

Management of Penetrating Cerebrovascular Injuries in Pediatric Trauma: A Retrospective Multicenter Study

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BACKGROUND: Blunt cerebrovascular injury is uncommon in the pediatric population; penetrating cerebrovascular injuries are even rarer and are thus poorly understood.

OBJECTIVE: To describe the diagnosis and management of penetrating cerebrovascular injuries and describe outcomes of available treatment modalities.

METHODS: Clinical and radiographic data were collected retrospectively from a multicenter trauma registry for children screened for cerebrovascular injury during 2003 to 2013 at 4 academic pediatric trauma centers.

RESULTS: Among 645 pediatric patients evaluated with computed tomography angiography with blunt cerebrovascular injury, 130 also had a penetrating trauma indication. Seven penetrating cerebrovascular injuries were diagnosed in 7 male patients (mean age 12.4 years, range 12-18 years). Focal neurological deficit and concomitant intracranial injury were each seen in 2 patients. There were 2 intracranial carotid artery injuries, 4 extracranial carotid artery injuries, and 1 vertebral artery injury. The majority of injuries were higher than grade I (5/7; 71%): 2 were grade I, 1 grade II, 2 grade III, and 2 grade IV. The 2 patients with grade III injuries required open surgery, and 1 patient with a grade IV injury underwent endovascular treatment. Two patients suffered immediate stroke secondary to the penetrating cerebrovascular injury. There were no delayed neurological deficits from the penetrating injuries, and no patients died as a result of the injuries.

CONCLUSION: This is the largest series of penetrating cerebrovascular trauma in the pediatric literature. Although rare, penetrating cerebrovascular injuries can be high-grade injuries that require urgent recognition and may require aggressive endovascular and/or open surgery for treatment.

KEY WORDS: Penetrating, Cerebrovascular, Endovascular, Open surgery

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Penetrating cerebrovascular injury (PCVI) has an overall incidence of 0.45%.¹ Penetrating carotid artery injury represents 5% to 0% of arterial injuries,² and penetrating vertebral artery (VA) injuries occur even less frequently. PCVI can lead to cerebral infarction and significant neuro-

logical morbidity. Injury to the VA can lead to posterior circulation strokes, cortical blindness, quadriplegia, and death.³ Additional considerations in penetrating trauma include active bleeding, extravasation,⁴ delayed ischemia, and nerve transection or airway injury.⁵

With the rarity of these injuries, especially in pediatric patients, literature on the subject is lacking. Diagnosis of penetrating injuries is difficult because life-threatening injuries⁶ and poor neurological status are often present. We describe the diagnosis and management of PCVIs at 4 pediatric trauma centers and describe outcomes of treatment. This is the largest series of pediatric PCVIs to date.

ABBREVIATIONS: BCVI, blunt cerebrovascular injury; CTA, computed tomography angiography; GCS, Glasgow Coma Scale; ICA, internal carotid artery; PCVI, penetrating cerebrovascular injury; SAH, subarachnoid hemorrhage; VA, vertebral artery

TABLE 1. Grading of Cerebrovascular Injury

| Injury grade | Description | ICD-9 | AIS 90 score | |
|--------------|--|---------------------|--------------|-----------------------|
| | | | Intracranial | Cervical ^a |
| I | Luminal irregularity or dissection with <25% luminal narrowing | 900.03 ^b | 3 | 3 |
| II | Dissection or intramural hematoma with ≥25% luminal narrowing, intraluminal thrombus, or raised intimal flap | 900.03 | 3 | 3 |
| III | Pseudoaneurysm | 900.03 | 3 | 3 |
| IV | Occlusion | 900.03 | 4 | 3 |
| V | Transection with free extravasation | 900.03 | 5 | 4 |

^aAdd 1 point if neurological deficit (stroke) is not head injury related.

^bInternal carotid artery injury; ICD-9 code for common carotid artery injury is 900.01. Modified with permission from Biffi et al.¹⁰

METHODS

Study Population

This was a retrospective cohort study of patients from 4 level-1 pediatric trauma centers across the US. The cohort included all children (<19 years) who underwent computed tomography angiography (CTA) of the head or neck for suspected traumatic cerebrovascular injury during an 11-year period (January 1, 2003–December 31, 2013). The decision to obtain a CTA was at the discretion of the physician. Institutional Review Board and Privacy Board approval were obtained at each center with a waiver of patient consent.

