Contemporary management and outcomes of blunt thoracic aortic injury: A multicenter retrospective study

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BACKGROUND: Blunt thoracic aortic injuries (BTAIs) are composed of a spectrum of lesions ranging from intimal tear to rupture, yet optimal management and ultimate outcome have not been clearly established.

METHODS: This is a retrospective multicenter study of BTAIs from January 2008 to December 2013. Demographics, diagnosis, treatment, and in-hospital outcomes were analyzed.

RESULTS: Nine American College of Surgeons–verified Level I trauma centers contributed data from 453 patients with BTAIs. After exclusion of patients expiring before imaging (58) and transfers (13), 382 patients with imaging diagnosis were available for analysis (Grade 1, 94; Grade 2, 68; Grade 3, 192; Grade 4, 28). Hypotension was present on admission in 56 (14.7%). Computed tomographic angiography was used for diagnosis in 94.5%. Nonoperative management (NOM) was selected in 32%, with two in-hospital failures (Grade 1, Grade 4) requiring endovascular salvage (thoracic endovascular aortic repair [TEVAR]). Open repair (OR) was completed in 61 (16%). TEVAR was conducted in 198 (52%), with 41% of these requiring left subclavian artery coverage. Complications of TEVAR included endograft malposition (6, 3.0%), endoleak (5, 2.5%), paralysis (1, 0.5%), and stroke (2, 1.0%). Six TEVAR failures were treated by repeat TEVAR (2) or OR (4). Overall in-hospital mortality was 18.8%, and aortic-related mortality was 6.5% (NOM, 9.8%; OR, 13.1%; TEVAR, 2.5%) (Grade 1, 0%; Grade 2, 2.9%; Grade 3, 5.2%; Grade 4, 46.4%). The majority of aortic-related deaths (18 of 25) occurred before the opportunity for repair. Independent predictors of aortic-related mortality among BTAI patients were higher chest Abbreviated Injury Scale (AIS) score, grade, and Injury Severity Score (ISS); TEVAR was protective ($p = 0.03$; odds ratio, 0.21; confidence interval, 0.05–0.88).

CONCLUSION: Failures and aortic-related mortality of NOM following BTAI Society of Vascular Surgery Grade 1 to 3 injuries are rare. TEVAR seems independently protective against aortic-related mortality. Early complications of TEVAR have decreased relative to previous reports. Prospective long-term follow-up data are required to better refine indications for intervention.

LEVEL OF EVIDENCE: Level IV.

KEY WORDS: Trauma; aortic injury; endovascular; mortality; complications.

Blunt traumatic aortic injury (BTAI) remains the second most common cause of death following blunt mechanisms of injury, with a recent study documenting that one third of patients dying after motor vehicle crashes will have evidence of these injuries on subsequent autopsy.[1] Available data suggest that between 80% and 85% of patients sustaining BTAI die before reaching hospital care.[1] Among those that do survive to reach a capable health care facility, however, an evolution in care has taken place during the last two decades.

Thoracic endovascular aortic repair (TEVAR) has continued to replace traditional open surgical intervention as the primary means of treatment for BTAI. Previous reports have documented a significant improvement in morbidity and mortality following BTAI that has been associated with the transition from open repair (OR) to TEVAR.[2–11] In the largest non–industry-sponsored report to date, however, Demetriades et al.[2] of the American Association for the Surgery of Trauma (AAST) BTAI study group reported considerable rates of device- and access-related complications associated with the use of TEVAR for BTAI.

Considerable advances in care have occurred since the publication of the 2008 AAST multicenter study results. Further improvements in imaging capabilities have optimized the ability to better characterize and stratify injury. An image-based grading system was proposed, and new consensus driven clinical practice guidelines were published by the Society of Vascular Surgery (SVS).[12,13] The introduction of lower-profile, more conformable, trauma-specific devices has improved the safety profile of TEVAR. To date, however, there have been relatively limited non–industry-guided, multicenter data examining the impact of this evolution in care.

Our present report represents the largest contemporary multicenter retrospective BTAI study of its kind in the literature. We have conducted an examination designed to identify contemporary practice patterns of BTAI care and associated outcomes after treatment of these injuries.

PATIENTS AND METHODS

After individual institutional review board approval, nine American College of Surgeons–verified Level I trauma centers contributed data to this collaborative examination. BTAI patients treated at the respective facilities from January 2008 to December 2013 were identified using trauma registries, with retrospective imaging and chart review used to complete data collection. Patients dying before imaging or transferred from outside hospitals were excluded. Demographic variables examined included age, sex, mechanism of injury, and admission physiologic data. Trauma registry data provided Injury Severity Scores (ISSs), body region–specific Abbreviated Injury Scale (AIS) scores, and Glasgow Coma Scale (GCS) scores on arrival.

