A systematic review of blunt abdominal aortic injury and analysis of predictors for death

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Abstract

At present, there are few studies on blunt abdominal aortic injury (BAAI), and most of them are case reports. Little is known about this disease. So, a systematic review was conducted through extensive search of major databases. All literature that provided individual (non-identifiable) data for BAAI patients could be included without being limited by study design. Additionally, regression analyses of predictors for death after BAAI were conducted. The search resulted in 2,099 hits, and 102 case reports and 1 conference abstract included in the review then. After assessment using the Joanna Briggs Institute checklist, no low-quality studies were found. A total of 133 patients were included, with a median age of 34 and 73.7% being males. Their most common clinical manifestation was pain (65.6%). The most common severity of aortic lesion was grade A (intimal tear or intramural hematoma, 46.9%), and the most common location of aortic lesion was zone III (infrarenal aorta, 88.3%). The overall mortality after BAAI was 15.3%. The following are the predictors for death after BAAI identified through multivariate regression analyses: lower limb ischemia [relative risk (RR), 7.137; 95% confidence interval (CI), 1.154-44.161], cardiopulmonary arrest (RR, 10.250; 95% CI, 1.452-72.344), and injuries to other parts (other than abdomen and lumbar spine) of body (RR, 2.593; 95% CI, 1.189-5.655). In conclusion, this study provides a detailed quantitative summary of the characteristics of the clinical manifestations, diagnosis, treatment, and prognosis of BAAI, a deadly traumatic disease, and indicates that the three variables above are risk factors for death.

Introduction

Blunt abdominal aortic injury (BAAI) is believed to be caused by the injury to the aorta relates to the blunt biomechanical direct and indirect forces incurred on the abdominal aorta, which is tethered between the spinal column and the peritoneum and abdominal viscera [1]. It is rare both in adults and children [2]. According to previous studies, it represented only 4-6% of total aortic injuries and less than 1% of total blunt trauma [3-5]. Although uncommon, it is lethal. A high but variable mortality with published rates ranging from 17% to 92% was demonstrated by previous studies [5-8]. Compared with blunt thoracic aortic injury (BTAI), BAAI is much less common. This is thought to be due, in part, to the relatively fixed position of the entire length of the abdominal aorta compared with the thoracic aorta’s fixation only at the ligamentum arteriosum, and base of the heart [9].

For ease of exposure and repair at the time of surgery, Shalhub et al. divided all aortic lesion locations into 3 types [1]. This classification method was favoured by many researchers [10, 11]. On the other hand, for BTAI or nonspecific blunt aortic injury (BAI), researchers have developed many grading criteria for the severity of aortic lesions according to the pathological changes of injured aorta [12-15]. However, there are few studies on the effect of aortic lesion location and severity on the prognosis of BAAI patients. The therapeutic methods of BAAI mainly consisted of operation and conservative observation. Kondo et al. reported that the 24-h mortality and the hospital mortality of BAAI did not differ statistically among the various treatment modalities [16]. However, Sheehan et al. showed that patients who underwent aortic surgery had a statistically lower mortality than those who had not [17]. Other studies in this area are very few.

The only few previous studies did not address much of the core knowledge about BAAI, which makes us poorly understood about this dangerous traumatic disease. So, we conducted this worldwide systematic review. It was registered with PROSPERO (CRD42023408842) within accordance to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [18].

Materials And Methods

Ethical statement

As this is a review based on published literatures and does not contain any individual identification information, ethical approval and consents to participate are not required, which is in line with local regulations and policies. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Search strategy

A systematic search in the Excerpta Medica Database, PubMed, Web of Science, and Cochrane Library was performed on December 23, 2022. All words synonymous with or similar to “abdominal aortic injury” were searched to eliminate omissions. The full search strategy is showed in Supplemental File 1.

Study selection

The abdominal aorta was defined as the aorta from the diaphragm to the bifurcation into the right and left common iliac arteries. The samples were set as human individuals with BAAI who suffered any kinds of injury on abdominal aorta due to blunt or non-piercing external force causes. All brief information of the searched articles was imported into Endnote X9 for duplicate removal and brief review. Then, the full texts of all available articles that passed the preliminary screening were downloaded and reviewed to identify those that were finally included in the study.

The available ones from articles about abdominal aortic injury (AAI) obtained through primary search were all selected initially. And then, not limited by study design, any literature that reported individual data on BAAI patient could be included, allowing for missing values on variable. The exclusion criteria included (1) samples with concomitant thoracic aortic injury; (2) samples with pre-existing dilative aortic disease (such as aortic aneurysm) or aortic injury; (3) samples suspected of duplication; (4) articles which were published in non-English. If some of the BAAI samples reported in a certain article met the above selection criteria, they would be selected for inclusion in the presented review. Two authors (ML and CW) independently performed the data selection separately. Any discrepancies were resolved by consensus.