Data Collection

Trauma and radiology databases were queried to identify patients, and data were abstracted from medical and radiology records. Demographic information included treatment center, patient age, sex, and race. Mechanism of injury (motor vehicle accident, pedestrian vs vehicle, fall >1 or <1 story, nonaccidental trauma, other blunt injury, penetrating, hanging), initial Glasgow Coma Scale (GCS) score at neurosurgical evaluation, presence of focal neurological deficits on initial examination, and method of treatment for traumatic brain injury (medical vs surgical) were recorded. Radiological factors included the presence of concomitant intracranial injury, the presence of hypodensity on noncontrast head CT consistent with stroke, and Rotterdam score⁷ (a validated 6-point score based on initial noncontrast CT that predicts 6-month mortality in moderate and severe traumatic brain injury).⁸ If cervical spine imaging was performed, we recorded the modality, injury type (none, fracture, ligamentous injury, fracture dislocation), level, and specifically, fracture involving the foramen transversarium. Treatment modalities included medical (antiplatelet therapy, anticoagulation), endovascular, open surgery, or no treatment.

The primary outcome was the presence of PCVI diagnosed by CTA. Each injury was classified according to the blunt cerebrovascular injury (BCVI) scale (Table 1).⁹ Radiographic progression was defined as worsening of the vascular injury (either by grade or severity) on follow-up neurovascular imaging.

Statistical Analysis

Data from all centers were managed using Research Electronic Data Capture (REDCap) tools.¹⁰ Data were descriptively reported as means with standard deviations for continuous data and with percentages for categorical data.

RESULTS

Patient Characteristics

Six hundred forty-five pediatric patients were evaluated for traumatic cerebrovascular injury with CTA of the head or neck. One hundred thirty patients were specifically screened for penetrating trauma. Seven PCVIs were identified in 7 children, yielding an incidence of 5.4%. The mean age of patients was 12.4 years (range 3–18 years); all patients were male (Table 2).

Mechanism of Injury

Most children in this series had gunshot wounds (4/7, 57%; Table 2). Additional mechanisms included a crossbow arrow to the neck, wood chips from landscaping penetrating the orbital/supraorbital region, and a car antenna penetrating the cribriform plate into the anterior cranial fossa (Table 2).

Clinical and Radiographic Findings

Two of the 7 patients had a focal neurological deficit and 2 of 7 patients had a concomitant traumatic subarachnoid hemorrhage (SAH; Table 2). There were no associated blunt injuries in combination with PCVI nor associated temporal bone fractures or fractures through the carotid canal. Four patients had dedicated cervical spine imaging: 1 with an extracranial carotid artery injury had a fracture at C5 but no involvement of the foramen transversarium, and 1 with an intracranial carotid artery injury had evidence of ligamentous injury on magnetic resonance imaging without evidence of fracture.

Management

There were 2 intracranial and 4 extracranial carotid artery injuries and 1 VA injury (extracranial—V3 segment). Most injuries were higher than grade I (5/7; 71%): 2 grade I, 1 grade II, 2 grade III, and 2 grade IV. The 2 grade-I injuries were not treated because they were deemed to be minor injuries that did not warrant antiplatelet or anticoagulation therapy. The 2 patients with grade III injuries required open surgery for primary vessel repair for treatment of the traumatic pseudoaneurysm; 1 was also given antiplatelet therapy (aspirin) as secondary treatment after surgery for 30 days. One patient with grade IV injury underwent endovascular thrombectomy and was given antiplatelet therapy (aspirin) as secondary treatment for 180 days (case 5, described below). There were no complications as a result of primary or secondary treatment. The 2 patients with higher grade (1 grade II and 1 grade IV) injuries who were not treated had concomitant traumatic SAH that was a strict contraindication to medical

TABLE 2. Characteristics of Children Suffering From Penetrating Cerebrovascular Injury

| Case | Age/ sex | Mechanism of injury | GCS score | Focal neurological deficit | Associated intracranial injury | Location of injury | Grade of injury | Primary treatment | Follow-up imaging findings |
|------|-------------|--|--------------|---|--------------------------------------|-------------------------------|-----------------------|-----------------------------------|----------------------------------|
| 1 | 14/M | Accidental GSW to the neck | 15 | No | No | Extracranial carotid artery | III | Open surgery—direct vessel repair | Healing—improved vessel patency |
| 2 | 9/M | Car antenna through the cribriform plate into anterior cranial fossa | 3 | Yes—right-sided hemiparesis | Yes | Intracranial carotid artery | IV | None | N/A |
| 3 | 10/M | Accidental crossbow arrow to right neck | 15 | No | No | Extracranial carotid artery | III | Open surgery—direct vessel repair | Healing—improved vessel patency |
| 4 | 18/M | Accidental GSW to the left neck | 15 | No | No | Extracranial vertebral artery | I | None | No change in vessel patency |
| 5 | 18/M | GSW to the left face | 15 | Yes—right-sided Horner syndrome with left-sided hemiparesis | No | Extracranial carotid artery | IV | Endovascular—thrombectomy | N/A |
| 6 | 15/M | Accidental GSW to the left neck | 15 | No | No | Extracranial carotid artery | I | None | Healing—improved vessel patency |
| 7 | 3/M | Wood chip entering above the orbit | 3 | No | Yes | Intracranial carotid artery | II | None | Healing—improved vessel patency |

GSW, gunshot wound; GCS, Glasgow Coma Scale; N/A, not available.

treatment; they experienced no worsening or progressive neurological sequelae.

