Thoracic endovascular aortic repair of blunt traumatic thoracic aorta injury: A propensity score-matched analysis of the long-term clinical outcome

Yuanqing Kan
Zhongshan Hospital Fudan University
Xinsheng Xie
Zhongshan Hospital Fudan University Xiamen Branch: Fudan University Zhongshan Hospital Xiamen Branch
Ye Yuan
Zhongshan Hospital Fudan University
Daqiao Guo
Zhongshan Hospital Fudan University
Yi Si
Zhongshan Hospital Fudan University
Wan Zhang
Zhongshan Hospital Fudan University
Zhenyu Shi
Zhongshan Hospital Fudan University
Weiguo Fu
Zhongshan Hospital Fudan University
Lixin Wang (wang.lixin@zs-hospital.sh.cn)
Zhongshan Hospital Fudan University https://orcid.org/0000-0002-1379-3906

Research Article

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Abstract

Objectives: Patients of blunt traumatic thoracic aortic injury (BTAI) have different vessel property with those of primary type B aortic dissection (pATBAD). We hypothesize that thoracic endovascular aortic repair (TEVAR) may have better efficacy for BTAI patients than for pATBAD. This study aimed to compare the outcome of TEVAR for these two populations based on a prospectively built clinical database.

Methods: To reduce the baseline characteristic disparity between two groups, propensity score analysis with a match of 1:2 ratio was employed in BTAI and pATBAD patients who underwent TEVAR in a tertiary center from 2009 to 2018. Data including demographic, perioperative and follow up results were retrieved and analysed.

Results: A total of 41 BTAI and 82 pATBAD patients were enrolled. Baseline characteristics were comparable between both groups after match. The pATBAD group had a remarkably higher incidence of hypertension ($p < 0.001$). The total stent-graft covered length was significantly longer in the pATBAD group than in the BTAI group ($p = 0.016$). Aortic-related reintervention rate was significantly higher in the pATBAD group than in the BTAI group ($p = 0.027$). Higher rate of abdominal complete FL thrombosis was achieved in BTAI group than in pATBAD group (69.2% vs. 28.6%, $p = 0.001$).Overall, the early outcomes and long-term survival were similar in both groups.

Conclusions: TEVAR for BTAI patients show the acceptable clinical efficacy and safety when compared with the pATBAD. This study could provide more solid evidence for current clinical practice to support TEVAR for BTAI.

Introduction

Blunt traumatic thoracic aortic injury (BTAI) is a rare yet fatal disease, constituting less than 1% of chest trauma[1, 2]. With the advancement of transportation, BTAI caused by car accident is increasingly seen especially in developing countries. Kato et al. first reported the experience of utilizing thoracic endovascular aortic repair (TEVAR) for 10 BTAI patients in 1997[3], which was initially indicated for descending aortic aneurysm. Along with the progress of TEVAR technique, it has gradually been recommended to be the first-line intervention for BTAI[4]. However, the relevantly low level of evidence has still aroused controversies, unlike the well-established consensus in complicated primary type B aortic dissection (pTBAD)[5, 6]

BTAI commonly occurs after sudden deceleration, resulting from a combination of external forces exerting on the thoracic aorta[7]. On the contrary, pATBAD is usually caused by the joint effects of predisposing factors and structural weakness of the aortic wall, as is the case in hypertension or connective tissue disorder population[8, 9]. In consideration of the differences in baseline characteristics, the effect of the endovascular repair for both groups could be speculated to be different as well. Superior effect was expected in BTAI patients after TEVAR since this population of patients havn't preexisting risk

factors. Previously a couple of studies were conducted to explore the efficacy and safety of TEVAR for BTAI and pTBAD patients respectively using various endovascular devices[10–12], mostly in Western population[13–15]. However, to the authors' knowledge, currently there is no direct, comparative study regarding the clinical outcomes of TEVAR in BTAI patients versus in pATBAD patients.

Considering the commonly smaller sample size of BTAI patients at a single center and the great disparity of baseline conditions, this propensity-matched study was carried out in order to mitigate bias and investigate the efficacy of TEVAR for BTAI in comparison with pATBAD patients.

