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The Role of Surgical and Endovascular Repair of Blunt Traumatic Aortic Injury in the Modern Era: A Single-Center Experience

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ABSTRACT

Objective: To evaluate the efficacy of chest x-ray (CXR) in blunt traumatic aortic injury (BTAI) as a primary imaging tool in trauma patients.
Methods: We retrospectively reviewed our hospital records for blunt thoracic aortic injury patients who had a therapeutic intervention from January 2015 to February 2021. Patients' characteristics, initial chest x-rays, and computed tomography (CT) scan were extracted and re-evaluated.
Results: Eighteen patients matched the criteria of our research. The mean age and the injury severity score (ISS) was 29.8±11.2 and 38.4±14.4, respectively. Seven patients (38.9%) underwent thoracic endovascular aortic repair (TEVAR), and 11 (61.1%) had open surgery. The TEVAR group had significantly lower mean intensive care unit stay days (6.6±3.9 vs. 10.8±6.9 in open aortic repair (OAR), $p<0.05$). The percentile of patients requiring blood transfusion was significantly lower in the TEVAR group (57% vs. 100% in OAR, $p<0.05$). Mediastinal widening (66.7%) was the most common finding during the evaluation of initial chest x-rays. Interestingly, 22.2% of the initial x-rays were not remarkable for BTAI.
Conclusion: TEVAR is an advantageous choice in the management of BTAI. However, open aortic repair is the optimal decision in certain situations. It is suggested that the Interventional management of the BTAI must be performed by experienced vascular surgeons in a medical center capable of both OAR and TEVAR.

Keywords: Surgical; Endovascular; Repair; Blunt traumatic aortic injury (BTAI); Thoracic endovascular aortic repair (TEVAR); Trauma.

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Introduction

Blunt traumatic thoracic aortic injury (BTAI) is considered among the leading causes of death in road traffic collisions [1]. Various mechanisms such as falling from heights, motor vehicle accidents, and other rapid deceleration-based traumas are implicated in the pathogenesis of BTAI. Early diagnosis is essential for the patients who survive long enough to reach medical care. Computed tomography (CT) scan accurately estimates the anatomy of the aortic injury and adjacent injured organs [2]. Chest CT is an acceptable screening tool based on the necessary high sensitivity and ease of using in the trauma patients who suspected to have a descending thoracic aortic injury. There will always be artifacts and limitations that necessitate aortography for clarification, but three-dimensional software reconstruction of the aorta can help to diagnose of blunt aortic injury when findings are ambiguous [2-4]. However, the efficacy of taking and physical examination history should not be disregarded [5, 6].

The traditional management of BTAI includes open aortic repair (OAR) or non-operative management (NOM). Nowadays, the standard care for BTAI is thoracic endovascular aortic repair (TEVAR) which offers lower morbidity and mortality compared to OAR. Despite the apparent advantages, stent-related complications such as stent collapse, endoleak, and migration should not be underestimated. Furthermore, since the injury site is commonly at the aortic isthmus, the left subclavian artery origin is often covered by the stent graft, compromising the left upper extremity blood circulation. A more selective approach for patients might be required to undergo left common carotid-left subclavian artery bypass to prevent further complications [6, 7].

In this study, we intend to share our managing experience in BTAI patients at Shiraz University of Medical Sciences, the referral center in the south of Iran. In addition, we intend to evaluate the efficacy of chest x-ray (CXR) in BTAI as a primary imaging tool in trauma patients.