Outcomes and Follow-up

The 2 patients who suffered immediate neurological dysfunction were improving upon discharge after treatment (1 with open surgery for a grade III injury and 1 with endovascular therapy for a grade IV injury). There were no delayed neurological deficits and no deaths as a result of the PCVI. Two patients were discharged to rehabilitation, and the rest were discharged home.

Two patients received follow-up imaging with ultrasound (grade III injuries, both demonstrated healing and improvement on initial follow-up), 1 patient had a formal angiogram (grade I, no change on initial follow-up), 1 underwent CTA (grade II, healing and improvement on initial follow-up), 1 underwent magnetic resonance angiography (grade I, healing and improvement on initial follow-up), and 2 patients did not have follow-up imaging (both grade IV).

Case Examples

Case 3—Surgical Management

A 10-year-old boy was playing with a crossbow when it discharged and a spear-tipped graphite arrow fired into his neck.

He experienced no immediate neurological or hemodynamic alterations. The arrow impaled zone I of the anterior triangle on the right side, with the tip buried beneath the skin. The patient displayed no stridor, neck hematoma, erythema, crepitus, or vascular bruit and remained neurologically intact.

CTA of the neck demonstrated the arrow in the supraclavicular region, with the trachea deviated 7 mm to the contralateral side. A 6-mm, right common carotid pseudoaneurysm with an intimal flap was present 2 cm above the origin of the innominate artery (Figure 1). The right first and second ribs were fractured; the bony cervical spine was intact.

The laceration created by the arrow entry was expanded vertically, and the neck was explored. The arrow was transecting half of the common carotid, but there was no active extravasation. After systemic heparin therapy was administered, the carotid was clamped proximally and distally, and the arrow was carefully removed, revealing a sharp, transverse defect in the artery. This was closed with 6-0 Prolene suture before the clamps were removed and flow was restored. No other vascular injuries were observed, and the wound was irrigated and closed. The patient was discharged home 3 days postoperatively on 81 mg of aspirin daily. Carotid duplex ultrasound 4 weeks later demonstrated no flow abnormality, and the patient made a full recovery.

