## Title

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# Call for a new classification system and treatment strategy in blunt aortic injury

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***Objective:*** **The current Society for Vascular Surgery (SVS) classification scheme for blunt aortic injury (BAI) is descriptive but does not guide therapy. We propose a simplified classification scheme based on our robust experience with BAI that is descriptive and guides therapy.**

***Methods:*** **Patients presenting with BAI between January 1999 and September 2014 were identified from our institution's trauma registry. We divided patients into eras by time. Era 1: before the first United States Food and Drug Administration (FDA)-approved thoracic endovascular aortic repair (TEVAR) device (1999-2005); era 2: FDA-approved TEVAR devices (2005-2010); and era 3: FDA-approved BAI-specific devices (2010-present). Baseline demographic information, Injury Severity Score, hospital details, and survival were collected and compared. Our classification scheme was minimal aortic injury, SVS grade 1 and 2; moderate aortic injury, SVS grade 3; and severe aortic injury, SVS grade 4.**

***Results:*** **We identified 226 patients with a diagnosis of BAI: 75 patients in era 1, 84 in era 2, and 67 in era 3. Mean Injury Severity Score was 39.5 (range, 16-75). The BAI-related in-hospital mortality was significantly higher before endovascular introduction in era 1 (14.6% vs 4.8%; $P = .03$), but was not significantly different between eras 2 and 3 or before and after BAI-specific devices were introduced ($P = .43$). Of 146 patients (64.6%) who underwent aortic intervention, 91 underwent endovascular repair, and 55 underwent open repair. All but nine patients (94%) had a moderate or severe injury. Survival across all three eras of patients undergoing operative intervention was 80.2%. Survival in eras 2 and 3 was higher than in era 1 (86.4% vs 73.8%) but was not significant ($P = .38$). Of 47 patients in eras 2 and 3 with minimal aortic injury, 45 (96%) were managed nonoperatively, with no BAI-related deaths. After 2007, follow-up imaging was obtained in 38 patients (80%) with minimal aortic injury, and progression was not observed. Computed tomography scans showed the injury in 13 patients appeared stable, 19 had complete resolution (50%), and 6 had a decreasing size of injury.**

***Conclusions:*** **Our experience confirms that BAI-related mortality for patients who survive to presentation is now 5%. From our findings during the past 15 years, we propose simplification of the SVS grading criteria of BAI into minimal, moderate, and severe based on treatment differences among the three groups. Minimal aortic injury can be successfully managed nonoperatively without mandatory follow-up imaging. Moderate aortic injury can be managed semielectively with TEVAR, and severe aortic injury, requires emergency TEVAR. (J Vasc Surg 2016;64:171-6.)**

That blunt aortic injury (BAI) has a high rate of prehospital mortality has been well established. For patients who survive long enough for evaluation at a hospital, the current standard of treatment in adults with BAI is endovascular repair. Landmark trials and publications from the mid-2000s prospectively validated thoracic endovascular aortic repair (TEVAR) for adults with thoracic aortic aneurysms, with lower rates of paralysis, morbidity, and mortality compared with open surgical repair.[1-3] This was applied to patients with traumatic aortic injury in the American Association for the Surgery of Trauma (AAST) I trial.[2] Although a single United States Food and Drug Administration (FDA)-approved device for BAI was available at that time, device-related complications were still significant, and the AAST I trial called for urgent improvement of endovascular devices.

Technologic advances have continued to improve survival and decrease device-related complications.[2,4,5] Most recently in 2015, DuBose et al[6] cited improved outcomes with current devices approved for TEVAR in BAI. Three FDA approved devices were currently available for the treatment of BAI in the United States at the time of this publication.

Now that technology has evolved to effectively treat BAI, a new grading system based on severity of injury as it relates to treatment strategy is warranted. The most accepted and widely established grading system proposed by the Society for Vascular Surgery (SVS), while straightforward and descriptive, does not guide therapy.[4,7] We propose a simplified classification scheme combining SVS grades with our prior publication and high-volume experience with BAI that is both descriptive and provides a guide for therapy.

## METHODS

After gaining Institutional Review Board approval to conduct this study, including waiver of consent, we

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conducted a single-institution retrospective review of all patients diagnosed with BAI at our level 1 trauma center from January 1999 to September 2014 using the hospital's Trauma Database, which encompasses every trauma admission to our institution.

