

# Postoperative complications of endovascular blunt thoracic aortic injury repair

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Received 14 January 2021  
Accepted 14 June 2021

## ABSTRACT

**Background** Thoracic endovascular aortic repair (TEVAR) has become the standard of care for thoracic aortic aneurysms and increasingly for blunt thoracic aortic injury (BTAI). Postoperative complications, including spinal cord ischemia and paraplegia, have been shown to be less common with elective TEVAR than with open thoracic or thoracoabdominal repair. Although small cohort studies exist, the postoperative complications of endovascular repair of traumatic aortic injury have not been described through large data set analysis.

**Methods** A retrospective cohort analysis was performed of the American College of Surgeons Trauma Quality Improvement Program registry spanning from 2007 to 2017. All patients with BTAI who underwent TEVAR, as indicated by the Abbreviated Injury Scale or the International Classification of Diseases (ICD-9 or ICD-10), were included. Categorical data were presented as proportions and continuous data as mean and SD. OR was calculated for each postoperative complication.

**Results** 2990 patients were identified as having undergone TEVAR for BTAI. The postoperative incidence of stroke was 2.8% (83), and 4.7% (140) of patients suffered acute kidney injury or renal failure. The incidence of spinal cord ischemia was 1.9% (58), whereas 0.2% (7) of patients suffered complete paraplegia. Renal events and stroke were found to occur significantly more frequently in those undergoing TEVAR (OR 1.758, 1.449–2.134 and OR 2.489, 1.917–3.232, respectively). Notably, there was no difference between TEVAR and non-operative BTAI incidences of spinal cord ischemia or paraplegia (OR 1.061, 0.799–1.409 and OR 1.698, 0.728–3.961, respectively).

**Discussion** Postoperative intensive care unit care of patients after BTAI has historically focused on awareness of spinal cord ischemia. Our analysis suggests that after endovascular repair of blunt aortic trauma, care should involve vigilance primarily against postoperative cerebrovascular and renal events. Further study is warranted to develop guidelines for the intensivist managing patients after TEVAR for BTAI.

**Level of evidence** Level III.

## INTRODUCTION

Blunt thoracic aortic injury (BTAI) is a rare, although potentially catastrophic, injury which occurs in <0.5% of trauma patients reaching the hospital.<sup>1</sup> Historically, aortography has been considered the diagnostic standard, although transesophageal echo and CT have been used as these technologies appeared. Management had, until recent decades, relied on an open approach that was associated

with high rates of mortality and paraplegia.<sup>2</sup> The diagnosis and management of thoracic aortic injury have been revolutionized by the ready availability of CT arteriography and thoracic endovascular aortic repair (TEVAR).<sup>3,4</sup>

TEVAR, most frequently used for repair of thoracic aortic aneurysm, is not free of complications. Initially, these consisted primarily of device-related problems; as technology has been refined, these issues have become more uncommon.<sup>5</sup> A persistent concern has been spinal cord ischemia (SCI) and consequent neurological morbidity including paraplegia. Although this is common to both open and endovascular repair, the mechanisms responsible are different: open repair involves prolonged aortic clamping and intraoperative lack of spinal cord perfusion, whereas TEVAR involves permanent coverage of the vessels perfusing the spinal cord. These include the segmental medullary arteries, including the artery of Adamkiewicz, as well as the anterior spinal artery arising from the vertebral artery.

The latter is of theoretic relevance to trauma TEVAR in particular; the most common location of BTAI is at the ligamentum arteriosum, and repair frequently entails coverage of the origin of the left subclavian artery. Perfusion of the upper extremity relies on retrograde flow from the contralateral to the ipsilateral vertebral artery, reducing perfusion pressure of the anterior spinal artery that lies between and is fed by both. Regardless, initial studies indicated a reduced incidence of SCI with endovascular repair compared with open.<sup>5</sup>

The use of TEVAR has increased dramatically during the last decade, and its proliferation may be due to a lowered threshold for treatment of BTAI as a result of the perceived reduced morbidity of repair.<sup>6</sup> The actual incidence and type of complication associated with TEVAR for BTAI remain unclear; although small cohort studies exist, large data set analysis has not as yet been performed.<sup>7–11</sup> The aim of this study is to use a large national data set to delineate the modern morbidity of TEVAR in the setting of BTAI and the associated outcomes.