Material and Methods

This study approved by ethics committee of Shiraz University of Medical Sciences with the code number of IR.SUMS.MED.REC.1398.484. Hospital records were reviewed for BTAI cases with a surgical intervention from January 2015 to February 2021. Patients who were medically and conservatively managed are not included in this study. A total of 20 BTAI cases were admitted to our institution who underwent aortic repair. Data were extracted from the medical records included initial blood pressure, interval to treatment, packed cell use, abbreviated injury scale (AIS), injury severity score (ISS), initial CXR and computed tomography angiography (CTA), hospital and intensive care unit (ICU) length of stay (LOS), intervention-related and hospital course complications, and follow-up information. We examined the initial CXRs for mediastinal widening, aortopulmonary window obliteration, apical pleural capping, hemothorax, and rib fractures. Incidental findings irrelevant to BTAI were marked as “other findings.” Patients were graded by CTA findings (Figure 1A) which is the gold standard diagnostic modality, as follows: Grade I (intimal tear), grade II (intramural hematoma), grade III (pseudoaneurysm), grade IV (aortic free rupture) [8]. A surgeon and a radiologist confirmed all radiologic findings. The aortic injury was managed either by OAR (11 cases) or TEVAR (7 cases). Preoperatively, all patients received antihypertensive therapy to achieve systolic blood pressure (SBP) <100 mmHg and blood products if necessary. Procedures were performed after the stabilization of the patients. All procedures were performed at Shiraz University of Medical Sciences.

Open Aortic Repair

A team of vascular surgeons performed all OAR under general anesthesia. The injury site was repaired by a Dacron tube graft and the left thoracotomy approach (Figure 1B). The procedure were maintained distal aortic perfusion by femoral artery-femoral vein (FA-FV) cardiopulmonary bypass pump. The exception was a patient with myocardial contusion who underwent pulmonary vein-femoral artery bypass. Lumbar spine drains were not routinely placed. In 2 cases, we had to meticulously pack the thoracic cavity with a lap sponge due to diffuse oozing. After a 4-day interval, we removed the thoracic packings uneventfully.

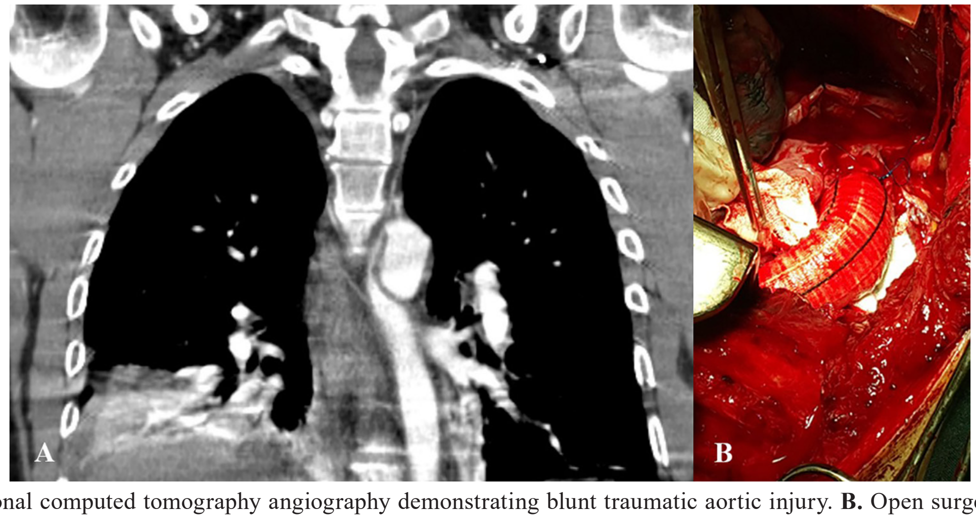

Fig. 1. A. Coronal computed tomography angiography demonstrating blunt traumatic aortic injury. **B.** Open surgery of the same patient. The aortic injury was replaced by Dacron graft.

