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ORIGINAL ARTICLE

Blunt aortic injuries in the new era: radiologic findings and polytrauma risk assessment dictates management strategy

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Abstract

Purpose Blunt aortic injuries (BAI) have historically been considered an indication for emergent surgical intervention. Nevertheless, the observation that the outcome of the concomitant traumatic injuries has a major impact on prognosis and the rise of thoracic endovascular aortic repair (TEVAR) as an effective therapy for BAI have significantly changed in recent years the treatment algorithm of this condition. Our objective was to identify findings associated with the aortic injury which would be the best predictor of prognosis, with the objective of guiding the decision-making process for selecting the optimal timing of aortic repair.

Methods We reviewed blunt aortic injuries from 3 Level I Trauma Centers from July 2008 to December 2016. We analyzed overall and BAI-related 30-day mortality in relation to: hemodynamics, timing of treatment, TEVAR vs open repair, and aortic injury grade as defined by the Society for Vascular Surgery. Based on computed tomographic angiography (CT scan) imaging, we selected the radiologic aortic findings most indicative of high mortality risk, which we defined as "Radiographic Severe Injury" (RSI): (1) total/partial aortic transection, (2) active contrast extravasation, or (3) the association of 2 of more of the following: contained contrast extravasation > 10 mm, periaortic hematoma, and/or mediastinal hematoma with thickness > 10 mm, or significant left pleural effusion.

Results Of a total of 76 consecutive patients, 50 (66%) underwent immediate repair, 24 (31%) delayed aortic repair, and 2 (3%) died prior to repair. 58 patients (76%) had TEVAR, while 16 (24%) had open repair. Overall mortality was 18% and BAI-related mortality was 13%. In BAI-related mortalities, 70% of patients had RSI. Patients with high risk of overall mortality had hypotension and tachycardia (SBP < 100, HR ≥ 100), high ISS, and required vasopressors. Factors only associated with BAI-related mortality included RSI.

Conclusion CT scan findings suggestive of RSI are predictive of mortality associated with BAI. Radiologic assessment of the severity of the aortic injury with characterization for the presence of RSI may represent the key factors to determine the optimal timing of treatment of the aortic injury and guide the overall treatment strategy.

Level of evidence IV.

Keywords Blunt traumatic aortic injury · Radiologic assessment · Endovascular therapy · Open repair

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Introduction

Blunt aortic injuries (BAI) represent the second leading cause of death from motor vehicle crashes accounting for 15% of all motor vehicle accident-associated deaths [1–3]. Death occurs at the scene of the accident in 70–90% of the cases [4–7]. According to historical case series, the majority of the patients with BAI (75%) who arrive to the hospital alive are hemodynamically stable, but only 10% survive more than 6 h [1, 3]. Patients arriving to the hospital alive most frequently present with injury at the aortic isthmus where periadventitial tissue seems to provide some degree of protection against free rupture [8]. The majority of patients with BAI have an associated closed head injury, multiple rib fractures, lung contusions, or orthopedic injuries [1].

The management of polytrauma patients with BAI is based on the application of the Advanced Trauma Life Support (ATLS) protocols where treatment of injuries is prioritized based on their acute lethal potential [9, 10]. Exsanguinating hemorrhages from any location and intracranial injury with mass effect take treatment priority. Definitive treatment of the aortic injury requires surgical intervention; however, the timing of repair with respect to other major traumatic injuries remains an area of active study. The timing of aortic repair is classified as immediate, within 24 h; deferred, within 7 days; and delayed if more than 7 days after the trauma. Delayed management could be effective in patients in critical conditions and with minor BAI, when longer recovery from the sequelae of the concomitant severe injuries may be required [11–14]. In the pre-operative period, patients are treated with strict blood pressure control to decrease the risk of aortic rupture; with the downside, however, of increasing the risk of secondary brain injury [10, 14–16].

The Society for Vascular Surgery (SVS) has proposed an injury grading system for BAI intended to rate the degree of severity [17, 18]. Nevertheless, this grading system has failed to find reliable clinical correlation with risk of aortic rupture and death [13, 17–19]. Our objective was to identify factors associated with BAI which would be predictors of poor prognosis, with the objective of guiding the decision-making process for selecting the strategy of therapy and the optimal timing of aortic repair.