## PATIENTS AND METHODS

### Overview

This is a retrospective, observational analysis of the American College of Surgeons Trauma Quality Improvement Program (ACS-TQIP) database including patient data from 2007 to 2017. ACS-TQIP is the largest and most comprehensive national trauma database and includes detailed

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**To cite:** Abdou H, Elansary NN, Darko L, et al. *Trauma Surg Acute Care Open* 2021;**6**:e000678.

clinical information from over 850 participating hospitals.<sup>12</sup> All participating hospitals are designated trauma centers, with most being level I or II. The data set includes demographic characteristics; clinical variables including vital signs; injury organ, region, type, and severity; therapeutic type and timing; and complications during hospitalization. Database access is granted by the ACS for selected research projects and for a fee. The stated purpose of the TQIP registry is to enable real-time data analysis and identification of areas for improvement of trauma care.

### TEVAR overview

TEVAR is typically performed in a hybrid operating room with fixed-imaging capability. On occasion, if circumstances require, the repair is performed in a non-hybrid operating room with a portable fluoroscopy unit. This standard has not changed during the study interval. In most institutions, TEVAR is performed by vascular surgeons; it requires both endovascular skill and an ability to perform open vascular surgery if necessary. This is usually done by vascular surgery on consultation by the primary trauma team. At certain trauma specialty centers, such as ours, trauma TEVAR is performed by surgeons with dual training in trauma and vascular surgery whose practice focuses on vascular and endovascular trauma surgery.

### Data extraction

Patients who sustained a BTAI were identified using Abbreviated Injury Scale (AIS) codes (4202XXX) and International Classification of Diseases (ICD-9) codes (901). Of those identified as having sustained a BTAI, patients who underwent TEVAR were identified using ICD-9 code 39.73 and ICD-10 code 02VW3DZ. All patients who met these criteria were included. Region-specific AIS scores were not used as inclusion criteria.

Data extracted from the database included demographics, vitals, injury pattern, Injury Severity Score (ISS), complications, and mortality.

### Analysis

Data queried from TQIP were stored locally and analyzed using IBM SPSS Statistics V.26.0 (SPSS, Chicago, IL). Categorical data were presented as proportions and continuous data as mean and SD. An OR with 95% CI was calculated for each complication.

## RESULTS

### Demography, injury pattern, and hemodynamic data

There were 2990 patients identified as having undergone TEVAR for BTAI. The mean time to TEVAR was 1.88 days ( $\pm 4.3$ ), with 2546 (85.2%) procedures being performed within 2 days of hospital presentation. Of the patients, 2220 (74.0%) were male, with an average age of 42.5 years ( $\pm 18.8$ ). The mechanism of injury was motor vehicle collision in 2078 (69.5%) of the reported cases. The mean systolic blood pressure (SBP) on arrival was reported for 2110 patients, with a mean of 122 mm Hg ( $\pm 29.5$ ); 266 (12.6%) patients presented with SBP  $< 90$  mm Hg. ISS was reported for 2566 patients, with a mean value of 34.7 ( $\pm 12.5$ ), with 2477 (96.5%) having an ISS  $> 16$ . Of the patients, 2537 (84.8%) required intensive care unit (ICU) admission. Demographic and injury data are summarized in [table 1](#).

