnosis of aortic injury has doubled over the last decade. That could be due to increasing sensitivity and use of CT. But, it is not clear if that number reflects a relative increase in incidence or is an absolute number that may only reflect more patients entered into the NTDB over that time interval. Please address that possibility.

Observation of injuries with nonoperative management has progressed over the past decade, but that practice was anathema in previous times due to the perceived risk of aortic rupture. Your data show approximately 20% of injuries were nonoperatively managed in 2003, and 30% in 2013. Both percentages seem awfully high to me, especially in 2003. I do not believe nonoperative management had evolved to that extent that early. Could there be a problem with the NTDB relative to coding for diagnosis and management?

The authors suggest the relative decrease in nonoperative management in the later years may be due to increasing acceptance of thoracic endovascular aortic repair (TEVAR) due to its lower morbidity. That may be the case, although the conundrum regarding the unusually high rate of nonoperative management in the early years complicates the interpretation. Nonetheless, this points to a challenge that the authors identify. We need to establish a standard injury grading system. That will permit a more thoughtful way to investigate nonoperative management, aspects of operative care, and outcomes.

As indicated by the title of the study, the most important issues addressed were related to endovascular management of the aortic