Methods

We reviewed blunt aortic injuries from three Level I Trauma Centers from July 2008 to December 2016. Two patients who died before treatment of the aortic injury (AI) could be established were excluded from the study. All diagnostic CT scan reports as per reading by the attending radiologist for each patient were reassessed and verified. We classified the aortic injuries as "Severe" (Radiographic Severe Injury, RSI) when they included findings of (1) total/partial aortic transection (Fig. 1), (2) active contrast extravasation (Fig. 2), or (3) the association of 2 of more of the following: contained contrast extravasation > 10 mm, periaortic hematoma and/or mediastinal hematoma > 10 mm, or left pleural effusion (Fig. 3). We analyzed overall mortality and BAI-related mortality (directly caused by the effects of the aortic injury) at 30 days in relation to factors such as: RSI, hemodynamic parameters on presentation (SBP, HR and need for vasopressor medications), timing of treatment of the AI (immediate, deferred or delayed), injury severity score (ISS), and AI grade as defined by the Society for Vascular Surgery Clinical Practice Guidelines [17]. AI grade was dichotomized as stable, grade I-II, and unstable, grade III-IV [19]. Descriptive statistics (Student's *T* test and Fishers exact test) were used to describe the patient population. Univariable and multivariable logistic regression was used to determine factors predictive of either overall mortality or BAI-related mortality. All analyses were conducted using STATA 14.2 (StataCorp College Station, TX). Institutional review board for human subject research approval was obtained at each individual trauma center.

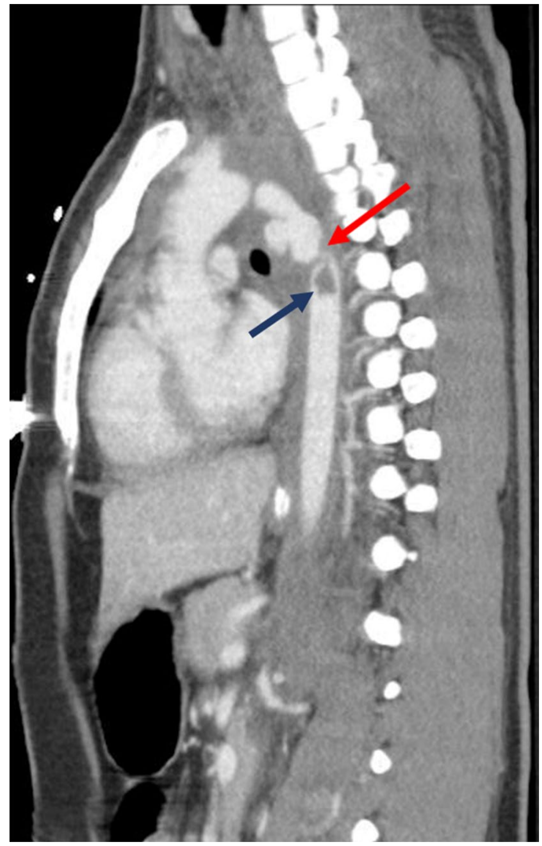

Fig. 1 CT scan image demonstrating aortic 'transection' near the isthmus (red arrow), also associated with intraluminal aortic thrombus as shown by the blue arrow. ('Transection' is defined by total or partial interruption of the column of intra-venous contrast flowing within the aortic lumen)

Results

A total of 76 consecutive cases were reviewed including 62 surviving patients and 14 fatalities (Table 1). The average age of patients was 46 years (range 15–100). Most patients had multiple severe trauma injuries with over half

