Implementation and results of a practical grading system for blunt thoracic aortic injury

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ABSTRACT

Objective: We previously proposed a grading system for blunt thoracic aortic injury (BTAI) designed to guide therapy. This study analyzed our outcomes since implementing this system.

Methods: A single-center, retrospective study was conducted of consecutive patients presenting with BTAI between January 2014 and December 2017. This grading system classified injuries into minimal, moderate, or severe on the basis of computed tomography imaging. Primary end points included timing of operation and mortality. Secondary end points included associated injuries, aortic anatomy, and operative details as well as 30-day follow-up.

Results: During the study period, 87 patients with BTAI were identified. The majority of patients had a moderate injury occurring just distal to the left subclavian artery (LSA); 59 patients underwent thoracic endovascular aortic repair (TEVAR), whereas none of the patients with minimal injury (n = 24) required surgical treatment. The mean time to repair was 53 hours (1-191 hours) for moderate injury and 3.6 hours (0-7 hours) for severe injury. The average diameter and length of the endograft was 26 mm and 112 cm, respectively, and the LSA was covered in 42% of patients. Intravascular ultrasound to confirm sizing was used in 83% of cases. Most patients (92%) received intravenous heparin during TEVAR; the remainder received only heparin sheath flush because of concern for intracranial hemorrhage. None of the patients underwent LSA revascularization or developed stroke or spinal cord ischemia as a result of the procedure. Operative complications were seen in 6% of patients and included 1 femoral pseudoaneurysm, 1 lower extremity compartment syndrome, 1 type II endoleak requiring LSA embolization, and 1 intracranial bleed. The 30-day mortality was 7% (one aorta-related death). On 30-day postoperative follow-up, computed tomography imaging uniformly revealed positive aortic remodeling, and no secondary aortic intervention was required.

Conclusions: Institutional implementation of our grading system has streamlined treatment of BTAI, and our results confirm the following: patients with minimal injury do not require surgical treatment; patients with moderate injury can safely undergo TEVAR in a semielective manner once they are stable from other injuries; and patients with severe injury require emergent repair. These procedures are expeditious and can be successfully performed percutaneously with a single endograft. Complications are rare, and follow-up reveals excellent remodeling of the aorta, likely resulting in lengthened interval surveillance requirements for these patients. (J Vasc Surg 2019;70:1082-8.)

Keywords: Blunt aortic injury; Vascular trauma; TEVAR; BTAI

Thoracic endovascular aortic repair (TEVAR) has become the preferred modality for treatment of blunt thoracic aortic injury (BTAI).[1,2] It has previously been reported that 75% of patients with BTAI died before arriving at a hospital.[3] The prehospital care now available and access to advanced computed tomography angiography (CTA) imaging have allowed many patients with this injury to survive. In addition, the American Association for the Surgery of Trauma (AAST) trials have shown that mortality and paraplegia are reduced with TEVAR. In the AAST-1 trial, all patients underwent open repair, whereas 65% of patients in the AAST-2 trial underwent TEVAR, with mortality declining from 22% in the AAST-1 trial to 13% in the AAST-2 trial.[4,5]

Patients with BTAI have numerous concomitant injuries, with Injury Severity Scores that range in the high 30s. The injuries include intracranial hemorrhage, pulmonary contusion, intra-abdominal solid organ injuries, and pelvic fractures that lead to prioritization of repair to prevent exsanguination. As treatment of BTAI has evolved to TEVAR, we are often faced with scenarios in which we must decide the acuity of repair in the face of these other injuries. Interestingly, the timing of the aortic repair was shorter in the AAST-1 trial (16.5 hours) vs the AAST-2 trial (54.6 hours), but the earlier operation did not result in lower mortality. The decrease in mortality seen in the AAST-2 trial is likely attributed to endovascular repair and a better understanding of the injury with regard to CTA characteristics.[4-6]

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A number of guidelines exist. The Society for Vascular Surgery (SVS) grading system is the most widespread classification scheme for BTAI currently used by vascular surgeons. In this grading system, four categories are defined: grade I, intimal tear; grade II, intramural hematoma; grade III, pseudoaneurysm; and grade IV, rupture.[7] This classification scheme, although descriptive, does not clearly guide therapy. We have previously published on our institution's grading system, which we think can guide therapy. In our classification, BTAI is classified as minimal, moderate, or severe. With minimal injuries, no further therapy or imaging is required. Moderate injuries are approached in a semielective manner, and severe injuries are repaired emergently[8-10] (Fig 1). We review our experience with BTAI since implementing this grading system at our institution with outcomes and descriptive details of these repairs.