Data extraction

Multiple variables of BAAIs as detailed as possible were set up for data extraction. The definitions and descriptions of each variable are shown in Supplemental File 2. Specifically, the “death after BAAI” was defined as any death due to the initial traumatic cause but excluding other causes such as a malignant cancer. The locations of aortic lesions were divided into 3 location zones [zone I (the zone from diaphragmatic hiatus to superior mesenteric artery (SMA), II (the zone including SMA and renal arteries), and III (the zone from infrarenal aorta to aortic bifurcation)] according to the method of Shalhub et al. [1]; and the injury severities of aortic lesions were divided into 5 grades {grade A (intimal tear or intramural hematoma), B [small pseudoaneurysm (less than 50% circumference)], C [large pseudoaneurysm (more than 50% circumference)], D (intraluminal truncation), and E (rupture)} further on the basis of Rabin et al.’s method [15]. Data extraction was performed by a pair of independent authors (HT and HZ). If, according to our definitions, the value (or classification) of a variable in an included article was not directly reported, these two authors will make independent judgments based on the description in the original text. Any queries and discrepancies were resolved through further discussion to reach a consensus.

Quality assessment

The original studies were assessed by the Joanna Briggs Institute (JBI) checklist for case reports [19]. This tool includes 8 items, which evaluate whether the descriptions of the clinical characteristics, diagnosis, treatment, outcome, and other aspects on the patients in every report are comprehensive and clear. The item is scored 1 point if answer “yes” or “not applicable” and scored 0 point if answer “no” or “not clear”. If multiple cases were reported separately by some study, they would be evaluated separately, and the score of the whole study would take the lowest value of those of the cases.

All included studies were classified as having “low” (0-3 points), “medium” (4-6 points), or “high” (7-8 points) methodological quality. Three independent authors (ML, ZG and LG) each finished quality assessments for all included articles. If opinions differed, the lower score was taken.

Statistical analysis

Continuous variables were presented as “mean ± standard deviation” or “median with interquartile range (IQR)”, and categorical ones were presented as “number with percentage”. Statistical analyses were conducted using the Stata version 16.0 software (StataCorp., College Station, TX, USA). All hypothesis tests were two-sided, and $P<0.05$ was considered to indicate a statistical difference. The age distributions of BAAI patients between genders were compared, using the Mann Whitney U test [20]. The constituent ratios of all samples in categorical variables were also calculated separately. The details of patients who died after BAAI were also described.

Setting the binary “death after BAAI” as outcome variable, the potential predictors were explored. Except obviously unrelated ones such as “diagnostic method”, all variables were entered into a binomial family generalized linear model (GLM) (link: log; standard error type: default; optimization method: maximum likelihood estimation) one by one for univariate regression analyses, using the relative risk (RR) with 95% confidence interval (CI) as measure [21]. To obtain a likely positive outcome while retaining as much detail as possible for categories, we tried multiple combinatorial modalities of core treatments and substituted the derived variables into the model separately. Then we attempted to simultaneously bring the obtained variables with P value <0.20 into the above GLM for adjusted multivariate regression analysis. But the model failed to converge and could not derive a result. So, a multivariate regression analysis of these variables using a robust Poisson family GLM (link: log; standard error type: robust; optimization method: maximum likelihood estimation) was performed. Only those variables with a P value <0.05 and an absolute RR value <1000 were accepted and considered as predictor. To assess the fitting ability, we also recorded the value of Akaike information criterion (AIC) [22] and log pseudolikelihood [23] of the final adopted regression model. Additionally, using Fisher’s exact test [24], patients with the calculated predictors were selected for subgroup analyses, to explore the influences of different treatment modalities on mortality in these specific patients. All statistical analyses were conducted by ML.

Results

Characteristics of studies and patients

The systematic search yielded a total of 2,099 articles before 1,123 duplicates were removed, following which 766 ones were excluded after title abstract sieve. Finally, 103 articles were included after full text assessment [25-127] (Supplemental File 3).

These articles included 102 case reports and 1 conference abstract. Of them, there were 14 (13.6%) ones which included multiple (2 to 7) cases. After quality assessment, there were 91 high-quality studies (88.3%), 12 medium-quality ones (11.6%), and no low-quality ones. All they were published from 1961 to 2021, of which 83 (80.6%) were published after 1990. And there were 25 reporting countries, with USA reporting the most frequently (48, 46.6%). One patient was injured abroad but went to USA later for treatment and was reported by American doctors [31]; the remaining patients were considered to have been injured and treated (if happened) in the reporting country. The authors of one article published in 2018 were from Serbia and Montenegro respectively [98], and the reporting country of this article was considered to be one rather than two. A total of 133 BAAI patients at a median age of 34 (IQR, 17-54) (ranged from 1 to 89) were included. The detailed characteristics of the included studies and patients are shown in Supplemental File 4. Among the patients, there were 35 females (26.3%), who were generally older than males ($P = 0.012$) (Supplemental File 5).

