Endovascular repair of traumatic axillosubclavian artery injuries

Jason Zhang, MD,a Rohan Basu, BS,a Andrew R. Bauder, MD,b Jon G. Quatramoni, MD,c Julia Glaser, MD,a Venkat Kalapatapu, MD, and Ann C. Gaffey, MD, MS,d Philadelphia, Pa; Cleveland, Ohio; and La Jolla, Calif

ABSTRACT
Gun violence reached a 20-year peak in 2020, with the first-line treatment of axillosubclavian vascular injuries (SAVIs) remaining unknown. Traditional open exposure is difficult and exposes patients to iatrogenic venous and brachial plexus injury. The practice of endovascular treatment has been increasing. We performed a retrospective analysis of SAVIs at a level I trauma center. Seven patients were identified. Endovascular repair was performed in five patients. Technical success was 100%. The early results suggest that endovascular treatment of trauma-related SAVIs can be performed safely and effectively. However, complications such as stent thrombosis or occlusion can occur, demonstrating the need for surveillance. (J Vasc Surg Cases Innov Tech 2022;8:23-7.)

Keywords: Axillary artery. Subclavian artery. Trauma

In 2020, firearm violence was responsible for nearly 20,000 homicides in the United States, reaching a 20-year peak.1 The incidence of axillosubclavian arterial injuries (SAVIs) has been low owing to the surrounding bony structures and the high pre- and in-hospital mortality secondary to rapid exsanguination and associated injuries.2-4 SAVIs can be especially difficult to treat owing to the complex regional anatomy, complicated exposure, presence of associated injuries, and limited clinical experience.

The surgical management of penetrating SAVIs has varied. Low-grade injuries, including minimal intimal injuries or occlusion without evidence of limb ischemia, can be managed nonoperatively with observation, serial imaging studies, and antiplatelet therapy.5 Higher grade injuries, including disruption or occlusion with evidence of ischemia, have traditionally involved an open surgical approach entailing a clavicular incision and median sternotomy or anterolateral thoracotomy for adequate exposure and control.2,5 Such open interventions have had a high rate of morbidity.6-8

Endovascular surgical options have continued to increase in popularity for the management of SAVIs in appropriate patients.9,10 Although mostly studied in hemodynamically stable patients, endovascular management of SAVIs has been associated with shorter operative times and less blood loss compared with open approaches with noninferior outcomes.11-13 Thus, we reviewed our contemporary experience of SAVIs treated endovascularly.

METHODS
After approval from our institution’s institutional review board, a retrospective medical record review was performed of a prospectively maintained trauma database. All patients who had presented with subclavian, axillary, brachial, and/or innominate artery injuries to the level 1 trauma center between January 2015 and January 2020 were reviewed. The outcome measures included technical success, hospital mortality, operative time, early (<30 days) complications, late (>30 days) complications, and reintervention rates.

RESULTS
Initial treatment. During the study period, seven patients were identified who had sustained a SAVI. Six of the patients were men, with a mean age of 29.3 years (range, 21-41 years). Six injuries had resulted from penetrating trauma. Two patients had presented in cardiacogenic and/or hypovolemic shock and one had undergone unsuccessful thoracotomy in the emergency department. The injury specifics are listed in Table I. A massive transfusion protocol was initiated for both hemodynamically unstable patients. The vascular pathology found on the imaging studies included two complete transections, one occlusion, one laceration, one pseudoaneurysm, and two cases thought to be...
vasospasm. Definitive signs of vascular trauma included one patient with active pulsatile bleeding and five patients with a loss of the radial pulse. The mean injury severity score for all seven patients was 29.6 (range, 1-75). The demographic and clinical features are listed in Table II.

At operative exploration, one patient was noted to have a return of arterial pulses consistent with vasospasm. The angiographic findings supported this clinical diagnosis. Thus, of the six surviving patients, a total of five stents were placed in five patients. Percutaneous femoral artery access was obtained in four of the five patients, and one patient had undergone brachial artery cutdown. Of the five stents used, four were self-expanding Gore Viabahn stents and one was a balloon-expandable Gore Viabahn VBX stent (Gore Medical, Flagstaff, Ariz). The VBX stent was placed in the innominate artery. Technical success was 100%. The mean duration of the procedure was 61.8 minutes (range, 42-105 minutes). No patient had required conversion to open repair. The mean length of stay for the patients with stents placed was 13.8 days (range, 2-29 days).