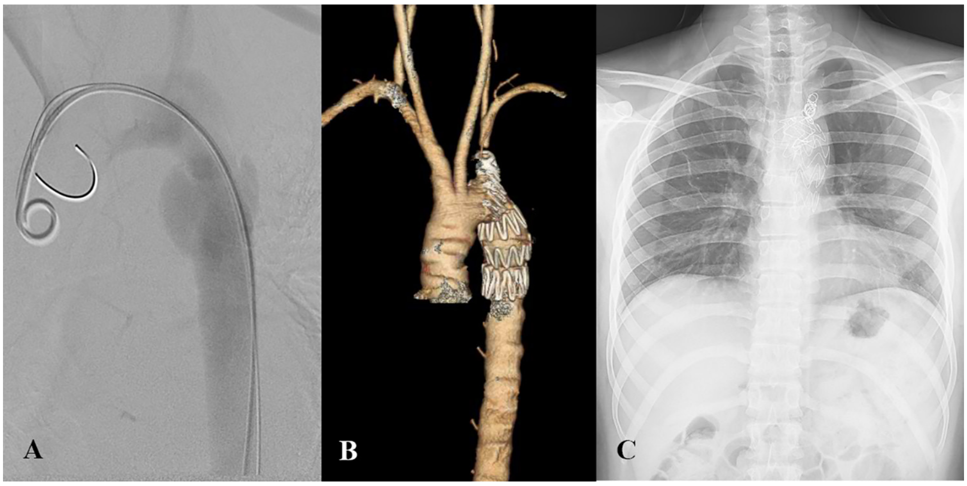

Fig. 2. A. Aortic angiogram demonstrating pseudoaneurysm in the descending aorta; **B.** 3-D reconstruction of the patient after thoracic endovascular aortic repair. The left subclavian artery is obliterated. **C.** Chest x-ray showing the stent-graft.

Thoracic Endovascular Aortic Repair (TEVAR)

TEVAR procedures were performed by a team of vascular surgeons and interventional cardiologists. The standard endovascular aortic repair through the femoral artery was performed using Zenith TX2 and Zenith Alpha (Cook Medical Inc.) endovascular stent grafts. Conventional intraoperative angiographic imaging was obtained before and after the stent-graft deployment. No patient needed urgent left common carotid-left subclavian bypass postoperatively. CT angiography (CTA) was acquired prior to being discharged (Figures 2).

Follow-up

As our routine follow-up surveillance, we visited all patients within a month, six months, and a year after the intervention. CXR and CTA were obtained from the OAR and TEVAR groups, respectively.

Statistical Analysis

In this study, we used SPSS version 23.0 (IBM, Armonk, NY, USA) to analyze the data. Descriptive statistics were used to demonstrate the characteristics of the included patients: frequencies (percentages) for categorical variables, mean±standard deviation (SD), and median (interquartile range [IQR]) for numerical variables. Kolmogorov-Smirnov test was applied to evaluate the variables' normality distribution. A Chi-square or Fisher's exact test was used to determine the differences in characteristics between TEVAR and open surgery groups. Independent sample t-test and Mann-Whitney U test were used to identify differences in continuous variables between these two study arms. P-value<0.05 was considered as statistically significant.

Results

Two cases were excluded from this study due to the unavailability of admission information and imaging. Among the 18 patients who remained, the average age was 29.8 years (range, 17 to 65 years); 83.3% of the patients were men, and the mean ISS was 38.4±14.4. (Table 1). In this cohort study, the mean admission SBP was 124.7±17.6, and 16.7% of the patients received no packed cells who all were in the TEVAR group. In 4 cases undergoing TEVAR, the left subclavian artery origin was obliterated due to proximity to the injury site.

Eleven (61.1%) patients underwent OAR with a mean ISS of 38.1±13.4 and a median interval of 1 day (range, 0 to 6 days). Two patients needed intervention for thoracic gauze pack removal. The OAR group's mean ICU and hospital length of stay (LOS) were 10.8±6.9 and 18.4±8.6, respectively. Follow-up visits revealed no complications or complaints regarding the OAR.

TEVAR was performed on 7 (38.9%) patients with a mean ISS of 39±16.9 and a significantly higher median treatment interval of 5 days (range, 1 to 130 days). There were no technical or device-related complications during the procedures. In 4 (57.1%) TEVAR cases, the left subclavian artery ostium was sacrificed for proper stent-graft deployment. One (14.2%) case underwent left common carotid-left subclavian artery bypass since he developed arm claudication in follow-up visits. TEVAR patients had mean intensive care unit (ICU) and hospital LOS of 6.6±3.9 and 15.3±6.8, respectively. ICU length of stay was significantly lower in the TEVAR group (p<0.05).