Clinical manifestations, diagnoses, treatments, and outcomes

The most common injury way of BAAI patients was the "direct strike (non seat belt)" (collision, fall, gas shock, etc.), accounting for 53.4%. The various clinical presentations of all patients were classified into 4 categories, with pain being the most common (65.5%). In addition, 5.0% of patients presented with cardiopulmonary arrest and 36.4% with shock. And taking the first day after trauma as the boundary, 11.8% of patients experienced delayed manifestations, while 4.2% had no acute manifestations. The constituent ratios of clinical manifestation variables are shown in Figure 1.

The most common diagnostic method was computed tomography (CT), accounting for 52.6%. Three patients were not diagnosed with BAAI until 7 months, 8 years, and 9 years after trauma respectively due to different reasons [41, 43, 58]. According to the established classifications, 88.3% of patients had an aortic lesion located in zone III, and 47.0% were grade A severity. Thrombosis at the aortic lesion was reported in 28.8%, and 78.3% were reported to have aortic degeneration. In addition, 66.9% of patients were injured to other organs in abdomen, 25.6% were injured to lumbar spine, and 23.3% were injured to other parts of body. Concomitant injuries up to 7 organs or tissues after trauma was reported in one patient [102]. Among all injured organs in abdomen, the gastrointestinal tract was the most common, accounting for 49.6% of all 133 BAAI patients. The constituent ratios of diagnosis variables are shown in Figure 2.

The most common treatment modality was primary open surgery (OS, 55.2%), followed by primary endovascular therapy (EVT, 24.0%) and others. One patient underwent percutaneous aortic stent implantation after failed conservative observation, but it was found intraoperatively that the stent migrated to suprarenal aorta, so he underwent open aorto-aortic bypass and recovered well [91]. He was considered to have received a secondary OS as the core treatment modality. Among the 114 patients who underwent operation treatment, the choice of their approach (OS or percutaneous EVT) was not statistically associated with the presence of neither injuries to organs in abdomen, to lumbar spine, or to other parts of body (P = 0.144, 0.240, and 0.486, respectively). The same situation also arised whether the gastrointestinal tract which was the most representative abdominal organ, was injured, i.e., of the 114 patients who underwent operations, 60 had gastrointestinal injury, and 29 of them underwent OS rather than EVT (P >0.999). After categorizing the timing of core treatment after injury, it was found that most patients were treated rapidly (within 3 days after injury) (64.5%). One patient received OS immediately after reception [43], whereas another patient was not treated until 9th year after injury because of a missed diagnosis [44]. The longest follow-up was 10 years [105]. 27.1% of patients had various non-fatal adverse events after treatment, of which acute renal failure was most common (47.8%). Some patients had up to 4 kinds of adverse events after OS, excluding multiple organ dysfunction syndrome [43, 45]. 5.0% and 10.0% of patients had residual chronic lower limb ischemia and neurological dysfunction as sequelae after treatment respectively. Finally, it was found that 19 patients (15.3%) died after BAAI. They were classified according to the time of death (Table 1). The constituent ratios of treatment and outcome variables are shown in Figure 3. Among the 53 cases with available data who had gastrointestinal injury and underwent operations, 3 died after BAAI in the OS group and none in the EVT group, which did not suggest a statistical difference (P = 0.543).

Death after BAAI

Due to failed convergence of the binomial regression model after selecting variables through univariate analyses, a robust Poisson GLM was taken for analysis and then derived several variables with P <0.05. However, the absolute RR values of some of these variables (including all the multiple categorical ones) are very exaggerated exceeding 1000, even reaching trillions. Therefore, multiple stepwise regression approaches (forward, backward, etc.) were taken in an attempt to find variables that destabilized the model. Then, a stable Poisson regression model with 86 observations included was obtained after excluding all multiple categorical variables. The AIC value of this model was 1.018, and the log pseudolikelihood value was -34.776. We collected all the variables in this model and tried the binomial regression again, but still failed in convergence. So, the Poisson regression model was adopted finally, and 3 statistically significant predictors (i.e. risk factors) for death after BAAI were obtained, which were lower limb ischemia (RR, 7.137; 95% CI, 1.154-44.161; $P = 0.035$), cardiopulmonary arrest (RR, 10.250; 95% CI, 1.452-72.344; $P = 0.020$), and injuries to other parts of body (RR, 2.593; 95% CI, 1.189-5.655; $P = 0.017$). The analysis details are shown in Table 2, and the adopted model results are also presented in a forest plot (Supplemental File 6).

After subgroup analyses, it was found that the mortality of BAAI patients with lower limb ischemia or injuries to other parts of body, whether undergoing primary operation or secondary operation, was lower than that of those who received conservative observation ($P = 0.020$ and 0.035 respectively); however, the mortalities with cardiopulmonary arrest did not differ significantly among different treatment modalities ($P > 0.999$). The details are shown in Supplemental File 7.

Discussion

Significance of this study

In this review, the multifaceted characteristics of BAAIs and risk factors for death were revealed. This can help clinicians to better recognize this rare but fatal traumatic disease and to take more timely and accurate treatment for high-risk patients.