Methods

Study population and clinical data source

From 2009 to 2018, over 700 patients with acute thoracic aortic syndromes underwent TEVAR in a tertiary center among which 41 BTAI patients were enrolled in this study. Propensity score analysis was employed to obtain a match of 1:2 ratio between BTAI patients and pATBAD patients, and a final group of 82 pATBAD patients were included in this study. Clinical data were retrospectively retrieved from the prospectively collected electronic medical record system. Data included baseline characteristics (age, gender, and comorbidities), aortic lesion types, perioperative characteristics (endovascular procedures and devices, perioperative mortality and complications), follow-up durations, long-term outcomes (late mortality and reinterventions), and aortic remodelling in terms of false lumen (FL) thrombosis. This study was approved by the Institutional Ethics Committee of Zhongshan Hospital Fudan University (B2019-031R), and individual consent for this retrospective analysis was waived.

Endovascular techniques and procedures

All of the enrolled patients underwent TEVAR in our tertiary center. Indications of BTAI group included grade III-IV BTAI[16]. For the BTAI group, medical treatments were given on admission to stabilize vital signs. Multidisciplinary treatment modalities were adopted in cases of severe concomitant multiple trauma injuries existing. Initial evaluations of the aorta were made by computed tomography angiography (CTA) for all patients.

Standard endovascular procedures were performed in both groups. SGs were chosen based on the pre-operative CT findings and the availability of various SG in the shelf as well. Chimney technique, as well as left carotid artery to LSA bypass or in situ-fenestration were chosen to revascularize supra-aortic arch branches if beyond zone 3 deployment of a SG was required to ensure sufficient proximal landing zone (PLZ).

Clinical outcomes and follow-up strategy

Routine follow-up was performed at three months, six months, one year, and yearly thereafter, consisting of clinical evaluation and CTA check. Thirty-day postoperative outcomes were defined as in-hospital

mortality and procedure-related complications, including spinal ischemia, stroke, retrograde type A aortic dissection (RTAAD), acute renal dysfunction and bowel ischemia. Long-term outcomes included overall mortality and aortic-related reinterventions during follow-up. Aortic remodeling was evaluated by the extent of FL thrombosis at the stented thoracic segment and the abdominal segment of the aorta, which was categorized into complete, partial, and patent status.

Statistical analysis

To minimize the bias of irrelevant baseline characteristic between two groups, a propensity score analysis (PSA) was performed using the nearest neighbor matching without replacement. History of hypertension was excluded for matching because of its effect in the pathogenesis of pATBAD. The logistic regression model was used to generate the score and a score-based matched control group using a caliper size of 0.005; the balance assessment was made using various tests and checking quantile-quantile plots. PSA was performed using STATA version 15.1 (Stata Corp LLC, College Station, TX, USA).

Independent-sample Student's *t*-tests and Wilcoxon rank-sum tests were applied to compare continuous variables, whereas chi-squared and Fisher exact tests were utilized to compare dichotomous variables. Overall survival and freedom from reintervention during follow-up were analyzed with Kaplan-Meier curves and Log-rank test. Statistical analyses were performed using the Statistical Package for Social Sciences version 25 (IBM SPSS Statistics, Chicago, IL, USA). P values less than 0.05 were considered statistically significant.

Results

Baseline characteristics

After using a propensity score matching approach, 41 BTAI patients and 82 pATBAD patients were enrolled in this study. Baseline demographic characteristics before matching and after matching are shown in Table 1. Comorbidities, including DM, CAD, COPD, renal insufficiency, hyperlipidemia, PAD, and history of smoking were comparable in both groups post-match. In the BTAI group, mechanisms of blunt injury consisted of motor vehicle accidents (65.9%), fall (19.5%), strike injuries (7.3%) and others (7.3%, **Table S1**). The extents of aortic injuries included 4 grade III (pseudoaneurysm, Fig. 1A) and 1 grade IV injuries (aortic rupture, Fig. 1B) according to the acknowledged grading system[3, 7]. Of note, the majority of our enrolled patients presented as aortic dissection (AD) (36/41, 87.8%) (Fig. 1C).

Table 1
Baseline demographic characteristics of BTAI group and pATBAD group.