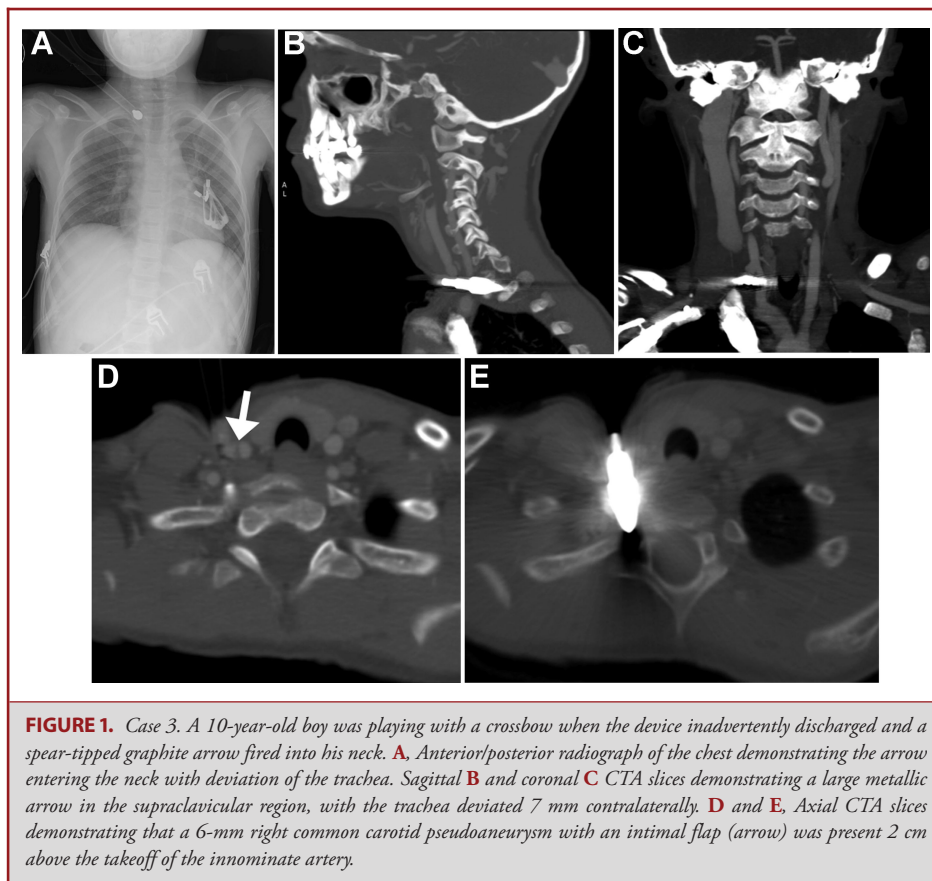


FIGURE 1. Case 3. A 10-year-old boy was playing with a crossbow when the device inadvertently discharged and a spear-tipped graphite arrow fired into his neck. **A**, Anterior/posterior radiograph of the chest demonstrating the arrow entering the neck with deviation of the trachea. **B**, Sagittal **B** and coronal **C** CTA slices demonstrating a large metallic arrow in the supraclavicular region, with the trachea deviated 7 mm contralaterally. **D** and **E**, Axial CTA slices demonstrating that a 6-mm right common carotid pseudoaneurysm with an intimal flap (arrow) was present 2 cm above the takeoff of the innominate artery.

Case 5—Endovascular Management

A 17-year-old boy received a gunshot wound in the face. The patient initially arrived with GCS 15, no obvious bleeding from his mouth, and an entry wound in the left cheek. CTA of the head revealed a bullet trajectory from the left cheek through the hard palate and the bullet lodged near the right internal carotid artery (ICA) close to the C2 lateral mass (Figure 2). The right ICA was completely occluded, with flow in the right external carotid and ophthalmic arteries and reconstitution of flow at the level of the cavernous carotid artery. The patient subsequently developed a progressive dense left hemiparesis, followed by a left-sided facial droop and a right-sided Horner syndrome. A catheter angiogram revealed complete occlusion of the right ICA resulting from a dissection distal to the bifurcation at the base of the skull. There was collateral flow from branches of the external carotid artery, through the ophthalmic artery, and across the anterior and posterior communicating arteries. A right M2 segment middle cerebral artery thrombus was noted. Penumbra 5MAX ACE and 3MAX catheters (Penumbra Inc., Alameda, California) were used to achieve successful thrombectomy, with restoration of flow in the right M2 segment with a thrombolysis in cerebral infarction scale score of 3 after the thrombectomy.

Despite restoration of flow to the cervical ICA, there was subsequent reocclusion, but there was improved collateral flow across the anterior communicating artery. Postoperatively, the patient's mean arterial pressure was maintained at 100 to 110 mm Hg, and he was started on 325 mg of aspirin daily. He was extubated and regained significant left-side function (4–4+/5 in the left extremities). He was discharged on postthrombectomy day 8 to outpatient rehabilitation. At 1-month follow-up, the patient was neurologically intact except for 4+/5 left-hand grip strength; ultimately, he was lost to follow-up.

DISCUSSION

Epidemiology and Diagnosis

Cerebrovascular injury resulting from trauma is relatively uncommon in the pediatric population, occurring in 0.3% to 15% of children who experience blunt trauma.^{11–14} In 1 study, among 54 children who had low-velocity penetrating injury of the brain and skull, 9% had vascular complications as a result.¹⁵ Another study had a 33% rate of major vascular injury in 21 pediatric patients with penetrating head and neck trauma.¹⁶ In our large series, the incidence of PCVI was 5.4%, providing