Characteristics of BAAIs

Most studies on BAAI were all case reports, showing the scarcity of BAAI. Among the 133 included BAAI patients, the median age of males was significantly lower than that of females (32 vs. 45, $P = 0.012$). The reason may be that men in adolescence or youth prefer to be exposed to intense activities, such as driving motor vehicles, playing football, boxing.

A direct blunt external force of sufficient magnitude can cause BAAI, and this type of trauma accounted for the majority (53.4%) in this review. While the proportion of patients who did not have a direct crash but were restricted by the seat belt and thereby developed a BAAI also reached 43.1%. We have recognized that the mechanism caused by these injury modalities is the combined compressive effect on the abdominal aorta (AA) by the anteriorly located abdominal viscera and the posteriorly located lumbar spine, associated with sudden deceleration [99, 128]. Meanwhile, we also found 4 (3.4%) patients who did not suffer any direct external force applied to abdomen, and their cause of injury was classified as back hyperextension that caused excessive traction on AA [82, 83, 88, 100]. Additionally, regardless of the injury way, damage to the lumbar spine may promote the development of BAAI due to the increased local force to AA [46, 47, 82].
The presented review shows that the clinical manifestations of BAAI patients are diverse. In addition to shock and cardiopulmonary arrest in severe cases, pain, lower limb ischemia, and neurological dysfunction were representative. Among them, the proportion of patients with pain in abdomen, chest, back, or lumbar flakes reached 65.5%, suggesting that pain may be the most common clinical symptom of BAAI patients. In addition to pain and lower limb ischemia due to reduced blood flow, we also found that 12.6% of patients had neurological dysfunctions with different degrees, such as paraplegia, hypoesthesia, asynodia and so on. The reason may be the direct injury of the lumbosacral spinal cord or plexus, or the damage of Adamkiewicz artery originating from AA and supplying blood directly to the lumbosacral spinal cord [129].

The majority (52.6%) of BAAIs were diagnosed by CT. It shows that CT has become the most important imaging examination for the diagnosis of BAAI, which is also in line with the views of many researchers [10, 130]. Up to 88.3% of patients' aortic lesions were in zone III which is from infrarenal aorta to the aortic bifurcation. However, there were only 15 cases of injury located in zone I (supra-SMA) and zone II (SMA to renal arteries). The reason may be that infrarenal AA is less protected compared with suprarenal AA [131]. Meanwhile, after regression analyses, there was not enough evidence to prove that different injury locations affected the mortality rate of BAAI. Severity grading criteria for aortic lesion have not been uniform [10, 15, 132]. After comparison, we referred to Rabin et al.'s method on BAI [15]. However, intimal tears belong to the mildest grade (grade A) by this grading standard, but apparently the large aortic dissections (ADs) with or without thrombosis leading to luminal obstruction cannot meet any grade including A. So, we add this severe AD as the grade D which was only milder to grade E (rupture) on the basis of this standard. Then we found that even so, the proportion of BAAI patients of the mildest grade A remained the highest (47.0%). This suggests that most BAAI patients have a mild damage on AA. Aortic degenerative pathology was present in 78.3% of patients and lumbar spine fractures in 25.6% with relevant reports. These two conditions may increase the susceptibility of trauma patients to BAAI based on the pathogenic mechanism theory that AA is compressed, and this is also in line with the ideas in several studies [18, 131].

The treatment of choice for BAAI patients by most clinicians was primary OS (55.2%), and the proportion of primary operation including primary EVT had even reached 79.2%. This suggests that the application of conservative treatment in BAAI is still limited. However, not all BAAI patients face the same risks obviously. Shalhub et al. believed that whether operation should be performed and which operation modality should be chosen depend on the location and severity of the aortic injury [1, 6]. Additionally, the results of this presented review suggest that clinicians' choices of operation modality were not related to the presence of injuries to other tissues or organs (especially those in abdomen). We believe that part of the reason for this is the habits and preferences of various medical centers and clinicians.

Generally, the causes of some unwanted or unexpected events in BAAIs could not be explained as traumatic or iatrogenic alone. So we collectively referred to these negative events after treatment (including conservative observation) as "adverse events" (excluding death). And we found that its proportion was 27.1%, which was similar to a previous study [17]. After excluding deaths that were apparently unrelated to BAAI (such as malignancies years later), the mortality after BAAI in the presented review was 15.3% (n = 19). The immediate cause of death in these patients was mostly haemorrhage after AA injury, even after treatments.