	Unmatched cohort			Matched cohort		
Characteristics	**BTAI** $N_1 = 41$	**pATBAD** $N_2 = 700$	**p**	**BTAI** $N_1 = 41$	**pATBAD** $N_2 = 82$	**p**
Age	45.8 ± 13.9	55.2 ± 12.7	< 0.001	45.8 ± 13.9	46.3 ± 12.2	0.842
Gender			0.040			0.887
Male	30(73.2)	596(85.1)		30(73.2)	59(72)	
Female	11(26.8)	104(14.9)		11(26.8)	23(28)	
Comorbidities						
Hypertension	15(36.6)	548(78.3)	< 0.001	15(36.6)	66(80.5)	< 0.001
DM	5(12.2)	106(15.1)	0.607	5(12.2)	13(15.9)	0.788
CAD	0(0)	48(6.9)	0.102	0(0)	1(1.2)	> 0.999
COPD	0(0)	30(4.3)	0.402	0(0)	0(0)	> 0.999
Renal insufficiency	0(0)	76(10.9)	0.016	0(0)	3(3.7)	0.550
Hyperlipidemia	1(2.4)	105(15.0)	0.021	1(2.4)	11(13.4)	0.060
PAD	3(7.3)	120(17.1)	0.129	3(7.3)	11(13.4)	0.382
Smoking	6(14.6)	121(17.3)	0.661	6(14.6)	11(13.4)	0.853
Data are present as mean ± SD or n(%).						

Perioperative characteristics

Perioperative characteristics of the matched cohorts are displayed in Table 2. Preoperative complications were compared between two groups, which indicated that renal ischemia was significantly more frequent in pATBAD group due to unilateral or bilateral renal artery malperfusion (p = 0.029). Durations from admission to surgery and lengths of stay were similar in both groups (p = 0.203 and 0.483). The BTAI group had three cases of surgical-exposed access via common iliac artery or infrarenal abdominal aorta to deliver SGs, whereas pATBAD group were all successfully established the femoral arterial assess (p = 0.035). Both groups employed a variety of SGs, among which only the utilization frequency of Hercules (Microport, Shanghai, China) reached a statistical difference (p = 0.011). The proportion of tapered SGs used in BTAI group was slightly higher than pATBAD group (19.5% vs. 12.2%, p = 0.279). Concerning SG size, it was found that overall total covered length was significantly longer in pTBAD group than in BTAI group (175.4 ± 25.5 mm vs. 161.9 ± 26.8 mm, p = 0.016).

Table 2
Perioperative characteristics of matched BTAI group and pATBAD group.

Characteristics		BTAI	pATBAD	p
Surgery duration(days)		8.5 ± 6.6	9.9 ± 5.4	0.20
Length of stay(days)		14.8 ± 8.7	15.8 ± 5.7	0.48
Branch vessel mal-perfusion	Bowel ischemia	0(0)	1(1.2)	0.10
	Renal ischemia	0(0)	9(11)	0.03
	Limb ischemia	0(0)	1(1.2)	0.10
Access	Femoral cut down	23(59)	44(53.7)	0.80
	Femoral puncture	13(33.3)	38(46.3)	0.12
	Open (Iliac artery or AA)	3(7.7)	0(0)	0.04
SG size(mm)	Length	161.9 ± 26.8	175.4 ± 25.5	0.02
	Proximal diameter	31.7 ± 4.2	32.7 ± 3.4	0.15
	Distal diameter	31.0 ± 4.1	32.1 ± 3.5	0.15
Tapered SG		8(19.5)	10(12.2)	0.28
SG brand	Valiant	20(48.8)	34(41.5)	0.44
	Zenith	9(22.0)	27(32.9)	0.21
	Hercules	4(9.8)	0(0)	0.01
	Ankura	3(7.3)	3(3.7)	0.40
	Relay	2(4.9)	1(1.2)	0.26
	TAG	2(4.9)	7(8.5)	0.72
	E-Vita	1(2.4)	2(2.4)	0.10
	Talent	0(0)	6(7.3)	0.18
	Castor	0(0)	1(1.2)	0.10
LSA coverage	1	22(53.7)	44(53.7)	0.10
	2/3	3(7.3)	2(2.4)	0.33

Data are present as mean ± SD or n(%).