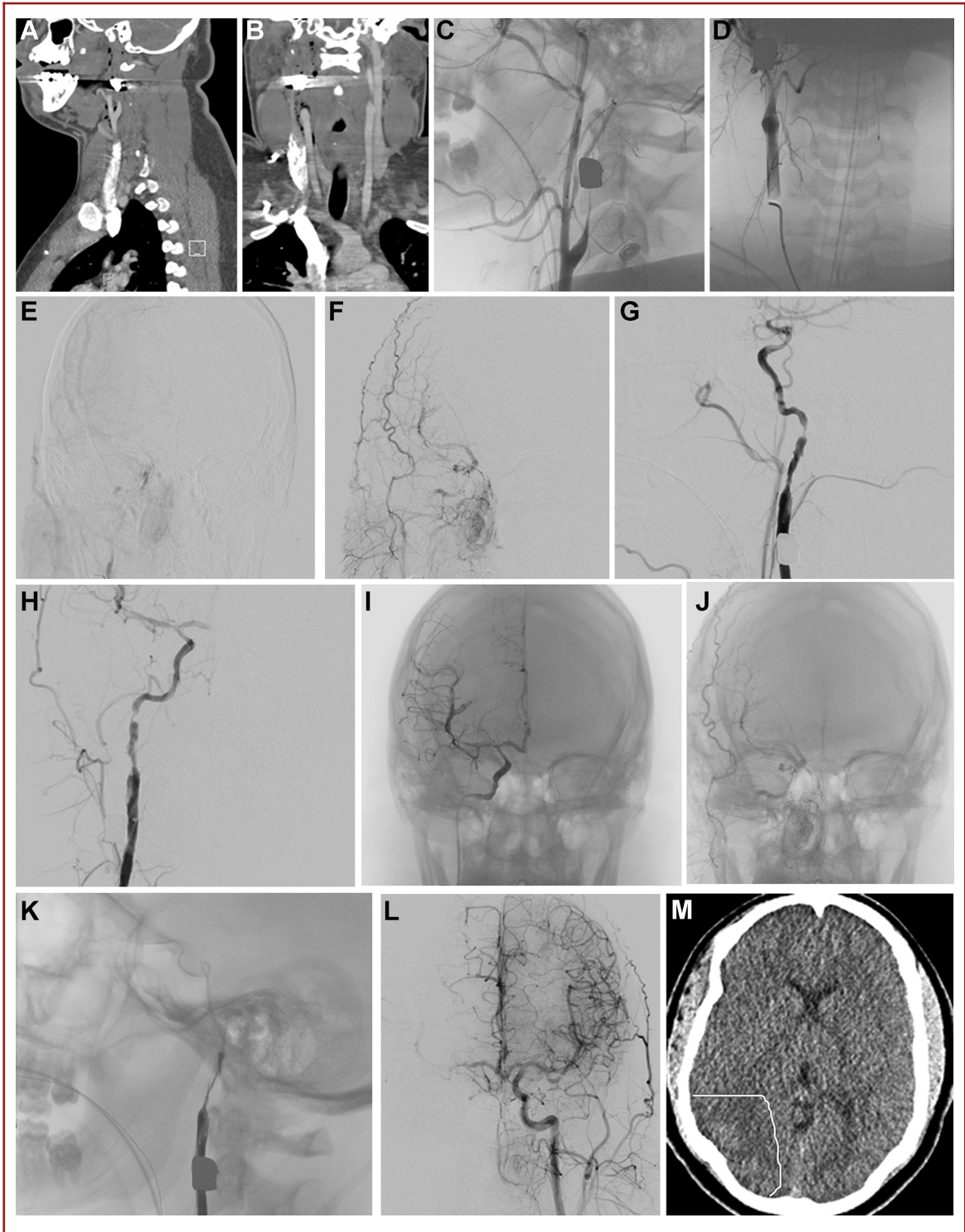


FIGURE 2. Case 5. A 17-year-old boy who experienced a gunshot wound to the neck. Sagittal **A** and coronal **B** CTA of the neck demonstrating occlusion of the right ICA just distal to the bifurcation. Pretreatment lateral **C** and anteroposterior **D** cerebral angiogram with right common carotid injection showing occlusion of ICA with preservation of the right external carotid artery. **E** and **F**, Pretreatment anteroposterior cerebral angiogram revealing minimal flow in the ICA and minimal flow in the right cerebral hemisphere **E** with collateral flow provided by the external carotid artery **F**. Lateral **G** and anteroposterior **H** and **I** cerebral angiogram showing reconstitution of flow through an irregular right ICA after mechanical thrombectomy. Anteroposterior **J** and lateral **K** cerebral angiogram showing reocclusion after treatment. Anteroposterior cerebral angiogram with left common carotid artery injection after reocclusion **L** showing collateral flow to the right middle and anterior cerebral artery distributions. **M**, Axial head CT taken postprocedurally, approximately 8 h after injury showing possible development of the right-sided watershed cerebral infarction (blue line).

preliminary pediatric epidemiological data. Because of the relative rarity of penetrating traumatic cerebrovascular injury, comparative data from adult patients are instructive. One study reported an overall mortality rate of 21% in adult patients with carotid arterial trauma,¹⁷ and another indicated 20% of patients with PCVI had neurological deficit.¹⁸ In our cohort, there were no deaths, and 2 of 7 patients (29%) presented with neurological deficit attributable to the lesion.

Early identification and treatment of traumatic cerebrovascular injury can limit the risk of subsequent neurological deterioration or deficit secondary to thromboembolic disease and/or vessel occlusion.^{8,12,14} CTA has become the most common screening method in the setting of trauma because of its widespread availability. In cases of penetrating trauma, however, CTA was shown to be less sensitive than digital subtraction angiography in detecting arterial injuries (sensitivity 73%, specificity 95%, positive predictive value 89%, negative predictive value 83%).¹⁹ The authors concluded that a considerable number of cerebrovascular injuries will be missed by CTA and that it should not be relied on for diagnosis and treatment planning for penetrating trauma.