Predictors for death after BAAI

The analysis results show that, the risk of death after BAAI is increased in patients with lower limb ischemia, cardiopulmonary arrest, or injuries to other parts of body. We believe that only severe AA injuries such as grade D/E are sufficient to cause lower extremity ischemic symptoms. So, the variable of lower limb ischemia can directly reflect the severity of ischemia caused by aortic injury. And acute limb ischemia is associated with many serious consequences including death, which has long been proved [133, 134]. The preliminary multivariable model did show that the severity of aortic disease (multiple categorical variable) directly influenced the mortality ($P<0.001$), but it was not adopted because of unusual RR values (over 1000). On the other hand, cardiopulmonary arrest and injuries to other parts of body both mean the severity of trauma to the whole body, not just to AA. In other words, other simultaneous injuries may also lead to death or aggravate the impact of AA injury on the body. It is very difficult to explore the specific initial cause of death of a patient with multiple injuries. Additionally, we also removed some variables because of their exceeded 1000 RR values. For example, the mortalities of zone I and II injuries that were more difficult to be exposed or controlled by OS were higher than that of zone III injuries, secondary EVT after failed conservative observation was associated with higher mortality than conservative treatment throughout, and so on. They should not be easily negated although not proven to be statistically valuable, because of the theoretical plausibility. The reason for the unusual RR values estimated is the small available sample size, likely. We look forward to more studies with large sample sizes.

Results of subgroup analyses suggest that, compared with conservative observation, both primary and secondary operation treatment (including OS and EVT) for BAAI patients with lower limb ischemia or injuries to other parts of body can reduce the risk of death ($P<0.05$). This proves the importance of operation treatment for the BAAI patients at high-risk. Meanwhile, the differences in protective effects between the three treatment modalities are not reflected among BAAI patients with cardiopulmonary arrest. Also due to the small sample size (n = 2 for this subgroup), we cannot easily make a conclusion that operation cannot play a role in reducing the risk of death in such BAAI patients.

Limitations

This review also has some limitations. First, since there were no uniform standards among the references, the descriptions of the variables were sometimes vague, affecting the accuracy of data extraction and analysis. Second, cases with good curative effect might be easier to be reported and published, while those that have unsatisfactory outcomes for various reasons might not. This may make the true mortality underestimate, increasing the publication bias.

Conclusions

BAAI is a lethal injury with diverse characteristics and a mortality rate of 15.3% at least. The increased mortality risk of BAAI is associated with lower limb ischemia, cardiopulmonary arrest, and injuries to other parts (other than abdomen and lumbar spine) of body. Operation (including OS and EVT) can reduce the mortality of BAAI patients with lower limb ischemia or injuries to other parts of body, even as a salvage measure after failure of conservative observation.

Declarations

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Tables

Table 1. Data from 19 patients who died after BAAI

Death type	n((n/19) ×100%)	Reference	Age (y)	Gender	Injury way	Clinical manifestations	Aortic lesion characteristics	Other injuries	Core treatment and it's timing	Time to death after injury	Immediate cause of death	Adverse events
Before diagnosis	5 (26.3)	Raul et al. [60]	70	M	DS	CA, S	Z III, G E, T, AD	A, LP, O	-	<1d	Hemorrhage	-
		Raul et al. [60]	2	M	DS	CA, S	G E	A, LP, O	-	<1d	Hemorrhage	-
		Raul et al. [60]	19	M	DS	CA, S	G E	A, O	-	<1d	Hemorrhage	-
		David et al. [78]	54	F	DS	P, LLI	Z II, G A, T	A, O	-	2d	Respiratory failure	-
		Desai et al. [92]	78	F	DS	CA, S	Z II, G A, AD	No	-	<1d	Hemorrhage	-
After diagnosis and before initial treatment	1 (5.3)	Harkin et al. [8]	7	M	DS	P, LLI, S	Z III, G E	No	-	<1d	Hemorrhage	-
During operation	2 (10.5)	Hewitt et al. [12]	65	M	SB	LLI, OM	Z III, G D, T, AD	A	POS, <3d	<1d	N/A	N/A
		Gordon et al. [93]	46	F	DS	CA, S	Z II, G E	LP	POS, <3d	<1d	Hemorrhage	Spinal cord injury
After initial treatment	10 (52.6)	Reisman et al. [14]	55	F	DS	P, LLI, ND, OM	Z III, G E, T, AD	A, O	POS, <3d	2mo	MODS	MODS
		Bergqvist et al. [19]	66	F	SB	P, LLI	Z III, G E, T, AD	No	POS, <3d	9d	Septic shock	MODS, Poor wound healing
		Sadaghianloo et al. [29]	15	M	DS	N/A	Z III, G B	A	CO, <3d	<1d	Hemorrhage	N/A
		Frydenburg et al. [30]	78	M	SB	LLI	G A, T	O	CO, <3d	<1d	Respiratory and renal failure	Respiratory and renal failure
		Frydenburg et al. [30]	71	F	SB	LLI	Z III, G D	O	CO, <3d	2d	Respiratory and renal failure	Respiratory and renal failure
		Michaels et al. [31]	60	F	SB	LLI, OM, S	Z III, G D	A	POS, <3d	4d	N/A	N/A
		Nucifora et al. [33]	36	M	DS	OM, S	Z III, G E	No	POS, <3d	<1d	Hemorrhage	N/A
		Tracy et al. [42]	13	M	DS	OM, S	Z III, G E	O	POS, <3d	<1d	Hemorrhage	No
		Macbeth et al. [69]	60	M	DS	P, LLI, ND	Z III, G D, T, AD	A	POS, 30d-1y	1.5mo	Septic shock	Septic shock, renal failure
		Warrian et al. [76]	36	F	SB	LLI, OM	Z III, G E, AD	O	POS, <3d	19d	MODS	MODS
On missed diagnosis	1 (5.3)	Katsoulis et al. [37]	41	M	DS	P, LLI, ND	N/A	A, LP	-	9d	Hemorrhage	No