Within this comprehensive database, we identified all patients with BAI using International Classification of Diseases, Ninth Revision diagnosis codes for BAI (thoracic 901.0) and procedural codes for endovascular repair (thoracic 39.73). Medical, operative, and radiology records were reviewed to ascertain prehospital data, imaging studies, and preoperative injury and access vessel sizing, concomitant injuries, operative details, hospital length of stay, and follow-up information. For patients lost to follow-up, the state Social Security database was queried for death certificates.

The Injury Severity Score (ISS) was reported as a median and range, time from injury to arrival was reported in hours and minutes, time to repair was reported in days, and length of stay reported in days. We divided patients into the following eras:

- Era 1: Before the first FDA-approved thoracic endovascular device (1999-March 2005)
- Era 2: The first FDA-approved TEVAR device Gore TAG (W. L. Gore and Associates, Flagstaff, Ariz; March 2005-June 2010)
- Era 3: FDA-approved BAI-specific devices (June 2010-present)

We compared hospital and follow-up course between eras. Lastly, we applied our proposed classification based on our results:

- Minimal: SVS grade 1 and 2 injuries, or no external contour abnormality and an intimal tear or thrombus, or both, sized <10 mm
- Moderate: SVS grade 3 injuries
- Severe: SVS grade 4 injuries

As a matter of review, the SVS criteria to grade BAI severity are as follows: grade 1—intimal tear, grade 2—intramural hematoma or large intimal flap, grade 3—pseudoaneurysm, and grade 4—free rupture.[4,7,8]

Statistical analysis was performed using SPSS 19 software (IBM Corp, Armonk, NY). Data are reported as a mean, standard deviation, median, and range where appropriate. Categoric and dichotomous variables were compared using the $\chi^2$ test. Related nonparametric continuous variables were compared using the signed rank and Wilcoxon signed rank test, and unrelated groups were compared using the Mann-Whitney *U* test. All *P* values reported are two-sided, and a *P* value of <.05 was considered significant.

## RESULTS

We identified 226 patients in our trauma database with a diagnosis of BAI treated at our medical center. The incidence of BAI across the study period was 0.26% of all trauma admissions to our institution. Table I highlights the demographics of our patient population. We grouped patients as described above by BAI treatment eras. Era 1 had 75 patients, era 2 had 84 patients, and era 3 had 67 patients. The mean ISS was 39.2 (range, 16-75) and did not significantly differ between eras. Mean ISS by SVS criteria is also listed in Table I, and was significantly different in grade 4 injuries only ($P = .001$). Of 146 patients (64.6%) who underwent aortic intervention, 91 had endovascular repair and 55 had open repair. The injury in 137 (94%) was classified as moderate or severe.

**Table I.** Demographic information

| *Variable* | *Mean ± SD (range) or No. (%) (N = 226)* | *ISS, mean ± SD* |
|---|---|---|
| Age, years | 42 ± 20.2 (6-91) | |
| Male | 167 (74) | |
| ISS | 39.2 ± 12.5 (16-75) | |
| Grade by SVS criteria | | |
| 1 | 50 (22.1) | 37.8 ± 13.2 |
| 2 | 12 (5.3) | 33.1 ± 9.7 |
| 3 | 149 (65.9) | 39.2 ± 10.9 |
| 4 | 15 (6.6) | 51.1 ± 22 |

*ISS*, Injury Severity Score; *SD*, standard deviation; *SVS*, Society for Vascular Surgery.

The left subclavian was covered in 33 of 91 patients (36.1%), and one patient required delayed revascularization after complaints of arm fatigue on outpatient follow-up. All patients with minimal injury in era 3 were managed nonoperatively, and no patients in era 3 had an open operative intervention. Mean time to repair of moderate injuries in era 3 was 2.1 days (range, 1 hour to 7 days). Mean time of arrival to time of repair for severe injuries in era 3 was 8 hours (range, 30 minutes to 21 hours).

Eight patients with severe injury in eras 2 and 3 underwent an attempt at operative repair. Six were endovascular attempts, and two were open. Two patients in the endovascular group died in the operating room before deployment. Both patients in the open group died in the operating room. The four patients (50%) who survived endovascular repair were discharged from the hospital. Images from one of these patients are seen in Fig 1. Table II details the treatment modality of each era by our proposed classification scheme.