The mean age of patients in our cohort (12.4 years) suggests that older children are at higher risk and more likely to experience PCVI, likely because they participate in more high-risk behavior. As in the adult population, most children in this series had gunshot wounds (4/7, 57%); however, low-velocity PCVI seems to be more common in children, in whom the mechanisms of injury may differ from those in adults, with significant consequences despite low-energy force. For example, Graham et al²⁰ described 2 children left with permanent hemiparesis after experiencing ischemic infarction as a result of low-velocity penetrating trauma through the oral cavity.

Two patients in our series had concomitant intracranial injury with GCS of 3 and had higher velocity trauma with a penetrating component. There were 2 ICA injuries, 4 external carotid artery injuries, and 1 VA injury. In the study by Richardson et al,¹⁸ the common carotid and ICA were the most frequently injured in adults (20 and 5 injuries, respectively). A majority of injuries in our study were higher than grade I. The likelihood of higher grade injuries to progress if not treated has not been studied in children; thus, although penetrating trauma initially can be clinically and neurologically silent, a low diagnostic threshold should be held when evaluating these patients.

Management

With the paucity of data regarding the management of PCVI in children, guidance is drawn from the management of BCVI. In treating penetrating injuries in the broader context of BCVI, there is sufficient level II evidence supporting the use of antithrombotic therapy for grade I–II lesions, while grade III lesions and patients with early neurological deficits should be considered for operative intervention. Risk modeling for BCVI²¹ has been validated²² in the pediatric population; similar large studies are necessary for penetrating cerebrovascular trauma.

Although the experience with BCVI can be extrapolated to help guide PCVI treatment, there are 3 important differences. First, the mechanisms of vascular injury are fundamentally different. With blunt external force, vascular insult results from shearing or avulsion of the vessel lumen, whereas a penetrating force pierces the layers of the vessel wall, causing active extravasation or pseudoaneurysm formation. Second, in PCVI, the offending object often remains lodged within the target tissue and any treatment algorithm must include plans for safe removal. In rare situations, it may be appropriate to leave the object in situ if safe surgical removal is not possible and the retained foreign body poses minimal risk. Third, wound contamination and infection prophylaxis must be incorporated into the management strategy for PCVI. The risk of wound infection can be mitigated with broad-spectrum antimicrobial therapy. This may also help prevent subacute mycotic aneurysm formation. Although these 3 differences are likely to impact the overall treatment plan of a patient with vascular injury, the immediate cerebrovascular goals are the same: re-establishment of target cerebral tissue perfusion and minimization of future thromboembolic risk.

The evolution of endovascular treatment of traumatic arterial injuries has changed the historical paradigm of ligation vs direct repair¹⁸; however, the differences between children and adults with respect to blood vessel pliability, growth, and elasticity may play a role in pediatric treatment options. One patient in our series was treated endovascular thrombectomy.

Penetrating VA injury may be associated with catastrophic complications, even fatalities,²³ but the patient in this series with grade I VA injury did not require treatment. Higher grade injuries affecting the posterior circulation are possible, and aggressive management with antithrombotic therapy and surgical fixation as spinal column injuries with instability may be necessary.

Short-term angiographic follow-up for grade I–III injuries is recommended.¹² In this series, both patients with untreated grade I injuries underwent follow-up imaging that demonstrated healing and improvement. This suggests that grade I injuries may have a benign natural history in the setting of PCVI. One of the 2 patients not treated because of the strict contraindications of traumatic SAH underwent follow-up imaging with CTA that demonstrated evidence of healing rather than worsening injury.

Limitations

The retrospective design of the study inherently limits the information available. For example, functional outcome scales were not reliably reported in the existing medical record. Although this was multi-institutional study, more sites and patients would be needed to analyze efficacy for different treatment modalities and provide conclusive recommendations. Although this represents the experience and practice among 4 large, metropolitan tertiary referral centers, treatment and practice patterns are not standardized, and treatment decisions were made on a case-by-case basis.²⁴ Only patients screened with CTA were included, which may have selected toward lower grade, less life-threatening injuries, as higher grade injuries and higher acuity patients may have been taken directly to surgery or underwent urgent catheter angiography.

CONCLUSION

This is the largest series of penetrating cerebrovascular trauma in pediatric patients. Although rare, PCVIs are high-risk injuries that require urgent recognition and may require aggressive endovascular and/or open surgery for treatment. A serious vascular insult may not be accompanied by focal neurological deficits or a poor GCS, so a high index of suspicion is essential. Larger multi-institutional series are needed to identify negative risk factors and determine optimal treatment strategies.