As shown in Table 2, the main complication in both TEVAR and OAR groups was pulmonary atelectasis (50%). Moreover, thromboembolic events (16.7%) and pneumonia (16.7%) were the most occurring in BTAI patients. In our cases, we had neither stroke nor spinal cord ischemia.

The mortality rate was 5.5% (1 of 18 patients). This patient was transferred to our institution with prolonged ischemia of both lower extremities and underwent urgent OAR since a proper stent was unavailable. The cause of death was a multi-organ failure. It must be noted that no patient died before or during the procedures.

Table 1. Characteristics of the patients in thoracic endovascular aortic repair versus open aortic repair.

Variables		Total; N=18	TEVAR[e]; n=7	OAR[b]; n=11	*p* value[a]
Age (year); mean±SD[d]		29.8±11.2	33.9±15	27.3±7.7	0.236
Sex; n (%)	Male	15 (83.3%)	5 (71.4%)	10 (90.9%)	0.280
	Female	3 (16.7%)	2 (28.5%)	1 (9.1%)	
Blood pressure, mm Hg; mean±SD[d]	Systolic	124.7±17.6	132.3±16.2	119.9±17.4	0.151
	Diastolic	75.7±12	78.7±11.5	73.7±12.4	0.406
Packed cells given	Received; n (%)	15 (83.3%)	4 (57.1%)	11 (100%)	0.017[f]
	Amount (units); mean±SD	5.2±3.7	3.9±4.3	6.1±3.2	0.228
Interval to procedure, days	Duration; median [Q1, Q3]	2 [1-5.25]	5 [2-8]	1 [1-2]	0.047 [f]
	Early (<24 hours); n (%)	8 (44.4%)	1 (14.2%)	7 (63.6%)	0.040 [f]
	Delayed (>24 hours); n (%)	10 (55.6%)	6 (85.7%)	4 (36.3%)	
BTAI[c] grade; n (%)	Grade 3	16 (88.9%)	6 (85.7%)	10 (90.9%)	0.732
	Grade 4	2 (11.1%)	1 (14.2%)	1 (9.1%)	
Abbreviated injury scale; mean±SD[d]	Chest	5.1±0.4	5±0.6	5.1±0.3	0.675
	Head and neck	0.8±1.3	0.3±0.8	1.2±1.5	0.120
	Face	0.2±0.4	0±0	0.3±0.5	0.141
	Abdomen	1.3±1.5	1.7±1.3	1.1±1.6	0.378
	Extremities	2.2±1.1	2±1.2	2.4±1	0.423
	External	1±0.5	0.9±0.4	1.1±0.5	0.319
Injury severity score; mean±SD[d]		38.4±14.4	39±16.9	38.1±13.4	0.901
Admission duration (days); mean±SD[d]	Hospital	17.2±7.9	15.3±6.8	18.4±8.6	0.437
	ICU	9.2±6.2	6.6±3.9	10.8±6.9	0.161

[a]Chi-Square/Fisher's exact test or Mann-witney/independent sample t-test; [b]OAR: open aortic repair; [c]BTAI: Blunt thoracic aortic injury; [d]SD: standard deviation; [e]TEVAR: thoracic endovascular aortic repair; [f] P-value section indicates significant association.

Table 2. Outcomes of the included patients in thoracic endovascular aortic repair versus open aortic repair.

Outcomes	Total N=18 (%)	TEVAR[a] n=7 (%)	OAR[b] n=11 (%)	*p* value[d]
Atelectasis	9 (50%)	3 (42.8%)	6 (54.5%)	0.629
Thromboembolic events	3 (16.7%)	1 (14.2%)	2 (18.1%)	0.829
Pneumonia	3 (16.7)	1 (14.2%)	2 (18.1%)	0.829
AKI[c]	1 (5.5%)	0 (0%)	1 (9.1%)	0.412
Arm claudication	1 (5.5%)	1 (14.2%)	N/A	-
Stroke`	0 (0%)	0 (0%)	0 (0%)	1.0
Spinal cord ischemia	0 (0%)	0 (0%)	0 (0%)	1.0
Endoleak	0 (0%)	0 (0%)	N/A	-
Paraplegia	0 (0%)	0 (0%)	0 (0%)	1.0
Mortality	1 (5.5%)	0 (0%)	1 (9.1%)	0.412

[b]OAR: open aortic repair; [a]TEVAR: thoracic endovascular aortic repair; [c]AKI: Acute kidney Injury; [d]Chi-Square/Fisher's exact test.