METHODS

This study was approved by the University of Washington Institutional Review Board. A waiver of the need to obtain consent from patients was approved. This is a retrospective cohort study of all patients diagnosed with BTAI at our level I trauma center from January 1, 2014, to December 31, 2017. Patients were identified using the hospital's trauma database, which includes every trauma patient admitted to our institution. Using this comprehensive database, we identified all patients with BTAI by *International Classification of Diseases, Ninth Revision* diagnostic codes for BTAI (thoracic 901.0) and *Tenth Revision* codes (injury of thoracic aorta, S25.0). Medical records, including referral facility records, transportation records, and radiology records, were reviewed to establish injury mechanism, concomitant injuries, operative details, anatomic findings, and outcome. Our grading system classified injuries into minimal, moderate, or severe on the basis of preoperative computed tomography (CT) imaging. Minimal injuries are defined as having no external aortic contour abnormality and an intimal tear or thrombus, or both, sized $<$10 mm. Moderate injuries are those with any external aortic contour abnormality, such as a pseudoaneurysm, or an intimal tear $>$10 mm. Severe injuries are those in which active extravasation is visualized or a contained rupture with a left subclavian artery (LSA) hematoma $>$15 mm.

Each initial CT scan was reviewed retrospectively by a vascular surgeon blinded to the treatment performed for each patient at the moment of the injury. The vascular surgeon then classified each CT scan as having a minimal, moderate, or severe aortic injury. Clinical end points included timing of operation and mortality. Secondary end points included associated injuries, aortic anatomy, and operative details as well as 30-day follow-up.

ARTICLE HIGHLIGHTS

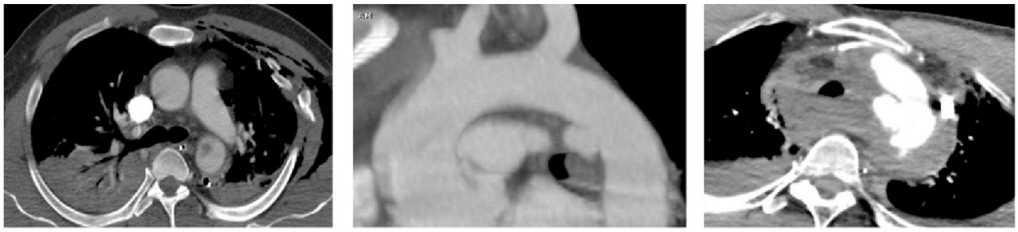
- **Type of Research:** Single-center, retrospective cohort study
- **Key Findings:** During a 3-year period, 87 patients were treated; 28% presented with minimal blunt thoracic aortic injury (BTAI), 63% with moderate, and 9% with severe. None of the patients with minimal injury underwent surgical repair. There were 59 patients who underwent thoracic endovascular aortic repair; 86% were performed percutaneously. None of the patients developed stroke or spinal cord injury or required reintervention.
- **Take Home Message:** Patients with moderate BTAI can be repaired in a semielective manner, patients with severe BTAI require emergent repair, and those with minimal BTAI do not require surgical treatment. The majority of operative procedures are percutaneously performed in an expeditious fashion with low fluoroscopy time and contrast material use.

Data were analyzed using Microsoft Excel 2013 software (Microsoft, Redmond, Wash) and SPSS version 19 (IBM Corp, Armonk, NY). The Injury Severity Score was reported as a median and range; other continuous data were presented as means and standard deviation. Timing to repair was measured in all patients in hours from admission to our emergency department to anesthesia start time in the operating room; that includes patients transferred from another hospital.

RESULTS

A total 87 patients with BTAI were identified during the study period in our trauma database. Of those, 67 (77%) were male; mean age was 47 years (16-91 years). The mean Injury Severity Score was 36 (4-75). Associated injuries were seen in every patient, with 30% of patients presenting with concomitant intracranial hemorrhage, 44% with solid organ injury, 38% with a pelvic fracture, and 42% with a long bone fracture. Patients with intracranial injuries were evaluated by the neurosurgery team; surgical repair was performed when the neurosurgical service thought the intracranial injury was stable, as demonstrated in at least two consecutive head CT scans. Bovine arch anatomy was seen in 13% of patients. Mean aortic diameter proximal to the injury was 23 mm (16-30 mm) by CT scan measurements. Table I contains demographic and anatomic features per type of BTAI.