Table III describes the in-hospital mortality by era and treatment modality. All-cause in-hospital mortality across the three eras was 20.4% and did not differ between eras ($P = .21$). All-cause mortality in era 3 was lower than in eras 2 and 1 (14.9%, 19%, and 26.7%, respectively), but only trended toward significance ($P = .08$). Survival across eras of all patients undergoing operative intervention was 80.2%. Operative survival in eras 2 and 3 was higher vs era 1 (86.4% vs 73.8%) but was not significant ($P = .38$). BAI-related in-hospital mortality was significantly higher in era 1, before endovascular introduction (14.6% vs 5.3%; $P = .03$), but was not significantly different before and after BAI-specific devices were introduced between eras 2 and 3 ($P = .43$).

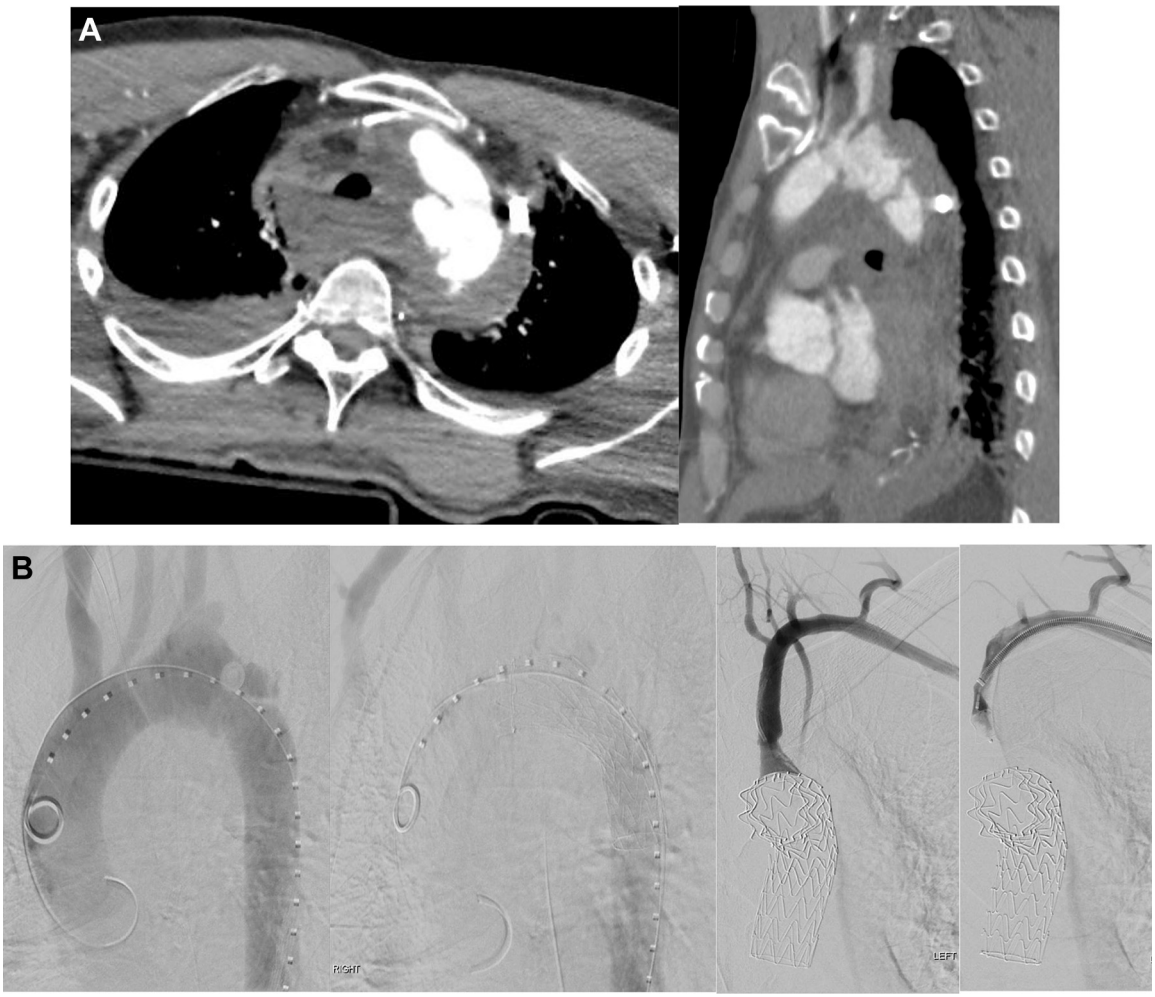



**Fig 1.** Severe blunt aortic injury (BAI) treated with emergency thoracic endovascular aortic repair (TEVAR). **A,** Computed tomography (CT) angiography shows an external contour abnormality and active contrast extravasation into the mediastinum. **B** (from *left* to *right*), Angiogram shows active contrast extravasation and a large external contour abnormality just distal to the left subclavian. TEVAR is performed showing persistent flow into the injury from the left subclavian. Retrograde access through the left subclavian and plug at the origin resulted in adequate seal.

Open operative BAI-related mortality vs endovascular BAI-related mortality was significant, with endovascular mortality less than half that of the open mortality rate (8.8% vs 20%; $P = .05$). Although follow-up is routinely poor in nonoperative trauma, follow-up imaging was obtained in 38 patients (80%) with minimal injury after 2007, and no progression was observed in any of these patients. The injury on the computed tomography (CT) scans for 13 patients appeared stable, 19 had complete resolution (50%), and 6 had a decreasing size of injury noted, but the mean interval scan length of time was only 5 ± 3.5 days (range, 1-17 days).