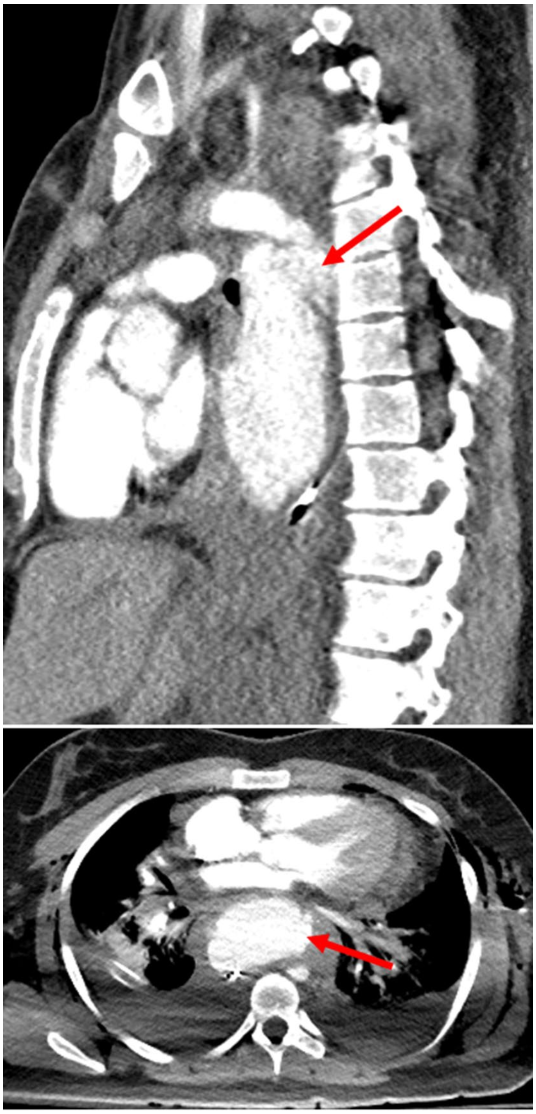

Fig. 2 Sagittal and transverse images of a large intravenous contrast extravasation as shown by red arrows (irregular IV contrast contour outside the aortic wall boundaries)

of the cohort (54%) presenting with ISS greater than 26. ISS, systolic blood pressure < 100, HR ≥ 100, and pressor requirements differed significantly between patients that survived and those who did not (Table 1). Most patients, 68%, received immediate treatment of their aortic injury, 26% received deferred treatment while more immediately life-threatening injuries were managed, and only 7% underwent delayed repair. Seventy-six % of patients were treated with TEVAR, 21% received a traditional open surgical repair, and 3% died prior to repair. Overall mortality was 18% and BAI-related mortality was 14% (Table 1). In BAI-related mortalities, 70% of patients had RSI.

Overall mortality was associated with high ISS, hemodynamic instability, and vasopressors requirement (Table 2).

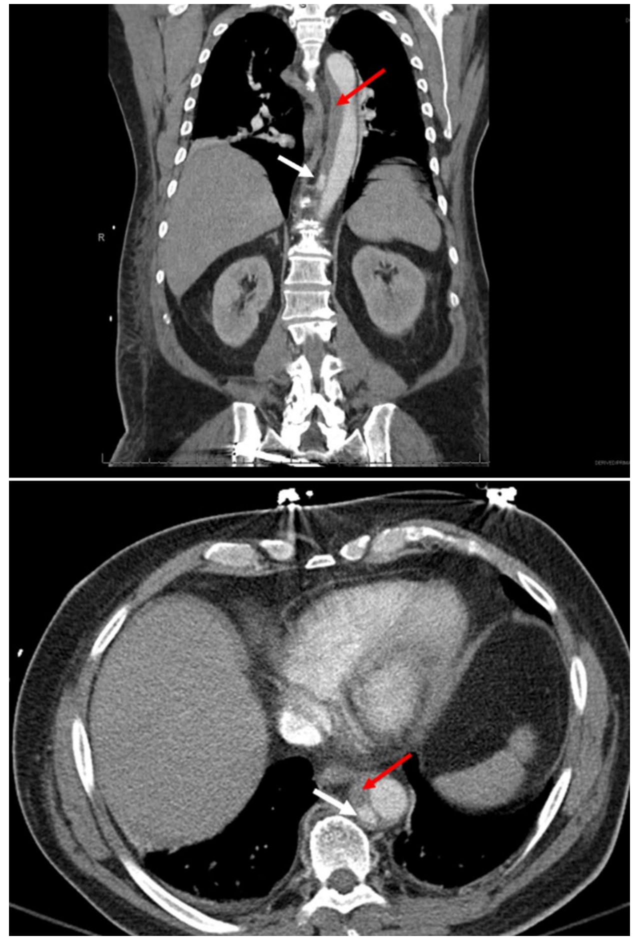

Fig. 3 Coronal and transverse images of peri-aortic hematoma (red arrows) and aortic pseudoaneurysm as shown by white arrows (pseudoaneurysm is defined by a regular intravenous contrast contour outside the aortic wall boundaries)

Hypotension (SBP < 100) was most strongly correlated with increased overall mortality and BAI-related mortality (Table 2). AI grade, per the SVS classification, and RSI were not statistically significant independent predictors for risk of overall mortality. Factors associated with BAI-related mortality included ISS, SBP < 100, HR ≥ 100, and vasopressors requirement. AI grade was not found to correlate with BAI-related mortality or overall mortality (Table 2), whereas RSI association with BAI-related mortality was statistically significant (Table 2). No factors were independently predictive of mortality when adjusting for other predictive factors.