BAAI: blunt abdominal aortic injury; M: male; F: female; DS: direct strike; SB: seat belt; CA: cardiopulmonary arrest; S: shock; P: pain; LLI: lower limb ischemia; OM: other manifestations; ND: neurological dysfunction; Z: zone; G: grade; T: thrombosis; AD: aortic degeneration; N/A: not available; A: injuries to organs in abdomen; LP: injuries to lumbar spine; O: injuries to other parts of body;

POS: primary open surgery; CO: conservative observation; MODS: multiple organ dysfunction syndrome

able 2. Univariate and multivariate analysis of death after BAAI

Variable		Univariate analysis		Multivariate analysis 1†		Multivariate analysis 2‡	
	Num of obs	Relative risk (95% CI)	*P* value	Relative risk (95% CI)	*P* value	Relative risk (95% CI)	*P* value
Age (y)	124	1.018 (1.001-1.035)	**0.040**	1.054 (1.019-1.090)	**0.002**	1.004 (0.988-1.020)	0.598
Female	124	2.182 (0.966-4.929)	**0.061**	0.494 (0.098-2.499)	0.394	1.794 (0.788-4.083)	0.164
Injury way	104						
Direct strike		Reference					
Seat belt		0.851 (0.335-2.166)	0.735				
Back hyperextension		1	-				
Pain	110	0.264 (0.108-0.648)	**0.004**	0.263 (0.100-0.689)	**0.007**	0.967 (0.255-3.659)	0.960
Lower limb ischemia	110	2.106 (0.883-5.023)	**0.093**	8.170 (0.738-90.486)	0.087	7.137 (1.154-44.161)	**0.035**
Neurological dysfunction	110	1.267 (0.416-3.857)	0.677				
Other manifestations	110	1.397 (0.577-3.379)	0.459				
Cardiopulmonary arrest	110	6.667 (3.580-12.415)	**<0.001**	2.70e+07 (1.62e+06~4.50e+08)	**<0.001**	10.250 (1.452-72.344)	**0.020**
Delayed manifestations	110	0.439 (0.064-3.030)	0.403				
No immediate manifestations	106	1	-				
Shock	99	2.207 (0.976-4.990)	**0.057**	2.715 (0.603-12.224)	0.193	2.552 (0.799-8.152)	0.114
Aortic lesion location	113						
Zone I		1	-	9.28e-08 (1.86e-08~4.64e-07)	**<0.001**		
Zone II		3.281 (1.159-9.293)	**0.025**	2.82e-07 (5.07e-08~1.57e-06)	**<0.001**		
Zone III		Reference		Reference			
Aortic lesion severity	111						
Grade A		Reference		Reference			
Grade B		4.143 (0.429-40.050)	0.219	5.97e+05 (9.29e+04~3.84e+06)	**<0.001**		
Grade C		1	-	2.93e+05 (2.59e+04~3.33e+06)	**<0.001**		
Grade D		6.444 (1.284-32.334)	**0.024**	8.45e+11 (1.09e+11~6.58e+12)	**<0.001**		
Grade E		11.393 (2.706-47.968)	**0.001**	2.06e+12 (2.99e+11~1.42e+13)	**<0.001**		
Thrombosis at aortic lesion	110	1.750 (0.659-4.648)	0.261				
Aortic degeneration	23	0.972 (0.287-3.292)	0.964				
Injuries to organs in abdomen	124	0.569 (0.251-1.292)	**0.178**	0.909 (0.399-2.071)	0.821	0.624 (0.273-1.426)	0.263
Injuries to lumbar spine	124	0.914 (0.330-2.534)	0.863				
Injuries to other parts of body	124	2.700 (1.209-6.031)	**0.017**	4.775 (0.387-58.855)	0.222	2.593 (1.189-5.655)	**0.017**
Core treatment	102						
Primary operation		0.363 (0.115-1.142)	**0.083**	2.882 (0.519-15.994)	0.226		
Secondary operation		1	**-**	3.12e+04 (7.06e+03~1.38e+05)	**<0.001**		
Conservative observation		Reference		Reference			
Timing to core treatment after injury	91						

<3d		Reference	
3d-30d		1	-
30d-1y		0.363 (0.051-2.603)	0.313
≥1y		1	-
Adverse events	23	1	-
Residual lower limb ischemia	95	1	-
Residual neurological dysfunction	10	1	-

AI: blunt abdominal aortic injury; Num of obs: number of observations; CI: confidence interval

†All variables with a *P* value <0.20 from univariate analysis were included in the model; ‡Variables with a *P* value <0.20 from univariate analysis and a relative risk value <1000 from multivariate analysis 1 were included in the model