## DISCUSSION

We previously published a new classification scheme for BAI based on the presence or absence of an external contour abnormality.[8] With our updated data, we now propose a combination of this classification with the SVS grades to create a simplified system based on treatment and additional follow-up information regarding the natural history of minimal, moderate, and severe aortic injuries (Fig 2). As stated above, minimal injuries are defined as having no external contour abnormality and an intimal tear or thrombus, or both, sized <10 mm. On the basis of previous studies from our institution and our current findings regarding progression of minimal injuries, we no longer routinely image these patients in follow-up; however, we cannot recommend eliminating all follow-up in these patients because this was a small patient cohort with very short-term interval scans. Furthermore, some patients had stable-sized injuries on the first follow-up imaging. The presumption is that with medical therapy, the injuries will continue to resolve. These patients can be managed medically with antiplatelet therapy. We currently recommend 81 mg aspirin for 4 to 6 weeks.

**Table II.** Open, endovascular, and nonoperative treatment of blunt aortic injury (BAI) over the past 15 years by proposed BAI injury classification system

| *Variable* | *Era 1 1999-3/2005 (n = 75), No. (%)* | *Era 2 3/2005-6/2010 (n = 84), No. (%)* | *Era 3 6/2010-present (n = 67), No. (%)* | *Totals (N = 226), No. (%)* |
|---|---|---|---|---|
| Open repair | 43 (57.3) | 12 (14.2) | 0 | 55 (24.3) |
| Aortic injury | | | | |
| Minimal | 3 | – | – | 3 |
| Moderate | 33 | 10 | – | 43 |
| Severe | 7 | 2 | – | 9 |
| Endovascular repair | 22 (29.3) | 33 (39.3) | 36 (53.7) | 91 (40.2) |
| Aortic injury | | | | |
| Minimal | 4 | 2 | – | 6 |
| Moderate | 18 | 27 | 34 | 79 |
| Severe | – | 4 | 2 | 6 |
| Nonoperative | 10 (13.3) | 39 (46.4) | 31 (46.3) | 80 (35.4) |
| Aortic injury | | | | |
| Minimal | 8 | 23 | 22 | 53 |
| Moderate | 2 | 16 | 9 | 27 |
| Severe | – | – | – | – |
| LSA covered | 2/22 | 11/33 | 20/36 | 33/91 (36.3) |
| Revascularized | | | 1 | 1/91 (1.1) |

*LSA*, Left subclavian artery.