SVS grade of injury[12] was confirmed by individual review of imaging obtained. A participating radiologist, trauma surgeon, or vascular surgeon conducted this radiographic review. Additional imaging information was collected, which included length of injury, diameter of lesion (for pseudoaneurysms), and associated imaging findings including presence and size of hemothorax as well as the presence of mediastinal hematoma with evidence of compression. Volume of associated hemothorax on computed tomography (CT) was estimated by the method previously described by DuBose et al.[14] Residual hemothorax was then categorized according to this CT scan estimate into one of three categories (small, ≤300 cc; moderate, 301–900 cc; large, >900 cc). Treatment variables, including type and timing of intervention from admission, were

TABLE 1. Demographics of BTAI Patients, Overall and by Management Selection (Nonoperative vs. Operative [TEVAR or OPEN])

	Total (N = 382)	NOM Only (n = 123)	Operative Management (TEVAR or Open) (n = 259)	*p*
Age, mean (SD), y	41.8 (17.8)	44.7 (18.0)	40.4 (17.6)	0.028
Male, n (%)	278 (72.8)	49 (32.5)	64 (24.7)	0.112
Mechanism				
Motor vehicle collision, n (%)	249 (72.8)	79 (65.6)	170 (68.3)	0.896
Motorcycle collision, n (%)	55 (14.4)	19 (15.4)	36 (13.9)	0.896
Fall, n (%)	28 (7.3)	10 (8.1)	18 (6.9)	0.896
Automobile vs. pedestrian, n (%)	36 (9.4)	12 (9.8)	24 (9.3)	0.896
Other blunt, n (%)	14 (3.7)	3 (2.4)	11 (4.2)	0.896
Hypotension (SBP < 90) on arrival, n (%)	56 (14.7)	24 (20.2)	32 (12.5)	0.062
Admission GCS score ≤ 8, n (%)	112 (29.3)	37 (30.8)	75 (29.3)	0.809
ISS, median [interquartile range]	34.0 [14]	34.0 [19]	34.5 [14]	0.556
Head AIS score ≥ 3, n (%)	139 (36.4)	49 (40.5)	90 (34.9)	0.305
Chest AIS score ≥ 3, n (%)	375 (98.2)	120 (99.2)	255 (98.8)	1.000
Abdominal AIS score ≥ 3, n (%)	132 (34.6)	46 (38.0)	86 (33.3)	0.418
Extremity AIS score ≥ 3, n (%)	157 (41.1)	51 (42.1)	106 (41.1)	0.911
SVS injury grade, n (%)				
Grade I	94 (24.6)	72 (58.5)	22 (8.5)	<0.001
Grade II	68 (17.8)	19 (15.4)	49 (18.9)	0.475
Grade III	192 (50.3)	25 (20.3)	167 (64.5)	<0.001
Grade IV	28 (7.3)	7 (5.7)	21 (8.1)	0.529
Imaging modality used for diagnosis, n (%)				
CTA alone	361 (94.5)	111 (90.2)	250 (96.5)	0.867
CTA + angiography	9 (2.4)	2 (1.6)	7 (2.7)	0.867
Angiography alone	2 (0.5)	0 (0)	2 (0.8)	0.867
CTA + angiography + intravascular ultrasound	10 (2.6)	10 (8.1)	0 (0)	0.867
Pseudocarctation, n (%)	13 (3.4)	2 (1.6)	11 (4.2)	0.238
Mediastinal hematoma with evidence of compression, n (%)	103 (27.0)	21 (17.1)	82 (31.7)	0.003
Associated hemothorax, n (%)	110 (28.8)	31 (25.2)	79 (30.5)	0.334
Hemothorax > 300 cc, n (%)	40 (10.5)	13 (44.8)	27 (36.0)	0.501
Hemothorax > 500 cc, n (%)	18 (4.7)	7 (24.1)	11 (14.7)	0.261
Hemothorax > 1,000 cc, n (%)	5 (1.3)	2 (6.9)	3 (4.0)	0.617
Medical management, n (%)	184 (48.2)	87 (74.4)	97 (37.7)	<0.001
Goal blood pressure achieved, n (%)	148 (38.7)	60 (84.5)	88 (85.4)	1.000
Craniotomy/craniectomy, n (%)	4 (1.0)	3 (2.4)	1 (0.4)	0.100
Laparotomy, n (%)	87 (22.8)	24 (19.5)	63 (24.3)	0.361
Thoracotomy/sternotomy (not for TAI), n (%)	16 (4.2)	8 (6.5)	8 (3.1)	0.169
ICU LOS, median [interquartile range]	7.0 [13]	5.0 [10]	8.0 [15]	<0.001
Hospital LOS, median [interquartile range]	14.0 [19]	9.0 [16]	16.5 [21]	<0.001
Ventilator days, median [interquartile range]	4.0 [11]	1.0 [7]	5.0 [13]	0.002
PRBC 24 h, median [interquartile range]	1.0 [5]	0.0 [4]	1.0 [5]	0.958
Fresh frozen plasma 24 h, median [interquartile range]	0.0 [3]	0.0 [4]	0.0 [3]	0.311
Paralysis related to BTAI or BTAI treatment, n (%)	1 (0.3)	0 (0)	1 (0.4)	1.000
Stroke, n (%)	6 (1.6)	4 (3.3)	2 (0.8)	0.088
Acute renal failure, n (%)	26 (6.8)	7 (5.7)	19 (7.3)	0.666
Deep venous thrombosis, n (%)	23 (6.0)	5 (4.1)	18 (6.9)	0.359
Pulmonary embolism, n (%)	25 (6.5)	6 (4.9)	19 (7.3)	0.507
Catheter-related urinary tract infection, n (%)	30 (7.9)	5 (4.1)	25 (9.7)	0.067
Blood stream infection, n (%)	46 (12.0)	10 (8.1)	36 (13.9)	0.130
Hospital-acquired pneumonia, n (%)	36 (9.4)	5 (4.1)	31 (12.0)	0.014
Ventilator-associated pneumonia, n (%)	50 (13.1)	9 (7.3)	41 (15.8)	0.023
Acute lung injury/adult respiratory distress syndrome, n (%)	45 (11.8)	10 (8.1)	35 (13.5)	0.173
Sepsis, n (%)	56 (14.7)	8 (6.5)	48 (18.5)	0.002
In-hospital mortality, n (%)	72 (18.8)	43 (35.0)	29 (11.2)	<0.001
Aortic-related mortality, n (%)	25 (6.5)	12 (9.8)	13 (5.0)	0.119