Discussion

Blunt aortic injuries remain a leading cause of trauma deaths particularly from motor vehicle crashes. In recent years, several studies have outlined the possible benefit of delaying treatment in select patient subgroups [11–16]. Furthermore,

Table 1 Study cohort

	Study cohort (*N* = 76)	Survived[1] (*N* = 62)	Deceased[1] (*N* = 14)	*P* value[2]
Age years, mean (SD)	46 (20)	46 (18)	51 (29)	0.410
Gender				0.212
Male, *N* (%)	54 (71)	46 (85)	8 (15)	
Female, *N* (%)	22 (29)	16 (73)	6 (27)	
ISS, median (IQR)	34 (23, 43)	31 (20, 38)	47 (33, 57)	< 0.001
ISS				0.578
Mild < 9, *N* (%)	4 (5)	1 (1)	0 (0)	
Moderate 9–15, *N* (%)	1 (1)	1 (2)	0 (0)	
Severe 16–25, *N* (%)	17 (22)	15 (24)	2 (14)	
Extreme 26–75, *N* (%)	54 (71)	42 (68)	12 (86)	
AI grade (SVS)				0.062
I, *N* (%)	14 (18)	12 (19)	2 (14)	
II, *N* (%)	15 (20)	14 (23)	1 (7)	
III, *N* (%)	4 (53)	33 (53)	7 (50)	
IV, *N* (%)	7 (9)	3 (5)	4 (29)	
SBP < 100, *N* (%)	27 (36)	16 (26)	11 (79)	< 0.001
HR ≥ 100, *N* (%)	31 (41)	21 (34)	10 (71)	0.015
Vasopressors, *N* (%)	14 (18)	7 (11)	7 (50)	0.003
Procedure				0.046
None, *N* (%)	2 (3)	0 (0)	2 (14)	
TEVAR, *N* (%)	58 (76)	48 (77)	10 (71)	
Open, *N* (%)	16 (21)	14 (23)	2 (14)	
Timing of procedure				0.881
Immediate, *N* (%)	50 (68)	41 (66)	9 (75)	
Deferred, *N* (%)	19 (26)	16 (26)	3(25)	
Delayed, *N* (%)	5 (7)	5 (8)	0 (0)	
RSI, *N* (%)	27 (36)	19 (31)	8 (57)	0.072
Complications aortic surgery, *N* (%)	4 (5)	2 (3)	2 (14)	0.152
Complications unrelated, *N* (%)	12 (16)	9 (82)	3 (60)	0.547
BAI-related mortality, *N* (%)	10 (14)	–	10 (71)	–

AI aortic injury grade group, *BAI* blunt aortic injury, *ICU* intensive care unit, *ISS* injury severity score, *IQR* interquartile range, *RSI* radiographic severe injury, *SD* standard deviation, *SVS* Society for Vascular Surgery, *TEVAR* thoracic endovascular aortic repair

[1]Thirty-day mortality

[2]Student's *T* test for continuous variables and Fisher's exact test for categorical variables

significant strides have been made in the management of these injuries by the rise of endovascular therapy, since treatment can be delivered faster and with less operative and postoperative risks [13, 21, 22]. Nonetheless, the choice of the most adequate timing for treatment of the aortic injury, particularly with respect to other major traumatic injuries, remains an area of active study. There are currently no clear guidelines for determining which patients may benefit from delayed aortic repair, nor there are validated methods of assessment of the severity of the aortic injury which would allow to choose when prioritize treatment of the aorta [13, 19]. In our series, conservative management of the BAI and delayed repair was selected per choice of the treating surgeon in situations where treatment of associated life-threatening injuries and improvement of the patients' conditions took priority over treatment of a "stable" aortic injury. However, no surgeon opted for a non-operative management [13, 23, 24].