Early (<30 days) complications. At 2 weeks after the initial intervention, patient 4 had presented with upper extremity numbness. Computed tomography angiography revealed an occluded subclavian stent (7-mm × 5-cm Viabahn; Gore Medical) despite dual antiplatelet therapy. The initial pre- and intraoperative images are shown in the Figure. An intravenous heparin infusion was started, and the patient underwent catheter-directed thrombolysis and thrombectomy with stent relining (6-mm × 6-cm Viabahn; Gore Medical) and was discharged with direct oral anticoagulant therapy.

Long-term follow-up. A summary of the cohort’s follow-up data is shown in Table III, with individual patient data presented in Table IV. The mean follow-up period was 48.6 weeks (range, 6-124 weeks), with three patients seen via telemedicine. All patients were asymptomatic, with no deaths.

**DISCUSSION**

Despite improvements in operative techniques and treatment options, the mortality rate of traumatic SAVIs has remained as high as 30%. The high mortality has resulted partly from the difficulty of vessel exposure, which is complicated by the various structures in proximity to the thoracic outlet. The optimal treatment has remained unclear. The traditional reference standard has been an open approach, which requires a clavicular incision and an associated sternotomy or thoracotomy for as many as 50% of patients. Because of the associated morbidity, a shift has occurred toward endovascular-based therapy during the past two decades. Although the literature has remained limited to case series and small retrospective studies, the technical success rates for endovascular procedures have ranged from 66% to 100%, with most studies reporting no periprocedural mortality.

With the addition of endovascular intervention to treat these injuries, we are increasing our armamentarium. The proper selection of trauma patients suitable for endovascular repair is essential. Although most studies have included hemodynamically stable patients, we believe that endovascular intervention can be used as a

---

**Table I.** Injury characteristics of study patients (n = 7)

| Variable          | No. (%) |
|-------------------|---------|
| Artery injured    |         |
| Axillary          | 2 (28)  |
| Subclavian        | 3 (43)  |
| Innominate        | 1 (14)  |
| Brachial          | 1 (14)  |
| Injury            |         |
| Transection       | 2 (28)  |
| Laceration        | 1 (14)  |
| Pseudoaneurysm    | 1 (14)  |
| Vasospasm         | 2 (28)  |
| Occlusion         | 1 (14)  |

**Table II.** Demographics of patients who had undergone initial endovascular therapy (n = 5)

| Variable                        | Mean (range) or no. (%) |
|---------------------------------|-------------------------|
| Age, years                      | 28 (21-38)              |
| Male sex                        | 5 (100)                 |
| Injury distribution             |                         |
| Blunt                           | 1 (20)                  |
| Penetrating                     | 4 (80)                  |
| Mechanism                       |                         |
| Gunshot wound                   | 3 (60)                  |
| Stabbing                        | 1 (20)                  |
| Motor vehicle collision         | 1 (20)                  |
| Presenting definitive signs      |                         |
| Hypotension (SBP < 90 mm Hg)    | 2 (40)                  |
| Motor/sensory deficit           | 2 (40)                  |
| Active pulsatile bleeding       | 1 (20)                  |
| Diminished pulses               | 4 (80)                  |
| Injury severity score           | 26.2 (15-41)            |
| Patients with preoperative CTA  | 5 (100)                 |
| Stents                          |                         |
| Self-expanding Viabahn stent    | 4 (80)                  |
| Balloon-expandable VBX stent    | 1 (20)                  |
| Operative time, minutes         | 61.8 (42-115)           |

CTA, Computed tomography angiography; SBP, systolic blood pressure.
stabilizing intervention in hemodynamically unstable patients, if not as definitive treatment, as shown in our study, albeit for a very limited sample. The use of an endovascular approach will help to overcome the issue of time-consuming dissection and the risk of collateral injury to the surrounding neurovascular structures.