**Table III.** Mortality across eras

| *Mortality* | *Era 1 1999-3/2005 (n = 75), No. (%)* | *Era 2 3/2005-6/2010 (n = 84), No. (%)* | *Era 3 6/2010-Present (n = 67), No. (%)* | *Totals (N = 226), No. (%)* | P |
|---|---|---|---|---|---|
| All-cause in-hospital mortality | 20 (26.7) | 16 (19) | 10 (14.9) | 46 (20.4) | |
| BAI-related death | 11 (14.6) | 4 (4.8) | 4 (6) | 19 (8.4) | |
| Open | 9 | 2 | – | 11/55 (20) | .05 |
| Endovascular | 2 | 2 | 4 | 8/91 (8.8) | |
| Pre- and post-TEVAR | 11 (14.6) | 8 (5.3) | | | .03 |

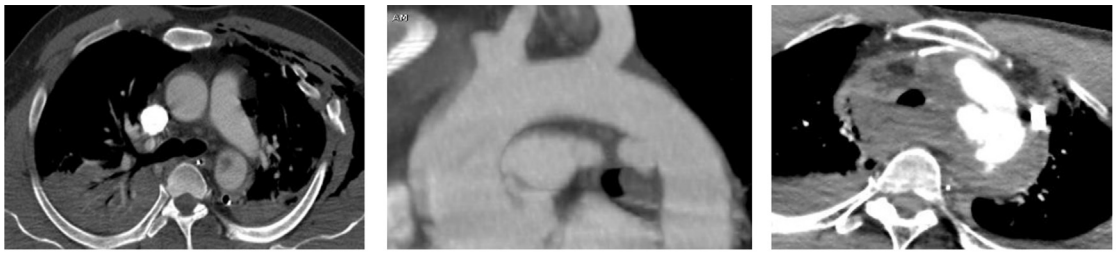
*BAI*, Blunt aortic injury; *TEVAR*, thoracic endovascular aortic repair.

In the multi-institutional review by Dubose et al[6] in 2015, they also concluded that patients with minimal injuries who were managed nonoperatively (grade 1 and 2 SVS criteria in their report) had no difference in any presenting demographics, risk factors, or in-hospital outcomes compared with patients treated with TEVAR. No progression was noted in our 38 patients with minimal injuries who had follow-up imaging. The follow-up imaging was done while the patient was still in the hospital recovering from other injuries. Although this is a retrospective observation, we no longer routinely repeat imaging for any of these patients, but as stated above, this is based on a limited number of patients. Follow-up in trauma patients is routinely poor, and although we do recommend outpatient follow-up, most patients discharged from our institution do not return for their scheduled posthospitalization visit. Furthermore, repeated CT scanning in young persons may be more detrimental over time than after a minimal injury.[9]

On the basis of the original definition of minimal aortic injuries by Malhotra et al[10] and several previous studies[8,11-13] regarding size of intimal tear >10 mm and concomitant presence of mediastinal hematoma, we place patients with intimal flaps >10 mm into the moderate category because their mechanism of injury is more severe and progression has been noted. Although it is difficult to suggest repairing an isolated 11-mm intimal tear, the length of tear >10 mm has been associated with other radiologic findings indicative of more severe aortic trauma, such as mediastinal hematoma, multifocal intimal tears, and progression to dissection or external contour abnormalities when left untreated.[8,10-13]

There is also controversy surrounding what a grade 2 injury actually constitutes. Simeone et al[14] (isthmus only) and the Vancouver simplified system both classify grade 2 as something similar to what Starnes et al[8] published in 2010 and 2012, and now what we classify as a moderate injury with an intimal tear >1 cm or the presence of an external contour abnormality.[15,16] With improved CT technology, grade 2 injuries are increasingly correctly classified as SVS grade 1 or grade 3, or in our proposed system, as minimal or moderate injuries. Our system delineates nonoperative vs operative management between grades, which was the goal in the creation of this system.

Moderate injuries are any external contour abnormality, such as a pseudoaneurysm, or an intimal tear >10 mm.



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

**Fig 2.** Harborview blunt aortic injury (*BAI*) classification system.

Semielective repair of these injuries during the first 24 to 72 hours is recommended after stabilization of concomitant injuries and only if these other injuries are deemed survivable. We place these patients on antiplatelet and anti-impulse therapy as a bridge to TEVAR. In our series, 27 patients with moderate injuries were treated nonoperatively across eras. These patients most commonly had sustained concomitant severe closed head injuries that were deemed nonsurvivable, and intervention was withheld. Less commonly, a moderate injury was seen on the initial scan but was small in size or felt to be an artifact. Repeat imaging revealed resolved injury while in the hospital. Four patients from era 2 (2005-2010) with small moderate injuries were not repaired, and three were subsequently lost to follow-up. The fourth patient underwent delayed open repair for progression of a pseudoaneurysm that was present on initial imaging. We do not recommend nonoperative management of moderate injuries because the presence of an external contour injury indicates injury to all layers of the aortic wall and will not resolve, and we no longer leave any moderate injuries untreated.