† Type I endoleak = Type I endoleak at the completion of procedure

AA = abdominal aorta. SG = stent-graft. LSA = left subclavian artery.

Characteristics		BTAI	pATBAD	p
	1/2	4(9.8)	11(13.4)	0.56
	0	12(29.3)	23(28.0)	0.89
Chimney technique		2(4.9)	1(1.2)	0.26
Type I endoleak†		9(22)	28(34.1)	0.16
Data are present as mean ± SD or n(%).				
† Type I endoleak = Type I endoleak at the completion of procedure				
AA = abdominal aorta. SG = stent-graft. LSA = left subclavian artery.				

Postoperative early outcomes

No BTAI patient deceased before discharge. While the in-hospital mortality of pATBAD group was 4.9% (4/82, p = 0.3) due to RTAAD in one patient, visceral ischemia in one patient, and multiple organ dysfunction syndrome (MODS) in two patients. Incidence of the composite endpoint of early procedure-related major adverse events (MAE) was significantly lower in the BTAI group than the pATBAD group (p = 0.005) (Table 3).

Table 3
Postoperative early outcomes of matched BTAI group and pATBAD group.

Outcomes	BTAI	pATBAD	p
In-hospital mortality	0(0)	4(4.9)	0.30
Spinal cord ischemia	0(0)	3(3.7)	0.55
Stroke	0(0)	0(0)	/
RTAAD	0(0)	4(4.9)	0.30
Acute renal dysfunction	0(0)	1(1.2)	0.10
Visceral ischemia	0(0)	2(2.4)	0.55
Data are present as mean ± SD or n(%).			
RTAAD = retrograde type A aortic dissection.			

Follow-up and late outcomes

The BTAI group had an average time of 65.9 ± 38.3 months for clinical follow-up and 34.0 ± 30.5 months for radiographic follow-up, while the pATBAD group had an average time of 66.6 ± 39.2 months and 46.8 ± 36.4 months respectively. Fifteen BTAI patients (36.6%) and 22 pATBAD patients (28.2%) were unable to

reach for regular follow-up CTA examinations (p = 0.348). Additionally, 6 BTAI patients (14.6%) and 14 pATBAD patients (17.9%) were not able to continue clinical follow-up (p = 0.646). Figure 2 shows the Kaplan–Meier curves of overall survival rate and freedom from the aortic-related reintervention rate during 5-year clinical follow-up. Late mortality was similar in both groups (p = 0.556). BTAI group showed a significantly lower rate of aortic-related reintervention compared with pATBAD (p = 0.027). No stent-graft infolding, migration, or collapse was observed in both groups.

Aortic remodeling

The extent of FL thrombosis at the stented thoracic segment and abdominal segment during radiographic follow-up showed in Table 4. Complete FL thrombosis was achieved in a comparable proportion of both groups at thoracic aorta (p = 0.25). In contrast, a remarkable higher rate of abdominal complete FL thrombosis was found in BTAI group than in pATBAD (69.2% vs. 28.6%, p = 0.001). In contrast, 55.4% pATBAD patients showed continuous FL perfusion with partial FL thrombosis in the distal aorta, which was significantly higher than that in BTAI patients (19.2%, p = 0.002).

Table 4
FL thrombosis at stented thoracic segment and abdominal segment of matched BTAI group and pATBAD group.

FL thrombosis		BTAI	pATBAD	p
Thoracic segment	Complete	23(88.5)	43(76.8)	0.250
	Partial	1(3.8)	14(25)	0.029
	Patent	2(7.7)	3(5.4)	0.650
Abdominal segment	Complete	18(69.2)	16(28.6)	0.001
	Partial	5(19.2)	31(55.4)	0.002
	Patent	3(11.5)	13(23.2)	0.250
Data are present as n(%).				
BTAI = blunt traumatic aortic injury. **FL** = false lumen. **pATBAD** = primary acute type B aortic dissection.				