A comparison of our grading system and the SVS grading system is seen in Table II. In 63% (55) of patients, a moderate injury occurred distal to the LSA; minimal injuries were seen in 28% (24) of patients and severe in 9% (8) of patients. None of the patients underwent open aortic repair. There were 68% (59) of patients who underwent TEVAR, 95% (52) of moderate injury and 87% (7) of



MINIMAL	MODERATE	SEVERE
▪ No external contour abnormality ▪ Intimal tear and/or thrombus is <10mm	▪ External contour abnormality or intimal tear >10mm	▪ Active extravasation ▪ LSA hematoma >15mm
NO INTERVENTION ▪ Optional follow-up imaging	**SEMI-ELECTIVE REPAIR** ▪ Stabilization of concomittant injuries ▪ Impulse control	**IMMEDIATE REPAIR** ▪ BAI takes first priority

Fig 1. Harborview blunt thoracic aortic injury (BTAI) grading system. *BAI,* Blunt aortic injury; *LSA,* left subclavian artery.

Table I. Baseline characteristics by severity of injury

	Minimal aortic injury (n = 24)	Moderate aortic injury (n = 55)	Severe aortic injury (n = 8)
Age, years	50 (18-86)	46 (16-89)	45 (18-91)
Male	20 (83)	43 (76)	4 (50)
ISS	35 (4-66)	38 (17-66)	43 (17-75)
Intracranial hemorrhage	4 (17)	20 (36)	2 (25)
Spine fracture	11 (46)	36 (65)	3 (37)
Solid organ injury	10 (42)	24 (44)	4 (50)
Pelvic fracture	10 (42)	19 (34)	3 (37)
Long bone fracture	10 (42)	25 (45)	2 (25)
Bovine arch anatomy	1 (4)	7 (13)	3 (37)
Aortic diameter proximal to injury, mm	24 (17-29)	23 (16-30)	22 (20-25)

ISS, Injury Severity Score.
Categorical variables are presented as number (%). Continuous variables are presented as median (range).

severe injuries, whereas none of the patients with minimal injury (n = 24) underwent surgical treatment. Three patients with moderate or severe injury did not receive surgical treatment and received comfort care measures only following the patient's family's wishes; 1 presented with diffuse axonal injury, 1 presented with a devastating head injury, and 1 had a history of dementia. The patient with a severe injury was 91 years old, and the family did not consent for surgical treatment; this is the only patient who died of aortic injury. The mean time to operative repair from admission to our institution was 53 hours (1-191 hours) for moderate injury and 3.6 hours (0-7 hours) for severe injury.

All procedures were performed under general anesthesia. Mean operative time was 79 (29-168) minutes with a mean fluoroscopy time of 4.8 (2.1-9.6) minutes. We routinely used activated clotting time (ACT) for monitoring of heparin dosage, which was performed as a point-of-care test in the operating room. During most of the study period, our point-of-care ACT machines were not linked to our medical records, and the ACT results were unfortunately not reliably collected. The average diameter and length of the endograft was 26 mm and 112 cm, respectively. There were 33 patients (56%) who received a Gore C-TAG device (W. L. Gore & Associates, Flagstaff, Ariz), 23 patients (39%) who received a Medtronic Talent or Valiant device (Medtronic, Santa Rosa, Calif), and 3 patients (5%) who received a Cook Zenith device (Cook Medical, Bloomington, Ind). None of the patients required brachial access or body floss

Table II. Operative findings and outcomes by severity of injury

SVS classification system	Grade I (n = 21)		
	Grade II (n = 6)		
		Grade III (n = 52)	
			Grade IV (n = 8)
Harborview BTAI grading system	Minimal aortic injury No contour abnormality	Moderate aortic injury Any contour abnormality or >10-mm intimal flap	Severe aortic injury Aortic rupture
No. of patients	24	55	8
Beta blocker	6 (25)	46 (84)	2 (25)
Surgical repair			
Open	0	0	0
TEVAR	0	52	7
Timing of operative repair, hours since admission	N/A	53 (1-191)	3.6 (0-9)
Operative time, minutes		80 (40-168)	76 (29-132)
Contrast material use, mL		70 (25-160)	48 (30-80)
Fluoroscopy time, minutes		4.8 (2.1-9)	5.7 (3.1-9.6)
IVUS use		45 (87)	4 (57)
Subclavian artery coverage		22 (42)	3 (43)
Successful percutaneous closure		45 (81)	6 (85)
Length of stay, days	15 (3-72)	25 (4-103)	20 (5-50)
30-day CTA follow-up	15 (65)	44 (85)	6 (86)
30-day mortality	1 (4)	4 (7)	1 (12)
Aorta-related mortality	0	0	1 (12)