The Endovascular Skills for Trauma and Resuscitative Surgery Working Group reported that endovascular procedures were successful in 96.9% of patients.\textsuperscript{15} Additionally, Branco et al\textsuperscript{10} evaluated 153 patients (18 endovascular and 135 open) after controlling for the injury severity score, blood pressure, Glasgow coma scale, and other demographic factors. They found significantly lower in-hospital mortality among the endovascular group (5.6% vs 27.8%; \( P = .04 \)), in addition to a lower incidence of surgical site infections and sepsis.\textsuperscript{10}

Ultimately, the long-term patency of covered stents in a historically young trauma patient population is of concern. The rate of graft thrombosis has been cited at 6% to 31% in the literature. However, the inconsistent follow-up has made these data inexact.\textsuperscript{3,10,13,15,20,21} Stents in this location are theoretically at an increased risk of occlusion owing to the compression and elongation of the stent between the first rib and clavicle in the thoracic outlet. In our cohort of five patients, one patient had developed early thrombosis despite antiplatelet therapy.
adherence. The patient's subclavian stent had likely been oversized as a 7-mm stent initially, because the stent was relined with a 6-mm stent after thrombolysis, which was patent on computed tomography angiography at 4 weeks. Although not studied in this particular location, excessive oversizing of self-expanding stents in the iliofemoral system has been associated with restenosis.

Regarding surveillance, the rate of 1-year follow-up within trauma patients at our institution has been <20%. We have, thus, used trauma outreach coordinators to assess for effort-induced arm fatigue when telephone follow-up visits are possible. If a patient were symptomatic, immediate instructions to present to the hospital were provided.

Overall, we successfully used endovascular interventions to treat SAVIs. Endovascular repair can help stabilize a patient with possible concomitant injuries or provide time for adequate resuscitation. We have demonstrated that proper adoption of endovascular treatment of such morbid injuries can lead to a durable repair and leaves open the option for surgical bypass in the case of stent occlusion. The immediate complication rates were low; however, long-term management is essential.

**CONCLUSIONS**

The results from our study have shown that endovascular treatment of trauma-related SAVIs can be performed safely and effectively with reduced operative times and morbidity compared with open exposure, although complications such as stent thrombosis can occur. Long-term data and prospective trials are needed to further investigate ideal patient selection and the outcomes of stenting vs open repair for this population.

**REFERENCES**

1. Gun Violence Archive. Mass shootings in 2020. Available at: https://www.gunviolencearchive.org/reports/mass-shooting/year=2020. Accessed April 10, 2021.
2. Demetriades D, Chahwan S, Gomez H, Peng R, Velmahos G, Murray J, et al. Penetrating injuries to the subclavian and axillary vessels. J Am Coll Surg 1999;188:290-5.
3. Weller CJ, Cogbill TH, Kallies KJ, Ramirez LD, Cardenas JM, Todd SR, et al. Contemporary management of subclavian and axillary artery injuries—a Western Trauma Association multicenter review. J Trauma Acute Care Surg 2017;83:1023-31.
4. Sobnach S, Nicol AJ, Nathire H, Edu S, Kahn D, Navsaria PH. An analysis of 50 surgically managed penetrating subclavian artery injuries. Eur J Vasc Endovasc Surg 2010;39:155-9.
5. Weinberg JA, Moore AH, Magnotti LJ, Teague RJ, Ward TA, Wasmund JB, et al. Contemporary management of civilian penetrating cervicothoracic arterial injuries. J Trauma Acute Care Surg 2016;81(3):502-6.
6. Hota P, Dass C, Erkmen C, Donuru A, Kumaran M. Poststernotomy complications: a multimodal review of normal and abnormal post-operative imaging findings. AJR Am J Roentgenol 2016;206(3):711-25.
7. Fabregues Oliet A, Zarain Obrador L, Perez-Diaz D, Turegano Fuentes P. Trap-door incision for penetrating thoracic trauma: an obsolete approach? Case Rep Surg 2014;2014:1-3.
8. Rubright J, Kelleher P, Beardsley C, Paller D, Shackford S, Beynon B, et al. Long-term clinical outcomes, motion, strength, and function after total claviclecucotomy. J Shoulder Elbow Surg 2014;23:236-44.
9. Branco BC, DuBose JJ, Zhan LX, Hughes JD, Goshima KR, Rhee P, et al. Trends and outcomes of endovascular therapy in the management of civilian vascular injuries. J Vasc Surg 2014;60:1297-307 e1.
10. Branco BC, Boutrous ML, DuBose JJ, Leake SS, Charlton-Ouw K, Rhee P, et al. Outcome comparison between open and endovascular management of axillosubclavian arterial injuries. Presented at the