### Complications and outcomes

The postoperative complications with the highest incidence were acute kidney injury (AKI)/acute renal failure (ARF) and stroke with 140 (4.7%) and 83 (2.8%) cases, respectively. Notably, 33 of the 83 (39.8%) patients who suffered stroke had an associated

**Table 1** Patient demographics

Parameter	Mean or proportion
<b>Demographics</b>	
Male, n (%)	2220 (74.0)
Age, mean (SD)	42.5 (18.8)
Race, n (%)	
Caucasian	2058 (68.8)
African American	445 (14.9)
Asian	42 (1.4)
Other	445 (14.9)
Mechanism, n (%)	
MVC	2078 (69.5)
MCC	343 (11.5)
Pedestrian struck	255 (8.6)
Fall	194 (6.5)
Other	120 (4.0)
<b>Injury data</b>	
ISS, mean (SD)	34.7 (12.5)
ISS $> 16$ , n (%)	2477 (96.5)
<b>Admission physiology</b>	
HR, mean (SD)	102 (24.3)
RR, mean (SD)	21 (6.7)
Temperature ( $^{\circ}\text{C}$ ), mean (SD)	36 (2.1)
GCS, mean (SD)	11.2 (5.1)
SBP (mm Hg), mean (SD)	122 (29.5)
SBP $< 90$ (mm Hg), n (%)	266 (12.6)
<b>Other</b>	
Hospital LOS, n (SD)	18.9 (17.9)
ICU LOS, n (SD)	12.2 (11.7)
ICU admission, n (%)	2537 (84.8)

GCS, Glasgow Coma Scale; HR, heart rate; ICU, intensive care unit; ISS, Injury Severity Score; LOS, length of stay; MCC, Motor Cycle Collision; MVC, motor vehicle collision; RR, respiratory rate.

Blunt Cerebrovascular Injury (BCVI). These were followed by SCI (58, 1.9%), surgical site infection (56, 1.8%), and unplanned return to the operating room (47, 1.6%). Myocardial infarction (MI) occurred in 16 (0.5%) of these patients. Notably, only 7 (0.2%) patients suffered paraplegia. A full list of complications is presented in [table 2](#).

To assess the management of SCI and paraplegia, data on carotid subclavian bypass and lumbar drain placement were abstracted from TQIP. Of the patients with TEVAR, 80 (2.7%) underwent carotid subclavian bypass and 49 (1.6%) underwent lumbar drain placement. Of the carotid subclavian bypasses performed, 61 (76.3%) were performed the same day as TEVAR. Seventeen (34.7%) lumbar drains were performed simultaneously with TEVAR.

When compared with BTAI patients who did not undergo TEVAR, several complications were found to occur more frequently in the TEVAR group, including AKI/ARF (1.758, 1.449–2.134), stroke (2.489, 1.917–3.232), unplanned return to the operating room (1.578, 1.139–1.186), and coma (2.605, 1.061–6.395). Notably, there was no difference between TEVAR and non-operative BTAI incidences of SCI (1.061, 0.799–1.409), paraplegia (1.698, 0.728–3.961), and MI (1.541, 0.885–2.683). [Table 3](#) presents the OR for all complications examined.

**Table 2** Incidence of complications in patients undergoing thoracic endovascular aortic repair after blunt thoracic aortic injury

Complication	n (%)
Acute kidney injury/acute renal failure	140 (4.7)
Stroke	83 (2.8)
Spinal cord ischemia	58 (1.9)
Surgical site infection	56 (1.8)
Unplanned return to the operating room	47 (1.6)
Bleeding	44 (1.5)
Extremity compartment syndrome	21 (0.7)
Open aortic repair	21 (0.7)
Myocardial infarction	16 (0.5)
Paraplegia	7 (0.2)
Coma	7 (0.2)
Extremity ischemia	2 (0.1)
Wound disruption	2 (0.1)

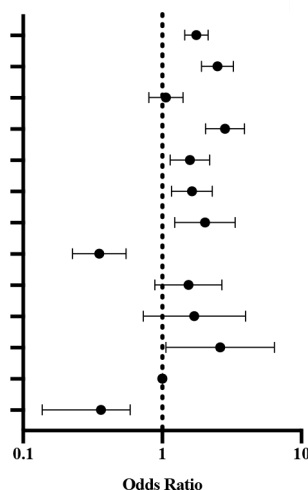
Of the patients, 2867 (95.9%) survived to discharge; 1058 (35.4%) patients went home from the hospital and 1433 (47.9%) patients were transferred to inpatient rehabilitation. Disposition information for the remainder of the patients was not recorded. Of the 123 (4.1%) mortalities, care was withdrawn for 53 (43.1%) patients.