BTAI, Blunt thoracic aortic injury; *CTA,* computed tomography angiography; *IVUS,* intravascular ultrasound; *N/A,* not applicable; *SVS,* Society for Vascular Surgery; *TEVAR,* thoracic endovascular aortic repair.
Categorical variables are presented as number (%). Continuous variables are presented as median (range).

through-and-through wiring techniques for positioning or deployment of the endograft. The LSA was covered in 43% of patients. Intravascular ultrasound (IVUS) to confirm sizing was used in 83% of cases. All the endografts were delivered through a common femoral artery approach; conduits were not required in this cohort. Successful percutaneous access and repair were achieved in 86% of patients. Most patients (92%) received intravenous heparin during TEVAR; the remainder received only heparin sheath flush because of concern for intracranial hemorrhage. None of the patients underwent LSA revascularization or developed stroke or spinal cord ischemia as a result of the procedure. Five patients had more than one surgical intervention performed during the index procedure; of note, all those cases were patients with moderate aortic injuries. None of the patients with severe injuries underwent other procedures more than TEVAR during the index procedure. In detail, one patient underwent TEVAR with abdominal washout and pelvic external fixation; one had TEVAR with abdominal washout, another with pelvic external fixation, and another with femoral internal fixation; and one patient had a washout of large degloving thigh injury after completion of TEVAR. Operative complications were seen in 6% of patients and included 1 femoral pseudoaneurysm, 1 lower extremity compartment syndrome, 1 type II endoleak requiring LSA embolization, and 1 intracranial bleed. The 30-day postoperative follow-up CT imaging was obtained in 85% of patients undergoing TEVAR and uniformly revealed positive aortic remodeling. Of the 24 patients with minimal aortic injuries, 15 (65%) had follow-up imaging, with a mean time between injury and repeated imaging of 42 days (range, 2-182 days) Resolution or improvement of injury was seen in all the follow-up studies for minimal aortic injuries.

No patient in our cohort had evidence of unsatisfactory remodeling, manifested as persistent or enlarging pseudoaneurysm sac, and no secondary aortic intervention was required (Fig 2). The 30-day mortality was 7%. One aorta-related death occurred in a 91-year-old woman who presented with a severe BTAI and had multiple comorbidities. Her family decided against surgical treatment, and she died <6 hours after admission.

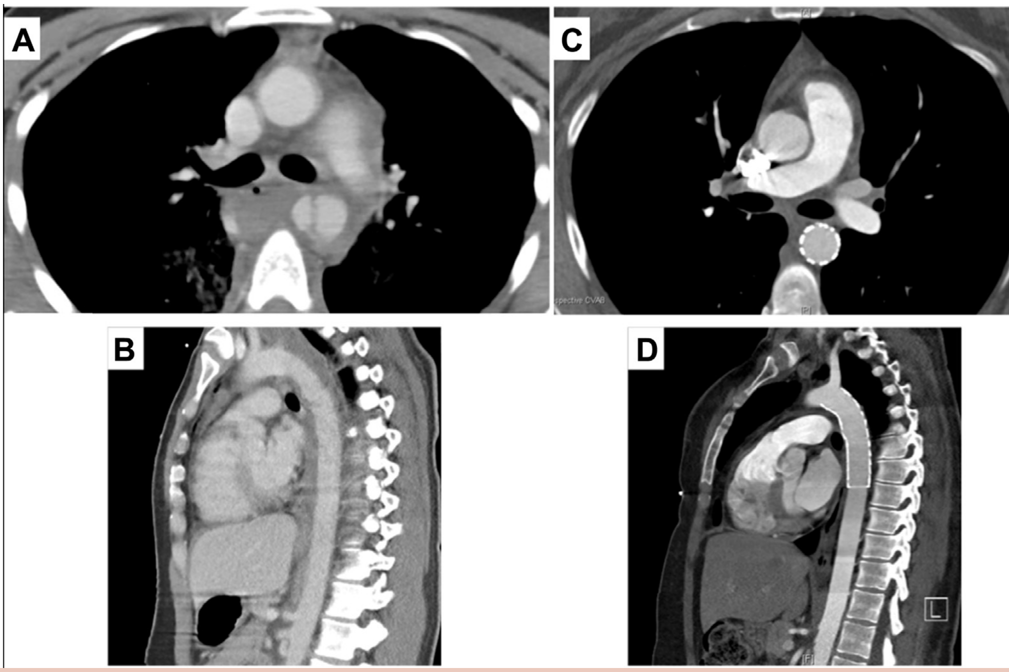


Fig 2. A and **B,** Trauma computed tomography (CT) scan showing moderate blunt aortic injury in axial and sagittal views. **C** and **D,** CT scan performed 1 year after thoracic endovascular aortic repair (TEVAR) showing aortic remodeling without any remaining pseudoaneurysm sac.