The current classification systems of BAI proposed in the literature [17–20], which were established to grade the severity of the AI with the objective of guiding treatment planning, did not find reliable clinical correlation with prognosis [13, 18, 19]. Therefore, we aimed to identify the radiologic and clinical findings which could help guide the strategy of therapy for patients who need immediate treatment of the aortic injury versus patients whose treatment can

Table 2 Logistic regression of factors known to predict risk of overall mortality and BAI-related mortality

	OR (CI)	*P* value[1]	OR (CI)	*P* value[1]
Age	1.01 (0.98, 1.04)	0.406	1.01 (0.98, 1.04)	0.665
ISS	1.07 (1.02, 1.11)	0.003	1.07 (1.02, 1.12)	0.004
SBP < 100	10.54 (2.61, 42.65)	< 0.001	24.00 (2.84, 203.14)	0.004
HR ≥ 100	4.88 (1.37, 17.44)	0.015	7.48 (1.47, 38.17)	0.016
Pressors	7.86 (2.12, 29.12)	0.002	6.33 (1.52, 26.33)	0.011
AI grade (SVS)	2.65 (0.67, 10.45)	0.164	6.63 (0.79, 55.41)	0.081
RSI	3.02 (0.92, 9.90)	0.068	5.37 (1.28, 22.90)	0.023
	Adjusted mortality OR (CI)	*P* value[2]	Adjusted BAI-related mortality OR (CI)	*P* value[2]
ISS	1.04 (1.00, 1.09)	0.074	1.05 (1.00, 1.11)	0.062
SBP < 100	5.54 (0.71, 43.47)	0.103	13.16 (0.89, 195.18)	0.061
HR ≥ 100	0.99 (0.14, 6.88)	0.991	1.16 (0.12, 10.74)	0.898
Pressors	1.55 (0.2S, 8.66)	0.616	0.77 (0.12, 4.96)	0.786
RSI	–		2.51 (0.46, 13.75)	0.290

AI aortic injury grade group, *BAI* blunt aortic injury CI, *95%* confidence interval, *HR* heart rate, *ISS* injury severity score, *OR* odds ratio, *RSI* radiographic severe injury, *SBP* systolic blood pressure, *SVS* society for vascular surgery

[1]Univariate logistic regression

[2]Multivariate logistic regression

be delayed in favor of the treatment of other major concomitant injuries. We selected the CT scan findings (RSI) that, in our clinical practice, represent a marker of life-threatening aortic injury and would dictate immediate aortic repair. We observed that RSI was associated with mortality directly related to the aortic injury suggesting that the presence of RSI would indicate need for emergent aortic surgical intervention. In a relatively recent prospective multicenter study sponsored by the American Association for the Surgery of Trauma (AAST), the effect of early versus delayed repair was observed in 178 patients admitted with BAI between 2005 and 2007. The study concluded that 'delayed repair of stable blunt thoracic aortic injuries is associated with improved survival'. In the study, patients 'in extremis' were excluded from analysis and an overall mortality of 12.4% was reported. The study fails to define the parameters used to classify a patient as 'in extremis' and does not discuss the characteristics that defined an aortic injury as 'stable' [14].

Our data show that while factors suggesting hemodynamic instability are predictive of overall mortality and BAI-related mortality, RSI was the strongest predictor of BAI-related mortality not also related to overall mortality. Additionally, AI grade, as defined by the SVS, was not predictive of overall or BAI related mortality in our series of patients. Accordingly, in the AAST series the SVS AI grading had no correlation with the timing of aortic repair [14]. In our clinical practice, the decision regarding the plan of treatment of BAI is based on the characteristics of the injury as seen on CT scan imaging and on evaluation of the clinical factors related to the severity of the associated injuries [13, 19–22]. For this reason, we elected to categorize only the radiologic findings which are marker of a life-threatening injury rather than provide a grading system of the entire spectrum of aortic injuries. ISS has been used to predict risk of morbidity and mortality associated with blunt trauma since the 1970's. It was demonstrated initially to correlate well with length of stay, need for major surgery, significant disability, and death [25, 26] and continues to be a valuable tool used prominently in trauma databases to assign an objective value to traumatic injuries and predict risk for significant morbidity/mortality. As expected, in our experience, commonly used trauma parameters such as hemodynamic instability and ISS did correlate with overall mortality. However, only RSI was found to correlate specifically with BAI-related mortality and not overall mortality. This suggests that RSI may function as an adequate means to assess the degree of aortic injury and thereby dictate the timing of aortic repair. The SVS AI grading system is based on the following criteria: (grade I) intimal tear; (grade II) intramural hematoma; (grade III) pseudoaneurysm; (grade IV) rupture. Under this system, grade I-II are considered mild and grade III-IV are considered severe [17–19]. In our investigation, we created criteria for radiographic severe injury and used this as a binary variable (severe versus the others) rather than creating a full grading system. Radiographically severe injuries were those meeting any of the following criteria: [1] total/partial aortic transection, [2] active contrast extravasation, or [3] the association of 2 of more of the following:

contained contrast extravasation > 10 mm, periaortic hematoma and/or mediastinal hematoma thicker than 10 mm, or significant left pleural effusion. We evaluated multiple injuries where a pseudoaneurysm was found in isolation, without significant associated hematoma or extravasation, which did not meet criteria for RSI. Thus, many injuries that would be graded III by the SVS system were not included in our RSI classification since they did not meet our selection criteria. In our study, AI grade I-III had a survival rate of > 80%, while grade IV was below 50%. This suggests that patients with AI grade III injuries, considered severe injury in the SVS classification, have outcomes comparable to grades I and II (Table 1). Recently, the SVS has suggested a simplification of his grading system by classifying Grade I–II as mild, grade III as moderate, and grade IV as severe [19]. Our study suggests that this change might continue to overestimate the risk of significant morbidity/mortality for many isolated pseudoaneurysms, that according to some recent reviews in selected cases could be managed non-operatively [13, 23, 24]. Nonetheless, the ideal management for stable pseudoaneurysms after BAI remains a subject needing further study.

Given the rapid expansion of TEVAR in recent years, our group included a limited number of patients undergoing open repair. Assessing the outcome of patients undergoing open versus endovascular treatment was not the purpose of our study, since TEVAR offers the advantages of faster delivery of therapy, prevention of a dangerous operation with partial cardiopulmonary bypass or hypothermic circulatory arrest, and less risk of postoperative paraplegia. Furthermore, TEVAR offers the potential benefit of allowing simultaneous delivery of other therapies for associated injuries, such as cranial decompression, transcatheter embolization or exploratory laparotomy, which would be significantly delayed by performing open surgical repair. This is supported by findings in the literature that have consistently shown benefit for TEVAR over open repair in BAI [13, 27–35]. In our series, open repair was selected only when TEVAR was not a feasible option, such as in cases with intraluminal aortic thrombus, small size of the aorta and/or of the femoral vessels, or presence of a total aortic transection which prevented delivery of endovascular therapy (Fig. 1). Open repair was more common in the first few years of our study period since endovascular devices available on the market were used “off-label” to treat BAI and were not yet available in sizes to allow treatment of patients with small aortas or small femoral arteries [19]. Nevertheless, open repair remains a viable treatment strategy with lesser mortality and morbidity compared to historical series [20]. Incidentally, our series has also shown that the radiologic evidence of endoluminal thrombus and/or distal embolization was associated with high mortality, suggesting that this finding could be another factor included in the RSI classification as a pathognomonic sign of high mortality risk (Fig. 1). Future studies will be required to verify this observation. As last consideration, our series has a very small number of patients who died before any treatment was established. If historical series had reported that number to be significant, most recent reports have shown that of the patients surviving BAI at the scene, less than 5% would die of a direct aortic complication after arrival at the hospital [21]. The improvement of the techniques of resuscitation and trauma management, along with a consistent and early application of anti-impulsive therapy, has positively impacted on the post-admission hospital mortality [21].

Limitations in this study are predominantly related to the relatively small sample size and the retrospective design. Nonetheless, our cohort has the unique advantage compared to other studies to be contemporary to the availability of TEVAR for the treatment of this condition and represents one of the largest BAI survey in the modern era of endovascular aortic therapy. Large-scale studies will be needed to validate RSI as a system adequately reflecting of the severity of the aortic injury in correlation with its mortality risk.

Conclusion

The surge of TEVAR as the new standard for treatment of BAI has lowered the operative mortality and morbidity for the treatment of this condition. However, the optimal timing for the delivery of therapy remains still unclear with respect to the identification of the patients who would require immediate intervention versus the ones for whom postponing treatment of the aortic injury would be preferable. We propose a new imaging classification system of BAI aimed at identifying the type of injuries associated with the highest mortality risk. Radiologic assessment of the severity of the aortic injuries by characterization of the presence of RSI and triage with respect to the concomitant traumatic injuries should represent the primary factors to direct management strategy indicating the optimal timing for aortic repair and guiding treatment priorities.

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Compliance with ethical standards

Conflict of interest No authors have conflicts of interest to report.

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