## DISCUSSION

Postoperative ICU care of patients who have undergone TEVAR for BTAI has historically focused on awareness of SCI to prevent paraplegia.<sup>2,5</sup> The advent of TEVAR itself has reduced the incidence of SCI and paraplegia as compared with patients who underwent open repair, with previous large studies reporting paraplegia rates of 3% to 9% in those undergoing open repair.<sup>2,5</sup> However, this devastating complication persists and substantial efforts are made to prevent it. The data presented here suggest that after TEVAR for BTAI, care should involve vigilance primarily against postoperative cerebrovascular and renal events. Interestingly, patients undergoing TEVAR were not

**Table 3** OR of complications in patients undergoing thoracic endovascular aortic repair after blunt thoracic aortic injury

Complication	OR (95% CI)
Acute kidney injury/acute renal failure	1.758 (1.449 to 2.134)
Stroke	2.489 (1.917 to 3.232)
Spinal cord ischemia	1.061 (0.799 to 1.409)
Surgical site infection	2.821 (2.042 to 3.898)
Unplanned return to the operating room	1.578 (1.139 to 2.186)
Bleeding	1.634 (1.165 to 2.291)
Extremity compartment syndrome	2.026 (1.228 to 3.342)
Open aortic repair	0.352 (0.226 to 0.549)
Myocardial infarction	1.541 (0.885 to 2.683)
Paraplegia	1.698 (0.728 to 3.961)
Coma	2.605 (1.061 to 6.395)
Extremity ischemia	1.001 (1.000 to 1.002)
Wound disruption	0.587 (0.137 to 2.519)



demonstrated to be at increased risk of SCI or paraplegia when compared with all patients diagnosed with BTAI, suggesting that their incidence may reflect the injury itself, rather than its repair.

This finding may be a reflection of improved procedural technique as well as postoperative diligence on the part of the surgeon and critical care provider. Pre-emptive carotid subclavian bypass or lumbar drain placement may also play a role in the reduced rate of SCI and paraplegia, as reflected by the frequency with which these procedures were performed on the same day as the index operation.

Given its large sample size, TQIP enables robust evaluation of infrequent events. Our analysis confirmed the rarity of postoperative SCI and paraplegia. Previous studies evaluating TEVAR for BTAI used data sets an order of magnitude smaller than TQIP and have over-represented the true incidence.<sup>2-5</sup> TQIP's sheer size allows an assessment of the current morbidity of TEVAR in the setting of BTAI that is arguably the most accurate to date.

Our data suggest room for improvement in the rates of postoperative AKI and neurological adverse events, but this will require collaboration between the surgeon and the critical care provider.

Intraoperatively, surgeons must maintain strict wire discipline near the great vessels and be mindful of contrast load during trauma TEVAR. Consideration should be given to heparinization and its appropriateness given the patient's full injury profile. Critical care providers who manage these patients postoperatively must be aware of these potential complications and the intraoperative and postoperative factors that may contribute to their development. Improvement in the incidence of these complications has potential for substantial benefit, given the known increase in morbidity and mortality associated with these conditions.<sup>13,14</sup>

Evidence suggests that, in the absence of effective treatment of renal injury, an emphasis on early recognition and management of renal injury is the optimal approach to this problem.<sup>13</sup> Frequently, a failure to recognize AKI commonly results in a delay of care.<sup>13</sup> We hope that the data presented here bring attention to the importance of vigilance against incipient AKI and early intervention in patients who undergo TEVAR for trauma. Several risk scores and high-prediction models can aid in identifying patients who are most at risk.<sup>15-20</sup> Some of these scores are targeted for patients who have undergone surgery or been exposed to large amounts of contrast,<sup>15,16,18</sup> but none specific to trauma patients. Early nephrology consult has also been demonstrated to be helpful in preventing and managing AKI and ARF, particularly in the ICU setting.<sup>21,22</sup> A collaborative team may be especially useful in the context of a patient with complex, multiple injuries.