DISCUSSION

In the 3-year time period reviewed since implementing this grading system, we had 87 patients present to our institution with BTAI. If we were to classify these patients according to the SVS classification, it would be as follows: grade I, 21 patients; grade II, 6 patients; grade III, 52 patients; and grade IV, 8 patients. In our grading system, the classification is as follows: minimal aortic injury, 24 patients; moderate aortic injury, 55 patients; and severe aortic injury, 8 patients. It is obvious that our severe injury and the SVS grade IV injury patients correlate as it is an aortic rupture and requires immediate treatment. It is the SVS grade I and grade II classes that elicit difficulty in identifying the correct treatment and management. In our classification scheme, the patients with minimal injury required no intervention and likely no further follow-up, whereas almost all of the moderate injuries underwent repair in a semielective fashion. The natural history of SVS grade I and grade II injuries has been evaluated by Osgood et al[11] in a retrospective study reviewing a 10-year period at their institution. They identified 50 grade I and grade II injuries that were classified further as 46 grade I injuries and four grade II injuries. Forty-one patients had follow-up imaging at a mean 86 days after injury and 23 of 43 patients (55%) had complete resolution of their injury; 17 patients (16%) had no change and two patients (5%) progressed to grade III injuries with a mean time to progression of 16 days. They concluded that injury progression is rare, and we believe this finding is consistent with our experience; in the 24 patients with minimal injury, we did not request additional imaging. Interestingly, 65% of the minimal injury group underwent CTA for evaluation of other injuries, and in review of these images, no patient had evidence of progression of the BTAI to a higher grade. Currently, no established follow-up protocol for this population of patients has been developed, and many are lost to follow-up as they arrive at our institution from a wide geographic area.

The SVS guidelines recommend early TEVAR for BTAI and delayed TEVAR (>24 hours) for those who have concomitant injuries that make repair prohibitive.[7] The mean timing of TEVAR for the patients with moderate-grade injury was 53 hours in our series; it was performed in a semielective manner once it was deemed safe because of the other injuries sustained and to ensure that the procedure on these polytrauma patients was not unnecessarily performed "after hours." The optimal timing for the repair is decided in conjunction with the critical care team and other teams involved in the patient's care and taking into account the other life-threatening injuries. In this group, 36% of patients had an intracranial hemorrhage and 65% had a spinal fracture that required a period of stabilization before pursuing repair. The use of the grading system at our institution allows the other services involved (trauma surgery, neurosurgery, and orthopedic surgery) to understand that a TEVAR is *required* but is not an *emergent* procedure. In these situations, we institute antihypertensive therapy with impulse control. This therapy has been standard at our institution for BTAI since Fabian et al[12] published the beneficial findings in 1998.

Numerous observational studies have identified the benefit of delayed repair in well-selected patients, and our findings in the moderate injury patients support this concept.[13-16] In a study by Marcaccio et al,[17] BTAI was studied in a large database (National Trauma Databank National Sample Program); 2045 patients with BTAI were identified, and 507 who underwent TEVAR with complete data could be analyzed. There were 378 patients who underwent early TEVAR (<24 hours), whereas 129 underwent delayed TEVAR (>24 hours). Mortality was 11.9% in the early TEVAR patients and 5.4% in the delayed TEVAR patients. After adjustment for confounders, decreased mortality was evident on multivariable analysis, indicating that delayed repair has a reduced mortality vs early repair. We believe their study supports our grading system as we had a 4% mortality rate in the moderate aortic injury group with no aorta-related mortality of repair performed in a semielective fashion.