TABLE 2. Treatment and Outcomes of BTAI by SVS Grade

	Total TAI (N = 382)	Grade I Injury (n = 94)	Grade II Injury (n = 68)	Grade III Injury (n = 192)	Grade IV Injury (n = 28)
NOM only, n (%)	122/382 (31.9)	72/94 (76.6)	19/68 (27.9)	24/192 (12.5)	7/28 (25.0)
Goal blood pressure achieved when medical primary or adjunctive used	148/382 (38.7)	51/94 (54.3)	15/68 (22.1)	73/192 (38.0)	9/28 (32.1)
Treatment failure medical management only	2/122 (1.6)	1/72 (1.4)	0/19 (0)	1/24 (4.2)	0/7 (0)
TEVAR salvage	2/122 (1.6)	1/72 (1.4)	0/19 (0)	1/24 (4.2)	0/7 (0)
Open salvage	0/122 (0)	0/94 (0)	0/19 (0)	0/24 (0)	0/7 (0)
Open surgical repair	61/382 (16.0)	5/94 (5.3)	5/68 (7.4)	42/192 (21.9)	9/28 (32.1)
Treatment failure OR	0/61 (0)	0/17 (0)	0/5 (0)	0/42 (0)	0/9 (0)
Endovascular repair	198/382 (51.8)	17/94 (18.1)	44/68 (64.7)	125/192 (65.1)	12/28 (42.9)
Subclavian coverage	82/198 (41.4)	9/17 (52.9)	15/44 (34.1)	53/125 (42.4)	5/12 (41.7)
Endograft malposition at initial TEVAR	6/198 (3.0)	0/17 (0)	0/44 (0)	4/125 (3.2)	2/12 (16.7)
Endoleak	5/198 (2.5)	1/17 (5.8)	1/44 (2.3)	3/125 (2.4)	0/12 (0)
Early stent fracture	0/198 (0)	0/17(0)	0/44 (0)	0/125 (0)	0/12 (0)
Early stent migration	1/198 (0.5)	0/17 (0)	0/44 (0)	0/125 (0)	1/12 (8.3)
Access site pseudoaneurysm	1/198 (0.5)	0/17 (0)	0/44 (0)	1/125 (0.8)	0/12 (0)
Access site persistent or delayed bleeding requiring intervention	1/198 (0.5)	0/17 (0)	1/44 (2.3)	1/125 (0.8)	0/12 (0)
Treatment failure TEVAR	6/198 (3.0)	0/17 (0)	1/44 (2.3)	3/125 (2.4)	2/12 (16.7)
TEVAR salvage	2/198 (1.0)	0/17 (0)	0/44 (0)	2/125 (1.6)	0/12 (0)
Open salvage	4/198 (2.0)	0/17 (0)	1/44 (2.3)	1/125 (0.8)	2/12 (16.7)
Any intervention					
Procedure-related aortic perforation	0/382	0/94 (0)	0/68 (0)	0/192 (0)	0/28 (0)
Paralysis, n (%)	1/382 (0.3)	0/94 (0)	0/68 (0)	0/192 (0)	1/28 (3.6)
Stroke, n (%)	6/382 (1.6)	2/94 (2.1)	3/68 (4.4)	1/192 (0.5)	0/28 (0)
Reoperation for bleeding attributable to TAI, n (%)	0/382 (0)	0/94 (0)	0/68 (0)	0/192 (0)	0/28 (0)
In-hospital mortality, n (%)	72/382 (18.8)	12/94 (12.8)	14/68 (20.6)	32/192 (16.7)	14/28 (50)
Aortic-related mortality, n (%)	25/382 (6.5)	0/94 (0)	2/68 (2.9)	10/192 (5.2)	13/28 (46.4)
Aortic-related mortality occurring before opportunity for repair, n (%)	18/382 (4.7)	N/A	0/2 (0)	9/10 (90.0)	9/13 (69.2)

N/A, not applicable.

obtained from operative reports and medical records. Trauma registry data and chart review identified complications and in-hospital outcomes.

Aortic-related mortality was defined as death attributed (on review of the individual site primary investigator) as directly attributable to aortic injury.

Statistical Analysis

Data were analyzed using SPSS version 22.0 (SPSS, Inc., Chicago, IL) and SAS version 9.3 (SAS Institute, Inc., Cary, NC). Continuous variables were compared using Student's *t* test and the Mann-Whitney U-test. The X^2 test or Fisher's exact test was used to compare categorical variables. Data are reported as adjusted odds ratio with 95% confidence intervals. Statistical significance was set at a $p < 0.05$. Multivariable logistic regression analysis was used to identify independent risk factors for overall mortality and aortic-related mortality. Candidate variables were identified for inclusion if they showed reasonable nonmissingness (<5% missing) and biologic plausibility or previous use in the literature as risk factors or confounders. We did not use statistical criteria from univariate testing for variable selection. Selection was by forward selection, with the score X^2 entry value set at $p = 0.05$.

Generalized partial coefficients of determination (pseudo R^2) values were computed by the method of Cox and Snell.[15]

RESULTS

Four hundred fifty-three patients with BTAI were identified. After exclusion of patients expiring before imaging (58) and transfers (13), 382 patients with imaging diagnosis were available for analysis. Mean age was 41.8 years; 72.8% of the patients were male. The dominant mechanism of injury was motor vehicle crash, constituting 72.8% of all BTAI causes (Table 1). Hypotension, defined as systolic blood pressure (SBP) less than 90 mm Hg on arrival, was present in 56 patients (14.7%) on admission. A GCS score of 8 or less on admission was documented for 29.3%.