This study offers important insight into the morbidities of TEVAR for BTAI and differences from elective aneurysm repair. It is important to note the inherent limitations of this retrospective study, including the potential for selection bias and the reliance on data accuracy. Although the TQIP database is a high-quality information archive maintained by the ACS, there is the inherent risk of missing and mis-coded data when they are entered by innumerable institutions and their staff. Furthermore, the relative lack of granularity that comes with a database of this size can limit more indepth evaluation.

## CONCLUSIONS

Our data suggest that the highly morbid postoperative complications associated with endovascular thoracic aortic aneurysm repair—SCI and paraplegia—are less prevalent when TEVAR is

performed for blunt aortic trauma. Perioperative vigilance may be more effectively focused on prevention of cerebrovascular events and renal complication, both of which had significant incidence in this patient group. Further study is warranted to develop guidelines for the intensivist managing patients after TEVAR for BTAL.

**Contributors** HA, JD, JJM, and RK designed the study. HA, NNE, and LD completed the data collection. HA, NNE, LD, and JJM completed the data analysis. HA, JJM, and RK wrote the article. NNE, LD, JD, and TS provided critical revisions.

**Funding** The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

**Competing interests** None declared.

**Patient consent for publication** Not required.

**Ethics approval** This study was exempt from institutional review board approval (HP-00085892) at the University of Maryland Medical Center as ACS-TQIP is a publicly available, deidentified database.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available in a public, open access repository, via the American College of Surgeons Trauma Quality Improvement Program (ACS-TQIP) database.