Discussion

This study performed a PSA to reduce the bias to the most extent and compare the effect of TEVAR for BTAI and pTBAD, intending to add more evidence to the clinical decision especially about BTAI in this TEVAR era. The BTAI group exhibited a more satisfying early outcome with no adverse events within 30 days postoperatively. Late mortality was similar in both groups, but the BTAI group showed a significantly lower rate of aortic-related reintervention. Regarding aortic remodeling, a remarkable higher rate of abdominal complete FL thrombosis was found in BTAI group than in pATBAD. Previously there was no study directly comparing BTAI and pTBAD due to the discrepancy of these two types of pathologies, such

as the younger age distribution of BTAI patients. Therefore we perform this PSA study. After PSA, patient demographics and comorbidities turned into similar in both groups, which reduced the potential bias mainly caused by the older age distribution in the overall pATBAD cohort. The unmatched incidence of hypertension remained high in pATBAD, which was to be expected since it's one of the crucial factors in AD pathogenesis.

In the present investigation, BTAI patients had an average duration from admission to surgery of 8.5 ± 6.6d (0–31 d), comparable with the 9.9 ± 5.4 d (1–23 d) of pATBAD patients. The intervention time of BTAI has been discussed for years. Society for Vascular Surgery 2011 guideline recommends an urgent repair for BTAI patients[4]. However, Ultee et al. found that early TEVAR on the day of admission was a risk factor for 30-day mortality[19]. Demetriades et al. and Marcaccio et al. both discovered a strong survival advantage with delayed repair, though with potentially higher morbidities of postoperative complications[20, 21]. European Society for Vascular Surgery 2017 guideline recommend delayed intervention for BTAI patients without large hematoma as IIa class of evidence[6]. In our BTAI cohort, only 3 patients underwent early repair on the day of admission, with one aortic rupture and 2 AD. Delayed TEVAR was performed in 92.7% of BTAI patients after the stability of the general condition. Favorable 30-day outcomes of BTAI patients were observed in our study with an absence of in-hospital mortality and complications, as well as a comparable overall length of stay in-hospital with the pATBAD group, further strengthening the current evidence of delayed repair for BTAI. Concerning endovascular procedures, the pATBAD group was found to have a significantly longer average SG coverage than the BTAI group, which could be explained by the difference of aortic lesion characteristics in two groups. There was a tendency toward higher incidence of spinal cord ischemia in the pATBAD group, yet no statistical significance was observed.

Previously Alberta et al.[22] have compared aortic arch morphology among TBAD, BTAI, and descending thoracic aneurysm, discovering an overall smaller aortic diameter in BTAI patients, especially around zone 3. Theoretically, BTAI happened in the population with the originally healthy aorta. Therefore, the aortic morphology might differ from those of aortic dilative diseases. In our study, interpretations should be cautiously given about the result of SG proximal and distal diameters, which was slightly larger in the pATBAD group than the BTAI group, yet was not found to be significantly different. Hercules Low-Profile Thoracic SG was used only in the BTAI group in our center, which has smaller size of devices, providing more options in decision making process. It's worth noting that hypovolemic aortic status was commonly presented in BTAI patients upon intervention, possibly leading to SG undersizing after fluid resuscitation, which could give rise to device-related complications such as SG migration or type I endoleak. Therefore, a slightly more oversizing rate was usually considered for BTAI patients. Paradoxically, excess oversizing could also result in severe incidences like RTAAD and bird-beak sign, which puts this issue in a dilemma and would require overall more comprehensive consideration. Combined with the above finding, the observation of similar SG diameters in both the groups could be attributed to the fact that most of the patients were transferred to our center from secondary or local hospitals after urgent management, whom were already corrected for hypovolemia. Besides, there was no post-operative RTAAD in BTAI group, yet

four cases happened in pATBAD group (p = 0.3), which could be related to the suitable proximal oversizing rate adopted during our practice. Moreover, Alberta et al. found that the trauma patients were oversized more than the aneurysm patients at the distal landing zone (DLZ)[23], which could raise the concerning of distal stent graft-induced new entry (SINE) due to the radial expanding force exerted by SG on distal healthy aorta in BTAI patients. Tapered SGs could be a more suitable choice for BTAI patients because of their segmented lesion. More extensive studies would be beneficial for probing into this focus.