BTAI patients had a median ISS of 16.0 (interquartile range, 16). There were also a substantial number of patients with elevated (≥3) AIS score for the body regions of head (36.4%), abdomen (34.6%), and extremities (41.1%). Trauma laparotomy was required for 22.8% of the patients overall, with a smaller portion requiring thoracotomy/sternotomy (4.2%) for indications not specifically related to BTAI or craniotomy/craniectomy (1.0%) (Table 1).

TABLE 3. Comparison of TEVAR Versus OR for BTAI

	TEVAR (n = 198)	OR (n = 61)	*p*
Age, mean (SD), y	41.7 (17.1)	35.8 (16.6)	0.020
ISS, median [interquartile range]	34.0 [14]	39.5 [16]	<0.001
Grade I Injury, n (%)	17 (8.6)	5 (8.2)	1.000
Grade II Injury, n (%)	44 (22.2)	5 (8.2)	0.015
Grade III Injury, n (%)	125 (63.1)	42 (68.9)	0.448
Grade IV Injury, n (%)	12 (6.1)	9 (14.8)	0.056
Head AIS score ≥ 3, n (%)	64 (32.5)	26 (42.6)	0.167
Chest AIS score ≥ 3, n (%)	195 (99.0)	60 (98.4)	0.556
Abdominal AIS score ≥ 3, n (%)	19 (31.1)	67 (34.0)	0.757
Extremity AIS score ≥ 3, n (%)	24 (39.3)	82 (41.6)	0.768
Mediastinal hematoma with evidence of compression, n (%)	51 (25.8)	31 (50.8)	<0.001
Associated hemothorax, n (%)	58 (29.3)	21 (34.4)	0.525
Craniotomy/craniectomy, n (%)	0 (0)	1 (0.5)	1.000
Laparotomy, n (%)	52 (26.3)	11 (18.0)	0.233
Thoracotomy/sternotomy (not for TAI), n (%)	3 (1.5)	5 (8.2)	0.019
ICU LOS, median [interquartile range]	8.0 [15]	8.5 [17]	0.892
Hospital LOS, median [interquartile range]	16.0 [21]	17.5 [21]	0.399
Ventilator days, median [interquartile range]	5.0 [13]	3.5 [15]	0.991
PRBC 24 h, median [interquartile range]	0.0 [4]	3.0 [8]	0.002
Fresh frozen plasma 24 h, median [interquartile range]	0.0 [3]	2.0 [7]	0.021
Reoperation for bleeding attributable to TAI, n (%)	0 (0)	0 (0)	1.000
Paralysis, n (%)	1 (0.5)	0 (0)	1.000
Stroke, n (%)	2 (1.0)	0 (0)	1.000
Acute renal failure, n (%)	14 (7.1)	5 (8.2)	0.781
Deep venous thrombosis, n (%)	15 (7.6)	3 (4.9)	0.578
Pulmonary embolism, n (%)	17 (8.6)	2 (3.3)	0.260
Catheter-related urinary tract infection, n (%)	20 (10.1)	5 (8.2)	0.807
Blood stream infection, n (%)	27 (13.6)	9 (14.8)	0.834
Hospital-acquired pneumonia, n (%)	21 (10.6)	10 (16.4)	0.259
Ventilator-associated pneumonia, n (%)	30 (15.2)	11 (18.0)	0.555
Acute lung injury/adult respiratory distress syndrome, n (%)	25 (12.6)	10 (16.4)	0.520
Sepsis, n (%)	33 (16.7)	15 (24.6)	0.188
In-hospital mortality, n (%)	17 (8.6)	12 (19.7)	0.021
Aortic-related mortality, n (%)	5 (2.5)	8 (13.1)	0.003

CT angiography (CTA) was used as the primary modality to diagnose and characterize injury in 94.5% of the patients. Traditional angiography was used among a smaller portion of patients as an adjunct of CTA (2.4%) or as the sole primary means of defining injury (0.5%). For 2.6% of the patients, a combination of CTA, angiography, and intravascular ultrasound was used to fully characterize the extent of BTAI (Table 1).

The distribution of SVS grades encountered included 94 Grade I injuries (24.6%), 68 Grade 2 (17.8%), 192 Grade 3 (50.3%), and 28 Grade 4 (7.3%). Hypotension (SBP < 90 mm Hg) was present on admission in 56 (14.7%). Associated radiographic findings included mediastinal hematoma with evidence of compression on surrounding structures in 27.0%. An associated hemothorax was identified in 28.8% (>300 cc, 10.5%; >500 cc, 4.7%; and >1,000 cc, 1.3%) (Table 1).

Available data on blood pressure management after identification of BTAI were limited. Adequate documentation of pharmacologic medical blood pressure impulse control, as either the primary treatment or an adjunct to other intervention, was noted in 48.2%. Among those patients, documentation of achievement of defined goal blood pressure was available in 38.7%

Nonoperative management (NOM) was selected as the initial management of choice in 32.2% (Table 2) of the patients, with two in-hospital failures (Grade 1 and Grade 4). Both of these patients underwent subsequent endovascular (TEVAR) salvage without complication. On univariate comparison with patients undergoing repair (Table 1), patients selected for NOM were significantly older, were more likely to have SVS Grade I injuries, and less likely to have associated mediastinal hematoma noted on imaging. As a group, they had shorter hospital and intensive care unit (ICU) stay and fewer ventilator days. Overall mortality among NOM patients was 35.0%, with an aortic-related mortality of 9.8%, compared with 11.2% overall mortality and 5.0% aortic-related mortality for those undergoing aortic repair (either TEVAR or OR) (Table 1).