Figures

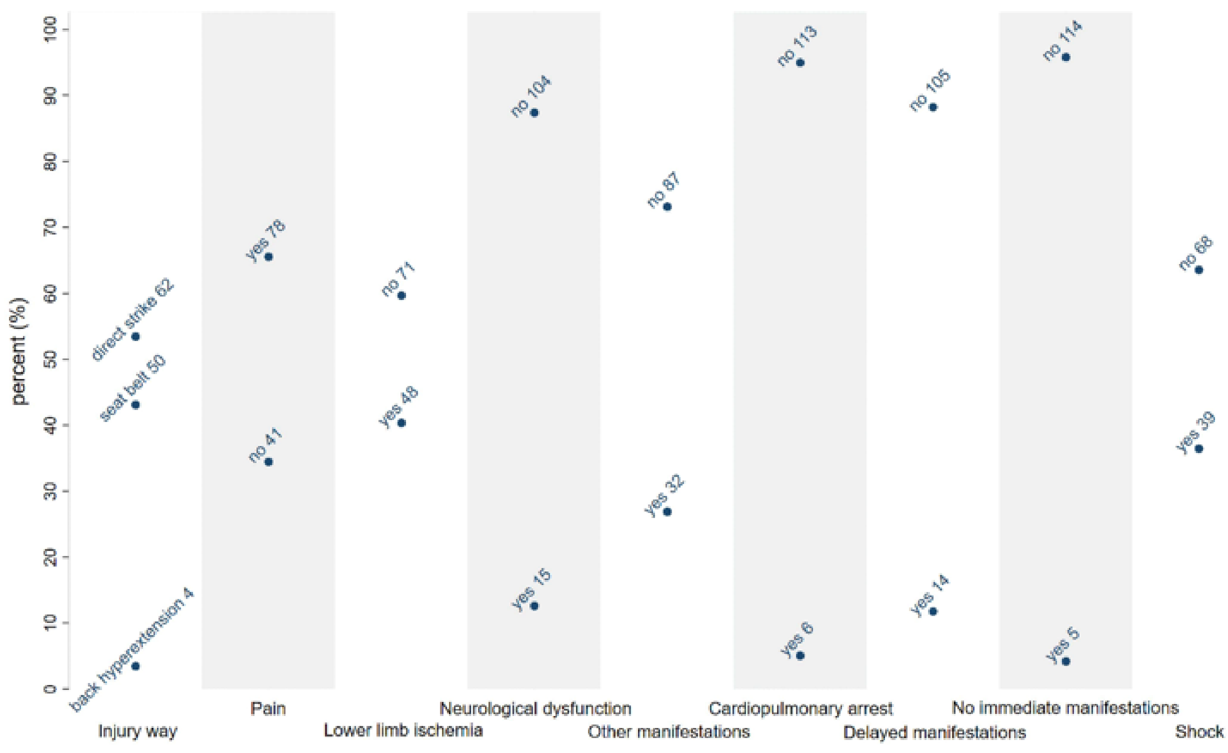

Figure 1

Constituent ratios of each clinical manifestation variable. The numbers of patient were labelled in the figure.