Early and long-term outcomes were encouraging in this study. The pATBAD group appeared to have a significantly higher reintervention rate than the BTAI group during follow-up, which was coincidentwith the finding of previous studies[24, 25]. However, this was to be recalled that an unneglectable portion of patients were lost to follow-up despite the similar rate as previously report[26]. The possible reasons were the following: 1. As a high-volume tertiary center with advanced medical service, patients with the acute aortic syndrome were more likely to be transferred to our hospital at the time of onset but would prefer to receive CTA scan at local hospitals instead during follow-up, due to the potential cost of transportation or accommodation. 2. Young or middle-aged patients of BTAI with an originally healthy status itself could make them less compliant during follow-up. However, it could be assumed that patients who did not came back to our center for follow-up were most likely those without severe complications or without the need for reintervention. Therefore, the bias caused by loss of follow-up would actually affirm the conclusions deducted from the current results further. FL thrombosis was chosen as the parameter to assess aortic remodeling in this study. FL thrombosis was more favorable at distal aorta in BTAI group than pATBAD, which should be explained carefully since distal aorta was less involved in BTAI patients at the beginning with limited samples. However, this finding could still partially suggest that aortic lesion would rarely progress in BTAI patients, and the long-term efficacy of endovascular repair was satisfying in our cohort.

Results from our PSA indicated a favorable effect of TEVAR for BTAI patients, even superior to the pATBAD group. This study could provide more solid evidence for current clinical practice to support TEVAR for BTAI.

Our study had several limitations. First, this was an observational cross-sectional study from a single center with limited sample sizes, and the proportion of loss to follow-up was an inevitable weakness of such study design. Second, we were not able to adjust for all the potential confounding factors which could influence the comparison between two groups.

Declarations

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Conflicting interests

The authors have disclosed that they have no significant relationships with, or financial interest in, any commercial companies pertaining to this article.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Author's Contributions

YQK did the literature research and wrote a part of the manuscript. XXS and YY contributed to the idea of the manuscript, wrote the first draft of the manuscript. DQG wrote a part of the manuscript. YS and WZ designed the tables. ZYS draw the figures. WGF and LXW guide the writing. All the authors reviewed the manuscript and approved the submitted version.

Ethical approval

All procedures performed involving human participants were in accordance with the

ethical standards of the institutional research committee, and with the 1964 Helsinki

declaration and its later amendments or comparable ethical standards. The present study was reviewed and approved by the Ethics Committee of the Zhongshan Hospital, Fudan University.