OR was selected for 61 patients (16%) (Table 2), at a mean time from admission to repair of 36.4 hours (within 6 hours, 49.1%; within 24 hours, 78.7%; within 48 hours, 80.3%) Five patients died during the attempt at OR. In-hospital

TABLE 4. Demographics and Outcomes of Minimal (SVS Grade I and II) BTAI—NOM Versus TEVAR

	NOM (n = 91)	TEVAR (n = 61)	*p*
Age, mean (SD), y	42.3 (16.5)	40.6 (15.9)	0.519
Male, n (%)	64 (66.7)	41 (67.2)	1.000
ISS, median [interquartile range]	34.0 [18]	33.0 [16]	0.672
Hypotension (SBP < 90) on arrival, n (%)	12 (13.0)	8 (13.1)	1.000
Admission GCS score ≤ 8, n (%)	23 (24.7)	17 (28.3)	0.707
Head AIS score ≥ 3, n (%)	33 (35.1)	19 (31.1)	0.728
Abdominal AIS score ≥ 3, n (%)	33 (35.1)	24 (39.3)	0.613
Extremity AIS score ≥ 3, n (%)	40 (42.6)	27 (44.3)	0.869
Mediastinal hematoma with evidence of compression, n (%)	5 (5.2)	12 (19.7)	0.007
Associated hemothorax, n (%)	15 (15.6)	15 (24.6)	0.211
Goal blood pressure achieved with medical adjuncts, n (%)	51 (91.1)	15 (93.8)	1.000
Craniotomy/craniectomy, n (%)	3 (3.1)	1 (1.6)	1.000
Laparotomy, n (%)	17 (17.7)	17 (27.9)	0.165
Thoracotomy/sternotomy (not for TAI), n (%)	2 (2.1)	1 (1.6)	1.000
ICU LOS, median [interquartile range]	5.5 [9]	8.0 [15]	0.157
Hospital LOS, median [interquartile range]	12.0 [12]	16.0 [22]	0.026
Ventilator days, median [interquartile range]	1.5 [8]	5.0 [12]	0.233
PRBC 24 h, median [interquartile range]	0.0 [2]	0.0 [4]	0.882
Fresh frozen plasma 24 h, median [interquartile range]	0.0 [2]	0.0 [2]	0.566
Paralysis, n (%)	0 (0)	1 (1.6)	0.634
Stroke, n (%)	4 (4.2)	1 (1.6)	0.649
Acute renal failure, n (%)	8 (8.3)	3 (4.9)	0.531
Deep venous thrombosis, n (%)	4 (4.2)	6 (9.8)	0.188
Pulmonary embolism, n (%)	4 (4.2)	6 (9.8)	0.188
Catheter-related urinary tract infection, n (%)	6 (6.3)	5 (8.2)	0.751
Blood stream infection, n (%)	12 (12.5)	6 (9.8)	0.798
Hospital-acquired pneumonia, n (%)	4 (4.2)	5 (8.2)	0.311
Ventilator-associated pneumonia, n (%)	8 (8.3)	7 (11.5)	0.582
Acute lung injury/adult respiratory distress syndrome, n (%)	11 (11.5)	9 (14.8)	0.626
Sepsis, n (%)	9 (9.4)	11 (18.0)	0.142
In-hospital mortality, n (%)	19 (19.8)	6 (9.8)	0.119
Aortic-related mortality, n (%)	0 (0)	2 (3.3)	0.149

complications of OR are listed in Table 3. In-hospital mortality for this group was 8.6%, with an aortic-related mortality of 2.5%. There were no reported delayed failures of operative repair during the in-hospital course.

TEVAR was conducted in 198 (52%) (Table 2) at a mean time from admission to repair of 75.4 hours (22.2% within 6 hours, 60.6% within 24 hours, 70.7% within 48 hours). Left subclavian artery coverage (LSAC) was required in 41.4%.

TABLE 5. Independent Predictors of All-Cause and Aortic-Related Mortality Among BTAI Patients

Variable	Cumulative R^2	R^2	Adjusted Odds Ratio (95% Confidence Interval)	*p*
All-cause mortality				
ISS (continuous)	0.1378	0.1378	1.06 (1.02–1.09)	0.0006
NOM	0.2174	0.0796	20.47 (8.02–52.23)	<0.0001
SVS grade (linear continuous)	0.2638	0.0464	2.45 (1.55–3.87)	<0.0001
Admission GCS score	0.2894	0.0256	0.88 (0.83–0.95)	0.0007
PRBCs required during the first 24 h	0.3134	0.024	1.10 (1.04–1.17)	0.0015
Aortic-related mortality				
ISS (continuous)	0.1282	0.1282	1.07 (1.01–1.14)	0.0152
SVS grade (linear continuous)	0.2053	0.0771	17.18 (3.99–73.99)	<0.0001
TEVAR (dichotomous)	0.2213	0.016	0.21 (0.05–0.88)	0.0331
Chest AIS score (continuous)	0.2421	0.0208	6.41 (1.28–32.11)	0.0239

R^2, coefficient of determination.