Table 3. On admission chest X-ray findings of the patients in thoracic endovascular aortic repair versus open aortic repair.

Findings; n (%)	Total N=18 (%)	TEVAR[a] n=7 (%)	OAR[b] n=11 (%)	*p* value[d]
Mediastinal widening	12 (66.7%)	5 (71.4%)	7 (63.6%)	0.732
Hemothorax	9 (50%)	4 (57.1%)	5 (45.4%)	0.629
Aortopulmonary window obliteration	5 (28.8%)	2 (28.5%)	3 (27.2%)	0.952
Rib fracture	4 (22.2%)	1 (14.2%)	3 (27.2%)	0.518
Apical pleural capping	2 (11.1%)	1 (14.2%)	1 (9.1%)	0.732
Other findings	2 (11.1%)	1 (14.2%)	1 (9.1%)	0.732
No specific finding for BTAI[c]	4 (22.2%)	2 (28.5%)	2 (18.1%)	0.605

[a]TEVAR: thoracic endovascular aortic repair; [b]OAR: open aortic repair; [c]BTAI: Blunt thoracic aortic injury; [d]Chi-Square/Fisher's exact test.

It is shown in Table 3 that the most common finding in the initial CXR of BTAI patients was mediastinal widening with 12 cases (66.7%). Nine patients (50%) had hemothorax, five patients (28.8%) had aortopulmonary window obliteration, four patients (22.2%) had rib fracture, and finally, two patients (11.1%) had apical pleural capping. Four patients (22%) had no remarkable findings indicating BTAI.

Discussion

In managing BTAI patients, making an urgent diagnosis is of utmost importance. This can be challenging in small hospitals where CT scan is unavailable or limitedly used due to economic matters. Our study coincides with Gutierrez *et al*. study that suggested BTAI could be potentially missed by a normal CXR [9]. Our results demonstrate that 22% of the patients had no remarkable findings to indicate BTAI, and 32.3% had normal mediastinum in the CXRs. Furthermore, a multi-central study of 24,010 chest imaging of level I trauma patients with 42 definite cases of aortic injury showed that none of the classic CXR findings of BTAI such as mediastinal widening are sensitive enough to make the diagnosis [10]. These findings call for an emphasis on take collision mechanism, trauma severity, and medical suspicion into consideration during decision-making. CXR is used as a screening method in trauma patients but there must be no hesitation for CT angiography in certain cases.

BTAI is managed by NOM, OAR, and TEVAR, depending on staging and patient characteristics. Traditionally, OAR was unfavored due to high rates of paraplegia and spinal cord ischemia. However, these complications significantly declined after routine use of a cardiopulmonary bypass pump during the aortic surgeries. Since the approval of TEVAR, there has been a significant drop in the number of OAR in BTAI. In the light of recent studies, TEVAR is the standard care for BTAI with lower rates of complications and improved outcomes. On occasions in which the patient requires intervention, OAR is chosen only when TEVAR is not possible due to unfavored anatomical criteria or unavailability of the proper size of the stent graft [6, 11, 12].

In a study on BTAI management trends, Grigorian *et al*. concluded that the TEVAR rate has increased in recent years with replacing OAR in many cases [13]. Moreover, another study by Scalea *et al*. also showed that fewer cases are managed non-operatively (87.5% in 2003 vs. 67.8% in 2013) as more cases are treated by TEVAR [11]. The benefits of TEVAR outweigh the risks of NOM for many clinicians. These findings could be concerning since this trend may lead to an increase of device-related complications in low-grade BTAI patients previously managed non-operatively with no complications. In this study, we had no device-related complications such as endoleak, stent-graft migration, or device collapse, but a 9% rate was observed in a retrospective study of BTAI patients [14]. There are also concerns regarding the long-term aortic remodeling in TEVAR patients.