Disclosures

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REFERENCES

- Asensio JA, Valenziano CP, Falcone RE, Grosh JD. Management of penetrating neck injuries. The controversy surrounding zone II injuries. *Surg Clin North Am*. 1991;71(2):267-296.
- Kumar SR, Weaver FA, Yellin AE. Cervical vascular injuries: carotid and jugular venous injuries. *Surg Clin North Am*. 2001;81(6):1331-1344, xii-xiii.
- Sarkari A, Singh PK, Mahapatra AK. Lethal penetrating stab injury to the vertebral artery: a case report with review of literature. *Asian J Neurosurg*. 2016;11(3):317.
- McConnell DB, Trunkey DD. Management of penetrating trauma to the neck. *Adv Surg*. 1994;27:97-127.

- Burgess CA, Dale OT, Almeyda R, Corbridge RJ. An evidence based review of the assessment and management of penetrating neck trauma. *Clin Otolaryngol*. 2012;37(1):44-52.
- Maier H, Tisch M, Lorenz KJ, Danz B, Schramm A. Penetrating injuries in the face and neck region. Diagnosis and treatment. *HNO*. 2011;59(8):765-782.
- Maas AI, Hukkelhoven CW, Marshall LF, Steyerberg EW. Prediction of outcome in traumatic brain injury with computed tomographic characteristics: a comparison between the computed tomographic classification and combinations of computed tomographic predictors. *Neurosurgery*. 2005;57(6):1173-1182; discussion 1173-1182.
- Liesemer K, Riva-Cambrin J, Bennett KS, et al. Use of Rotterdam CT scores for mortality risk stratification in children with traumatic brain injury. *Pediatr Crit Care Med*. 2014;15(6):554-562.
- Biffl WL, Moore EE, Offner PJ, Brega KE, Franciose RJ, Burch JM. Blunt carotid arterial injuries: implications of a new grading scale. *J Trauma*. 1999;47(5):845-853.
- Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381.
- Azaraksh N, Grimes S, Notrica DM, et al. Blunt cerebrovascular injury in children: underreported or underrecognized? A multicenter ATOMAC study. *J Trauma Acute Care Surg*. 2013;75(6):1006-1011; discussion 1011-1012.
- Jones TS, Burlew CC, Kornblith LZ, et al. Blunt cerebrovascular injuries in the child. *Am J Surg*. 2012;204(1):7-10.
- Kopelman TR, Berardini NE, O'Neill PJ, et al. Risk factors for blunt cerebrovascular injury in children: Do they mimic those seen in adults? *J Trauma*. 2011;71(3):559-564; discussion 564.
- Bromberg WJ, Collier BC, Diebel LN, et al. Blunt cerebrovascular injury practice management guidelines: the Eastern Association for the Surgery of Trauma. *J Trauma*. 2010;68(2):471-477.
- Domingo Z, Peter JC, de Villiers JC. Low-velocity penetrating craniocerebral injury in childhood. *Pediatr Neurosurg*. 1994;21(1):45-49.
- Martin WS, Gussack GS. Pediatric penetrating head and neck trauma. *Laryngoscope*. 1990;100(12):1288-1291.
- Unger SW, Tucker WS, Jr, Mrdeza MA, Wellons HA, Jr, Chandler JG. Carotid arterial trauma. *Surgery*. 1980;87(5):477-487.
- Richardson R, Obeid FN, Richardson JD, et al. Neurologic consequences of cerebrovascular injury. *J Trauma*. 1992;32(6):755-758; discussion 758-760.
- Bodanapally UK, Shanmuganathan K, Boscak AR, et al. Vascular complications of penetrating brain injury: comparison of helical CT angiography and conventional angiography. *J Neurosurg*. 2014;121(5):1275-1283.
- Graham CJ, Schwartz JE, Stacy T. Stroke following oral trauma in children. *Ann Emerg Med*. 1991;20(9):1029-1031.
- Ravindra VM, Riva-Cambrin J, Sivakumar W, Metzger RR, Bollo RJ. Risk factors for traumatic blunt cerebrovascular injury diagnosed by computed tomography angiography in the pediatric population: a retrospective cohort study. *J Neurosurg Pediatr*. 2015;15(6):599-606.
- Ravindra VM, Bollo RJ, Sivakumar W, et al. Predicting blunt cerebrovascular injury in pediatric trauma: validation of the "Utah Score". *J Neurotrauma*. 2016;34(2):391-399.
- Tannoury C, Degiacomo A. Fatal vertebral artery injury in penetrating cervical spine trauma. *Case Rep Neurol Med*. 2015;2015:571656.
- Dewan M, Ravindra VM, Gannon S, et al. Treatment practices and outcomes following blunt cerebrovascular injury in children. *Neurosurgery*. 2016;79(6):872-878.