Two patients died during the conduct of TEVAR, neither as a result of aortic perforation related to the conduct of procedure. Observed procedure-related complications following TEVAR included endograft malposition (6, 3.0%), endoleak (5, 2.5%), paralysis (1, 0.5%), and stroke (2, 1.0%). The sole paralysis patient was an 81-year-old male requiring 20-cm device coverage of the thoracic aorta. The patients experiencing stroke after TEVAR were of ages 62 years and 85 years. Both had required coverage of the left subclavian artery to facilitate TEVAR. Six TEVAR failures requiring reintervention were reported. These underwent subsequent salvage via repeat TEVAR (2) or OR (4). Only one of these patients, a repeat TEVAR, experienced what was declared an aortic-related mortality. The remainder survived to discharge. Overall in-hospital mortality was 8.6% following TEVAR, with a 2.5% aortic-related mortality reported.

Univariate comparison of TEVAR patients (198) with OR patients (61) (Table 3) revealed that OR patients had a significantly higher median ISS and were more likely to have associated mediastinal hematoma causing compression on preoperative imaging. In addition, OR was associated with a higher packed red blood cell (PRBC) requirement within the first 24 hours after admission. Of note, patients undergoing OR were also significantly more likely to undergo thoracotomy or sternotomy for non-BTAI indications. As outlined previously, open surgical intervention occurred at an earlier mean time than TEVAR (36.4 hours vs. 75.4 hours).

Patients with minimal BTAI (SVS Grade I and II injuries) selected for NOM underwent univariate comparison with those with minimal BTAI undergoing TEVAR (Table 4). There were no statistically significant differences between the two groups with regard to any of the collected variables or outcomes.

Postoperative complications were common in the overall BTAI population. Appreciable rates of acute renal failure (7.1%), deep vein thrombosis (7.6%), pulmonary embolism (8.6%), catheter-related urinary tract infection (10.1%), blood stream infection (13.6%), as well as both hospital- (20.6%) and ventilator-associated pneumonia (18.4%) were documented. Acute lung injury or adult respiratory distress syndrome was noted to occur in 16.4%. Sepsis was diagnosed in 24.6%. Mean hospital and ICU length of stay (LOS) were 23.7 days and 12.9 days, respectively. Overall in-hospital mortality for all patients with BTAI was 18.8% (NOM, 34.4%; OR, 19.7%; TEVAR, 8.6%), with an aortic-related mortality of 6.5% (NOM, 9.8%; OR, 13.1%; TEVAR, 2.5%) (Grade 1, 0%; Grade 2, 2.9%; Grade 3, 5.2%; Grade 4, 46.4%).

The majority of aortic-related deaths (18 of 25) occurred before the opportunity for completion of OR or TEVAR. Of the seven patients dying after OR (3) or TEVAR (4), all had an ISS of greater than 25. Three had a GCS score of 3 on arrival, with a head AIS score of 3 or greater. Two required massive transfusions within the first 24 hours, and three required emergent laparotomies. Five of these patients died within 24 hours of admission, one died on hospital Day 1, and the final patient expiring in the ICU after 36 days because of ventilator-associated pneumonia and multiorgan failure.

Multivariate logistic regression (Table 5) identified the independent predictors of all-cause mortality among patients with BTAI as higher ISS or SVS BTAI grade, lower admission GCS score, higher number of PRBCs used during the first 24 hours, and NOM. Independent predictors of aortic-related mortality included higher ISS, higher SVS grade, and higher chest AIS score. TEVAR use proved to be protective against aortic-related mortality in our population (Table 5).

DISCUSSION

The present report represents the largest contemporary multicenter collaboration examining BTAI outcomes in the endovascular era. Our findings, along with those of recent smaller reports, document the continued emergence of TEVAR as the primary treatment for BTAI in anatomically suitable patients.[3–11] While, as our present findings illustrate, the majority of BTAI patients continue to die of associated injuries, the present examination documents an improving profile of safety and efficiency associated with TEVAR use within the framework of improved ability to characterize BTAI.

In their landmark 2008 report, Demetriades et al.[2] of the AAST BTAI study group documented significant improvements in BTAI care associated with the transition from open to endovascular repair. In their examination of 193 patients with BTAI, they found that TEVAR was associated with significantly decreased transfusion requirements and lower mortality compared with OR. Our present results are consistent with these original findings, with a significantly lower PRBC requirement (mean, 5.9 U vs. 3.1 U, $p < 0.002$) in the first 24 hours and a lower overall mortality (8.6% vs. 19.7%, $p = 0.021$) and aortic-related mortality (13.1% vs. 2.5%, $p = 0.003$) among TEVAR-treated patients compared with their OR counterparts.

One of the important findings of the 2008 report of the AAST BTAI study group was the significant rate of TEVAR-related complications that were observed.[2] Demetriades et al. noted that 18.4% of the patients undergoing TEVAR had some form of stent graft–specific complication, most notably endoleak at 13.6%. The continued advancement of endovascular technologies since this report, including the increasing use of Food Drug Administration (FDA)–approved devices specific to aortic trauma, has improved the ability to avoid these adverse events following TEVAR. In our present series (Table 2), six malpositions of endograft at initial TEVAR occurred (3.0%). The post-TEVAR endoleak rate was only 2.5%. Only one delayed stent migration was noted. In addition, just two access site complications (one pseduoaneurysm, one persistent bleeding requiring intervention) were documented. It is important to note, however, that six defined TEVAR treatment failures were encountered in our series. All underwent subsequent salvage with reintervention (two repeat TEVARs, four open surgical interventions). One patient treated with repeat TEVAR experienced aortic-related mortality. No other mortalities were observed among the TEVAR failures.