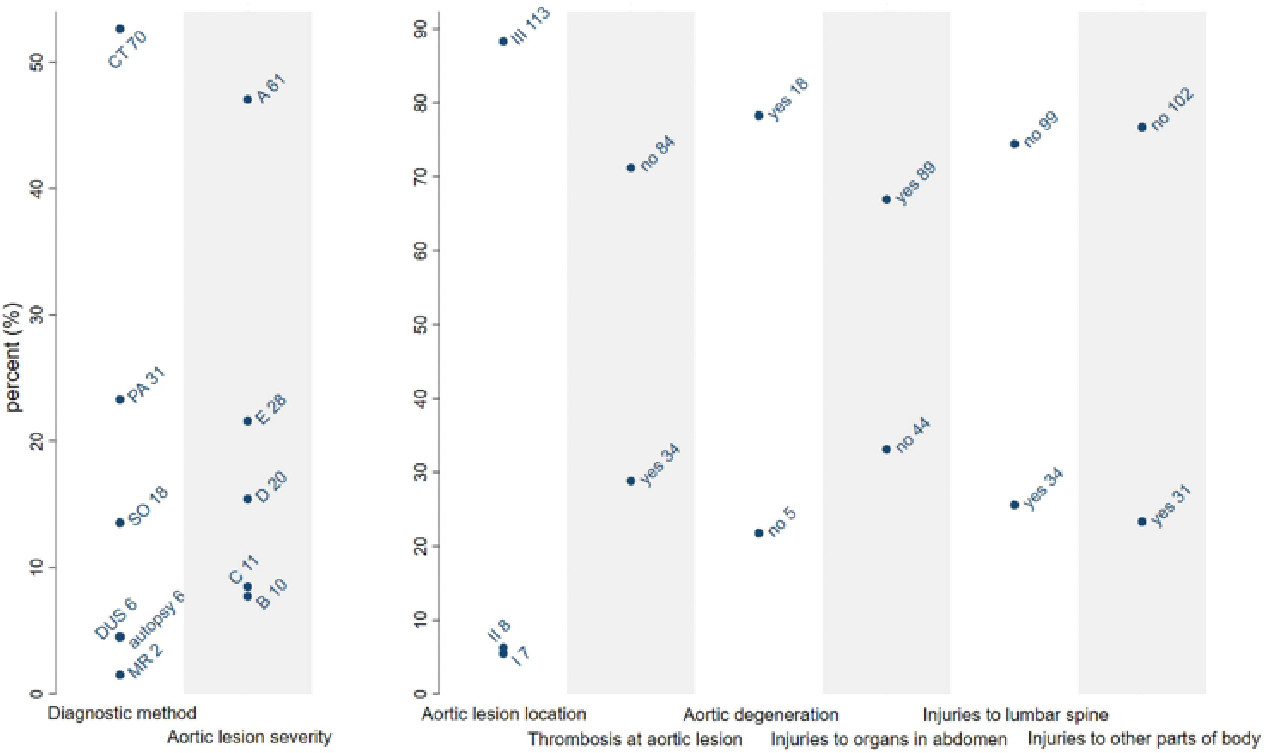

Figure 2

Constituent ratios of each diagnostic variable. The numbers of patient were labelled in the figure. CT: computed tomography; PA: percutaneous aortogram; SO: surgical operation; DUS: doppler ultrasound; MR: magnetic resonance.

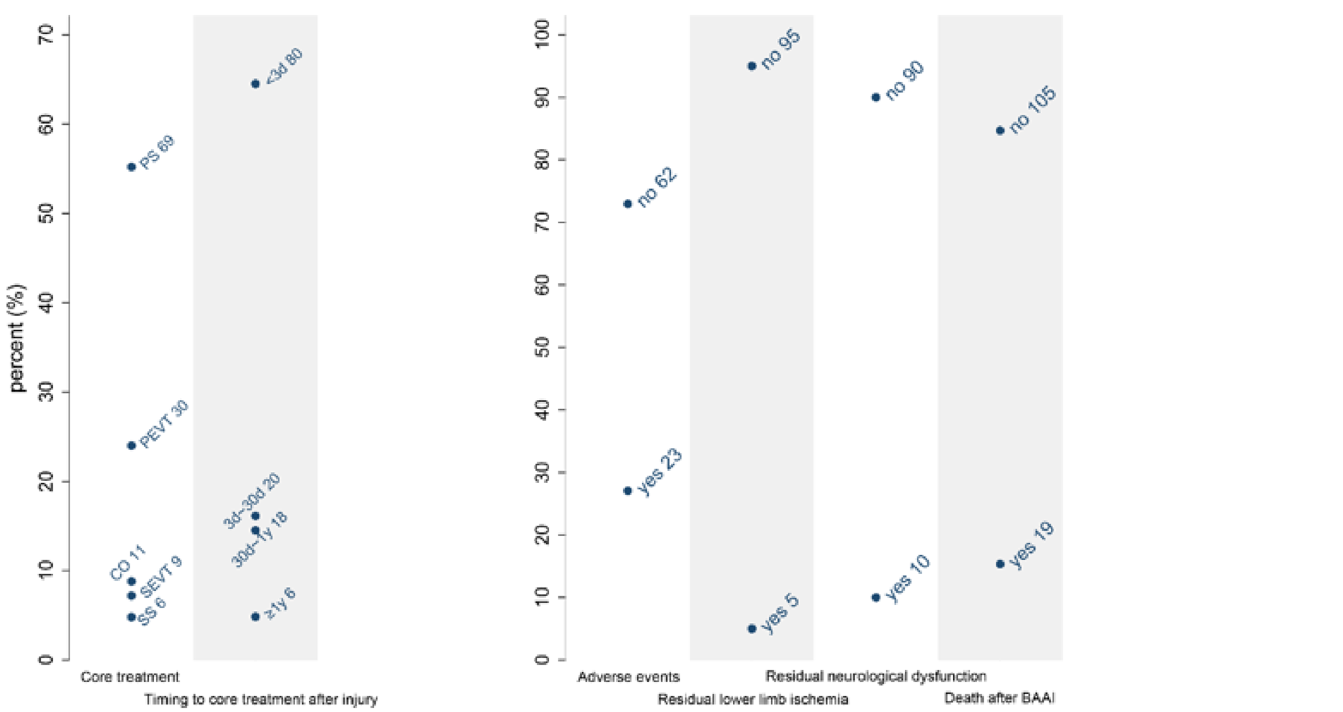

Figure 3

Constituent ratios for each treatment and outcome variable. The numbers of patient were labelled in the figure. PS: primary surgery; PEVT: primary endovascular therapy; CO: conservative observation; SEVT: secondary endovascular therapy; SS: secondary surgery.

Supplementary Files

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