Forbes *et al*. demonstrated that the aortic diameter increases in the follow-ups of 21 BTAI patients who underwent TEVAR [15]. Beru *et al*. conducted a retrospective review of 32 BTAI patients who underwent TEVAR. It was concluded that the proximal and distal stent-graft landing zone and the aortic diameter significantly increased. It was mentioned that about 22% of the patients in the study required secondary intervention due to device-related complications [16].

Device-related complications are not the only downside of TEVAR. In a 2020 retrospective study of 61 TEVAR patients in a tertiary center by Mccurdy *et al*., 36% of the patients' left subclavian artery origin was obliterated by the stent graft, and 16% required left common carotid-left subclavian artery bypass [17]. These findings correlate to our data as the subclavian artery was covered by stent-graft in 57.1% of the TEVAR group, and 14.2% of the patients needed further bypass to maintain upper extremity perfusion.

Another interesting finding in Mccurdy *et al*. study was a decrease in BTAI cases, especially in grade IV through the years of the study. It was concluded that many cases were probably managed in the primary hospital by TEVAR without being transferred to the referral center [17]. Undoubtedly, a diminished patient load could be beneficial for a tertiary referral center. On the other hand, these procedures are performed in centers that were not previously prepared for an OAR. We believe that surgical interventions for BTAI in primary hospitals should be limited to critical cases in which a delayed approach is lethal such as aortic rupture. In these centers, the focus must be on initial resuscitations, patient stabilization, and medical management of BTAI. Many studies have indicated that perioperative death is rare with proper medical management. It has been demonstrated that a delayed approach in certain candidates is associated with reduced overall mortality [18, 19]. In our study, 85% of TEVAR patients underwent the delayed procedure (significantly higher vs. 36.6% in OAR; $p<0.05$) with a median of 5 days intervals. We had no mortality due to delayed intervention. This considerable difference among these groups was possible since some OAR patients were candidates for urgent TEVAR, but the proper stent graft was unavailable at the time, making urgent OAR inevitable. This led to an accumulation of early interventions in the OAR group in our study.

At last, Interventional management of BTAI must be practiced by expert vascular surgeons in a center capable of both OAR and TEVAR and preferably in hybrid operating rooms where a switch from TEVAR to OAR is possible. However, due to recent widespread trends toward endovascular approaches in vascular surgeries, newly trained vascular surgeons may find themselves unconfident to perform OAR [20-23].

Our main limitation in this study was the low quantity of our cases. This is probably since BTAI is a rare condition. Moreover, we did not have access to possible BTAI cases in our institutional region who died before reaching the hospital or receiving NOM. Unfortunately, the low number of aortic injury cases led to statistically insignificant comparisons in some results.

In conclusion, we believe that CXR findings are insufficient for decision-making in trauma patients. There must be no hesitation for a CT scan when there is clinical suspicion of BTAI. Although TEVAR has revolutionized the care for aortic injuries, the question is raised whether the growth rate of TEVAR is worth to discuss complications. Moreover, the precise indications for choosing between NOM, TEVAR, and OAR remain unclear. The medical centers where interventional management of BTAI is performed should be properly equipped for both TEVAR and OAR. Finally, further studies are required to describe the durability of the stent grafts and possible long-term outcomes of aortic dilatation in TEVAR patients.

Declarations

Ethics approval and consent to participate: This study approved by ethics committee of Shiraz University of Medical Sciences with the code number of IR.SUMS.MED.REC.1398.484. The patients consented to the use of related medical record and images for educational purposes.

Consent for publication: None declared.

Conflict of interests: The authors declared that there is no conflict of interest.

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Authors' contributions: Hamed Ghoddusi Johari, Ahmad Hosseinzadeh and Javad Kojuri: Study conception and design. Seyed Arman Moein: Acquisition of data. Seyed Arman Moein and Reza Shahriarirad: Drafting of the manuscript and critical revision of the manuscript. Amirhossein Roshanshad, Seyed Arman Moein and Reza Shahriarirad: Analysis and interpretation of data. All authors read and approved the final version of the manuscript.

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