Other traditional concerns following aortic repair after BTAI have included paralysis and stroke. As has been demonstrated by previous investigators, our study continues to support a decrease in paralysis after TEVAR compared with historical rates reported with OR.[2] In our present report, only one patient overall with BTAI (0.3%) experienced paralysis. This BTAI patient was an 81-year-old with an SVS Grade IV

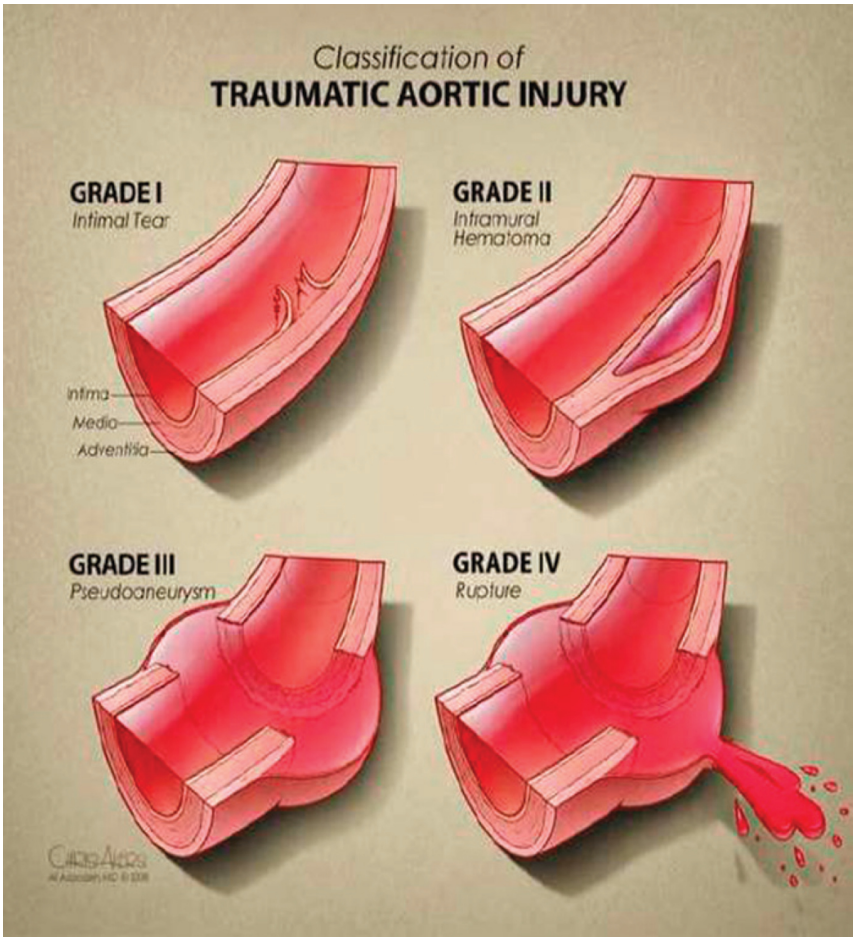

Figure 1. SVS blunt thoracic aortic injury grading.

injury requiring 20 cm of thoracic aortic coverage during subsequent TEVAR. Stroke occurred in 1.6% (6 of 382) of all BTAI patients in our series. Three of these patients presented with GCS score of 3 on arrival and a head AIS score of 3 or greater. Among the two patients experiencing stroke after TEVAR (1.0% of TEVAR-treated BTAI), ages were 62 years (SVS Grade III injury) and 85 years (SVS Grade II injury). Both required LSAC for the treatment of BTAI. The older age in all of the TEVAR patients with paralysis and stroke is associated with increased risk of aortic atherosclerotic disease. This risk should be considered in risk stratification for aortic intervention among BTAI patients.

LSAC was required in 41.4% of the patients treated with TEVAR in our present series. This figure is consistent with the experience of recently published experiences.[3–11] Subclavian steal and stroke remain concerns among patients requiring LSAC for adequate coverage of BTAI. The rate of stroke in our patients requiring coverage was 2.4% (2 of 82 patients). Recent literature continues to support, however, that intentional coverage of the left subclavian in this setting is well tolerated in both the short term and the long term. McBride et al.[16] recently reported their review of 82 patients undergoing TEVAR during a span of 7 years. No patients requiring LSAC required subsequent intervention during hospitalization. After discharge, patients undergoing LSAC did not have an increased likelihood of symptoms (pain, numbness, paresthesia, fatigue, cramping) compared with TEVAR controls not requiring LSAC. Although the risk of LSAC complications should continue to be carefully considered, the ongoing evolution of endovascular techniques and devices may soon obviate the need for LSAC altogether. Laser fenestration[17,18] and "chimney/snorkel"[13,19] stent adjuncts are already described for use in this setting, primarily as an adjunct in patients who are at high risk to develop steal syndrome or stroke after TEVAR. Branched and fenestrated aortic devices, currently used routinely in countries outside the United States, are also presently in trials. The introduction of these latter capabilities into the armamentarium of BTAI care has the potential to relegate LSAC to historical interest for the majority of BTAI patients requiring TEVAR.

Improved imaging capabilities also continue to optimize the ability to identify and characterize BTAI. The granularity of information obtained from these studies has provided for the development of grading systems that can be used to guide subsequent management. Azizzadeh et al.[20] were among the first to describe a functional grading system for BTAI. This system (Fig. 1), subsequently adopted by the SVS, has been used to develop the SVS clinical practice guidelines for BTAI care.[12] Our present review suggests that contemporary

practice for the majority of BTAI patients is consistent with SVS recommendations. As per SVS recommendation, the majority of Grade I BTAI patients in our present study were managed without repair (76.6%). Also in agreement with SVS recommendations, the majority of Grade II, III, and IV injuries were treated via either TEVAR or OR (72.1%, 87.0%, and 75%, respectively).