| Pt. No. | Sex: age, years | Injury mechanism | Injury location | Injury | SBP < 90 mm Hg on arrival | Definitive signs of injury | Operative time, minutes | Early complications (≤30 days) | Follow-up period, weeks | Follow-up findings (≤30 days) |
|---------|----------------|------------------|----------------|--------|---------------------------|--------------------------|--------------------------|---------------------------|--------------------------|---------------------------|
| 1       | Male: 34       | CSW              | Left axillary  | Vasospasm | No                        | No                       | 115                      | None                      | Telephonic, 12/4         | Asymptomatic; aspirin therapy |
| 2       | Male: 38       | Stab             | Left subclavian| Transection | Yes                      | Active pulsatile bleeding; pulses absent | 52                      | Occlusion at 14 days requiring thrombectomy and relining | Clinic, 8                | Patent stent on duplex ultrasound |
| 3       | Male: 26       | CSW              | Right axillary | Transection | Yes                      | Pulses absent            | 47                      | None                      | Telephonic, 52           | Asymptomatic              |
| 4       | Male: 21       | Blunt            | Left subclavian| Occlusion   | No                       | Pulses absent            | 42                      | None                      | Telephonic, 51           | Patent stent on CTA at 4 weeks; asymptomatic at 51 weeks; aspirin therapy |
| 5       | Male: 21       | CSW              | Right innominate| PSA        | No                       | Pulses absent            | 53                      | none                      | Clinic, 8                | Asymptomatic; pulses intact |

CTA, Computed tomography angiography; CSW, gunshot wound; PSA, pseudoaneurysm. Pt. No., patient number. SBP, systolic blood pressure.
11. Xenos ES, Freeman M, Stevens S, Cassada D, Pacanowski J, Goldman M. Covered stents for injuries of subclavian and axillary arteries. J Vasc Surg 2003;38:451-4.

12. Carrick MM, Morrison CA, Pham HQ, Norman MA, Marvin B, Lee J, et al. Modern management of traumatic subclavian artery injuries: a single institution's experience in the evolution of endovascular repair. Am J Surg 2010;199:26-34.

13. Shalhub S, Stames BW, HatsuKami TS, Karmy-Jones R, Tran NT. Repair of blunt thoracic outlet arterial injuries: an evolution from open to endovascular approach. J Trauma 2011;71:E114-21.

14. McKinley AG, Carrim AT, Robbs JV. Management of proximal axillary and subclavian artery injuries. Br J Surg 2000;87:79-85.

15. Chopra A, Modrall JG, Knowles M, Phelan HA, Valentine RJ, Chung J. Uncertain patency of covered stents placed for traumatic axillo-subclavian artery injury. J Am Coll Surg 2016;223:67-74.

16. Naidoo NG, Navsaria P, Beningfield SJ, Natha B, Cloete N, Gill H. Stent graft repair of subclavian and axillary vascular injuries: the Groote Schuur experience. S Afr J Surg 2015;53:5-9.

17. Gilani R, Tsai PI, Wall MJ Jr, Mattoo KL. Overcoming challenges of endovascular treatment of complex subclavian and axillary artery injuries in hypotensive patients. J Trauma Acute Care Surg 2012;73:771-3.

18. Castelli P, Caronno R, Piffaretti C, et al. Endovascular repair of traumatic injuries of the subclavian and axillary arteries. Injury 2005;36:778-82.

19. Patel AV, Marin ML, Veith FJ, Kerr A, Sanchez LA. Endovascular graft repair of penetrating subclavian artery injuries. J Endovasc Surg 1996;3:382-8.

20. du Toit DF, Lambrechts AV, Stark H, Warren BL. Long-term results of stent graft treatment of subclavian artery injuries: management of choice for stable patients? J Vasc Surg 2008;47:739-43.

21. Desai SS, DuBose JJ, Parham CS, Charlton-Ouw KM, Valdes J, Estrera AL, et al. Outcomes after endovascular repair of arterial trauma. J Vasc Surg 2014;60:1309-14.

22. Saguner AM, Traupe T, Räber L, Hess N, Banz Y, Saguner AR, et al. Oversizing and restenosis with self-expanding stents in iliofemoral arteries. Cardiovasc Intervent Radiol 2012;35:906-13.