Severe injuries are those in which active extravasation is visualized or a contained rupture with a left subclavian hematoma >15 mm in size is seen.[8] These patients should be repaired immediately to prevent further extravasation and rapid decline. In eras 2 and 3, eight patients with severe injury survived to the hospital. Half of these patients died while in the operating room. Two were undergoing access for TEVAR, and two were attempts at open repair with emergency department thoracotomy and aortic cross-clamp. The four patients who survived their endovascular repair were discharged from the hospital. Our preference is to operate on these patients immediately upon diagnosis because the mortality of a severe injury was high (50%) in our series. It is essential to accurately diagnose a contained rupture as a severe injury with presence of a large left subclavian hematoma or large mediastinal hematoma, or both, and treat these patients in an emergent fashion.

In era 3, our most contemporary experience, four patients who were endovascular candidates died of BAI-related causes. One patient, described above, had a severe injury and arrested and died while on the operating room table undergoing an attempt at TEVAR. One patient had a moderate injury that was repaired; however, the device migrated proximally on the day of surgery, causing a large left-sided stroke that aggravated a serious closed head injury, with rapid decline and death. Lastly, two patients with moderate injuries ruptured and died on hospital day 1 while in the intensive care unit awaiting stabilization of concomitant closed head and spinal cord injuries.

We also question if there is still a role for primary open surgical repair in the endovascular era. Access to high-quality rapid imaging is making it possible to plan and treat moderate and severe injuries with endovascular repair. We acknowledge the possibility of subsequent operations for left subclavian coverage or delayed open explant and repair for device-related complications. Of 91 endovascular repairs over all eras, with 36 cases of left subclavian coverage, we performed one carotid-to-subclavian bypass and two open explants, with a mean time of 3 years from the time of injury. Endovascular repair of a life-threatening injury

allows stabilization and time to resuscitate an unstable patient, and a subsequent carotid-to-subclavian bypass or transposition or explant months to years later for device-related complications is an acceptable option once these patients have survived their initial trauma and can present electively for open reconstruction. Primary surgical repair should be reserved for patients with aortas too small for conventional devices. Before the decision to perform open intervention, we recommend repeat imaging of the thoracic aorta after adequate resuscitation if the circumstances allow.

There are several important limitations to our study to highlight. First, this is a retrospective, single-institution experience, although high volume and over many years.

The second is that we have limited follow-up imaging after discharge in patients after operative repair and in those with minimal injuries. Although we believe TEVAR is durable in BAI, we cannot discount the possibility of long-term complications arising from graft implantation and growth over many years.

The third is that our trauma center serves approximately one-fifth of the United States land mass, requiring a high percentage of seriously injured trauma patients to travel long distances, implying that they are stabilized before transfer. Our data may not capture as many unstable severe BAI patients because they never make it to our institution.

Future directions include prospectively validating our classification system and reporting long-term outcomes, in particular, regarding the limited imaging follow-up in minimal injuries.

## CONCLUSIONS

Our experience confirms that BAI-related mortality is now 5% at a high-volume level 1 trauma center for patients arriving alive at the hospital. On the basis of our findings during the past 15 years, we propose simplification of the SVS grading criteria of BAI into minimal, moderate, and severe injury based on treatment differences among the three groups. In our experience, minimal aortic injury can be successfully managed nonoperatively with optional follow-up imaging and antiplatelet therapy; however, larger studies are warranted. Moderate aortic injury can be managed semielectively with TEVAR, and severe aortic injury, although rare (<7% of all injuries in this series), requires emergency TEVAR. Open repair is reserved for patients who are not suitable for endovascular repair, but we emphasize the use of TEVAR to temporize a severe injury, with the need for subsequent open repair as an acceptable risk.

## AUTHOR CONTRIBUTIONS

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

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