It is important to note, however, that alternate grading systems and algorithms have been recently proposed. Both the Vancouver simplified grading system[21] and the alternate classification scheme proposed by Starnes et al.[22,23] have suggested that additional elements of CTA-discernible BTAI data may be of import in guiding therapy. Specifically, these groups have examined the impact of specific aortic lesion dimensions in dictating the need for treatment versus medical management alone. The Maryland group led by Rabin et al.[24] has also proposed that associated secondary signs of injury are important for consideration—specifically the presence of extensive mediastinal hematoma and large left hemothorax. In our present series, we specifically included the parameters from these studies in our analysis of predictors for overall and aortic-related mortalities. None proved predictive in the model used. Our data do suggest, however, that some of these variables require additional investigation. For example, patients with associated mediastinal hematoma were significantly more likely to undergo OR over TEVAR (Table 3). The impact of this decision on outcome remains unclear. In addition, among what some investigators might characterize[21–23] as "minimal injuries" (Grade I and II BTAI) (Table 4), there was no difference in any presenting demographics, risk factors, or in-hospital outcomes between patients undergoing NOM and those undergoing TEVAR. This finding suggests that there may be variability between centers regarding the treatment of these specific injuries. Given that no difference in in-hospital outcomes is apparent, there is a substantial need for collaborative long-term study of these patients to compare the natural history of both untreated injuries and patients treated with TEVAR.

Our present report also notes that OR, while diminished in frequency of use compared with historical controls, continues to be an important potential tool of BTAI care in select patients. The timing of open treatment in our present series seems to have undergone a shift compared with the 2008 AAST report of Demetriades et al.[2] In their report, the mean time from injury to OR was 67.6 hours. Our contemporary series found that, when used, OR was conducted at a mean time from admission of just 36.4 hours. In fact, nearly half (49.1%) of the patients treated via open means underwent repair within 6 hours of admission. We also noted that patients undergoing OR (Table 3) over TEVAR were more significantly injured (mean ISS, 42.4 vs. 35.6), more likely to have an associated mediastinal hematoma with evidence of compression, were more likely to require thoracotomy/sternotomy for non-BTAI indications, and required more PRBCs within the first 24 hours of admission. While specific institutional and surgeon capabilities may have contributed to OR use, our findings suggest that the use of OR has continued to shift toward the emergent setting and situations where the lesion is not anatomically suitable for TEVAR or where resources required for TEVAR cannot be marshaled in time for the treatment.

Ultimately, our study confirms that patients sustaining BTAI continue to die primarily of the burden of associated injuries (Table 5). On multivariate analysis, the strongest independent risk factor for both overall and aortic-related mortalities is the overall ISS (adjusted odds ratio, 1.06; confidence interval, 1.02–1.09; $p < 0.006$; $R^2 = 0.1378$), with other important risk factors including decreased GCS score and increased PRBC requirement within the first 24 hours of admission. As expected, an elevated SVS grade of BTAI injury was associated with both increased overall and aortic-related mortalities (Table 5). Our study is the first contemporary multicenter examination, however, to identify TEVAR as independently protective against aortic-related mortality.

Our study does have important limitations that should be highlighted. The retrospective nature of our investigation is associated with well-known inherent limitations. This is most glaringly highlighted in the inability to better characterize intent, goals, and success of medical blood pressure control for either the primary treatment of BTAI or as an adjunct to TEVAR/OR. We also failed to capture the intent or practice of anticoagulation, lumbar drain use, and approaches to the practices of arterial bypass after LSAC. Although our study captured data beginning in 2005, after the FDA approval of two endovascular devices specifically for BTAI use, we did not in each instance record if FDA devices were used or if the recommended-for-use guidelines were followed in each instance. Although our present study was multicenter in design, all participating centers were verified trauma centers with advanced capabilities for BTAI care. Extrapolation of our findings to a wider array of care environments should, therefore, be exercised with caution. We also recognize that even during the 5-year time frame of study, some changes in practice may have occurred. Our failure to capture the year of injury (we can only confirm that the injury occurred during the relatively brief contemporary study time frame) introduces the potential for residual confounding by cohort time that we are not able to address directly.

Our study is also limited in the availability of specific data regarding treatment failures and the six deaths occurring during the procedure (two TEVARs; four ORs). Although we can confirm that none of these deaths occurred because of aortic perforation in the conduct of repair (a categorical variable captured in our data collection), the precise cause of death was not well elucidated in each instance. In addition, although aortic-defined mortality was defined a priori for our study group, the definition used left room for interpretation by the assessing primary site investigator from each site. Standardized definitions for aortic-related mortality in this setting would be useful. Finally, our study captured only in-hospital outcomes. There is a significant need for long-term studies on outcomes of both untreated and treated BTAI patients.

CONCLUSION

Our study is the largest contemporary examination of BTAI in the literature. Our findings suggest that optimal BTAI care remains an ongoing challenge of trauma care in the endovascular era. In the context of contemporary practice, NOM failures for SVS Grade I to III injuries are rare, but TEVAR use seems independently protective against aortic-related mortality.

TEVAR-specific complication rates have declined compared with previous reports. There remains a persistent need to examine the optimal treatment of BTAI, particularly lower-grade injuries. Long-term studies are required to determine the natural history of both untreated and treated BTAI.

AUTHORSHIP

This work represents the original efforts of the investigators. All listed authors contributed to the study design, data collection, data interpretation, and manuscript development.

DISCLOSURE

The authors declare no conflicts of interest.

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