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Figures

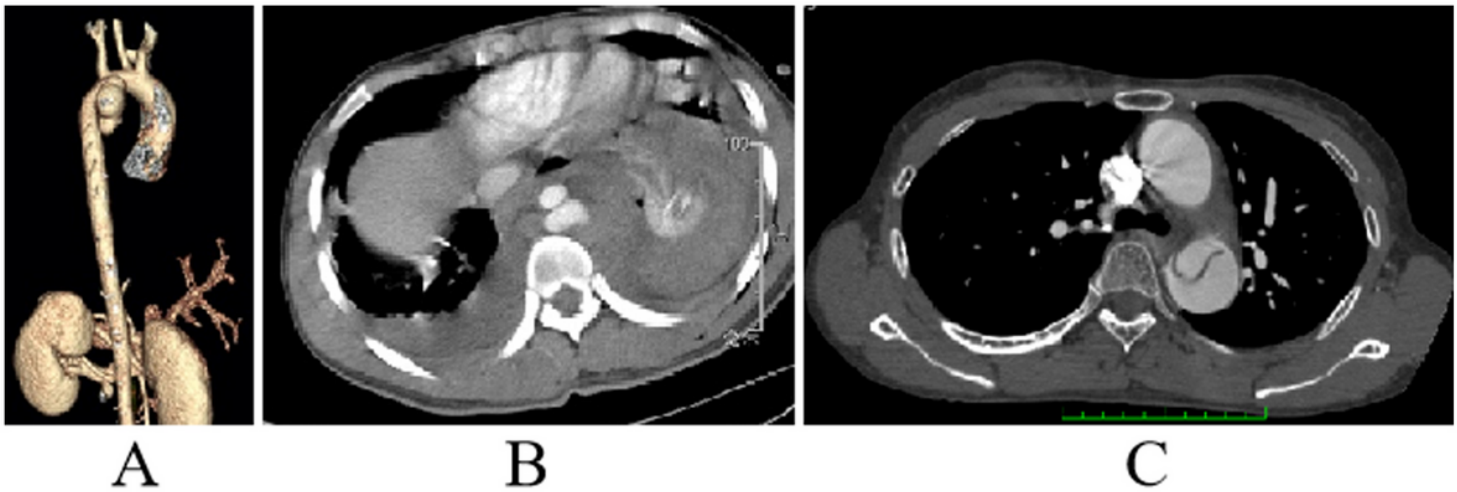

Figure 1

Aortic lesion types in the BTAI group. A: Pseudoaneurysm. B: Aortic rupture. C: Aortic dissection. BTAI=blunt traumatic thoracic aortic injury.

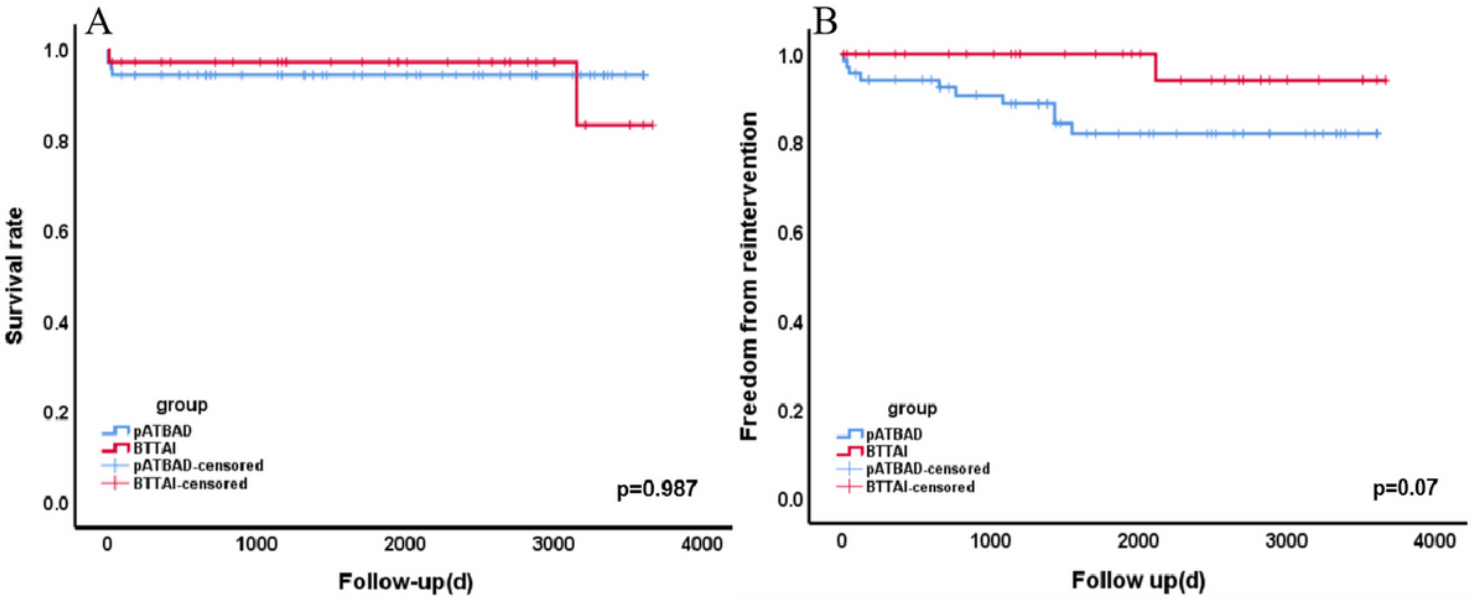

Figure 2

Kaplan-Meier curves of the outcomes of BTAI group and pATBAD group during 5-year clinical follow-up. A: Overall survival rate. B: Freedom from aortic-related reintervention rate. **BTAI**=blunt traumatic aortic injury. **pATBAD**=primary acute type B aortic dissection.

Supplementary Files

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- SupplementalTable.docx