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COMMENTS

Traumatic cerebrovascular injuries whether blunt or penetrating, adult or pediatric, are rare; however, when present, they demand an up-to-date thoughtful medical/surgical or endovascular management.¹⁻⁵ Flow-limiting, no flow limiting, aneurysmal, and totally wiped out injuries require a combination of antiplatelet and restoration of flow

management while preventing shower emboli and devastating stroke and subarachnoid hemorrhage. The investigators of this submission have presented a detailed view of 7 of 130 (5.4%) pediatric penetrating head and neck injuries associated with carotid and vertebral injuries. Gunshot wounds to head and neck were the most frequent mechanisms (seen in 4), although lower velocity objects such as radio antenna, wood chip, and crossbow were noticed in 3. Three patients had intimal injuries with preserved flow, 2 had traumatic aneurysms, and 2 complete occlusion of the main artery. Stroke was noticed in 2 patients. The 2 aneurysms were repaired surgically and medical management was applied for 3 grades 1 and 2 patients. Endovascular management to permanently occlude an artery and prevent recanalization and distal shower emboli was performed in 1 of 7 patients. Although retrospective, this submission is well-written. One view needs to be stressed and that is the reality that penetrating vascular injuries of head and neck are rare, however when they occur, they need a multidisciplinary approach to prevent further ischemic injuries and to re-establish flow to the central nervous system and interrupt the occurrence of embolic stroke.

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1. Aarabi B. Traumatic aneurysms of brain due to high velocity missile head wounds. *Neurosurgery*. Jun 1988;22(6 Pt 1):1056-1063.
2. Aarabi B. Management of traumatic aneurysms caused by high-velocity missile head wounds. *Neurosurg Clin N Am*. Oct 1995;6(4):775-797.
3. Bodanapally UK, Shanmuganathan K, Boscak AR, et al. Vascular complications of penetrating brain injury: comparison of helical CT angiography and conventional angiography. *Journal of neurosurgery*. Nov 2014;121(5):1275-1283.
4. Jinkins JR, Dadsetan MR, Sener RN, Desai S, Williams RG. Value of acute-phase angiography in the detection of vascular injuries caused by gunshot wounds to the head: analysis of 12 cases. *AJR. American journal of roentgenology*. Aug 1992;159(2):365-368.
5. Serbinenko FA, Lazarev VA. [Use of balloon catheters in cases of traumatic pseudoaneurysm of the carotid artery complicated by profuse nosebleed]. *Zh Vopr Neirokhir Im N N Burdenko*. Nov-Dec 1981(6):9-16.

The assessment and management of penetrating intracranial cerebrovascular injury (PCVI) requires a prompt yet thorough medical and, when necessary, neurosurgical approach. Unfortunately,

apart from case reports, cohort studies on PCVI in the pediatric population are lacking. Here, the authors present the largest cohort study (n = 7) in the literature on this topic. All patients underwent a CT angiogram (CTA) of the head or neck. CTA is advantageous as it is a fast test; however, if clinical suspicion is high and the patient is stable, DSA should also be considered due to its higher sensitivity. Of note, 5 of the 7 patients did not have neurologic symptoms, again emphasizing the importance of correctly diagnosing PCVIs when there is high suspicion based on the mechanism of injury. As we have learned in military blast neurotrauma there may be a need to repeat the CTA at a consistent delayed timepoint interval due to the known propensity for delayed pseudoaneurysm after blast injury. It would also be interesting to perform transcranial Doppler evaluation in these patients both to determine the relative risk for vasospasm, which may be higher in the pediatric population, as well as to assess for the presence of emboli and the impact of medical therapy to mitigate this risk.

In the adult population, overall mortality associated with PCVI has been reported in about one-fifth of the patients; in this pediatric cohort there were no deaths. Though the cohort is small, this difference potentially highlights the importance of acute management and the need for pediatric-specific recommendations. Three patients with injury grades III and higher underwent surgical management (2 open and 1 endovascular); 2 of these patients were also given antiplatelet therapy. Three patients with injury grade II and below were treated medically. Two grade I patients did not have antiplatelet or anticoagulation therapy. In patients with subarachnoid hemorrhage, no antiplatelet or anticoagulation therapy was given. These findings suggest that the current practice for PCVIs at level-1 pediatric trauma centers is as follows: endovascular or open surgical repair for grades III and IV with or without medical management, and medical management for grades I and II as long as no subarachnoid hemorrhage is present.

I congratulate the authors for undertaking a difficult but important topic. We look forward to additional studies building on this foundation to help create standards of practice for this thankfully rare pediatric patient population.

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