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#### REFERENCES

- Demetriades D. Blunt thoracic aortic injuries: crossing the rubicon. *J Am Coll Surg* 2012;214:247–59.
- Fabian TC, Richardson JD, Croce MA, Smith JS, Rodman G, Kearney PA, Flynn W, Ney AL, Cone JB, Luchette FA, et al. Prospective study of blunt aortic injury: multicenter trial of the American association for the surgery of trauma. *J Trauma* 1997;42:374–80.
- DuBose JJ, Leake SS, Brenner M, Pasley J, O'Callaghan T, Luo-Owen X, Trust MD, Mooney J, Zhao FZ, Azizzadeh A, et al. Contemporary management and outcomes of blunt thoracic aortic injury: a multicenter retrospective study. *J Trauma Acute Care Surg* 2015;78:360–9.
- Akhmerov A, DuBose J, Azizzadeh A. Blunt thoracic aortic injury: current therapies, outcomes, and challenges. *Ann Vasc Dis* 2019;12:1–5.
- Demetriades D, Velmahos GC, Scalea TM, Jurkovich GJ, Karmy-Jones R, Teixeira PG, Hemmila MR, O'Connor JV, McKenney MO, Moore FO, et al. Operative repair or endovascular stent graft in blunt traumatic thoracic aortic injuries: results of an American association for the surgery of trauma multicenter study. *Journal of Trauma: Injury, Infection & Critical Care* 2008;64:561–71.
- Scalea TM, Feliciano DV, DuBose JJ, Ottochian M, O'Connor JV, Morrison JJ. Blunt thoracic aortic injury: endovascular repair is now the standard. *J Am Coll Surg* 2019;228:605–10.
- Bobadilla JL, Wynn M, Tefera G, Acher CW. Low incidence of paraplegia after thoracic endovascular aneurysm repair with proactive spinal cord protective protocols. *J Vasc Surg* 2013;57:1537–42.
- Elkbuli A, Dowd B, Spano PJ, Smith Z, Flores R, McKenney M, Boneva D. Thoracic Endovascular Aortic Repair Versus Open Repair: Analysis of the National Trauma Data Bank. *J Surg Res* 2020;245:179–82.
- Kim HM, Cho YK, Kim JH, Seo T-S, Song MG, Jeon YS, Cho SB, Im NY. Clinical outcomes of the Seal® thoracic stent graft for traumatic aortic injury in a Korean multicenter retrospective study. *Ann Vasc Surg* 2019;61:400–9.
- Cheng Y-T, Cheng C-T, Wang S-Y, Wu VC-C, Chu P-H, Chou A-H, Chen C-C, Ko P-J, Liu K-S, Chen S-W. Long-Term outcomes of endovascular and open repair for traumatic thoracic aortic injury. *JAMA Netw Open* 2019;2:e187861.
- Calvo RY, Bansal V, Dunne CE, Badiee J, Sise CB, Sise MJ. A population-based analysis of outcomes after repair of thoracic aortic emergencies in trauma. *J Surg Res* 2018;231:352–60.
- Trauma Quality Improvement Program (TQIP) [Internet]. American College of Surgeons. <https://www.facs.org/quality-programs/trauma/tqip/center-programs/tqip> (28 Oct 2020).
- Liu KD, Goldstein SL, Vijayan A, Parikh CR, Kashani K, Okusa MD, Agarwal A, Cerdá J. . AKI!Now Initiative of the American Society of Nephrology. AKI!Now Initiative: Recommendations for Awareness, Recognition, and Management of AKI. *Clin J Am Soc Nephrol* 2020;15:1838–47.
- Cox K, Banerjee D. Acute renal failure in critically ill patients: current evidence-based practices. *R J Med J* 2019;102:22–5.
- Thakar CV, Arrigain S, Worley S, Yared J-P, Paganini EP. A clinical score to predict acute renal failure after cardiac surgery. *J Am Soc Nephrol* 2005;16:162–8.
- Mehran R, Aymong ED, Nikolsky E, Lasic Z, Iakovou I, Fahy M, Mintz GS, Lansky AJ, Moses JW, Stone GW, et al. A simple risk score for prediction of contrast-induced nephropathy after percutaneous coronary intervention: development and initial validation. *J Am Coll Cardiol* 2004;44:1393–9.
- Srisawat N, Kulvichit W, Mahamitra N, Hurst C, Praditpornsilpa K, Lumlertgul N, Chuasuwan A, Trongtrakul K, Tasnarong A, Champunot R, et al. The epidemiology and characteristics of acute kidney injury in the Southeast Asia intensive care unit: a prospective multicentre study. *Nephrol Dial Transplant* 2020;35:1729–38.
- Park S, Cho H, Park S, Lee S, Kim K, Yoon HJ, Park J, Choi Y, Lee S, Kim JH, et al. Simple postoperative AKI risk (spark) classification before noncardiac surgery: a prediction index development study with external validation. *J Am Soc Nephrol* 2019;30:170–81.
- Chiofolo C, Chbat N, Ghosh E, Eshelman L, Kashani K. Automated continuous acute kidney injury prediction and surveillance: a random forest model. *Mayo Clin Proc* 2019;94:783–92.
- Tomašev N, Glorot X, Rae JW, Zielinski M, Askham H, Saraiva A, Mottram A, Meyer C, Ravuri S, Protsyuk I, et al. A clinically applicable approach to continuous prediction of future acute kidney injury. *Nature* 2019;572:116–9.
- Mehta RL, McDonald B, Gabbai F, Pahl M, Farkas A, Pascual MTA, Zhuang S, Kaplan RM, Chertow GM. Nephrology consultation in acute renal failure: does timing matter? *Am J Med* 2002;113:456–61.
- Askenazi DJ, Heung M, Connor MJ, Basu RK, Cerdá J, Doi K, Koyner JL, Bihorac A, Golestaneh L, Vijayan A, et al. Optimal role of the nephrologist in the intensive care unit. *Blood Purif* 2017;43:68–77.