The operative details of our series underscore the significant evolution of endovascular therapy since the AAST-2 trial in 2008. At that time, only one endograft had been developed, the Gore TAG, and it was designed for thoracic aneurysms. Many of the endovascular procedures were performed with aortic cuffs and devices not designed for this disease.[3,5,18] The Gore device has been modified (C-TAG), and two additional devices are now available and approved by the Food and Drug Administration to treat BTAI. Our experience with BTAI also reveals that this procedure can be performed in an efficient manner. The average operative time for the patients with moderate injury was 80 minutes, and the average fluoroscopy time was 4.8 minutes, with an average contrast material use of 70 mL. In addition, in this group, 87% underwent IVUS to confirm the proximal and distal diameters. Our institution as well as others have published on the discrepancies of the initial CTA measurement in the hypovolemic trauma patient vs the resuscitated patient and strongly recommends IVUS measurements to adequately size the endograft.[19,20] We advocate for percutaneous access and were successful in 81% of the moderate injury patients. One patient had a femoral pseudoaneurysm that required thrombin injection, and in those patients with percutaneous access failure, an intraoperative controlled cutdown was performed without issue. The patients with severe injury had a shorter time to the operating room (3.6 hours), a shorter procedure (76 minutes), and less contrast material (48 mL), all of which are consistent with an emergent procedure; however, in this group, the fluoroscopy time was slightly longer (5.7 minutes), perhaps related to less use of IVUS (57%).

In the majority of our patients (58%), we were able to preserve the LSA. In those cases in which we did cover the LSA, no patients required revascularization or had a stroke. Many of the earlier recommendations for revascularization of the LSA used the indications for aneurysmal disease.[21] The SVS clinical practice guidelines recommend selective revascularization of the LSA for BTAI.[7] More recently, McBride et al[22] found that intentional coverage of the LSA is safe and without complications, although they did acknowledge that long-term follow-up is difficult in this population of patients. The current instructions for use for the thoracic endografts recommend 20 mm of healthy proximal and distal aortic landing zones. The instructions for use do not specify a difference between BTAI and aneurysms. Loh et al[23] recently described their series in which they preserved the LSA in 20 patients with a proximal landing zone that was <20 mm and had excellent remodeling on follow-up imaging with healing of the aorta. In our series, coverage of the LSA did lead to a type II endoleak in one patient that required embolization of the proximal LSA. The injury pattern that is seen with BTAI may not mandate coverage of the LSA as the majority of patients have healthy nonaneurysmal aortas; but if coverage of the LSA is required to exclude the injury, few short-term complications have been reported. The average diameter of the endografts used was 26 mm and was based on oversizing of only 10%, with the majority undergoing IVUS for accurate measurements. The average length of the endograft was 112 cm, consistent with covering only the injured segment with acceptable healthy proximal and distal seal zone.

The 30-day mortality was 7% in our series, with one patient suffering an aorta-related death; that patient arrived with a severe injury, and her family elected to withhold surgical treatment because of her advanced age and severity of concomitant injuries. Postoperative complications included one intracranial hemorrhage and one type II endoleak requiring LSA embolization. Our mortality is less than in older series and consistent with more modern series.[24-26] The fact that five (83%) of the six deaths were not related to the aorta validates the overall severity of the associated injuries these patients suffer; 85% of patients in the moderate injury group and 86% of patients in the severe injury group who survived underwent 30-day follow-up CTA. All of the findings revealed excellent aortic remodeling, and no secondary aortic interventions were required.

Our study has several limitations. It is a retrospective series that is prone to inherent bias. Our institution, a level I trauma facility, has a well-established vascular surgery division that performs all of the vascular trauma procedures along with a large number of vascular emergencies that may not be consistent with other vascular practices in the country. In addition, we have well-established clinical protocols for entities such as ruptured abdominal aortic aneurysms that have increased the understanding of endovascular procedures for all of our operative team members. The use of this grading system is understood by the trauma service and other operative team members so that we do not have confusing issues on when to repair the aorta.

CONCLUSIONS

The implementation of this grading system has streamlined our treatment of BTAI. Patients with moderate injury can be repaired in a semielective manner, patients with a severe injury require an emergent repair, and those with minimal injuries do not require surgical treatment. The majority of operative procedures are percutaneously performed in an expeditious fashion with low fluoroscopy time and contrast material use. Aortic mortality is rare, and follow-up imaging reveals excellent aortic remodeling that can lead to fewer and longer interval surveillance periods for these patients.

AUTHOR CONTRIBUTIONS

Conception and design: EQ, BS, NT, NS
Analysis and interpretation: EQ, NS
Data collection: EQ, NS
Writing the article: EQ, BS, NT, NS
Critical revision of the article: EQ, BS, NT, NS
Final approval of the article: EQ, BS, NT, NS
Statistical analysis: Not applicable
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Overall responsibility: EQ

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